ARCI

ANNUAL REPORT 2015-16

ए आर सी आई

ARCI

ARCI is an Autonomous R&D Centre of Department of Science and Technology (DST), Government of India, set-up with a mission to develop unique, novel and techno-commercially viable technologies in the area of advanced materials and subsequently transfer them to industries.

THRUST AREAS

Nanomaterials

Engineered Coatings

Ceramic Processing

Laser Materials Processing

Fuel Cells

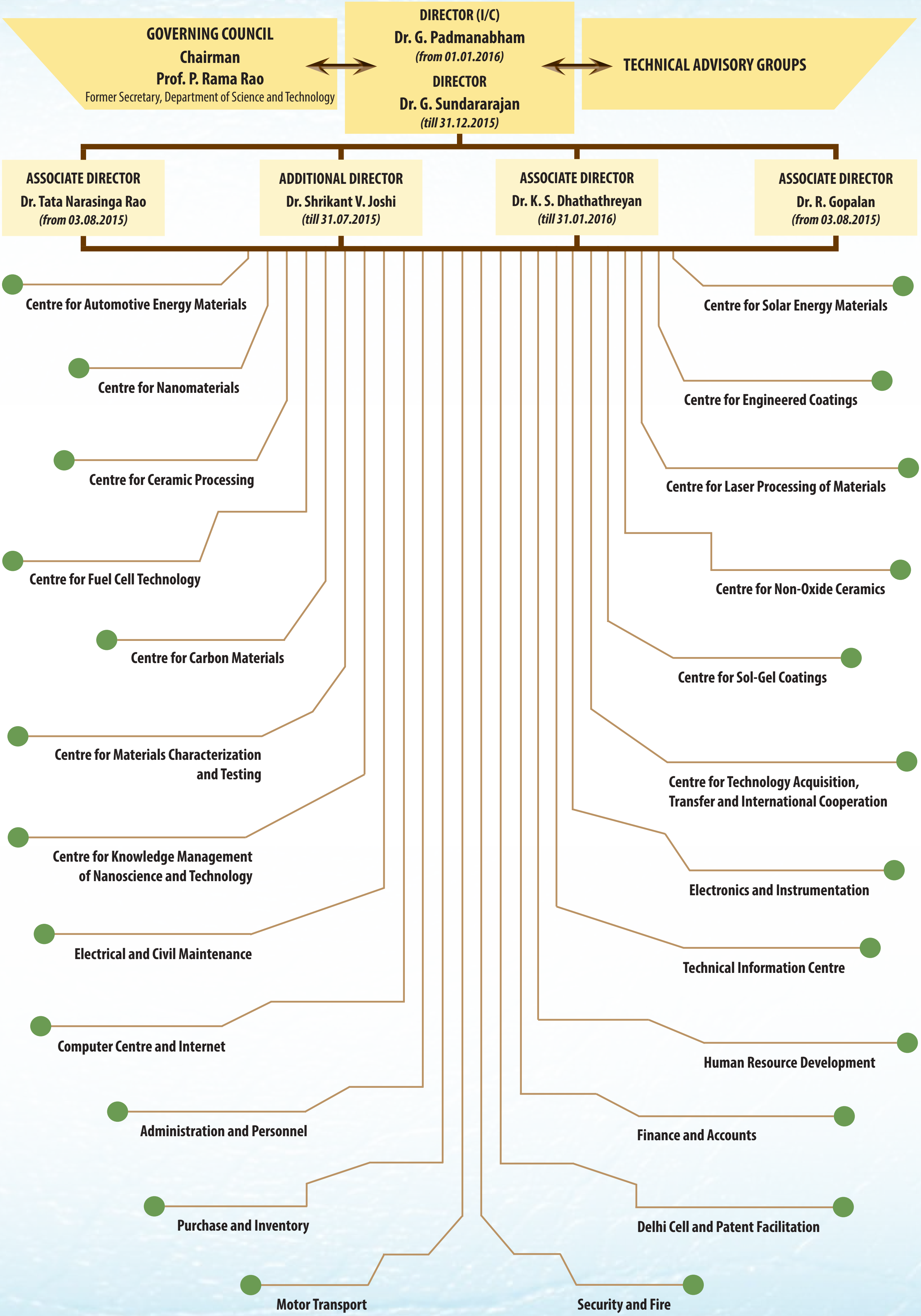
Sol-Gel Coatings

Solar Energy Materials

Automotive Research

CONTENTS

ORGANIZATIONAL STRUCTURE



International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI)

Governing Council *(as on March 31, 2016)*

Professor P. Rama Rao (Chairman)
Former Secretary
Department of Science and Technology

Professor Ashutosh Sharma
Secretary
Department of Science and Technology

Dr. Baldev Raj
Director
National Institute of Advanced Studies (NIAS)

Dr. Samir V Kamat
OS & Director
Defence Metallurgical Research Laboratory

Shri M. Narayana Rao
Former Chairman and Managing Director
Mishra Dhatu Nigam Limited

Professor V. Ramgopal Rao
Electrical and Electronics Department
Indian Institute of Technology-Bombay

Shri J. B. Mohapatra, IRS
Joint Secretary & Financial Adviser
Department of Science & Technology

Dr. Arabinda Mitra
Head, International Division
Department of Science & Technology

Member Secretary

Dr. G. Sundararajan
Director, ARCI (till December 31, 2015)

Dr. G. Padmanabham
Director (I/C), ARCI (from January 01, 2016)

International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI)

Technical Advisory Groups *(as on March 31, 2016)*

Chairman and Members of Technical Advisory Group (TAG) of each Centre of Excellence

Centre for Automotive Energy Materials

Dr. R. Muralidharan (Chairman)
Visiting Professor, Centre for Nano Science and Engineering (CeNSE), Indian Institute of Science, Bengaluru

Prof. S. Ram
Professor - Materials Science Centre
Indian Institute of Technology - Kharagpur

Shri K. R. A. Nair
Executive Director – Development
Lucas-TVS Limited, Chennai

Dr. R. Ranganathan
Senior Professor
Saha Institute of Nuclear Physics, Kolkata

Shri K. Umesh
President, MTS Testing Solutions India Pvt. Ltd. (A Part of MTS System Corporation-US), Chennai

Centre for Solar Energy Materials

Prof. R. O. Dusane (Chairman)
Professor-Dept. of Metallurgical Engineering & Materials Science, Indian Institute of Technology - Bombay

Prof. Pradip Dutta
Department of Mechanical Engineering
Indian Institute of Science, Bengaluru

Prof. Amlan J. Pal
Head - Department of Solid State Physics
Indian Association for the Cultivation of Science, Kolkata

Dr. M. Chandrasekharam
Principal Scientist-Inorganic & Physical Chemistry Division
Indian Institute of Chemical Technology, Hyderabad

Centre for Nanomaterials &
Centre for Carbon Materials

Prof. Ashutosh Sharma (Chairman - till January 8, 2015)
Secretary
Department of Science and Technology

Prof. Sundara Ramaprabhu
Alternative Energy & Nanotechnology Laboratory (AENL)
Department of Physics
Indian Institute of Technology - Madras

Prof. G. U. Kulkarni
Director
Centre for Soft Matter and Nanomaterials
Bengaluru

Prof. D. Bahadur
Department of Metallurgical Engineering
Indian Institute of Technology - Bombay

Prof. Ashok K. Ganguli
Director
Institute of Nano Science & Technology, Mohali

Centre for Engineered Coatings

Prof. A. Subrahmanyam (Chairman)
Department of Physics
Indian Institute of Technology - Madras

Dr. Harish Barshilia
Chief Scientist
National Aerospace Laboratories, Bengaluru

Dr. S. K. Seshadri
Emeritus Professor
Department of Metallurgical Engineering & Materials Science
Indian Institute of Technology - Madras

Dr. P. V. Ananthapadmanabhan
Former OS & Head, Laser & Plasma Technology Division
Bhabha Atomic Research Centre, Mumbai

Dr. Subrato Mukherjee
Head-FCIPT Division
Institute for Plasma Research, Gandhinagar

Centre for Ceramic Processing &
Centre for Non-Oxide Ceramics

Prof. Vikram Jayaram (Chairman)
Chairman - Department of Materials Engineering
Indian Institute of Science, Bengaluru

Dr. H.S. Maiti
INAE Distinguished Professor & Visiting Professor
Department of Ceramic Engineering
National Institute of Technology, Rourkela

Prof. L.M. Manocha
Department of Materials Science
Sardar Patel University, Vallabh Vidyanagar

Prof. Parag Bhargava
Department of Metallurgical Engineering & Materials Science
Indian Institute of Technology - Bombay

Dr. M. Vijaykumar
Scientist-G (Retd.)
Defence Metallurgical Research Laboratory, Hyderabad

Centre for Laser Processing of Materials

Prof. Indranil Manna (Chairman)
Director
Indian Institute of Technology - Kanpur

Dr. G. Madhusudan Reddy
OS & Group Head, Metal Joining Group
Defence Metallurgical Research Laboratory
Hyderabad

Prof. Ashish Kumar Nath
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Dr. Kamalesh Dasgupta
Outstanding Scientist, Laser & Plasma Technology Division
Bhabha Atomic Research Centre, Mumbai

Centre for Fuel Cell Technology

Dr. J. Narayana Das (Chairman)
Retd. OS & CC R&D (NSM & HR) – DRDO

Dr. B. Viswanathan
Emeritus Professor
Indian Institute of Technology - Madras

Dr. Mathew Abraham
Senior General Manager (R&D), Mahindra & Mahindra Limited
Mahindra Research Valley, Chennai

Prof. Prakash Chandra Ghosh
Department of Energy Science and Engineering
Indian Institute of Technology - Bombay

Centre for Sol-Gel Coatings

Prof. D. Chakravorty (Chairman)
Emeritus Professor
Indian Association for the Cultivation of Science, Kolkata

Dr. Goutam De
Chief Scientist & Head, Nano-structured Materials Division
Central Glass & Ceramic Research Institute, Kolkata

Dr. K.G.K. Warrier
Emeritus Scientist, Materials & Minerals Division
National Institute of Interdisciplinary Science & Technology
Trivandrum

Dr. Dibyendu Ganguli
Retd. Head, Sol-Gel Division
Central Glass & Ceramic Research Institute, Kolkata

Centre for Materials Characterization and Testing

Prof. Indradev Samajdar (Chairman)
Department of Metallurgical Engineering & Materials Science
Indian Institute of Technology - Bombay

Prof. B. S. Murty
Head, Department of Metallurgical & Materials Engineering
Indian Institute of Technology - Madras

Dr. Samir V Kamat
OS & Director
Defence Metallurgical Research Laboratory, Hyderabad

Dr. Satyam Suwas
Associate Professor, Department of Materials Engineering
Indian Institute of Science, Bengaluru

Prof. Sundararaman Mahadevan
Visiting Professor, Indian Institute of Technology - Madras

Centre for Technology Acquisition, Transfer and International Cooperation &
Centre for Knowledge Management of Nanoscience and Technology

Dr. Yogeswara Rao (Chairman)
Scientist 'G' and Head of Office (Retd.)
O/o Principal Scientific Adviser to the Govt. of India, New Delhi

R. R. Hirwani
Head - CSIR Unit for Research and Development of
Information Products, Pune

Dr. Premnath Venugopalan
Head, NCL Innovations & Intellectual Property Group
National Chemical Laboratory, Pune

Dr. Krishna Tanuku
Former Executive Director
Wadhwani Centre for Entrepreneurship Development (WCED)
Indian School of Business, Hyderabad

Prof. Rishikesha T. Krishnan
Director & Professor of Strategic Management
Indian Institute of Management, Indore

Director's Report

It gives me immense pleasure to present the Annual Report of ARCI for the year 2015-16, the 20th year of its operations. The Centre has maintained its high level of activity in terms of development of new materials and processes; providing solutions to industrial users; and transfer of technology for commercialisation.

R&D in the areas of nanomaterials, ceramics, coatings, laser processing and fuel cells, which have been the mainstay activities for a long time continued to deliver in terms of technology transfer and application development. Highlights of achievements are as follows:

- Silica aerogel flexible sheets technology has been transferred to industry. It has extensive applications in industrial thermal insulation and has attracted the highest technology transfer fees among any single technology transfers effected by ARCI till date.
- Self-cleaning textiles based on photocatalytic TiO_2 technology of ARCI are successfully commercialised by the technology receiver.
- Laboratory scale process for production of 2D-nanolayered tungsten/molybdenum disulfide has been developed. These materials have applications in petrochemical industry as nanostructured catalysts and lubricant additives in automotive applications. Scaling up of the process and field evaluation of the materials are being taken up in collaboration with industry partners.
- Activity of development of Oxide Dispersion Strengthened (ODS) steels has been extended to develop materials for fusion reactor applications through a major sponsored project.
- Detonation spray and plasma spray coating technologies have been successfully used to develop wear-resistant and abradable coatings for aircraft blades and vanes and delivered to the user.
- Indigenously built PEM fuel cell system was field tested through intermittent operation using hydrogen available at the site of a user company and they have now requested for more long term and wider usage of our fuel cells.
- Energy efficient technology for hydrogen generation by combining, reforming and electrolysis has been developed. With recently developed improved electrodes, catalyst and membrane, the cost also has been brought down substantially.
- Ultrafast laser micro machining facility which was set up last year has been successfully used for fabricating high precision components like control and shadow grids for pulsed microwave sources, liner slits for giant optical telescope and flash X-ray camera apertures. Micro cutting of flexible PCBs has been demonstrated based on which the industry partner is setting up a production facility.
- Low energy input processes such as laser brazing and cold metal transfer brazing have been used for dissimilar material joining aluminium alloys to steel and fabricate prototype demonstrator assemblies for automotive body lightweighting applications.
- Zinc sulphide technology which was transferred last year has now been productionised by the industry. This expertise on transparent ceramics has been successfully extended to fabrication of components with magnesium aluminate spinel which is harder than zinc sulphide and is expected to have extensive applications.
- In the area of porous ceramics, alumina tubes with moderate mechanical strength were developed for thermal management and initial trials on application of reticulated porous ceramics in burners have been attempted.
- Near-net shape porous SiC parts have been fabricated. They have possible applications in hot gas and molten metal filtrations, heat exchangers and volumetric solar radiation absorbers.
- Encouraging results have been obtained on sol-based nanocomposite coatings for chrome-free, self-healing, corrosion protection coatings on aluminum and its alloys used in automotive and aerospace applications.

I am happy to report here that the more recent initiatives on solar energy materials and automotive energy materials have started yielding results at laboratory scale. Highlights are:

- Li-ion Battery cells of 3 Ah and 10 Ah capacities have been fabricated and demonstrated. The next target is to fabricate 25 Ah battery pack in collaboration with user industry.
- Processes for production of Li-ion battery materials on large scale have been optimised.

- Magnet technology moved towards prototype development for alternators. More number of prototypes is under fabrication for extensive testing.
- High performance solar receiver tubes (> 95 % abs and < 0.15 ε) have been developed with possible application in medium temperature concentrated solar power systems.
- Perovskite solar cells with 8.5 % power conversion efficiency and moderate stability have been fabricated and demonstrated.

Translation of these research results into technology & products is expected to be further enabled through the setting up of “Technology Research Centre (TRC) on Alternate Energy Materials and Systems” with support of DST.

In summary, the Centre has been able to deliver new materials and processes for application in various industrial sectors and also tuned itself to intensify efforts in the direction of 'Make in India'. Considering the growing level of activity and the need for improved & safer working conditions, four new buildings have been constructed. Similarly, aggressive marketing efforts resulted in increasing the outreach of the Centre with many industries coming forward to collaborate with ARCI.

This year also marks the completion of a long and successful tenure of Dr. G Sundararajan as Director, ARCI, under whose leadership the Centre built up such nationally unique capabilities and international recognition in the field of materials research and technology development. On behalf of ARCI, I would like to place on record our great respect and appreciation to his commendable efforts in bringing ARCI to these heights.

I take this opportunity to thank all the employees for their unstinted cooperation and dedicated efforts in accomplishing the set targets and continuously innovating. Following pages, which constitute this report, contain an account by each of the scientists/technical officers on their best contributions to the Centre during this year. I would like to place on record the continuous support provided by DST and the key role played by the Governing Council in providing the right policy support, encouragement and guidance. The contributions of various Technical Advisory Groups in steering the R&D programmes in the right direction are noteworthy.

The performance of ARCI, as evidenced by the indicators presented below, has been excellent:

Performance Indicators

Parameters		**2014-15**	**2015-16**
No. of Employees		172	169
No. of Scientists		70	66
No. of Publications*		131	136
Indian Patents**	Granted	24	24
	Filed	59	71
International Patents**	Granted	9#	11#
	Filed	4	5
Scientists with Ph.D.		47	48
Scientists Registered for Ph.D.		10	9
No. of Deputations Abroad		31	22
No. of Conferences/Seminars/Training Courses (in India) attended by ARCI Personnel		393	407
ARCI Fellows***		68@	60
ARCI Trainees		67@	69
M.Tech./B.Tech. Project Students****		65@	81
Summer Students		55	59

* Includes journal publications, conference proceedings, and chapter in books
** Cumulative figures up to end of financial year
*** ARCI Fellows also include DST women scientist, Inspire faculty, ARCI-IIT Fellows, Post Doctoral Fellows, and Research Scholars
**** M. Tech/ B. Tech Project Students also include M. Sc Students
# includes same patent granted in multiple countries
@ includes persons who are continuing from previous years

(G. Padmanabham)

Centre for Automotive Energy Materials

The Centre for Automotive Energy Materials (CAEM) is located at Indian Institute of Technology Research Park, Chennai and functions as one of the Centres of Excellence of ARCI to meet and support the R&D demand of the automotive sectors in the country. The Centre focusses on (i) materials and components engineering in fabrication of Li-ion battery (LiB) of various chemistries and testing for electric vehicle (EV) applications, (ii) soft and hard magnets for alternators and motor applications, and (iii) fabrication of thermoelectric devices for waste heat recovery applications. The major breakthrough during 2015-16 is successful demonstration of LiB cells of 3 Ah and 10 Ah capacity. Currently, the Li-ion battery group is closely interacting with an EV manufacturer to develop 25 Ah battery pack for demonstration and testing. In an effort to bring more collaboration with industries, the LiB Team is interacting with two wheeler and three wheeler manufacturers and planning to fabricate the cells as per their specifications. The magnet team has moved forward in taking the magnet technology to prototype development for alternator applications in close collaboration with an Industry partner. More number of alternator proto types fabrication are underway and once performance is consistently achieved, the technology transfer will be aimed at. Adding to the strength of the Centre, the thermoelectric (TE) group has made a significant progress during this year, in making TE materials with high TE efficiency and fabricating a TE module. The team is working further to address the engineering issues related to the device fabrication. All the above three programmes are executed by the respective teams in mission mode through sponsored projects and highlights of the achievements during 2015-16 are reported by the scientists individually in this annual report.

Based on the above inherent research and technological strengths of CAEM, ARCI has got a major project from Department of Science & Technology for setting up a Technical Research Centre for Alternate Energy Materials & Systems.

R Gopalan
gopy@arci.res.in

G Sundararajan
gsundar@arci.res.in

Lithium Ion Battery for Electric Vehicle Application: Development of $LiFePO_4$/Graphite Prototype Cell and Testing

R Prakash ***rprakash@arci.res.in***

Energy storage is the vital technology that governs the development of electric vehicle (EV) globally. Battery is the only source of energy in full EVs that powers the electric motors through an appropriate management system. In spite of development of various porotype models, pure EVs are still not widely commercialized. However, after the introduction of hybrid electric vehicles in the market, the complete scenario of EV program has changed to a different dimension. The key challenge for EVs is to get suitable battery pack, because it has to store the required amount of energy in a given volume that is sufficient for long driving range and has a capability to recharge up to 80% state of charge in a short period of time. Lithium-ion battery has been mainly considered for EV applications. Two types of battery systems such as high power and high energy batteries have been developed. Unfortunately high power system yielded only short range, while high energy system cannot be recharged in a short time. In addition, size and design of battery is crucial to accommodate it in the available space in a car, as well as to maximize its efficiency.

In India, Mahindra Reva has introduced a pure EV car called E_2O, which is powered by lithium ion battery of 48V, 200Ah (10 kW) with a driving range of 80 km in a single charge. Complete charging of the battery takes about 5-8 h. In this regard, ARCI has collaborated with Mahindra Reva to develop an indigenous lithium ion battery pack of similar specification. Currently, we have developed prototype prismatic cell of 10 Ah has been developed using $LiFePO_4$ and graphite electrodes.

Cathode slurry was prepared by mixing of $LiFePO_4$, polyvinylidene fluoride (PVDF), carbon black and N-methyl-2-pyrrolidone (NMP), and anode slurry was prepared by mixing graphite, PVDF, carbon black and NMP. The viscosities of slurries were kept in the range between 15,000 and 30,000 cP (Fig. 1a). Slurries were coated on current collectors (Al/Cu) with a maximum width of 250 mm and a length of 200 mm, and dried subsequently. Double side coated electrodes with uniform thickness having loading areas of 14 mg/cm^2 for cathode and 9 mg/cm^2 for anode were prepared. Microstructures of the electrodes show uniform distribution of active materials, PVDF and carbon black (Fig. 1(b) and (c). The as-prepared electrodes were calendered to the desired thickness and porosity. Then the entire length of the electrodes were slit into the required width without any bur using slitting machine. Prismatic jelly rolls were wound in the winding machine having electrodes sandwiched between separator layers. The winding parameters were adjusted to get a sagging-free prismatic jelly roll (Fig. 1d), which showed a resistance of 5 GΩ confirming that there is no short circuit. Copper and aluminium tabs were connected to the respective terminals by ultrasonic welding. The cell was placed inside polypropylene container, the terminals were connected with lid, and sealed properly (Fig. 1d). Electrolyte ($LiPF_6$ in organic solvents) was filled under vacuum and the fill port was fitted with a pressure gauge to monitor the internal pressure during charge/discharge cycles.

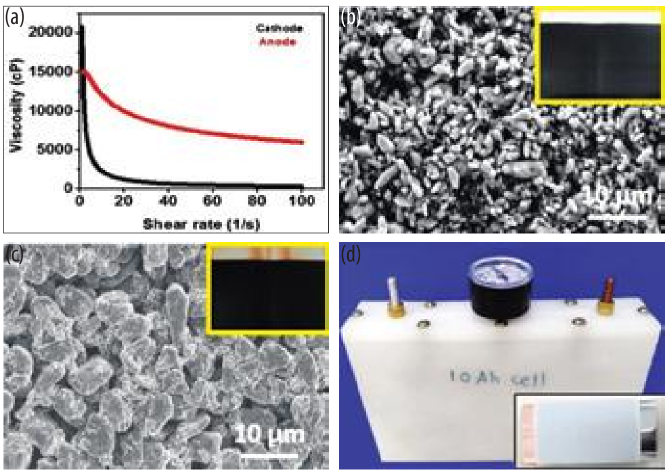


Fig. 1 10 Ah prototype cell fabrication process: (a) Viscosity of cathode and anode (b) SEM microstructure of cathode (cathode inset) (c) SEM microstructure of anode (anode inset) (d) 10 Ah prismatic electrode jelly roll (inset) and final 10 Ah Li-ion prototype cell

Testing facility for large format lithium ion battery (cell and pack) has been established. The life cycle tester has eight channels and each channel having 60V, 100A rating (Fig. 2a). Each channel can test at maximum peak power of 8 kVA DC and all channels can be parallel to perform high current rate testing experiments. Testing of the prototype 10 Ah cell was carried out using the equipment. The cell exhibited an open-circuit voltage of 200 mV, and was kept under equilibrium for two days. Initial formation cycles were carried out at 0.05 C rate. After that the cell was tested at 0.1 C rate. Charge-discharge profile and the cyclic stability for the first ten cycles are shown in Fig. 2b. It showed capacity of 9.2 Ah with 90% capacity retention. Further electrochemical characterizations are under process.

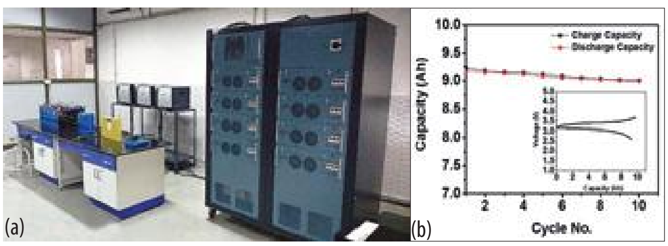


Fig. 2 10 Ah prototype cell testing: (a) Battery life cycle tester, (b) Cyclic stability and Charge-discharge cycle profile (inset)

Contributors: Sumit R Sahu, R Vallabha Rao, K Kumari, S Vasu, K Shanmugam, L Babu, S Jana, A Sivaraj, T P Sarangan, V V N Phanikumar, S Bhuvaneswari and R Gopalan

Development of Lithium Nickel Oxide Based Cathode Material for Lithium Ion Battery

M B Sahana *sahanamb@arci.res.in*

There is a strong drive for the development of electric vehicles (EVs) and hybrid electric vehicle (HEV), because of the depletion of non renewable energy source and environmental concerns coming from the fossil fuel. However, for EVs to dominate the market share, it is very essential to reduce the price and increase charging/ discharging cycle life of the lithium ion batteries, which are used as energy sources. One of the intrinsic properties that determine the cyclic life of lithium ion batteries is the cyclic stability of the electrode material. $LiNiO_2$ layered structure is extensively investigated as cathode material for lithium ion batteries because of its high theoretical capacity. However, due to the intrinsic difficulties of cation mixing during synthesis which leads to off-stoichiometry and irreversible phase transitions resulting in electrochemically inactive partially layered structure, it is very challenging to develop electrochemically active, $LiNiO_2$ based cathode materials with high cycle stability. One of the strategies that are considered to improve the electrochemical performance of $LiNiO_2$ is to substitute Ni with other metal ions such as Co for reducing antisite defect, Mn to prevent overcharging and Al toincrease thermal stability. In particular $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ and $LiNi_{0.8}Co_{0.15}AlO_2$ are considered to be promising cathode materials for lithium ion battery for EV and HEV applications.

$LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ and $LiNi_{0.8}Co_{0.15}AlO_2$ are prepared by co-precipitation of the mixed transition metal hydroxide, followed by solid state reaction of the hydroxide with lithium precursor. With the incorporation of carbon coating and morphology controlling additives, $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ cathode materials with good electrochemical performance have been developed. By suitably choosing the transition metal precursors and heat treatment condition, $LiNi_{0.8}Co_{0.15}AlO_2$ with uniform morphology is obtained. Formation of layered stature of $LiNi_{0.8}Co_{0.15}AlO_2$ is confirmed by powder XRD which is shown in Fig.1a. The microstructure of the sample revealed particles size of 200-400nm (Fig.1b). The electrochemical charging discharge cyclic stability curve given in Fig.1c, confirms the retention of 95% of discharge capacity at 2nd cycle and at 30th cycle. Formation of layered structure of $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ and uniform carbon coating on the particles are evident from the XRD of the sample given in Fig. 2a and TEM micrographs given in Fig. 2b, respectively. Uniform carbon coating on $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ has been achieved by pillaring of carbon source in transition metal hydroxide precursor. The carbon coated $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ has high retention capacity even after 300 cycles as can be seen in the charge/discharge cyclic stability curve given in Fig. 2c.

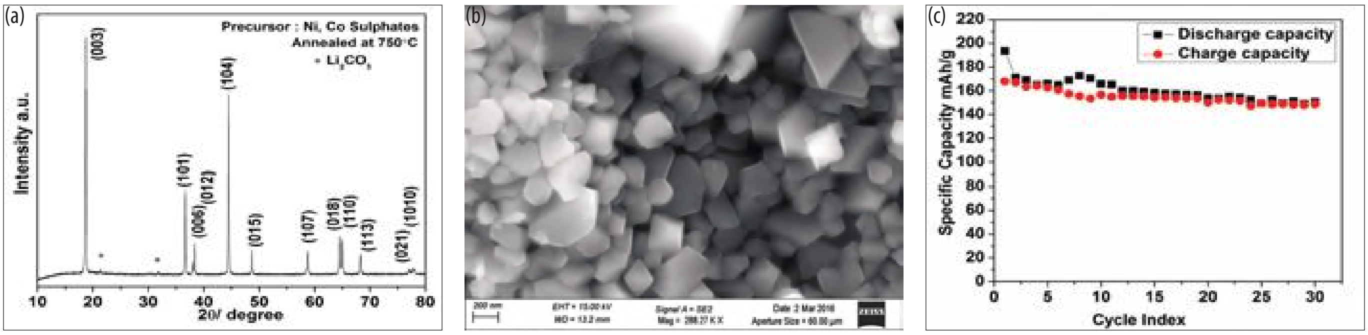


Fig.1 (a) XRD (b) SEM micrograph (c) charge/discharge cyclic stability curve of $LiNi_{0.8}Co_{0.15}AlO_2$

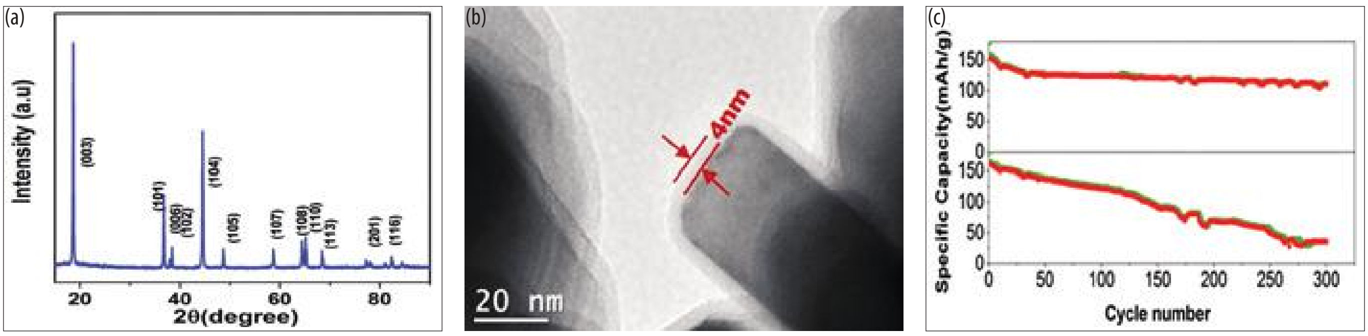


Fig.2 (a) XRD (b) SEM micrograph (c) charge/discharge cyclic stability curve of $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$

Contributors: S Vasu, N Sasikala and R Gopalan

High Grade Dopant Free $SrFe_{12}O_{19}$ Powders for Permanent Magnets

D Prabhu ***dprabhu@arci.res.in***

Permanent magnets are those which act as a constant source of magnetic field. They have a wide range of applications and are used in tiny electric motors of a hard disk drive to giant wind power generators. In particular it has become indispensable in automotive sector and nearly hundreds of magnets are used in a typical passenger car. Ferrite magnets are the most popular magnets in spite of the relatively low energy product (3-5 MGOe) owing to their low cost, corrosion resistance and abundant availability of raw materials. Commercial high grade ferrites (BH_{max} ~ 4-5 MGOe) are relatively costlier as they are doped with lanthanum and cobalt. Hence high performance ferrite powder without dopant has a huge market particularly in automotive industry due to large scale requirement. We have utilized a micronization process which yields high performance ferrite powders with coercivity ~ 5 kOe.

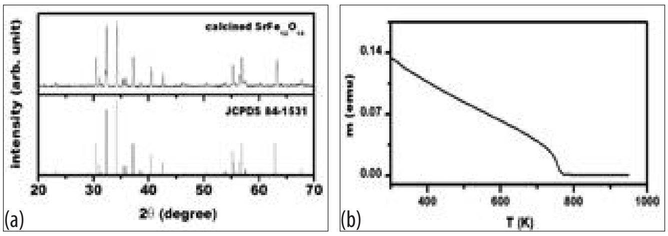


Fig. 1 (a) XRD pattern confirming the single phase of the calcined sample and (b) Thermomagnetization curve showing single Curie transition corresponding to $SrFe_{12}O_{19}$ phase

Strontium ferrite powders were prepared by the standard solid state reaction method in which $SrCO_3$ and Fe_2O_3 powders were taken in the molar ratio of 1:6 (Sr:Fe). The powders were thoroughly mixed using planetary ball mill for an hour. The mixed powders were made into pellets and calcined at 1473 K/7 h. Figure 1 (a) and (b) shows the X-ray diffraction pattern and the thermomagnetization curve for the calcined samples. The single phase nature could be confirmed from the XRD pattern as all the diffraction peaks could be identified to the $SrFe_{12}O_{19}$ phase (JCPDS 84-1531) and from the thermomagnetization curve by the presence of single curie transition (760 K).

The calcined powders were crushed and then micronized by introducing high pressure gas and the crushed powders in a circular chamber tangentially inducing inter particle collision. Figure 2 shows the magnetic hysteresis of the crushed powders and micronized sample. One could clearly observe the enhancement in coercivity. From SEM micrographs presented in figure 3 it could be seen that the particles have a plate like morphology in the calcined state while after micronization they are broken into more equiaxed individual particles. The average particle size was estimated to be about 0.7 ± 0.2 µm which is close to the theoretical single domain size of 0.5 µm of strontium ferrite. The presence of sharp edges, due to the plate like morphology of the calcined sample act as source of stray fields lowering the coercivity as anisotropy is reduced at these sharp edges. On the other hand, the micronized samples are more equiaxed with relatively rounded edges leading to the reduction of stray field and concomitantly enhanced coercivity. Commercially high coercivity ferrite powders are obtained by addition of La and Co which leads to increase in the cost.

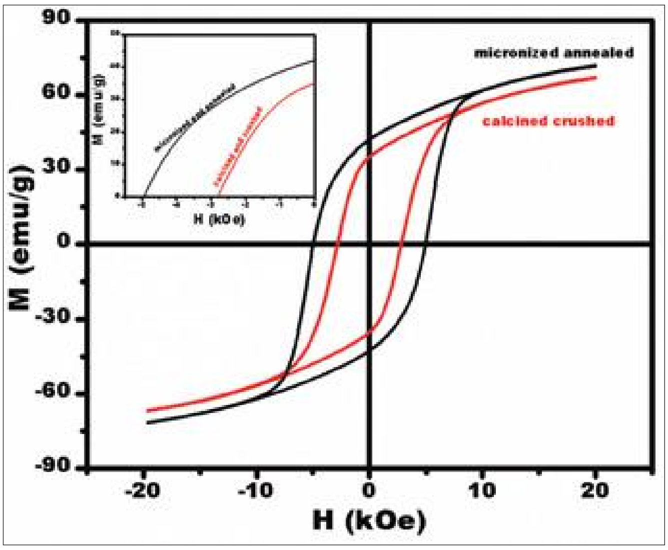


Fig. 2 Magnetic hystereis of the as-calcined and micronized sample showing the enhanced coercivity of the micronized sample. (Inset) Second quandrant demagnetization curves of the two samples

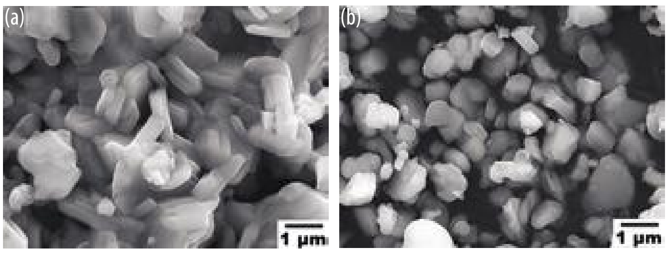


Fig. 3 SEM micrographs showing the (a) as-calcined sample with plate like particles and (b) micronized sample with more equiaxed and individual particles

The novelty of the present work is that the 5 kOe coercivity achieved is one of the highest values reported for the solid state method with small process duration and without addition of any dopants. With such promising intrinsic properties the powders can be used to make high performance magents which we plan to achieve by optimizing the sintering process.

Contributors: Ravi Gautam, A Eesha, Rajashekar, U Gowtham, S Vinoth, V Chandrasekaran and R Gopalan

Development of Sodium Ion Batteries as an Alternate to Li-ion Batteries

Sathiya Mariyappan ***sathiya@arci.res.in***

Li-ion batteries, with highest energy storage per unit mass and volume of any other batteries has completely engaged the portable market and is the most promising candidate for electric vehicle applications. However, the worldwide availability of lithium resources is inadequate to carry out the technology for future generation necessitating the need for exploration of new electrochemical energy storage devices. In particular, there are no lithium resources in India and moving towards sustainable energy storage device is a must for our country. With this in mind, the Centre has recently started the research activity of alternate energy storage devices and the main focus is put on sodium ion batteries.

Sodium, one member down to lithium in the periodic table, shows characteristics similar to that of lithium; Sodium ion batteries that work with the similar principle of lithium ion batteries are under development. However, the sodium ion battery technology is not fully explored worldwide and tremendous amount of research work is under progress. In this scenario, the research plan for the development of sodium ion batteries in the Centre starts from, (i) selecting the suitable electrode and electrolyte materials, (ii) assembling sodium ion full cells (coin cell level), (iii) demonstrating the technology in pouch cell level and, (iv) transferring the technology to pilot plant.

Towards this purpose, layered sodium transition metal oxides with high capacity and reversible sodium insertion property are selected as suitable positive electrode and hard carbon as negative electrode. Among the different forms of layered transition metal oxides (O1, O3 and P2), P2 type phases with high sodium ion conductivity is considered for the present study. P2 type sodium transition metal oxide was synthesized by hydroxide co-precipitation followed by solid state reaction. Synthesis was also carried out with the addition of sacrificial salt to avoid first cycle irreversibility associated with these P2 type materials. Fig. 1 shows the XRD pattern (left) and sodium reactivity (right) of (a and b) P2 type Na_xMO_2 where, x can be 0.7- 0.8 and M is one or more transition metal ions and (c and d) P2 type Na_xMO_2 with sacrificial salt. It can be seen from the figure that the P2 type Na_xMO_2 shows a huge first cycle irreversibility of ~35 mAh/g (Fig. 1 (b) inset) with reversible capacity of 120 mAh/g. The first cycle irreversibility is reduced/ nil in the composite made up of P2 type Na_xMO_2 and sacrificial salt (Fig. 1 (d) inset).

In another case, intergrowths of O1 type Na_xMO_2 and O3-type $LiMO_2$ are made by similar hydroxide co-precipitation followed by solid state synthesis. Such an intergrowth structure was found to reduce the phase transition associated with the sodium layered oxides during cycling. Fig. 2 (a) shows the X-ray diffraction pattern of the intergrowth structure (O1-Na_xMO_2 and O3 $LiMO_2$). The sodium reactivity of the phase shown in Fig. 2 (b) shows reduced phase transition during cycling.

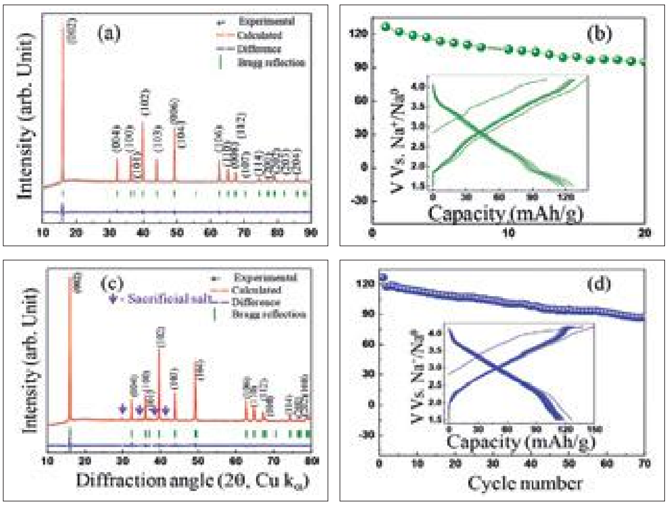


Fig. 1 XRD pattern (left) and galvanostatic charge- discharge profile (right inset) with capacity retention plot (right) of P2 type Na_xMO_2 (a and b), composite of P2 type Na_xMO_2 with sacrificial salt (c and d)

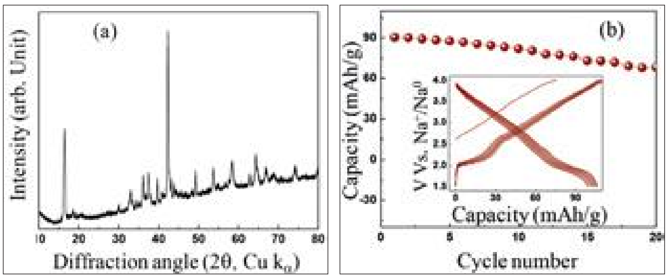


Fig. 2 X-ray diffraction pattern (a) and sodium reactivity (b) of the O1- Na_xMO_2- O3 $LiMO_2$ intergrowths. Capacity retention plot is shown in (b) and the inset shows the galvanostatic charge- discharge profile

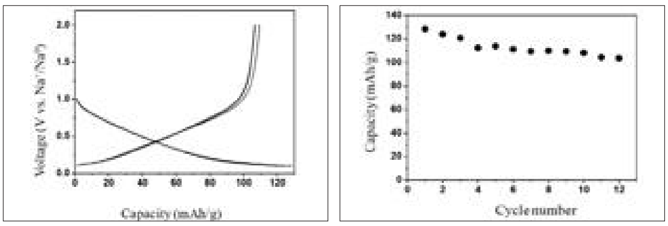


Fig. 3 Galvanostatic charge discharge profiles of hard carbon prepared from glucose (left) and its capacity retention plot (right) at C/10 rate

For the development of negative electrode materials, hard carbon was prepared by pyrolising glucose in inert atmosphere and optimization of various aqueous binders to stabilise the SEI layer. Electrochemical analyses are under progress. Initial studies (Fig. 3) with hard carbon negative electrode showed ~130mAh/g in the voltage window of 0.1 to 2 V at C/10 rate (1 sodium removal in 10 hours).

Contributors: Joy Thomas and R Gopalan

Effect of Doping on the Structural and Magnetic Properties of MnBi Alloys

S Kavita *skavita@project.arci.res.in*

Rare-earth-free permanent magnets are becoming more important due to increasing cost of rare-earth materials. MnBi is an attractive alternative to the permanent magnets containing rare earth elements, especially the ones for medium temperature applications (423–473 K) such as Nd–Fe–B–Dy and Sm–Co. The low temperature phase (LTP) MnBi has attractive temperature properties: its coercivity increases with increasing temperature, reaching a maximum of 2.6 T at 523 K. Therefore, MnBi has considerable potential as a permanent magnet at high temperatures especially in automobile industries for electric vehicle motor applications. However the major issue in this system is obtaining single phase of the LTP MnBi and the drop in magnetization. An attempt has been made to study the effect of doping on the structural and magnetic properties of the LTP MnBi.

$Mn_{55}Bi_{45}$, $Mn_{55}Bi_{40}X_5$ (X= Al) has been prepared by using arc-melting. The arc melted alloys have been homogenized at 573K for 24h. The annealed ingots were manually crushed and subjected to ball milling in Fritsch Ball mill with a ball to powder ratio of 1:10 and rotation speed of 50rpm. The structural characterization before and after milling has been done using CuKα (λ=1.54059Å) radiation in commercial powder x-ray diffractometer (PANalytical X'pert PRO). The magnetization measurements before and after milling has been carried out using Microsense Easy VSM Model EV9.

Figure 1 shows the XRD pattern of the alloys with milling, it has been observed that with milling the system is getting more homogenized which is evident by the increase in the intensity of the LTP MnBi peak. Figure 2 shows the hysteresis loops of the alloys before and after ball milling. The coercivity in the parent and the doped alloys has increased with milling which could be due to the decrease in particle size. It can be noted that there is a huge drop in magnetization in the parent compound. In the case of doped alloy, the drop in magnetization is less as compared to the parent compound. The detailed analysis of the magnetic properties with doping is in progress.

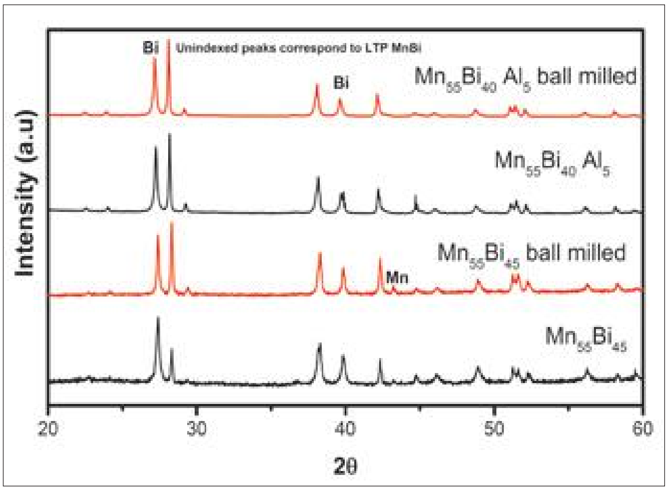
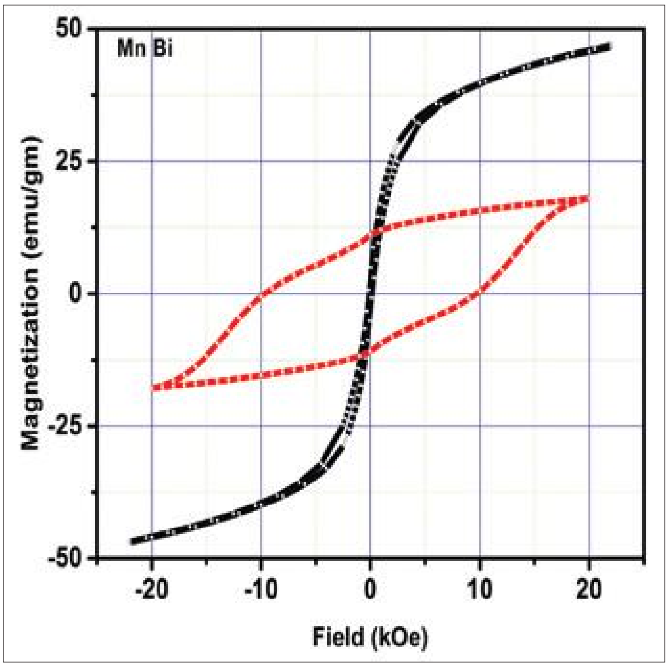


Fig.1 XRD pattern of MnBi alloys with milling



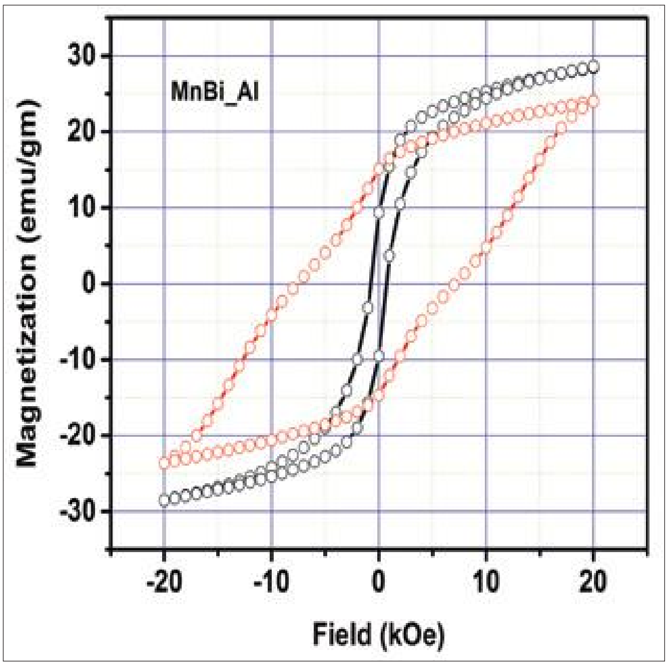


Fig.2 Hysteresis loops of the MnBi alloys before (black) and after (red) milling

Contributors: V V Ramkrishna and R Gopalan

Enhancement of Figure of Merit in Ni doped $CoSb_3$ Skutterudite Thermoelectric Material for Automotive Waste Heat Recovery

Manjusha Battabyal ***manjusha@project.arci.res.in***

Growing demand for alternative energy source has led to renewed interest in various energy fields like fusion energy, solar energy, waste heat recovery and so on. The waste heat recovery in automobiles is based on the thermoelectric (TE) technology that converts waste heat directly into electricity. The efficiency of the TE materials required for waste heat recovery is described in terms of figure of merit (ZT). For the best use of TE materials in automotive waste heat recovery, the ZT of the TE materials should be 2 or above at the operating temperature (600-900 K). Skutterudites are considered as efficient TE materials for automotive waste heat recovery applications due to their flexibility of fabrication and cost effectiveness.

Ni doped $CoSb_3$ skutterudite samples $Ni_xTe_{0.1}Co_{4-x}Sb_{12}$ (x =0, 0.3 and 0.5) are processed by ball milling and spark plasma sintering (SPS). The SPS pellets have dimension of 15 mm diameter and 4 mm thickness with density ~ 99%. The HRSEM performed on $Te_{0.1}Co_4Sb_{12}$ sample (Fig. 1) shows that the elements are distributed uniformly throughout the surface and the grain size varies between 150-200 nm. XRD investigation confirms that the sample is of single phase. In-situ high temperature XRD investigation confirms the stability of the $CoSb_3$ skutterudite phase and absence of any secondary phase in the temperature range starting from 300 K to 773 K (Fig. 2). The Raman spectroscopy experiments prove that Te filler atoms cause resonant optical vibrational modes between the Te filler atom and the host $CoSb_3$ skutterudite lattice. These optical vibrational modes scatter most of the heat carrying acoustic phonons. The lattice thermal conductivity calculated using the Debye model taking into account all the different phonon scattering mechanism confirms that the resonant phonon scattering has important contributions to the reduction of lattice thermal conductivity in Te doped $CoSb_3$ skutterudites. The ZT evaluated from the measurement of electrical resistivity (ρ), thermopower (S) and thermal conductivity (k) (Fig. 3) shows the enhancement of ZT in Ni doped $Te_{0.1}Co_4Sb_{12}$ skutterudites. Highest ZT ~ 1.3 has been achieved at 700 K in $Ni_{0.5}Te_{0.1}Co_{3.5}Sb_{12}$ sample. It proves that Ni doping helps in increasing the electrical conductivity in Te doped $CoSb_3$ skutterudites. To fabricate the TE module, both p-type and n-type TE materials having equivalent ZT values at the operating temperature are needed. Further work on improving the ZT in $CoSb_3$ skutterudite TE samples and skutterudite TE module fabrication is going on.

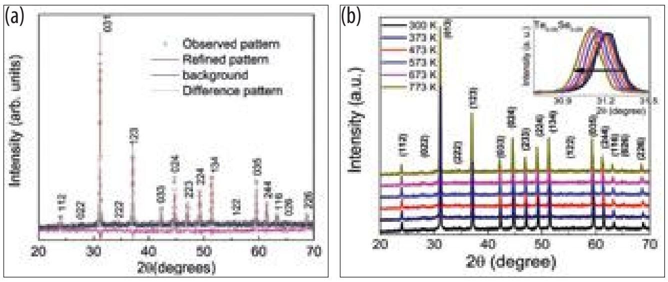


Fig. 2 (a) Rietveld analysis of the room temperature XRD data of the processed skutterudite sample and (b) *In-situ* high temperature XRD of one of the investigated skutterudite sample

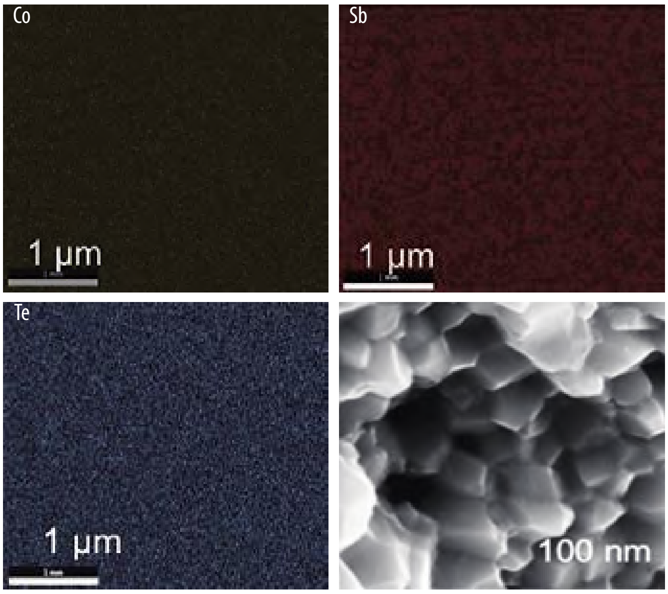


Fig. 1 Elemental EDS mapping of Co, Sb and Te on the $Te_{0.1}Co_4Sb_{12}$ sample surface. Extreme right image shows the high resolution SEM image of the fracture surface of the $Te_{0.1}Co_4Sb_{12}$ sample

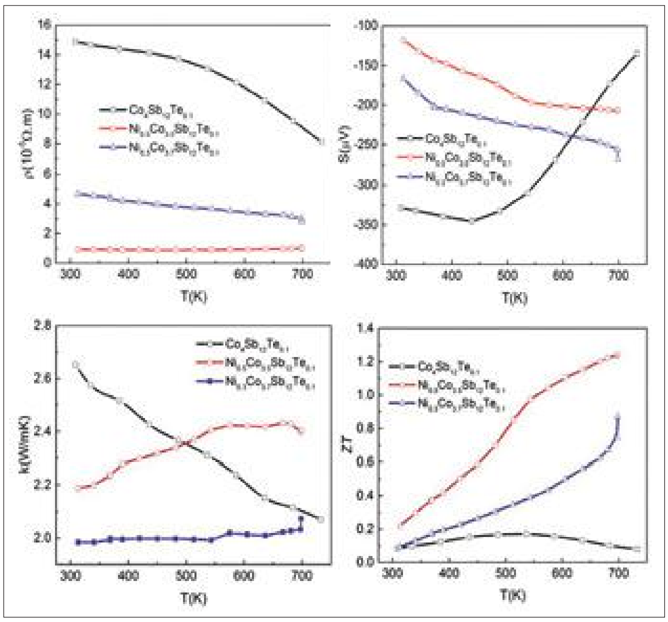


Fig. 3 Temperature variation of electrical resistivity (ρ), thermopower (S), thermal conductivity (κ) and figure of merit (ZT) of the studied samples

Contributors: B Priyadarshini, D Sivaprahasam and R Gopalan

Centre for Solar Energy Materials

The Centre for Solar Energy Materials (CSEM) is established at ARCI with the aim of developing solar energy conversion technologies which are expected to create niche markets in the rapidly growing Indian renewable energy sector. The prominent R&D activities at CSEM have encompassed a pilot line for CIGS module fabrication, development of cost effective CIGS and CZTS thin film solar cells by electrodeposition and ink-based routes and development of dye & perovskite-based next generation solar cells. Development of solar receiver tubes comprising indigenous selective absorber coatings for low, medium and high temperature concentrated solar power (CSP) applications and development of antireflective and dust repellent coatings for photo voltaic (PV) and CSP technologies constitutes another major area of activity. State-of-the-art characterization facilities are also available at CSEM to assist in accurate measurement of performance and durability of various PV and solar thermal devices.

$Cu(In,Ga)Se_2$ based solar cells are the most promising candidates among thin film solar cells leading with efficiency exceeding 21% and undergoing rapid commercialization to replace Si-based solar cell, having technological advantages of higher efficiency and possibility of making on flexible substrates. A typical $Cu(In,Ga)Se_2$ (CIGS) thin film solar cell on soda lime glass substrate consist of metallic Mo back contact, p-type CIGS absorber layer, an n-type CdS buffer layer, intrinsic ZnO layer and Al:ZnO transparent front contact and metallic Ni/Al contact grids to complete the cell, overall stack of 3.5 to 4 μm. Presently the efforts are being focused on technological development involving a two step process as well as non-vacuum process to make efficient CIGS thin film solar cell mini-modules on a substrate area of 300 mm x 300 mm. CIGS and CZTS thin film solar cells by electrodeposition is another important activity being perceived with an aim of realizing large-area uniform CIGS films using low-cost source materials. Highly crystalline CIGS absorber films with near ideal stochiometry are obtained by pulse-reverse electrodeposition technique and a maximum photocurrent of 4.3 mA was demonstrated in PEC cell. Present efforts are being focused on the fabrication of complete PV cell.

Perovskite solar cells (PSCs) rapidly gained prominence because of their high power conversion efficiency and low fabrication costs. Possibilities of tailoring the optical and electrical properties of perovskite through elemental composition offer the potential to realize transparent and flexible solar panels for building-integrated and vehicle-integrated photovoltaic applications. A maximum energy conversion efficiency of 8.5 % has been demonstrated in ambient processed, lab-scale PSCs. Current efforts are being focused on efficiency improvement, stability studies in real time environment and fabrication of prototype PSC module for technology demonstration.

Apart from solar PV technology, concentrated solar thermal power (CSP) technology is growing faster than any other renewable technology. The major challenge in CSP technology is reducing the cost of solar collectors by employing an economical solar receiver design. This demands development of low-cost solar functional coatings having the desired optical properties as well as very robust weather and thermal resistant properties. Considering the vast commercial potential, the centre has also been focusing on developing high and medium thermal stable selective absorber coatings and other functional coatings (e.g. anti-reflection, dust repellent and antireflection with super hydrophobic property). A high performance tandem absorber (α = >0.95 & ε at 300^{0}C < 0.16), broad band antireflection (>97% from 400-1500 nm) and dust repellent (>130^0 water contact angle with high transmittance) coatings with high weather and thermal stabilities has been demonstrated from lab to semi-pilot scale. Present efforts are being focused on the prototype demonstration for commercial exploitation.

S Sakthivel
ssakthivel@arci.res.in

Tata Narasinga Rao
tata@arci.res.in

High Performance and Environmentally Stable Broad Band Antireflective Coatings using Novel Ink-Bottle Mesoporous MgF_2 Nanoparticles for Solar Applications

S Sakthivel ***ssakthivel@arci.res.in***

In recent years, the development of broad-band anti-reflective coatings (BARCs) has attracted substantial research interest due to their high transmittance in a broad wavelength range (300 – 2500 nm) for diverse potential applications spanning photovoltaic (PV) systems, optical and architectural glasses, windscreens, high power lasers, windows and video display panels. The promise of utilizing BARCs in solar and optics is particularly immense. However, to achieve competitive conversion efficiencies, the coatings must transfer maximum incident light over a broad range of wavelengths and incidence angles, instead of transmitting only a limited range of wavelengths in the solar region. Due to their high refractive indices, optical elements like glass and polymeric transparent substrates suffer a reflection loss of about 8 - 9% in the visible spectrum of the solar radiation, there by resulting in effective transmission of < 91%. Such reflection losses are undesirable and detrimental to the overall light to electricity conversion efficiency in solar cells / solar thermal collectors or any other type of devices that require minimal reflection. Therefore, achieving broad band anti-reflection is a key to further enhancement of energy conversion in both solar PV and concentrated solar thermal power (CSP) based power generation.

There are several strategies to achieve broadband low reflection coatings. One of them is surface patterning by chemical modification of surface of transparent substrates. This, however, involves controlled etching of the substrate surface which reduces its mechanical strength. Using the mesoporous dielectric film generation technique, many research groups have achieved a high antireflective performance. However, generation and preservation of such a periodic mesoporous structure during synthesis and processing is challenging. More recently, MgF_2 nanoparticles with a variety of morphologies, for example hollow spherical particles, platelets, cubes, prismatic particles, nanorods of MgF_2 etc., have been reported. Only a few reported the development of antireflective coatings incorporating MgF_2 nanoparticles.

Moreover, Fabrication of environmentally and thermally stable antireflective layers with mesoporous MgF_2 nanoparticles on solar cover glass (for PV cells and CSP solar collectors) has not yet been reported. There are significant technical challenges that it poses.

The present work describes a new method for the synthesis of mesoporous MgF_2 nanoparticles for antireflective coating applications, with nearly 100% optical transparency (showing nearly zero reflection) in the visible range, high average percentage of transparency over a wide range of wavelengths from visible to NIR and easily tailorable refractive index. Unlike earlier approaches, novel MgF_2 nanoparticle morphologies having an ink-bottle type mesoporous structure were synthesized via novel lyothermal synthesis from coarse commercial MgF_2 hydrate particles. This method of MgF_2 nanoparticles synthesizing and anti-reflective (AR) film formation has excellent reproducibility, facile and greater applicability than any other conventional method of preparation of MgF_2 nanoparticles and their films. The excellent performance of AR coating using the novel ink-bottle type mesoporous nanoparticles was also confirmed by measuring the photovoltaic performance of c-Si solar cell with uncoated and coated PV cover glass.

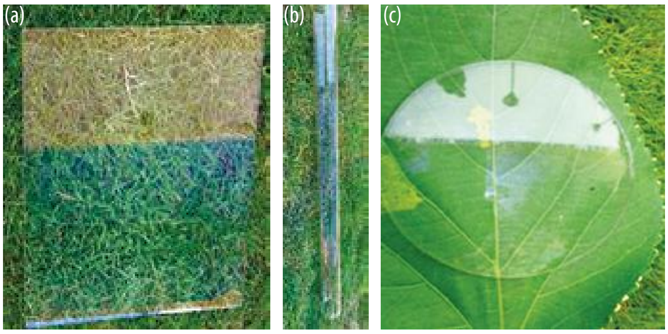
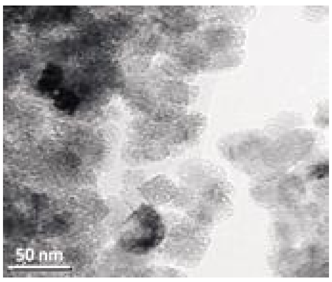


Fig. 3 Images of partially AR coated substrates: (a) PV cover glass (30 x 30 cm); (b) CSP cover glass tube (0.5 m length; 5 cm OD; 3 mm thickness): and (c) CR-39 lens (7.5 cm dia) (top portions are uncoated)



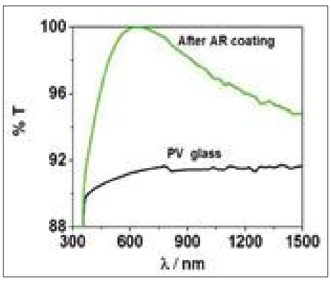


Fig.1 & 2 TEM image and Optical transmittance of ink-bottle type mesoporous nanoparticles

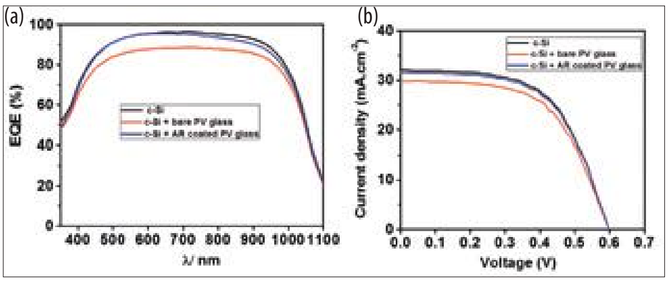


Fig. 4 (a) External quantum efficiency spectra and (b) Current-voltage characteristics of c-Si solar cell with uncoated and MNP-1 coated PV cover glass

Contributors: D Karthik and P Saloni

Nano-structured CIGS Thin-film Absorber Layer with Improved Performance for Solar Photovoltaic Applications

B V Sarada ***sarada@arci.res.in***

Chalcopyrite CIGS thin-films exhibit absorption coefficient much higher than that of crystalline Si, yet the efficiencies exhibited by CIGS based solar cells are lower, due to their lower minority carrier diffusion length. In this context, nano-structuring of the absorber material is expected to play an important role in enhancing the efficiency of these thin-films solar cells. Presently, nano-structuring of materials has gained much interest due to the unique properties achievable at nano-scale. One dimensional and two dimensional nano-structures are attractive for solar photovoltaic applications owing to their desirable physical properties. The geometry of these materials shows complimentary effect on the performance of photovoltaic devices. The nano-flake configuration with a thickness required to absorb light and with a suitable height of the flakes, where charge separation occurs in the orthogonal direction throughout the flake can be an attractive option. In this configuration, the distance travelled by minority carriers is equal to the thickness of the flake, which should decrease charge recombination, especially in semiconductors with short minority carrier diffusion length. Fabrication of nano-structured absorbers by low-cost method is crucial in the economic realization of nano-structured solar cells.

In the present study, $Cu(In,Ga)Se_2$ absorber films containing vertically aligned two-dimensional nano-flake structures through an intrinsic electrochemical dissolution phenomenon associated with the pulse electrodeposition technique have been fabricated and characterized. Tri-sodium citrate is used as the complexing agent (Figure 1a and inset). The chalcopyrite phase pure formation of CIGS nanoflakes is confirmed by the XRD and Raman Analyses. Figure 1 b shows XRD patterns of the CIGS structures with different deposition durations. No secondary phases like CIS, CGS, CIGS, $Cu_{2-x}Se$ were formed, which was confirmed by both XRD and Raman patterns. The bandgap of the nano-flaked CIGS is determined to be ≈ 1.21 eV from the Tauc's plots. The nano-flake structures of the CIGS are expected to increase surface area by several times compared to a planar CIGS film, thus improve the device performance by efficient absorption of light and effective transport of minority carriers in photovoltaic cells. The CIGS nano-flake structured thin-films exhibited a twenty-fold increase in photoresponse over planar films, ideal for solar cell applications. Effective absorption of sun light occurs due to the excess surface area of CIGS nano-flakes thus yielding increased probability for carrier generation. In addition, the larger surface area contributes to increased junction area between CIGS nano-flakes and electrolyte which in turn increases the depletion potential that is responsible for the separation of charge carriers. The CIGS thin-films with nano-flake structures prepared by environmental friendly, cost-effective and scalable pulse electrodeposition technique can be an ideal choice for their application in solar photovoltaic applications.

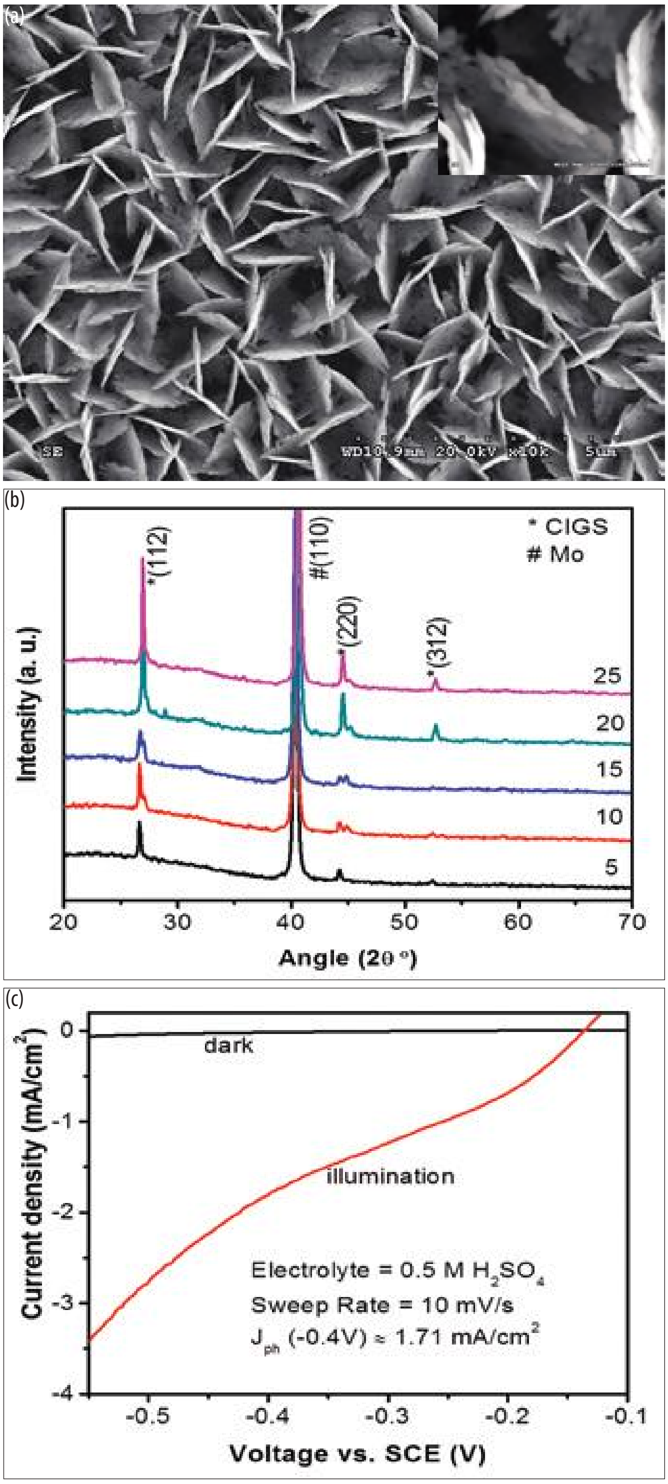


Fig. 1 (a) FESEM image of the nano-flake structures of the CIGS thin-films prepared by pulse electrodeposition technique, (b) XRD patterns of the CIGS structures prepared with different durations of deposition, (c) Photoelectrochemical performance of the CIGS absorber layer with nano-flake architecture

Contributer: M Sreekanth

Aluminium Doped Zinc Oxide Front Contact for Large Area CIGS Thin Film Solar Cell Applications

Sanjay R Dhage ***dhage@arci.res.in***

Aluminium doped Zinc oxide (Al:ZnO) is most popular transparent conducting oxide material as front contact for $CuInGaSe_2$ (CIGS) thin film solar cells as it is cheap, readily available, non-toxic and has better chemical stability. Al:ZnO thin films can be deposited by various methods such as sputtering, pulsed laser deposition, spray pyrolysis, e-beam evaporation and chemical vapour deposition but magnetron sputtering has evolved as a favourable deposition method since it is cheap and non-toxic and can also obtain high uniformity on large area. Low sheet resistance (5 Ω/□) and high optical transmission (> 80%) are desirable for high performance of CIGS thin film solar cells. Properties of sputtered Al:ZnO thin films are highly dependent upon sputter process parameters such as base vacuum, gas flow, power density and substrate temperature. At ARCI, we optimized various process parameters to obtain highly conductive and visible light transparent Al:ZnO thin films on soda lime glass (SLG) substrate of the size of 300 mm x 300 mm, suitable for CIGS thin film solar cell application.

Al:ZnO thin films with average thickness of about 910 nm were coated on SLG substrate of size 300 mm x 300 mm x 3 mm using a sputter coater equipped with a cylindrical rotating DC magnetron (Make: Singulus Technlogies Gmbh). Before sputtering, the SLG was cleaned using standard glass cleaning procedure. X-ray diffraction analysis confirmed formation of highly crystalline hexagonal wurtzite structure with preferred orientation along c-axis perpendicular to substrate. Highly dense uniform grain morphology of sputtered Al:ZnO thin film has been observed. Optical transmittance (Varian, Cary 5000) of 78.8% (figure 1) in visible region and sheet resistance (Loresta GP, Mitsubishi, Japan) of 5.57 Ω/□ was realized by optimizing sputter process parameters and substrate temperature. The values are very much acceptable for CIGS and various other applications such as transparent conductive oxide (TCO). High degree of thickness uniformity (better than ±3% standard deviation) of optimized Al:ZnO thin film on 300 mm x 300 mm area can be deduced from x-ray fluorescence spectroscopy, Figure 2. In order to further improve conductivity and optical transmittance, air annealing carried out on Al:ZnO thin films up to temperature of 500°C, realized best sheet resistance of 4.4 Ω/□ and optical transmittance of 81 % in visible region at the annealing temperature of 200°C. It is also important to note that the films were stable up to temperature of 300°C for Al_2O_3 formation which degrades electrical conductivity thereafter (Figure 3). In conclusion, highly conductive and visible light transparent Al:ZnO thin film as front contact for large area CIGS thin film solar cell application by DC magnetron sputtering was achieved successfully.

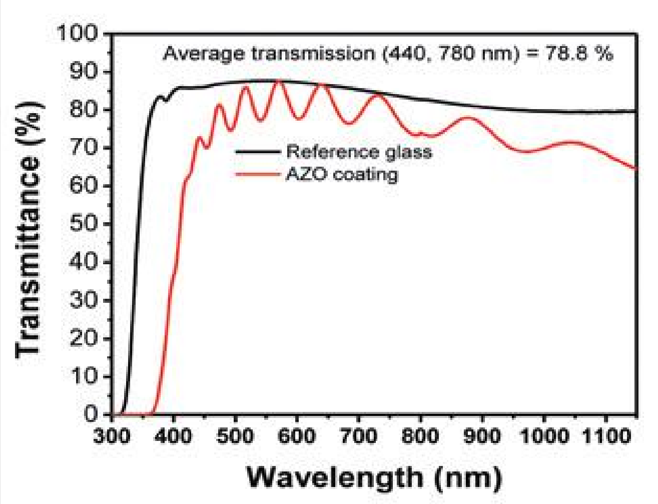


Fig.1 Optical transmittance of Al:ZnO thin film

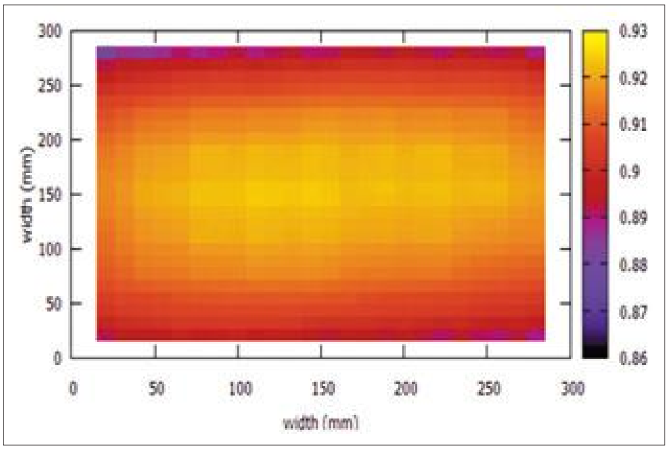


Fig. 2 Thickness map of Al:ZnO thin film on 300 mm x 300 mm soda lime glass substrate

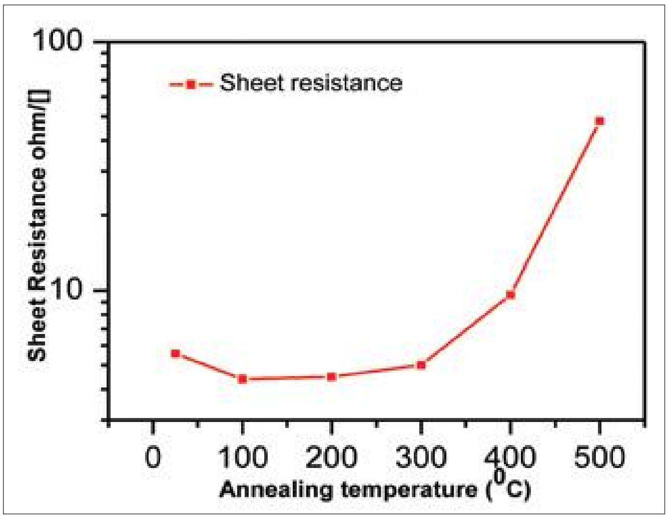


Fig. 3 Variation of sheet resistance with air annealing temperature of Al:ZnO thin film

Contributor: Amol C Badgujar

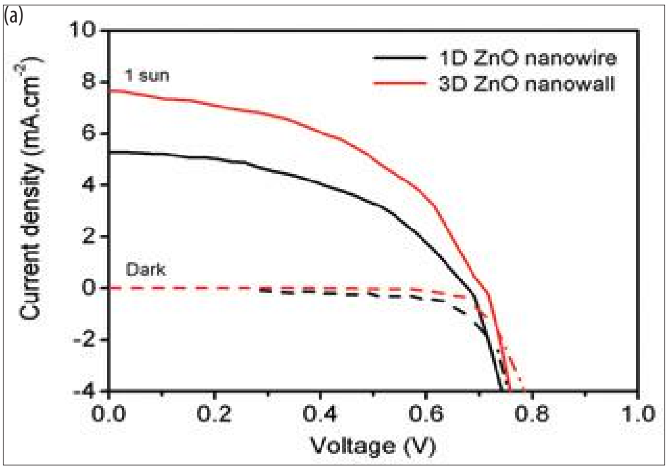
Aligned 3D ZnO Nanowall Electron Transporting Layer for Perovskite Solar Cells

Easwaramoorthi Ramasamy ***easwar@arci.res.in***

Zinc oxide (ZnO), with a direct band gap and high electron mobility is a promising candidate material for optoelectronic devices. In specific, the technological advantages of aligned one-dimensional (1D) ZnO nanowires are successfully demonstrated in nanolaser, light emitting diode and field effect transistor. The superior performance observed in devices constructed using 1D nanowire is usually attributed to enhanced electron transport and quantum confinement effect. Expanding from the 1D nanowires, aligned three-dimensional (3D) nanowalls are novel building blocks for devices those require not only facile carrier transport path but also the higher surface area. Nevertheless, aligned 3D nanowalls received less attention, presumably because of the difficulties in retaining their shape during the growth process. Here, we report a facile and scalable low-temperature solution approach to grow vertically aligned 3D ZnO nanowall on transparent conductive substrate by introducing a controlled amount of Al into a seed layer. The optimum amount of Al addition didn't affect the substrate's optical properties, yet provides facile control over the grown ZnO nanostructure. By varying Al content in the seed layer, the morphology of ZnO nanostructure is gradually changed from 1D nanowire to 3D nanowall arrays. Such vertically aligned 3D ZnO nanowall architecture grown on a transparent conductive substrate was demonstrated to be beneficial for electron transport in perovskite solar cells (PSCs). Fig.1 shows the cross-section SEM image of vertically aligned ZnO nanowall arrays grown on 3% Al-ZnO seed layer coated FTO glass substrate. Optimum grown nanowall arrays exhibit a uniform height of 2 µm and a wall thickness of ca. 50 nm. Methylammonium lead iodide ($CH_3NH_3PbI_3$) perovskite absorber layer was deposited on ZnO nanowall arrays by a two-step deposition process. Device fabrication was completed by sputter deposition of Au cathode.

Current-voltage characteristics of aligned ZnO nanowire and nanowall PSCs were studied in the dark and under simulated solar light (Fig.2). Both devices exhibit similar dark current, indicating there is not much change in the charge recombination kinetics. Nevertheless, notable difference was observed in photocurrent-voltage characteristics. Devices fabricated using 3D ZnO nanowall array show higher photocurrent density (JSC) and power conversion efficiency than those of 1D ZnO nanowire based devices. Comprehensive photovoltaic parameters of PSCs measured under 1 sun illumination (AM 1.5G, 100 mW.cm^{-2}) are provided at Fig. 2(b). The large effective surface area and cage-like open pores of aligned 3D ZnO nanowall architecture might have improved the perovskite loading, thereby higher light absorption and JSC. Efforts are now underway to incorporate hole transporting material in-between the perovskite absorber and metal cathode for realizing >10% power conversion efficiency.

(a)



(b)

Electron trasport layer	Voc [V]	Jsc [mAcm^{-2}]	FF	η F[%]
1DZnO nanowire	0.740	5.33	0.46	1.82
3DZnO nanowall	0.760	7.75	0.44	2.59

Fig. 2 Current-voltage characteristics curve (a) and device parameters of PSCs (b) with different electron transporting layer

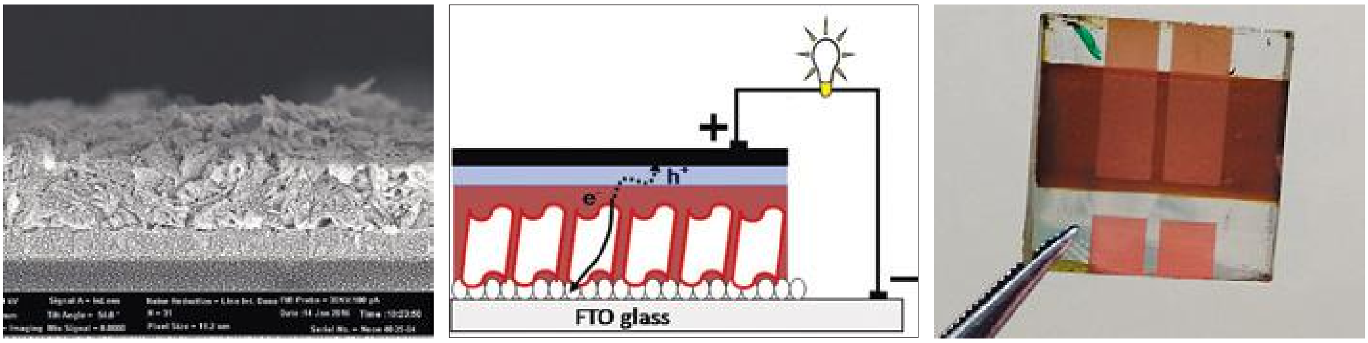


Fig.1 Cross-section SEM image of aligned ZnO nanowall array on FTO glass substrate (left), schematic (middle) and digital photograph of complete PSC (right)

Contributor: Nanaji Islavath

Particulate Free CdS Thin Films on 300 mm x 300 mm Glass Substrate for CIGS Thin Film Solar Cell Application

P Uday Bhaskar *pudayb@project.arci.res.in*

High Efficiency $CuInGaSe_2$ (CIGS) thin film solar cells utilizes Chemical Bath Deposited (CBD) CdS as a heterojunction partner to the CIGS absorber layer. CdS is normally being prepared by using Semi-automated CBD system established in our pilot line facility to make CIGS thin film solar cells on substrate size of 300 mm X 300 mm. During the Chemical bath deposition, precipitate particulates also form along with the CdS films which results in over estimation of final thickness and reduces the transmittance of the film. The objective of the work is to obtain particulate free CdS film by appropriately varying the Cadmium to Thiourea (Cd/Tu) and Cadmium to Ammonia (Cd/Amm) ratios.

Cd-salt, thiourea, ammonia and DI water were used as starting precursor solutions. Cd/Tu and Cd/Amm ratios were varied by changing the individual precursor concentrations. The deposition time for all experiments was kept constant for about 6 min. The CdS film properties such as, thickness, crystal phase, transmittance and band gap were determined.

Particulate free CdS film was achieved by changing the Cd/Tu and Cd/Amm ratio. As shown in Figure 1, Cd/Amm ratio, ammonia concentration was increased to slower the growth reaction and at the same time in Cd/Tu ratio, the thiourea concentration was decreased to reduce the growth rate. The number of particulates seen along with the CdS film were decreased by decreasing the Cd/Amm ratio. At higher Cd/Amm ratios, large no. of particulates adhere on the film whereas at lower Cd/Tu ratio the particulates are less but thickness values were found to be high. This is just a trade-off between Cd/Amm and Cd/Tu ratio to get particulate free with desirable thickness. Particulate free CdS film with thickness of 50 nm was obtained by choosing low value of Cd/Amm ratio and high value of Cd/Tu ratio. The final film thickness was determined by using X-ray Fluorescence spectroscopy (XRF) and found to be in good agreement with the values obtained from SEM cross-section and Zygo-optical profilometer. The structure of particulate free CdS film was determined by using X-ray diffraction measurements and TEM SAED Pattern. The XRD peaks and planes observed in SAED pattern shown in Figure 2, match with hexagonal structure of ICDD No. 00-001-0783. The transmittance of particulate free CdS film was found to be ~75 % and band gap value was determined as 2.47 eV. In conclusion, the particulate free CdS films can be obtained by balancing between the reaction rate and growth rate with the help of varying ammonia and thiourea precursor concentrations.

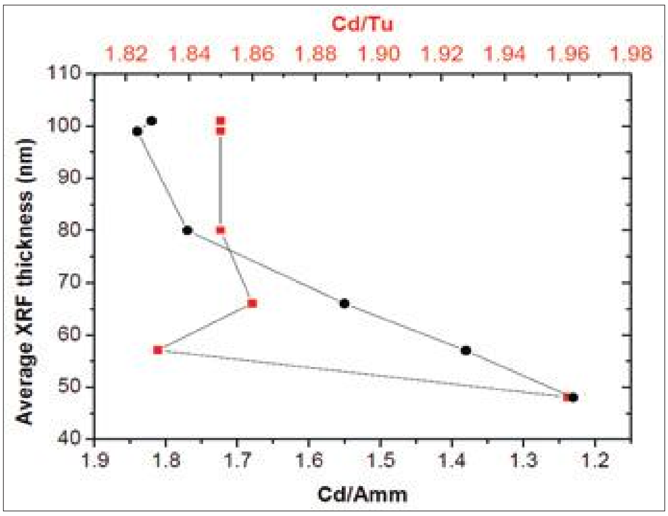


Fig.1 A plot of Cd/Amm and Cd/Tu Versus average film thickness

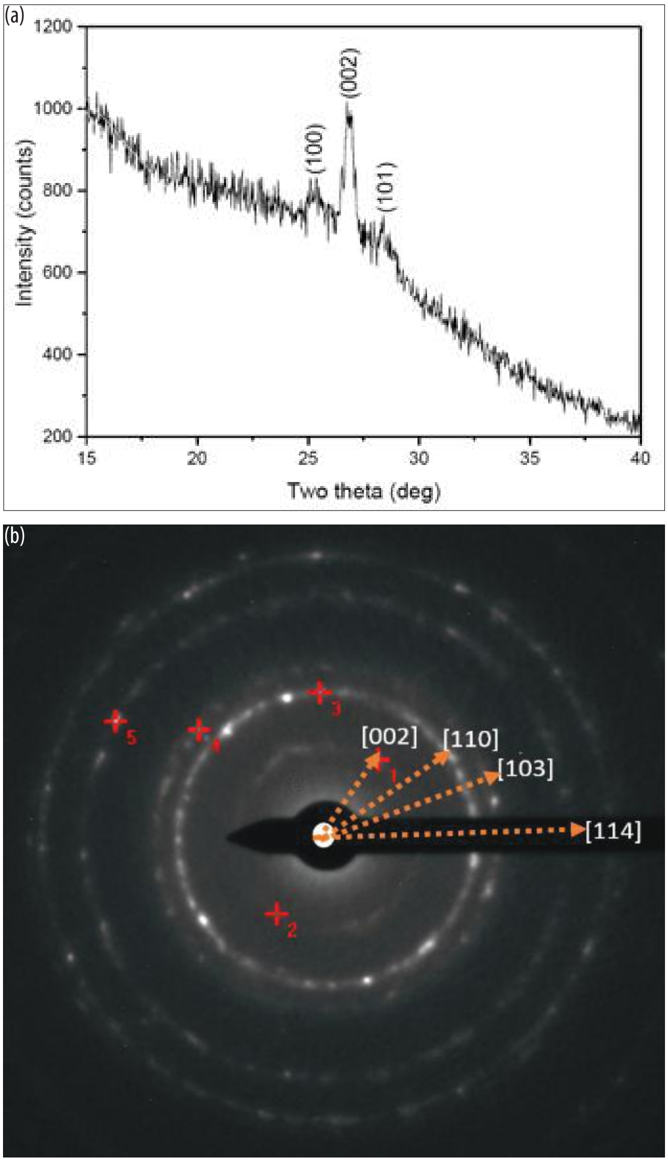


Fig. 2 (a) XRD spectrum (b) SAED pattern of Particulate free CdS film

Contributor: Sanjay R Dhage

Non-Vacuum Based Solution Processed $CuInS_2$ Thin Film Absorber for Solar Photovoltaic Application

Amol C Badgujar *badgujaramol@project.arci.res.in*

Copper indium disulphide ($CuInS_2$) is promising thin film absorber material along with its alloy CuIn1-x $Ga_x(Se_xS_{1-x})_2$ as direct band gap material with high absorption coefficient of order of 10^5 cm^{-1}. Cost effective non vacuum processes are generally employed to obtain large area deposition for chalcopyrite absorber thin films which usually comprises of precursor deposition by spin coating, spray pyrolysis, chemical bath deposition followed by sulphurization or selenization at high temperature of order of 400-550°C. In the present work, non-vacuum route of deposition by spray coating of molecular precursors at low temperature of 150°C followed by intense pulse light post-treatment under ambient conditions was adopted to obtain crystalline $CuInS_2$ thin films.

Precursor solution for spray pyrolysis comprised of hydrates of Copper nitrate, Indium nitrate and thiourea (All from Alpha Aesar) was dissolved in solvents to obtain clear solution. Precursor solution was sprayed using air brush on pre-cleaned Soda Lime Glass (SLG) substrate of size 75 mm x 25 mm x 3 mm placed vertically, substrate temperature was maintained at 150°C during spraying. Solution concentration and spray parameters such as air pressure, substrate temperature, spraying rate and nozzle substrate distance were optimized to control thickness of precursor thin film. Intense pulsed light (IPL) post treatment (Make Star Laser, India) was carried out on spray coated $CuInS_2$ precursor layer. The IPL post-treatment parameters such as pulse power, pulse width, pulse delay and number of pulses were optimized to obtain uniform $CuInS_2$ thin film, thickness of the film was found to be highly uniform over the full coating area.

All $CuInS_2$ thin films were characterized for crystal phase, elemental composition and opto-electronic properties. As sprayed films confirmed formation of $CuInS_2$ phase but with poor crystallinity, revealed from x-ray diffraction and Raman analysis. This can be attributed to slightly lower substrate temperature during spray. The precursor films were exposed to IPL for post treatment to improve the crystallinity. Films obtained by IPL post treatment confirmed phase pure $CuInS_2$ tetragonal chalcopyrite structure which is also complimented by Raman spectrum as shown in figure 1 wherein, peaks at 297 cm^{-1} corresponds to Cu poor CIS_2 phase. The Cu poor phase formation is also evidenced by EDS elemental composition. Cu poor $CuInS_2$ is essential for p-type conductivity of thin films. Dense large grains were evidenced from surface of IPL post-treated films compared to porous cracked morphology of as sprayed films, as can be seen from figure 2. Band gap of 1.4 eV was deduced from transmittance spectrum of IPL post-treated thin films and has shown better photo response than as sprayed thin films. In conclusion, spray pyrolysis followed by IPL treatment of $CuInS_2$ films is promising method for solar cell fabrication.

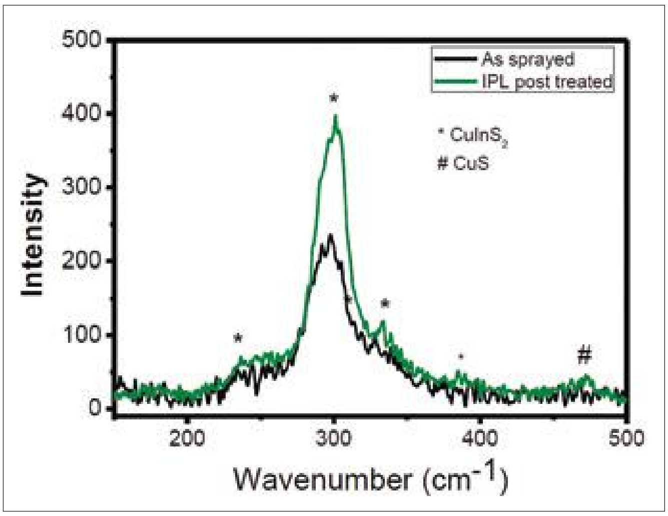


Fig. 1 Raman spectrum for as sprayed and IPL post-treated CuInS2 thin films

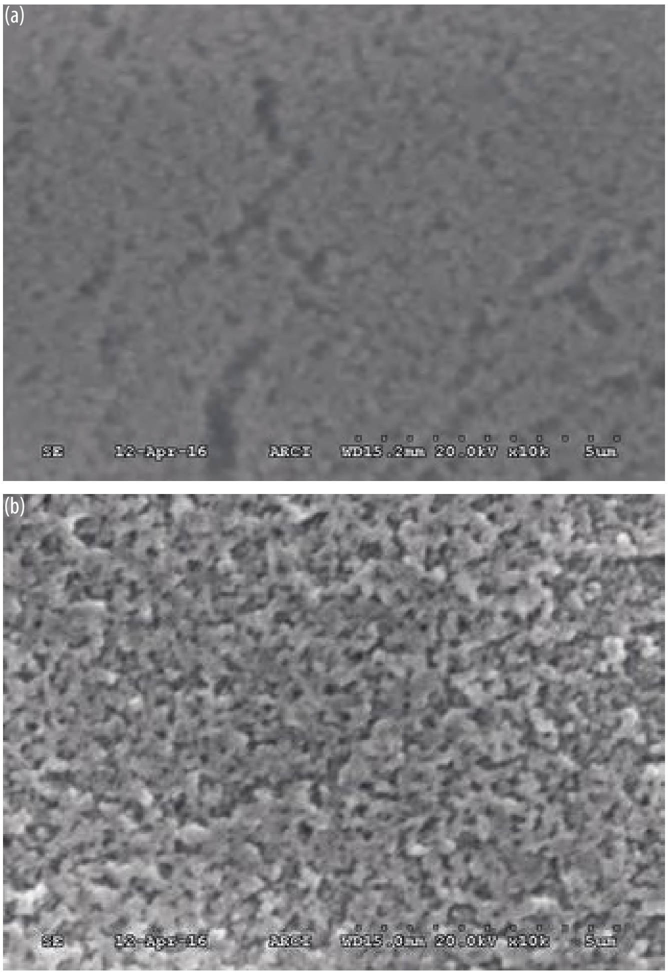


Fig. 2 FESEM surface images for (a) as sprayed and (b) IPL post-treated $CuInS_2$ thin films

Contributor: Sanjay R Dhage

Synthesis and Development of Mixed Halide Perovskite Solar Cells

Ganapathy Veerappan ***ganapathy.inspire@project.arci.res.in***

In the past several years, organic-inorganic halide based perovskites has become an exciting topic in the field of photovoltaic community for direct conversion of solar energy into electricity. Perovskite solar cells (PSCs) have overtook or on par with most solar cells by reaching efficiencies beyond 21.0%, which makes it a competitive energy source in the near future for commercialization.

Organic-Inorganic perovskites ($CH_3NH_3PbX_3$, X=I, Cl or Br) have unique properties such as, direct band gap, high absorption coefficient from visible to near IR region, faster carrier mobility, and low defect density. Though great research accomplishments has been achieved in short period for PSC, still the room for improvement is available.

In this work, we report the hole conductor-free mixed halide PSC with high efficiency by tuning the morphology of the perovskite films with different deposition techniques (one step, two-step process and new deposition method). The properties of the synthesized material and performance of the solar cells are characterized with the help of XRD, UV-vis spectrometer, FE-SEM and photovoltaic characterization.

Crystallinity and morphology of the perovskite are two important factors that directly influence the performance of the cell. Fig. 1 shows the surface morphological images of $PbCl_2$ and $CH_3NH_3PbI_{3-x}Cl_x$ film made by different deposition techniques. Fig. 1a shows the surface morphology of $PbCl_2$ film, $PbCl_2$ powder was dissolved in DMSO and deposited over the TiO_2 layer by spin coating and has lots of pinholes. Fig. 1b shows the surface morphology of $CH_3NH_3PbI_{3-x}Cl_x$ film, sample prepared by one step process in which $PbCl_2$ and methyl ammonium iodide (MAI) was dissolved in DMSO and deposited over the TiO_2 film, which has non-uniform film. Fig. 1c shows the film prepared by two step process, in this method the MAI solution was deposited over the $PbCl_2$ film, which has better film uniformity but small pin holes, Fig. 1d shows the film made by new deposition route, which has cuboid morphology with no pin holes.

The photovoltaic performances of the devices made by various deposition methods were measured under 0.86 Sun illumination and its corresponding spectra are given in Fig. 2. Device made with new deposition route (c) shows higher photovoltaic parameters (η=6.4%) when compared to the other two techniques ((a) one-step: η =2.8%, (b) two-step: η =4.1%).

In new deposition route, unique cuboid pin hole-free films were formed, exhibiting good absorption and high efficiency. From the non-optimized condition, we have achieved 6.4% of efficiency for the device prepared by new deposition method, and further work is under process for improving the efficiency beyond 10%.

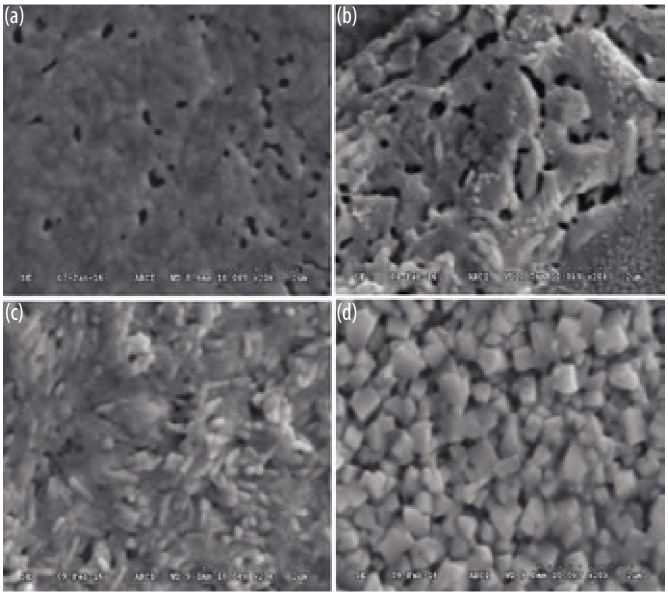


Fig. 1 (a-d) Surface morphological images of the mixed halide perovskite films prepared by different deposition techniques

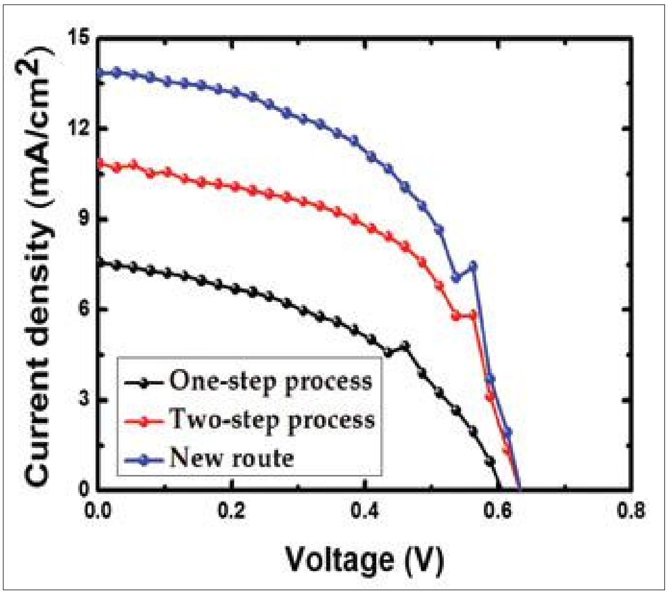


Fig. 2 IV curves for all the mixed halide perovskite films prepared by different deposition method

Contributor: M Suresh

Centre for Nanomaterials

The Centre for Nanomaterials (CNM) established at ARCI for the development, demonstration and production of nanopowders and nano structured components made a lot of progress during last year. One of the major accomplishments of the Centre is transferring technology based on photocatalytic TiO_2 to an Indian Company, which have in turn launched self cleaning jeans in the market with the brand name "Selfie" and "Sun Wash". The silica aerogel flexible sheets technology for thermal insulation application was also transferred to an Indian Company. Apart from technology transfer activities, Institute of Plasma Research initiated a major project with Centre for Nanomaterials for the development and production of oxide dispersion strengthened steel plates for fusion reactor. The other research activities being undertaken at the Centre are Li-ion batteries and Super Capacitors for electric vehicle (EV) applications, oxide dispersion strengthened steels for high temperature applications like blades for steam and gas turbines, additives to lubricants and grease, nanostructured materials as catalysts in oil refineries and petrochemical industries, and solar hydrogen materials. The stall displaying various nanomaterials/commercial products developed at the Centre received the 'Best Creative Design' Award during the Bangalore Nano 2015 exhibition.

Various nano powders such as $LiFePO_4$ and LTO for Li-ion battery and nano aluminium as additive to rocket propellant were produced on large scale using unique facilities such as Flame spray pyrolysis and RF induction plasma. Progressive reactive hot press intended to make continuous Fe/steel based PM components from blue dust was conceptualised, designed and successfully put into operation at the Centre. The progress made by the Centre is due to the concerted efforts of the dedicated scientists, research fellows, technical staff and students.

R Vijay
vijay@arci.res.in

Tata Narasinga Rao
tata@arci.res.in

Nano-structured Selenide Films for Thermo Electric Energy Generation

Pramod H Borse ***phborse@arci.res.in***

Nanostructured films of sulfide/selenides find potential applications in thermoelectric energy generation and optoelectronic industries. PbSe and SnSe systems have been seen as potential material systems for thermoelectric generator (TEG). We at ARCI are devising simple economic method for producing the nanostructured films so as to realize a low cost film for TEG application with reference to focus on automotive applications. The system is ideal due to its predicted high ZT value under moderate temperature ranges. We have deposited TEG films on required thermally stable substrate in a nanostructured configuration.

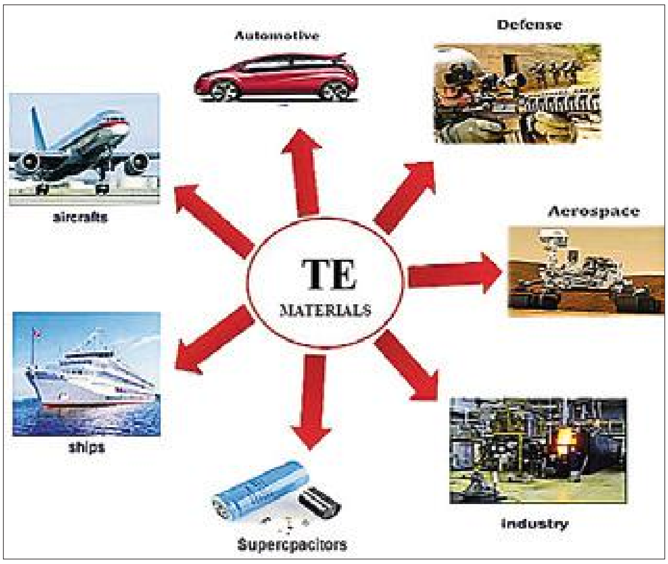


Fig.1 Various strategic and energy applications of thermoelectric materials

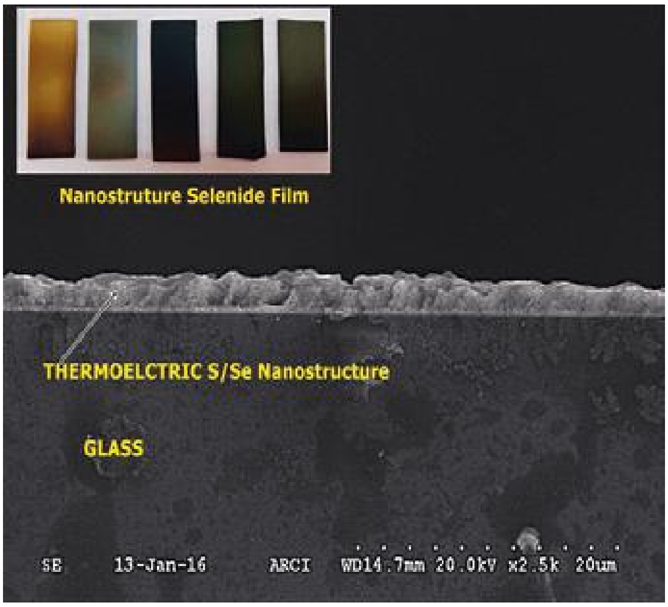


Fig. 2 Film cross-section and photograph of selenide nanostructure film with reference to optical properties

Figure 2 shows the films deposited on the glass substrate under various conditions accordingly one is able to tune the nano-morphology of the films. These are deposited by simple spraying of the precursor under moderate conditions. They show tunatbility with reference to optical properties indicating their application in the photo detection for IR radiation.

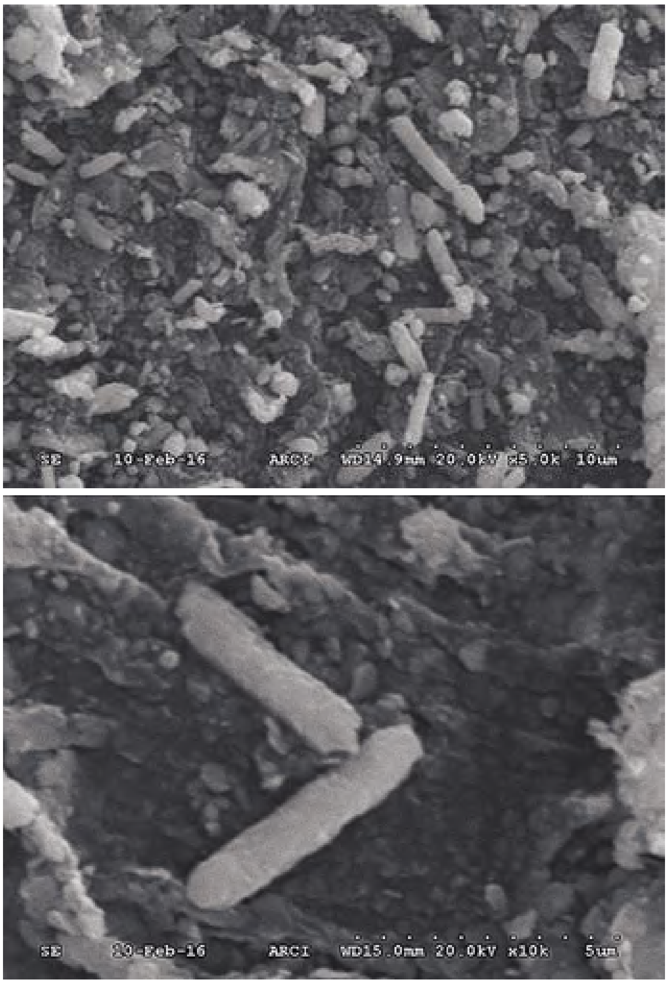


Fig.3 FESEM photograph of the oriented nanostructure of TEG material

Figure 3, shows the rod like nanostructured SnSe that is desirable for high ZT material. It is desirable to attain the b-axis oriented selenide film for achieving ZT>2.5. Such oriented films exhibits desirable electrical and thermal conductivity, which channelizes the charge carriers and phonons to yield high performing TEG material. The simple methodology is well suited for different applications in IR/optical detector, super capacitors, photoconductors, holographic-detectors etc. Efforts have been made to fabricate film based TEG module. Additionally, this deposition methodology may have potential commercial viability in various industries.

Contributors: Jyothichandra and R Gopalan

Development of Progressive Reactive Hot Press (PRHP) for High Density Fe or Fe-based PM Components

Malobika Karanjai ***malobika@arci.res.in***

Particulate materials (PM) processing, in addition to its well-known advantage of yielding near-net shape components, has other major advantages, like a) alloys from high melting point metals, b) metal / non-metal / ceramic composites, and c) composites of metals that do not dissolve into each other can be processed. Though PM has major applications in automobiles, aerospace and nuclear sectors, it is growing in other fields too. Most often, we tend to limit our development to inexpensive production methods; however we should take 'advantage' of the uniqueness of PM technology that produces high quality products, which the wrought materials technology cannot cater to.

The P/M processes that confer the said 'advantage' are hot consolidation techniques like hot-pressing and extrusion and yet these processing techniques are still restricted to the service of niche market because the hot processing equipments are still custom-built with very high capital cost. If these techniques have to achieve the wider spread required to ensure continual growth of PM industry, equipments amenable for continuous hot processing are required. The present effort is towards fulfilling that important requirement by rendering 'continuous' hot processing.

PM processing, as it evolved, incorporated newer processing steps like warm compaction, coining and sizing, re-pressing, hot rolling, forging, metal infiltration, injection moulding, pressure sintering, etc into the established processing pattern of sintering of green compacts or of powder/elemental powder alloy mixes in moulds. The said incorporation led to duplication of certain equipment and certain processing steps with the aim of achieving high density components with superior properties and minimizing energy requirements. This can be exemplified by production of friction materials like metallic brake and clutch segments used in automotives. The main constituent of these friction segments is Fe-powder which is typically produced by the 2-stage process where-in iron-oxide is reduced to iron powder through a high temperature (typically 900-1200°C) gaseous reduction in kilns. The output hard briquette is crushed into powders for further secondary stage processing in horizontal furnaces under hydrogen atmosphere. The caked output is again comminuted into different sizes to get the desired grades of Fe-powders. These powders are then mixed with different other elemental powders, compacted and sintered at high temperatures in bell-type pressure sintering furnaces in batches, akin to conventional batch–type hot presses to obtain the properties.

Needless to say that attempts at ARCI are to obviate the duplication of high temperature kilns and high-energy comminution equipments at different stages by design-development of a new continuous hot press which can accommodate different processing steps undertaken in different equipments, into one equipment. Fe powder or its oxide or metal-matrix composite compositions or compacts can be used to produce near-net shape products.

Fig. 1 Progressive Reactive Hot Press (PRHP)

The prototype 'process-in-built' equipment, Progressive Reactive Hot Press (PRHP), shown in Fig.1, designed and developed indigenously.

During commissioning, Hoganas iron powder ASC100.29 was fed into dies and fed into PRHP in continuous mode. At 1050°C, a load of 50 MPa was applied with a dwell time of 10s. The compact was unloaded after the furnace was cooled to 50°C. The compact density was approx. 85-87%. The oxygen and carbon contents were found to be 0.1 and 0.05 percent respectively. The SEM with EDAX analysed micrographs are shown in Fig. 2 & 3. Further R&D work is in progress to obtain pressure-temperature-time conditions for Fe-based components with superior properties.

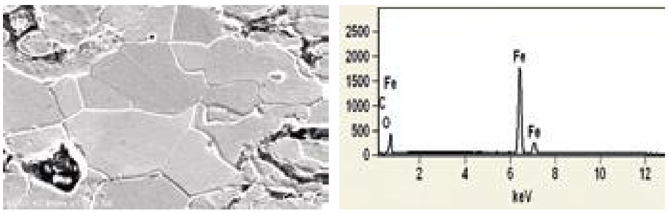


Fig. 2 SEM with overall EDAX

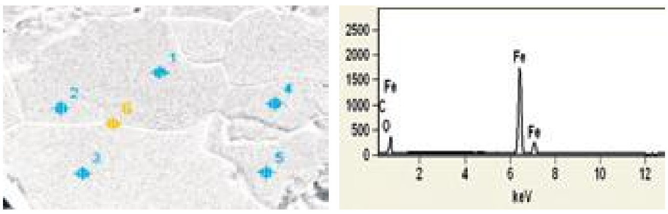


Fig. 3 SEM with EDAX at grain boundary

Contributor: A Siva Kumar

Development of 2D-Nanolayered Tungsten/Molybdenum Disulfide for Petrochemical and Automotive Applications

Joydip Joardar *joydip@arci.res.in*

Two dimensional nanosheet like structures in disulfides of heavy transition metals like tungsten and molybdenum have shown wide range of attractive properties, which can be harnessed for various applications as catalyst or lubricant in petrochemical and automotive sector apart from being a promising electrode material for Li-ion batteries and electrocatalyst for hydrogen evolution reaction (HER). However, the absence of commercially viable routes for their synthesis in bulk quantity and reproducible quality has been a major issue hindering their commercial exploitation. Recently, a modified technique has been developed by ARCI to generate such 2D structure in WS_2 and MoS_2, making use of a special reactor designed by ARCI (patent pending). The process offers unique control capabilites to synthesize tailor-made 2D structure in these disulfides. The thickness of these nanosheets as well as their size can be easily altered depending on the end use of the product. It may be noted that such change in the microstructure leads to alteration in the energy bandgap of the material, which in turn dictates its properties and performance. For example, a typical 2D nanosheet structure of WS_2 and MoS_2 produced by the modified ARCI method, as shown in Fig. 1a and b, has a bandgap of 1.6eV and 1.53eV, respectively. These are substantially higher than that of conventional coarse grade WS_2 (1.3eV) and MoS_2 (1.2eV). Figure 2 shows a change in the thickness of the nanosheet structure, as reflected by the relative diminishing of the x-ray diffraction peak from the 002 basal plane, which can be induced with change in the processing temperature.

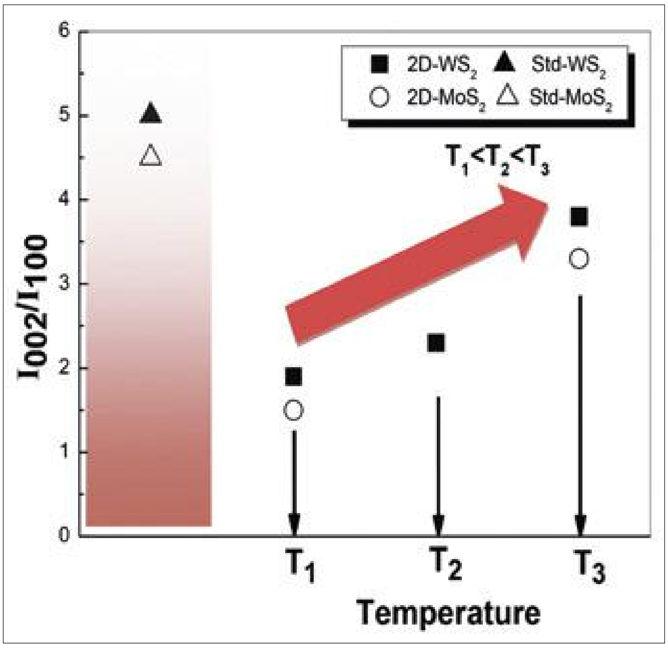


Fig. 2 Change in the relative intensity of XRD peak for 002 basal plane in WS_2 and MoS_2 nanosheets with increase in processing temperature. Lowering of 002 peak intensity or drop in the I_{002}/I_{100} ratio reflects thinning of the nanosheet. The ratio of intensities in case of standard (ICDD) conventional disulfides are also shown for comparison

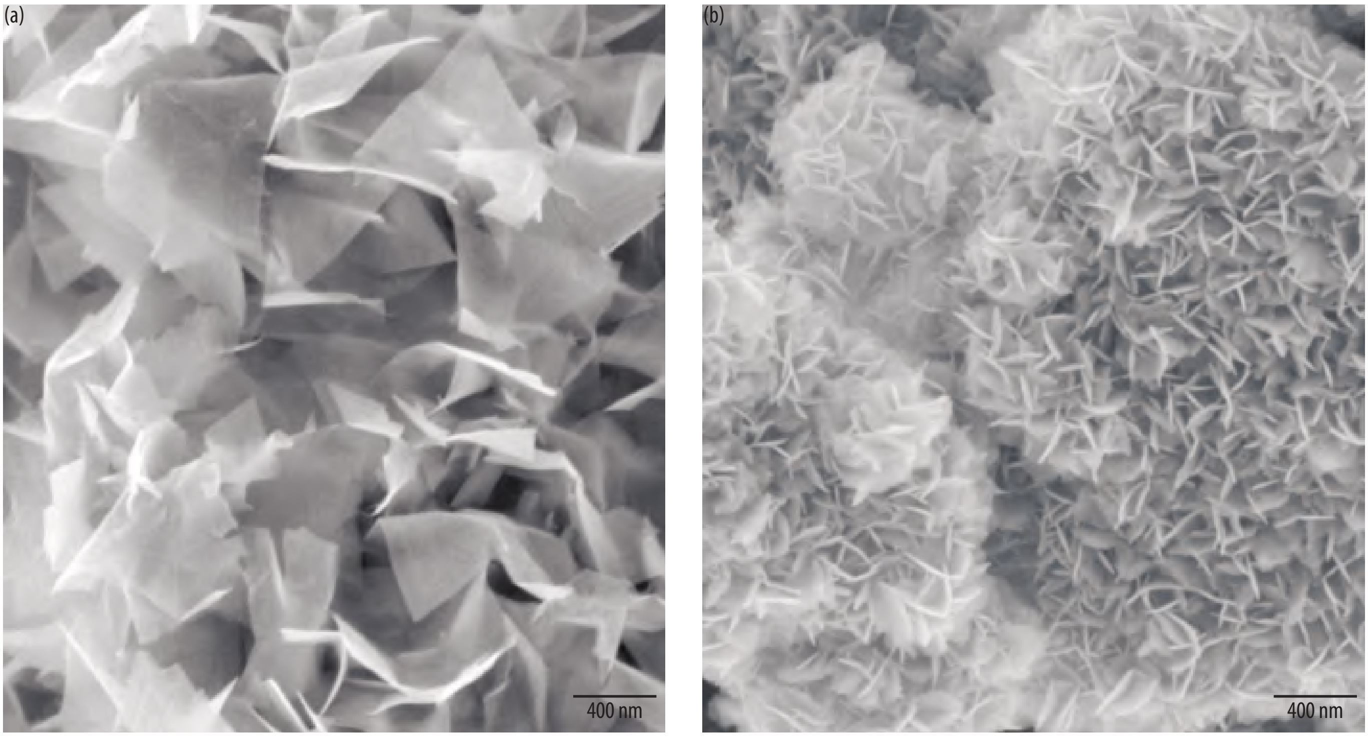


Fig. 1 Microstructure of 2D-nanolayered (a) WS_2 and (b) MoS_2 produced by a modified synthesis technique developed by ARCI. Based on the application and/or required properties, the size and thickness of these nanosheets can be altered by changing various processing parameters

Contributors: K Murugan, A Harish Kumar, Thati Puneeth and P V V Srinivas

Dynamic Strain Aging in Fine Grained Cu-1 wt%Al_2O_3 Composite

S B Chandrasekhar ***chandru@arci.res.in***

Cu–Al_2O_3 composites are extensively used in the automobile industry as spot welding electrodes, thereby attracting mechanical processing techniques for their successful fabrication. In this regard, the effects of strain rate, temperature and grain size on flow stress are important. The dependence of stress on strain rate, expressed by strain rate sensitivity index (*m*), is an important parameter for assessing the formability of metals. In Cu, *m* is reported to be varying between 0.007 and 0.02 at room temperature (RT). However, some solid solutions exhibit a decrease in flow stress with increase in strain rate to give negative value of *m*, the occurrence of which is a manifestation of dynamic strain ageing (DSA) phenomena.

Bulk Cu–1 wt% Al_2O_3 composite was obtained by mechanical alloying (MA) followed by consolidation using spark plasma sintering (SPS). The copper grain size and Al_2O_3 particles size in the consolidated sample were found to be 2 µm and 45 nm, respectively. True stress–true strain curves obtained at different initial strain rates ($\dot{\varepsilon}$) are given in Fig. 1. It is seen that flow stress as well as elongation at RT decreases with increasing $\dot{\varepsilon}$. Also, the yield point with Lüder strain and serrated flow curves are exhibited. In the present work, the serrations might result from discontinuous pinning and unpinning of dislocations by the impurity atoms (C and O). A given strain (ε) takes longer time (*t*) to be attained at lower $\dot{\varepsilon}$ than that at higher strain rate ($t=\varepsilon/\dot{\varepsilon}$) to make more solute atoms available for pinning the dislocations. This is because the solute atoms can migrate over a distance *x*, as controlled by the diffusion coefficient of solute (*D*) and time (*t*) available for diffusion, according to the well-known relation $x=\sqrt{Dt}$. This explains why the higher flow stress is seen at lower strain rate. Plastic deformation takes place by dislocation movement and, to some extent, by diffusion as favored for interstitial solute atoms at relatively lower temperatures.

The grain boundaries (GBs) and particles act as long range obstacles to dislocation motion but also as the sources for dislocations. Solute atmosphere in this respect represents short range obstacle to dislocation motion. In the course of deformation, the gliding dislocations get stopped by GBs and particles.

The presence of GBs, twins, dispersoids, precipitates (from Fe and probably its oxides in the presence of O and solutes) hinders dislocation motion and reduces the mobile dislocation density. This decreases the mean free path length for dislocation motion within the copper matrix. The dislocation-solute interaction is expected to occur within this length only.

Thus, effectively, less solute-dislocation pinning/unpinning could be expected. In view of this, the increment in stress during dislocation pinning and the decrease at the time of its release will be less in this material than generally observed in other materials. Probably, this is the reason for the appearance of weak serrations in the stress-strain curves in this composite. Furthermore, the weak serrations may also be contributed indirectly by the solute atoms being consumed at sites like GBs or by their mutual interactions and reaction with the copper matrix.

Presented below is some thought of looking at the role of impurity atoms and their interactions with static GBs and particles, along with the mobile and immobile dislocations as they evolve during DSA. In the early part of deformation, plastic strain in such material can continue only by transmitting these dislocations to the other side of such obstacles or by locally creating higher stresses to activate other adjoining sources to generate more dislocations. With the increasing strain, this process becomes difficult and further strains tend to be microscopically localized, extending from such obstacles.

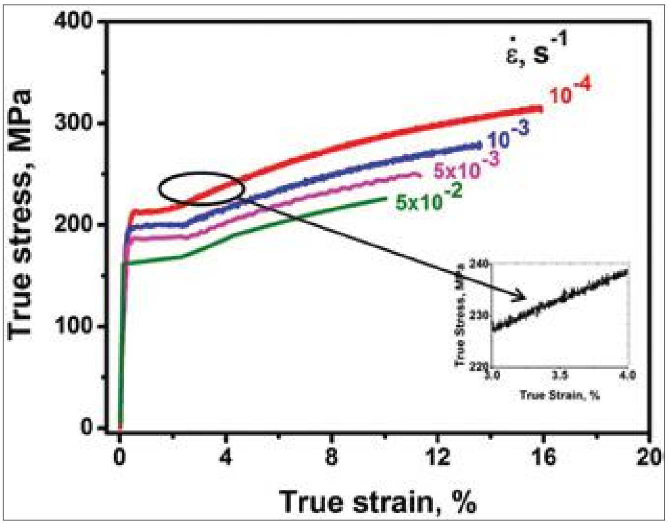


Fig. 1 True stress–strain curves at various strain rates

First the dislocation pile–up and then formation of high dislocation walls adjacent to GBs tend to make these original obstacles inactive. Instead, the dislocation–dislocation interactions become more important to result in strain hardening, along with some component of dynamic recovery by their mutual annihilation. For instance, the cell walls upon development of cell structure, limit the dislocation movement not to reach the GBs. Thus, the slip length (*L*) for dislocation glide gets increasingly reduced but the dislocation density (ρ) gets enhanced to achieve the strain (ε) according to $\varepsilon=\rho bL$, *b* being the Burgers vector. The presence of particles favors such a decrease in *L* and increase in *ρ* even much more, through the lower value of *L* between them. This eventually might favor material damage towards fracture over plastic deformation.

Contributors: Nitin Wasekar, M Ramakrishna, P Suresh Babu, Tata Narasinga Rao and B P Kashyap

Evaluation of Different C-based Materials as Potential Electrode Materials for Supercapacitors

Dibyendu Chakravarty *dibyenduc@arci.res.in*

Supercapacitor is an energy storage device with high power density and capacitance values significantly higher than conventional capacitors. The main objective of the work was to fabricate supercapacitors using carbon based electrode materials and evaluate their performance by electrochemical measurement through cyclic voltammetry and charge discharge analysis.

The specific capacitance of a supercapacitor can be obtained from CV curves using the formula:

$$Cs = \frac{2 \times \int I\, dv}{(v \times \Delta V \times m)}$$

where, I = response current in amps, v = potential scan rate in mV/s, m = mass of active material of single electrode in grams and ΔV = voltage difference.

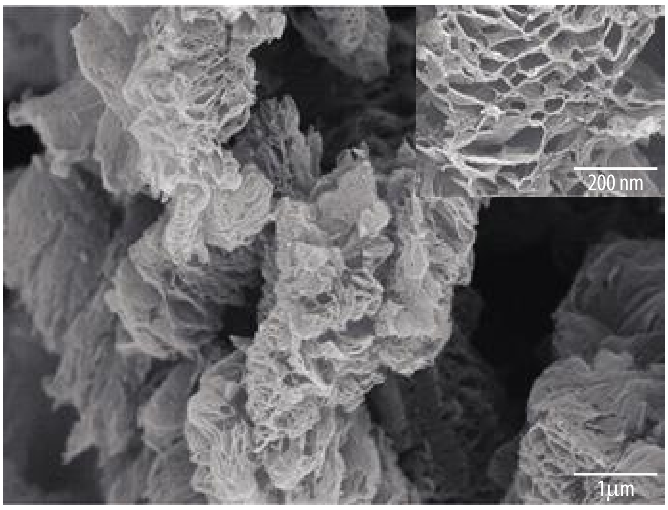


Fig. 1 SEM of rGO produced by Hummers method

Different materials used were exfoliated rGO produced by Hummers method and commercial rGO and compared with previously reported values*. The materials were characterized by SEM, TEM, XRD and Raman. The exfoliated rGO exhibited a highly spongy open kind of 3D microstructure with an interconnected network as shown in Fig.1. This kind of a microstructure led to retention of extremely high charges (> 1400 F/g) at scan rates of 5 mV/s for supercapacitors fabricated with this material, as shown in Table 1. A typical CV plot for the materials tested is shown in Fig. 2. Impressive values were also obtained at higher scan rates (100 mV/s) making these materials useful for commercial applications.

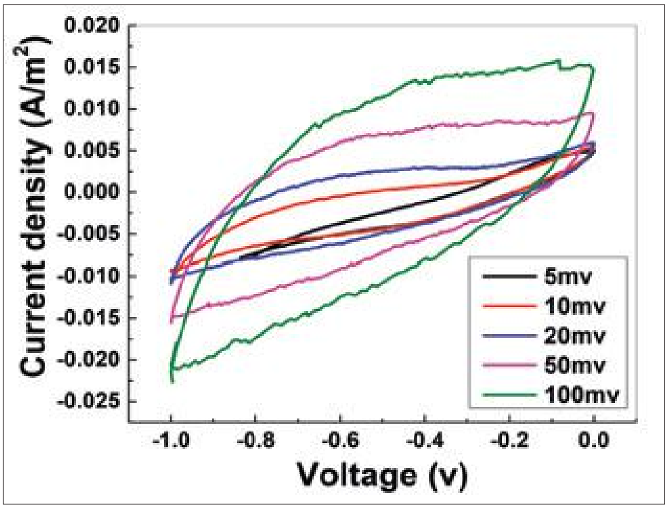


Fig. 2 CV plot of rGO at different scan rates

Table 1 Specific capacitance for various C-based materials used as electrodes

Electrode material	Specific capacitance for corresponding scan rate (F/g)				
	5 mv/s	10 mv/s	20 mv/s	50 mv/s	100 mv/s
Exfoliated rGO	1430	870	500	350	275
Commercial rGO	360	300	230	190	145
*rGO+ CoO	-	175	135	90	-
*rGO+ ZnO	330	300	250	-	135

The charge-discharge plot shown in Fig. 3 yields a specific capacitance value of 180 F/g. Lower current rates yield even higher values. The nature of the plot indicates the material to be suitable as a supercapacitor.

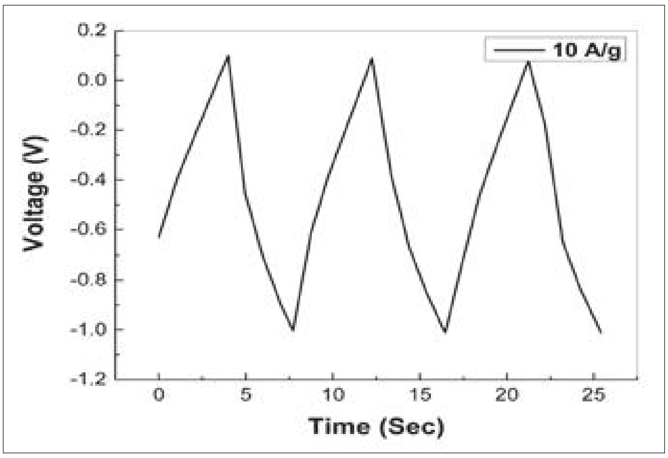


Fig. 3 Representative charge-discharge plot at 10 A/g current rate

Contributors: K Rashmi and A Jyothirmayi

Silica Aerogel Flexible Sheets for Industrial Thermal Insulation Application

Neha Y Hebalkar *neha@arci.res.in*

ARCI has embarked on world class product development for thermal insulation with the objective of indigenization under the 'Make in India' initiative. "Silica aerogel flexible sheets" have been developed. Recently the technology of manufacturing aerogel sheets has been transferred to an Indian industry for its commercialization. Silica aerogel is an ultra-low density nanoporous material known for its best thermal insulation property in wide range of temperatures from cryo to high. In spite of all the potential benefits of aerogels, its commercial use was restricted due to its fragile nature. ARCI's product made up of fiber-aerogel composite overcomes this limitation by making it mechanically stronger and flexible.

"Silica aerogel flexible sheets" are produced by in-filtering silica aerogel with inorganic fiber mat where the inorganic fiber mat can be of any type including ceramic, e-glass, high-glass etc., depending upon the need of application. The silica aerogel in this product has a special property of infra-red radiation reflection due to presence of ultra fine titanium dioxide particles uniformly distributed all through. These particles are prepared by novel method of in-situ precipitation in the sol-gel process. This helps to minimize the radiation by thermal conduction dominant at high temperature. The ultra low density of silica aerogel and its nanoporous nature drastically reduce conductive and convective heat transport. As an overall effect, such formed product is highly efficient in thermal insulation performance. Patent is applied for manufacturing process. The other salient features of the product include all the properties ideally required as the best thermal insulation material such as low thermal conductivity, low emissivity, corrosion resistance, chemical resistance, good compressive strength, light weight, moisture resistance, fire resistance, anti-fungal, low shrinkage, non-toxic and eco-friendly. Figure 1 depicts some of these features in the "Silica Aerogel Flexible Sheet"

Thermal insulation of the 10 mm sheet was tested by using thermography. In this case, one surface of the sample was heated using IR lamp and the temperature of cold surface on the other side was measured using infra-red camera. Figure 2 shows the time vs temperature graph for hot side (facing the light source) and cold side temperature (opposite side) for the 10 mm thick silica aerogel sheet prepared using e-glass fiber. At hot side temperature of 620°C, the cold side observed was 113°C. The ΔT was found to be 507 °C.

Such an excellent performance of thermal insulation of aerogel sheets is widely opening a gate-way to potential thermal insulation in various applications such as industrial insulation, architectural insulation, heat-cold storages, clothing, aerospace, automotive, solar devices, transportation and so on.

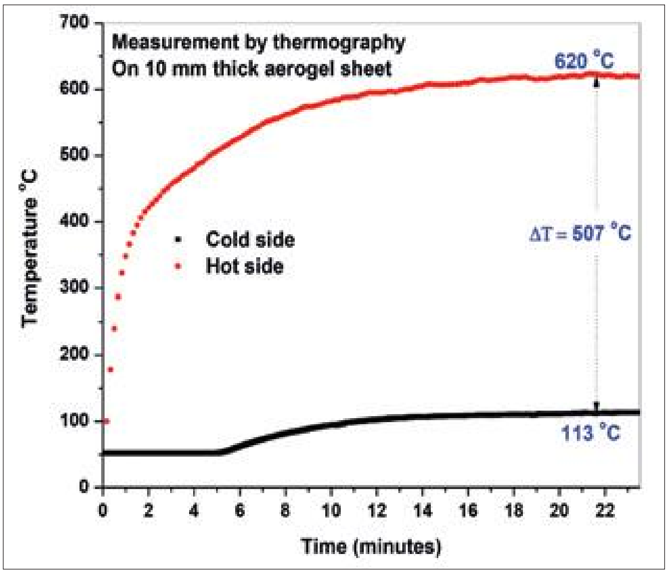


Fig. 2 Thermal insulation property of silica aerogel flexible sheet

Fig. 1 Roll of silica aerogel flexible sheet, aerogel sheet protecting flowers from the blue flame, water drop-let on surface of sheet showing hydrophobic nature, fire resistance of the sheet

Contributors: A Yamini, S Keerthi and Govind Kumar

Large Scale Synthesis of Spinel $Li_4Ti_5O_{12}$ Anode for Lithium Ion Batteries for Electric Vehicle Application

Kaliyan Hembram ***kaliyan@arci.res.in***

Rechargeable lithium ion batteries (LIBs) are currently considered as one of the promising electrochemical storage devices due to their high energy and power densities, and has widespread application ranging from consumer electronics to advanced electric vehicle technology. Although, conventional LIBs use graphite as anode material, that cannot meet the requirement of high power batteries for electric vehicle. Among the studied anode materials spinel $Li_4Ti_5O_{12}$ (LTO) is considered to be an excellent alternative material due to its unique properties. Firstly, LTO shows negligible lattice changes during lithium intercalation/de-intercalation processes. There is no volumetric and structural (zero-strain material) changes of LTO anode throughout the electrochemical process, resulting in extended cycle life of the battery. Secondly, the operating voltage of LTO is about 1.5V vs. lithium, which is the most preferable electrochemical stability window of non-aqueous electrolytes. Consequently, the formation of solid electrolyte interface (SEI) layer is inhibited, which improves the fast mobility of lithium ions during high power charge/discharge process. However, LTO suffers from poor electrical conductivity when subjected to high current rates.

To overcome this problem, various strategies have been implemented like decreasing the particle to nanometer scale, metal doping, carbon coating, etc. $LiFePO_4$ cathode material was successfully synthesised by flame spray pyrolysis (FSP) at Centre for Nanomaterials, ARCI. Presently, the focus is on large scale production of LTO anode material (Fig. 1a) using same technique. FSP has several advantages: (a) simple process, (b) ability to produce nanoparticles with homogeneous particle size distribution and (c) high yield. The as-prepared-powder was subjected to heat treatment process to convert amorphous material to crystalline form. The XRD pattern (Fig. 1b) of heat treated (HT) powder corresponds to pure spinel LTO phase. The morphology and particle size of the sample was characterized by FESEM and TEM, shown in figures 1c and 1d. FESEM image indicates nano agglomerated particles, whereas TEM image clearly shows the particles to be in the nanometer range with spherical morphology.

The electrochemical properties of the HT LTO nanopowder was evaluated by using lithium metal as reference electrode and 1M $LiPF_6$ in EC:DMC (1:1 v/v) as electrolyte. The two electrodes were separated by polypropylene membrane and the cells were assembled in argon filled glove box. Figure 2a shows the cyclic performance curves of LTO developed in ARCI with commercially available LTO. The FSP synthesized LTO yields discharge capacity comparable to that of commercial material at 1C rate. Figure 2b displays the rate capability curve of FSP LTO at different current rates. The cell displays stable charge/discharge profile at different current rates indicating good chemical stability of the electrode material. Attempts are being made to improve the electrochemical performance of LTO by carbon coating and fabricating the full-cells by using in-house synthesised electrode materials.

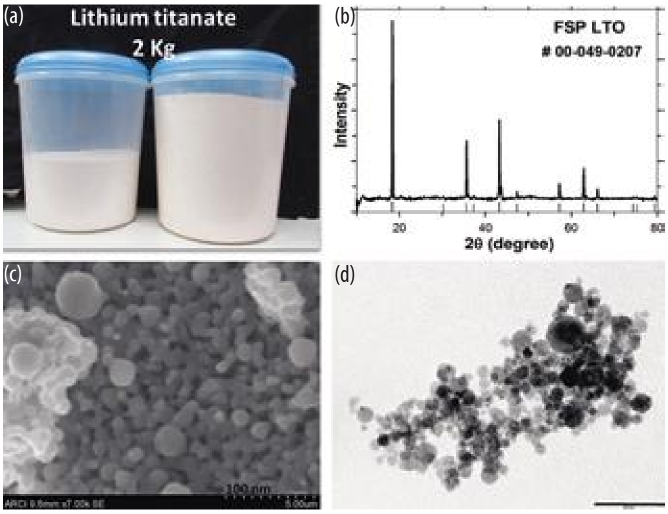


Fig. 1 (a) Photo image of asprepared LTO nanopowder, (b) XRD pattern of HT LTO, (c) and (d) are the FESEM and TEM images of HT LTO

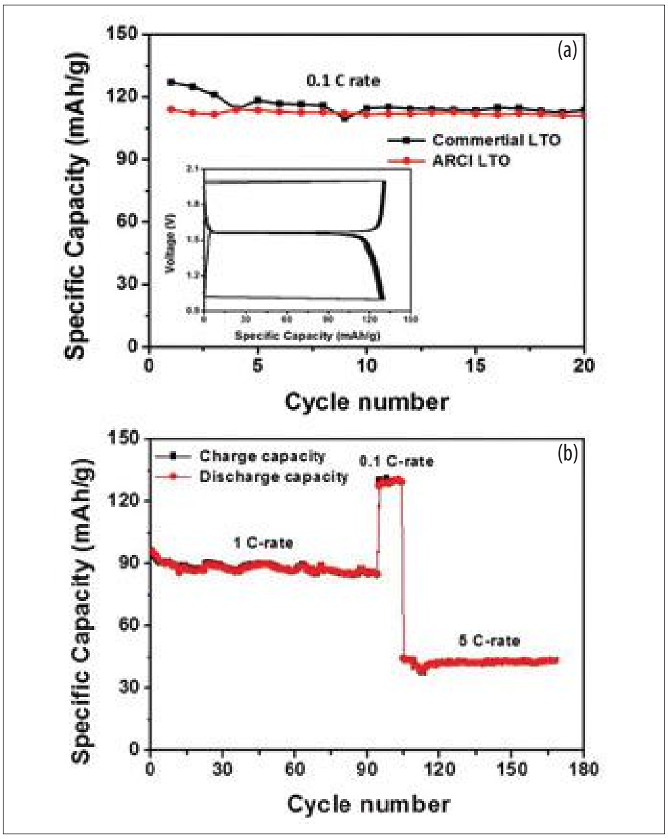


Fig. 2 (a) Comparative cycle performance curve of commercial and ARCI LTO anode material and (b) Rate capability of ARCI LTO at different current rates

Contributors: E Hari Mohan, P M Pratheeksha, S Anandan and Tata Narasinga Rao

An Efficient Three Dimensional Mesostructured Carbon for High Energy Density Supercapacitor Application

S Anandan ***anandan@arci.res.in***

As part of Technical Research Centre (TRC) programme, ARCI is actively pursuing development of efficient electrode materials for high power supercapacitors (SCs). SCs are energy storage systems that have better power density, excellent reversibility and longer cycle life than batteries, and have higher energy density than conventional capacitors. The performance of SCs depends on the nature and surface area of the electrode materials. The nanostructured materials particularly, three dimensional (3D) ordered mesoporous carbons (OMCs) are considered to be attractive electrode materials owing to their promising characteristics like well-ordered pore structure, narrow pore size distributions, high specific pore volume and high specific surface area. Further, 3D structured OMC facilitates ion transport by shortening diffusion pathways of electrolyte ions. The studies showed that pore size of OMCs is playing a crucial role to improve charge storage in SCs, which is not yet been completely realized. In ARCI, the work was mainly focused on the synthesis of 3D OMCs with different pore diameter [labelled as CMK-8 (100), CMK-8 (130) and CMK-8 (150)] to study the influence of pore size on charge storage. The synthesis of 3D OMC from mesoporous silica (KIT-6) by nanocasting technique is schematically shown in Figure 1(a). SAXS analysis confirms the presence of 3D cubic Ia3d structure. BET isotherm (Figure 1(b)) shows type IV isotherms with H1 hysteresis loop, indicating the presence of ordered mesoporous channels and the inset of Figure 1(b) shows the narrow pore size distribution of mesopores. The Raman spectrum in Figure 2(a) shows D and G bands of equal intensity with I_D/I_G ratio of 0.965, characteristics of nanocrystalline carbon with low graphitization degree. The TEM image in Figure 2 (b) exhibits honeycomb like morphology and the inset shows the presence of interconnected bi-continuous network of pore channels. The electrochemical performance of the OMC electrode materials along with a commercially available activated carbon (AC) were characterized by cyclic voltammetry (CV) and charge/discharge (CD) studies in a three electrode system using 6M aqueous KOH electrolyte. The specific capacitance (Cs) calculated from CV profiles at scan rate of 1 mV/s^{-1} & from discharge curves at current density of 1 Ag^{-1} for CMK-8 (100), CMK-8 (130), CMK-8 (150) and AC was found to be 163, 241, 227 and 109 F g^{-1} & 164, 239, 201 and 75 F g^{-1}, respectively. Though, CV curves of CMK-8(130) at different scan rates (Figure 3 (a)) show a slight deviation from the rectangular shape due to pseudocapacitive behavior, it exhibits high performance compared to other OMCs and AC. More importantly, CMK-8 (130) retains a Cs of 182 F g^{-1} (75% retention) even at high current density (50 Ag^{-1}), which is higher than other OMCs and AC (Figure C (ii)). The superior electrochemical performance of the CMK-8 (130) is mainly attributed to its effective pore size (~4 nm) in addition to 3D porous structure, high surface area, large pore volume, and interconnected mesopores. Further attempt is in progress to upscale OMCs and synthesize OMCs by template free method.

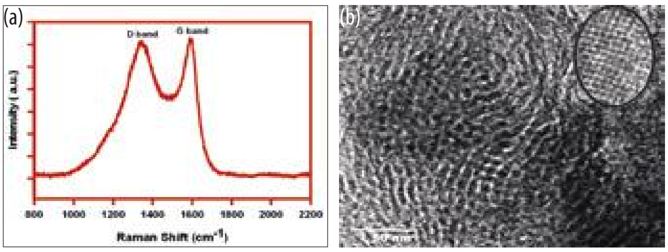


Fig. 2 (a) Raman spectrum and (b) TEM image

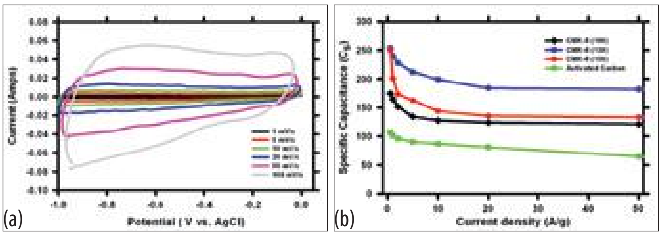


Fig. 3 (a) CV profile of CMK-8 (130) at various scan rates and (b) Rate capability of OMCs and AC

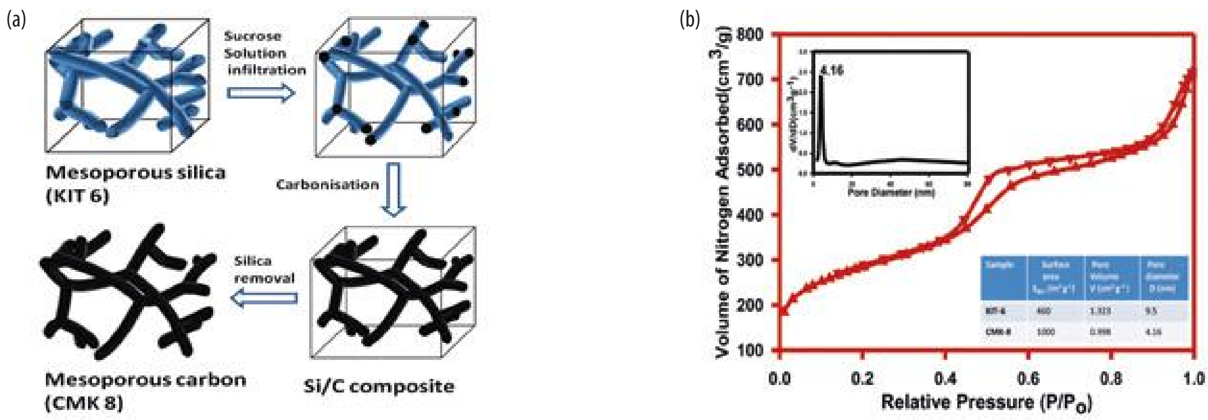


Fig. 1 (a) Schematic illustration for the formation of CMK-8 from KIT 6 and (b) N_2 sorption isotherm of CMK-8 (inset shows pore size distribution)

Contributors: K Nanaji, A Jyothirmayi and Tata Narasinga Rao

Synthesis and Characterization of Iron Aluminide Powders

S Sudhakara Sarma ***sssarma@arci.res.in***

Intermetallics based on Fe and Al are good candidates for use in high temperature applications because of their good mechanical properties, low density and excellent resistance to the oxidation and sufidation. But these materials are not being used for commercial applications due to poor ductility and toughness at room temperature. Research is going on worldwide to improve the ductility of Iron Aluminides by various methods. Refining the grain size of the material to nano scale is one of the interesting and feasible methods to increase the strength and enhance the room temperature ductility along with toughness.

Iron aluminides of interest are Fe_3Al and FeAl which are ordered BCC structures with DO_3 and B_2 crystal structures, respectively. In Fe_3Al, stable DO_3 structure exists in the Al range of 23-36 % from room temperature to 550^{0}C. Above 550^{0}C, an ordered Fe_3Al DO_3 structure transforms into the B_2 structure which finally changes to disordered solid solution. These ordered structures exhibit good properties at high temperatures because of long range order which reduces dislocation mobility. This reduced dislocation mobility also reduces the room temperature ductility and toughness. Attempts are being made to remove these drawbacks by developing nanostructured materials.

Iron aluminides of high temperature strength with good room temperature ductility and toughness are being currently synthesized and characterized.

Elemental iron and aluminum powders to form intermetallic Fe_3Al are milled in high energy horizontal ball mill (ZOZ Simoloyer) for 10 hours to get nanostructured powder. Powder sample is taken out after every hour of milling for characterization. SEM image of the 10 hour milled powder is shown in Fig. 1.

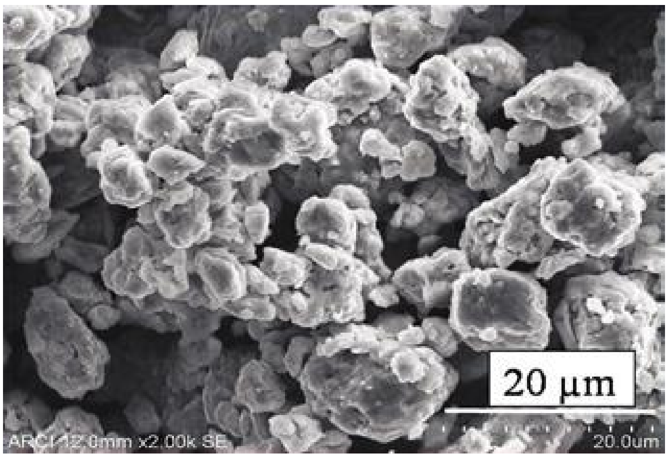


Fig.1 SEM image of 10 hr milled powder

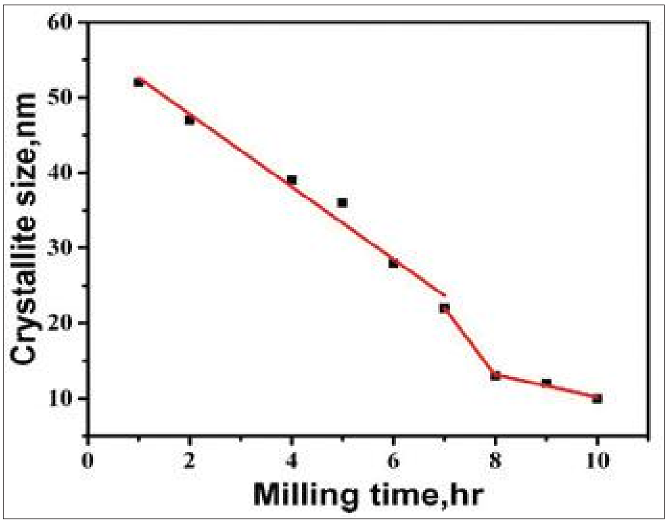


Fig. 2 Variation of crystallite size of the milled powder with time

Variation of crystallite size of the powder with milling time is shown in Fig. 2. It can be observed from the figure that crystallite size of the powder decreased till 8 hours of milling and reached a near-steady state beyond 8 hours of milling due to the equilibrium between fracture and welding of the powder particles during the milling. Crystallite size of 10 nm was achieved after 10 hours of milling.

Variation of hardness of the powder with milling time is shown in Fig. 3. The hardness of the powder increased with milling time due to decrease in crystallite size and increase in accumulated strain during milling.

Further work related to consolidation of powder into a component having good high temperature strength with reasonable ductility and toughness is in progress.

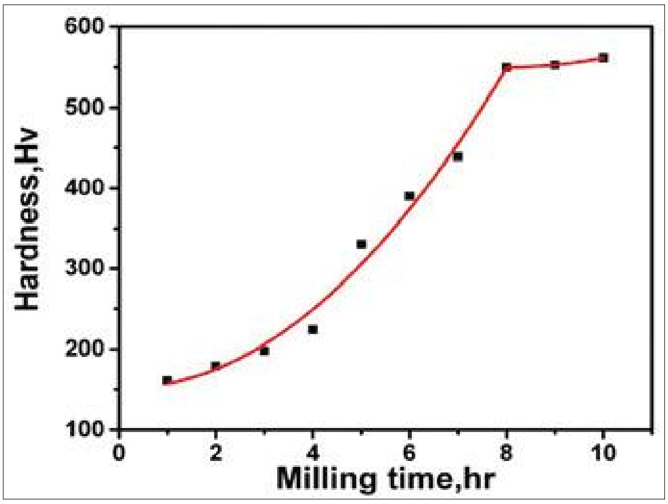


Fig. 3 Variation of hardness with milling time of the powder

Contributors: R Vijay and A Venugopal Reddy

Water Filters for Microbial and Fluoride Removal

J Revathi ***revathi@arci.res.in***

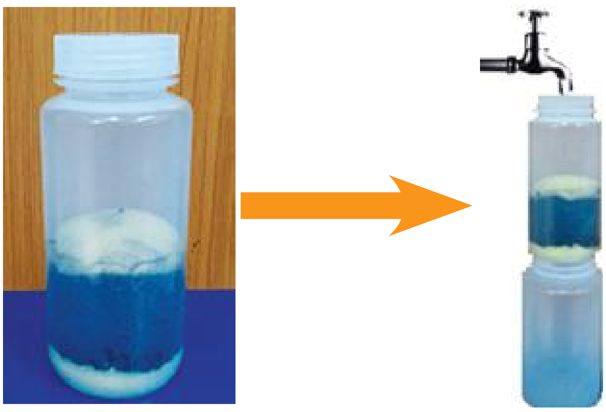
In continuation with nano silver treated ceramic filter candles that works on gravity filtration at a flow rate 1 Litre / hour, high flow rate of 1 litre / minute antimicrobial water filters were developed. Activated carbon prepared from biotemplates have an intrinsic hierarchical porous structure and have high surface area. These feautures enable activated carbon to be best water purifier as it adsorbs readily the organic and microbial pollutants in water due to electrostatic force of attraction. This activity fades out after filtering out about 10 litres of contaminated water. Moreover this activated carbon becomes a media for bio film formation which is even more harmful than the contaminated water.

Nano silver treated activated carbon will be an ideal solution for antimicrobial water filters. To execute this a novel nano silver suspension synthesis that involves environmental friendly ingredients is developed and the stability of the suspension is screened via accelerated 30 minutes 6000 rpm centrifuge stability test. It is important to use environmental friendly ingredients to develop a nontoxic antimicrobial water filter. This nano silver suspension is used to prepare nano silver treated activated carbon and ceramic filter candles. Keeping in view the market demand nano silver treated ceramic filter candles and nano silver treated activated carbon filled cartridges were developed. Microbial removal efficacy of these filters were tested at gravity flow and pressurized bacterial water flow conditions. Nano silver treated ceramic filter candle has a flow rate of 1 litre / 30 minute for gravity flow and 1 litre / minute for pressurized water flow condition. Nano silver treated activated carbon filled cartridge has a flow rate of 1 litre / 5 minute for gravity flow suitable for point of use applications and 1 litre / minute for pressurized water flow condition suitable for house hold water purifiers. These variable flow rate antimicrobial water filters are capable of removing 105 cfu/ml to 0 cfu/ml to cater to the needs of market.

Fluoride is the most harmful contaminant in drinking water as it causes fluorosis. Fluoride Adsorbent material impregnated activated carbon is developed for fluoride removal. Fluoride removal efficacy of ARCI's adsorbant material is tested with 10 ppm fluoride contaminated water and confirmed by ISE technique that the fluoride is less than 1.5 ppm in the treated water. The fluoride removal efficacy is consistent upto 25 litres of 10 ppm fluoride contaminated water. Experiments are in progress to improve the efficacy to 100 litres.

Table 1 ARCI water filters vs commercially available products

Commercial Products	Flow Rate	Capacity
ARCI-Ceramic filter candles under pressurized flow	1 litre / 5 minutes	Tested upto 500 litres (life cycle assessment in progress)
ARCI-Cartridge for point of use gravity flow (with Nano silver treated with activated carbon)	1 litre / 5 minutes	Tested upto 500 litres (life cycle assessment in progress)
Under Pressurized flow	1 litre / minute	Tested upto 500 litres (life cycle assessment in progress)
Company A	1 litre / 15 minutes	4000 litres
Company B	300-840 ml / hour	2500 litres
Company C	1 litre / 5 minutes	2000 litres
Company D	750 ml per loading Contact time : 30 minutes	450 litres



Cartridge for fluoride and microbial removal

- Cartridge with ARCI adsorbant material
- Flow Rate: 1 litre / 5 minutes
- Easy to carry
- Cost effective and requires no electricity
- Ensures Fluoride free water upto 25 litres
- Ensures microbial free water upto 500 litres

Contributors: N Satya Moulika, A Venkata Sai, KVB Vasantha Rayudu, R Vijay, Tata Narasinga Rao

DC Magnetic Characterization of Fe-P Alloy Fabricated Through Powder Extrusion

P Sai Karthik ***saikarthik@project.arci.res.in***

ARCI has major program for the development of Fe-P based soft magnetic materials for automotive application. Fe-1.8%P powder was extruded to a rod of Ø 16 mm. Fe-P alloy has almost zero phosphorus solubility in α-Fe (ferrite) at room temperature. Consistent with the Fe-P equilibrium phase diagram, the extruded rod was observed to have phosphorus segregation. To dissolve the phosphorus completely into bcc iron matrix, the extruded sample was subjected to solutionization heat-treatment at various temperatures. In this report, the effect of heat-treatment on the DC magnetic properties of the alloy is discussed.

The extruded rod (300 mm long) was cut into smaller samples of 30 mm length, given borax coating and solutionized at 1000°C, 1050°C and 1100°C for 1 hr and 2 hr at each temperature, and water quenched. The temperatures for the heat-treatment were decided based on phase diagram. Toroid samples (OD=13mm, ID=9mm & t=3 mm) were machined by EDM wire-cutting and wound with primary (30 turns) and secondary (40 turns) coils for magnetic characterization. Initial magnetization characteristics (DC) and B-H characteristics (full hysteresis loops(DC)) upto B=1 Tesla were measured using a B-H loop tracer (AMH-20K-HS, Laboratorio Elettrofisico Engineering Italy) at ARCI Chennai. Vibrating sample magnetometer (VSM) (EZ9; Microsense Inc. USA) was used to study the thermo-magnetic characteristics m Vs T (magnetic moment Vs temperature) of the alloy before and after solution treatment.

As seen in Fig. 1, the solutionized samples exhibited enhanced magnetic permeability (μmax) when compared to extruded sample. Heat-treatment at 1000°C for 2 hrs and 1100°C for 1 hr yielded highest permeability of 2200. Also it can be observed from Fig.1 that the magnetic induction values of solutionized samples are higher than that of extruded sample.

The coercivity (obtained from B-H curves in Fig. 2) of extruded sample was 3.1 Oersted (Oe) while that of solutionized samples varied narrowly between 1.2 to 1.8 Oe. As there is a strong correlation between mechanical hardness and coercivity (magnetic hardness), an attempt was made to understand the influence of solutionization treatment on indentation hardness of the alloy. It has been observed that the hardness of all samples is in the range of 318-329 HV. Even though the coercivity of the extruded sample (3.1 Oe) is higher than that of solutionized samples (1.2-2.0 Oe), the difference is not reflected in the indentation hardness measurements. It shows the influence of high phosphorus content (1.8 Wt %) on mechanical hardness of the alloy which is almost invariable with the heat-treatment it was subjected to.

The slightly better soft-magnetic characteristics in solutionized samples can be explained by the presence and absence of magnetic transformation in extruded and solutionized (1050°C-1H) samples, respectively as seen in m Vs T (magnetic moment Vs temperature) curves presented in Fig. 3. The transformation at 716 K in Fig. 3a corresponds to ferro-para transition of Fe_3P present in extruded sample. The absence of such transition in Fig. 3b indicated the total dissolution of phosphorus in the matrix which is responsible for better magnetic properties upon solutionization.

From DC magnetic characteristics, it is evident that heat-treatment at 1000-1100°C for 1-2 hours is optimal for solutionization. Further studies on AC magnetic characteristics of the samples as well as effect of low temperature annealing are under progress.

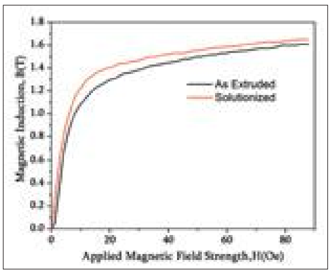


Fig. 1 Initial magnetization curves of extruded and solutionized samples

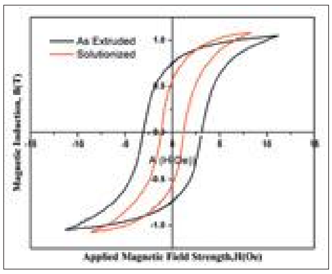


Fig. 2 B-H Loops of extruded and solutionized samples

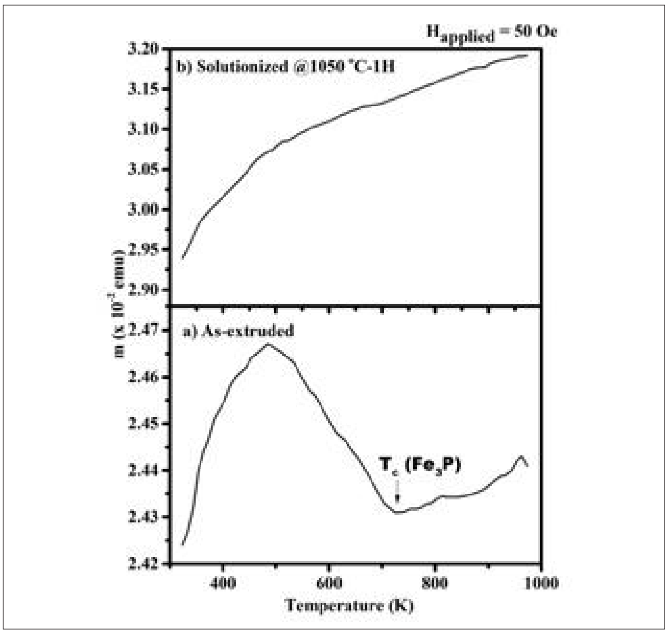


Fig. 3 m Vs T curves of (a) As extruded & (b) Solutionized samples

Contributors: Ravi Gautam, D Prabhu, V Chandrasekaran, R Vijay and R Gopalan

Pouch Cell Fabrication with $LiFePO_4$ Cathode and Graphite

A Bhaskar *akkibhaskar@gmail.com*

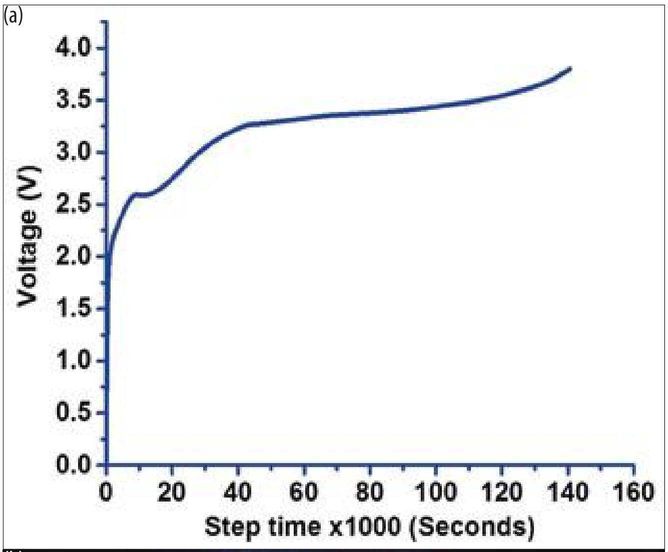
The flexibility in nature, better packing efficiency and lower weight makes the use of pouch cell and/or prismatic cell designs usable in many of the Li-ion battery applications. The thin format of these cells makes them particularly useful in most of the hybrid electric vehicles (EV) now-a-days. The packaging efficiency of pouch cell design is 90 to 95%, which is the highest among all battery packs. However, one main drawback of pouch cell design is low thermal management efficiency. Since work is in progress for large scale production of battery materials as well as to study its use for electrification in vehicle applications, it is extremely significant to design and develop pouch cells and then use it for EVs.

Here, at ARCI, pouch cells were fabricated using commercially available $LiFePO_4$ (Toda) as positive electrode and graphite as negative electrode. A polypropylene sheet was used as separator and 1M $LiPF_6$ dissolved in EC: DMC: EMC in 1:1:1 v\v ratio was used as electrolyte. Initially slurry was prepared with active materials ($LiFePO_4$ and graphite), acetylene black and PVDF by mixing in 8:1:1 ratio. The slurry was applied on both sides of the Al and Cu foils for positive and negative electrodes respectively, and dried at 80°C in vacuum oven for 10 hours. Based on the theoretical specific capacity values, the weight ratio of $LiFePO_4$ and graphite electrodes was maintained at 1:2. After coating, the foils were cut into 3.5 (W) X 4 cm (L) electrode strips with a provision for electrical connection (uncoated Al and Cu foil) and then the electrodes were calendared to obtain the desired thickness and porosity. Pouch cell assembly was prepared in two different configurations, one as layer by layer assembly (Fig. 1) and the other as prismatic cell type assembly. A total number of 6 layers of anodes and cathodes were used for the pouch cell fabrication. Stainless steel (100 µ thick) tabs were welded to the uncoated Al and Cu foils by using laser welding process.

For the preparation of pouch, three sides of laminated Al foils were sealed in open atmosphere. Then the assembly was transferred inside the glove-box and filled with adequate amount of electrolyte and sealed in vacuum. Prior to charging, the cell was kept for equilibration for ~10 hours. The final thickness of the pouch cell assembly was around 2 mm. The total weight of the active cathode $LiFePO_4$ was about 1.5 g based on which maximum current of 4.8 mA, which is equal to ~ C/50-rate was applied.

Fig. 1 Pouch cell assembly with $LiFePO_4$ cathode and graphite anode

(a)



(b)

Fig. 2 (a) Charge profile for pouch cell (b) Demonstration of cell using LEDs

Contributors: E Hari Mohan, Venkata Sai, K Nanaji, P Tejassvi, S Anandan and Tata Narasinga Rao

Development of W-1 wt%La_2O_3 Composite for Plasma Facing Material

PVV Srinivas ***pvv_srinivas@@arci.res.in***

Tungsten is one of the most promising materials for the plasma facing components of International Thermonuclear Experimental Reactor (ITER) due to its high melting point, good thermal conductivity, high strength at elevated temperature and low sputtering rate. However, tungsten faces serious challenges of brittleness: low-temperature brittleness, high-temperature or recrystallization brittleness and radiation induced brittleness. The addition of La_2O_3 to W increases the recrystallization temperature, lowers the ductile-to-brittle transition temperature (DBTT) and reduces the room temperature and recrystallization brittleness of W. The machinability of La_2O_3 dispersion strengthened W at ambient temperature is good as no micro-cracks form at the vicinity of the La_2O_3 dispersoids and they deform along with the matrix material.

In this work, the W-1 wt% La_2O_3 composite was prepared by mechanical alloying (MA) and consolidated using spark plasma sintering (SPS). The powder mixture was mechanically milled for 4 hr in a high energy ball mill using WC-Co vessel and balls with the ball to powder ratio of 8:1. WC-Co balls and vials were used to minimize the contamination. The vial was filled with the raw materials tungsten and La_2O_3 powder along with the grinding balls and sealed under argon atmosphere. The rotation speed of 200 rpm was used for MA. The milled powder was subsequently consolidated using spark plasma sintering (SPS) at various temperatures varying from 1300–1750°C to obtain various density levels. A constant heating rate of 100°C/min and a holding time of 5 min was used for all the samples. The sintered samples were characterized for phase determination using X–ray diffraction, microstructure using scanning electron microscope (SEM) attached with energy dispersive spectroscopy and mechanical properties using Vickers microhardness tester.

Densification in SPS is affected by three main parameters: sintering temperature, applied pressure and holding time. In this study, the sintering of the powder was studied primarily as a function of the sintering temperature, while the other parameters were kept constant. Highly dense samples cannot be prepared if pore boundary separation cannot be suppressed during densification. The latter calls for establishing the sintering conditions under which tungsten diffusion is controlled to such a level that grain boundary (GB) migration rate is slower than that of pore diffusion. As it has been well established, when the GB migration rate is higher than the pore diffusion rate, pores are often separated from the GBs and gets entrapped inside the rapidly growing grains.

So, a series of SPS trials were designed to achieve high density, by holding the samples at 1100°C for 5 minutes before further heating to the targeted sintering temperature ranging from 1300°-1750°C. The variation in density of the consolidated material as a function of SPS temperature is given in Fig. 1. The results show that the density increased from 85 to 97% of the theoretical with increase in SPS temperature from 1300°C to 1750°C for a constant pressure of 100 MPa and a soaking time of 5 min when all the samples were held at an intermediate temperature of 1100°C for 5 min. This kind of a two-step sintering is imperative to ensure high densification in the final component. It is obvious that the relative density of W–1 wt% La_2O_3 composite improved by the increase in SPS temperature.

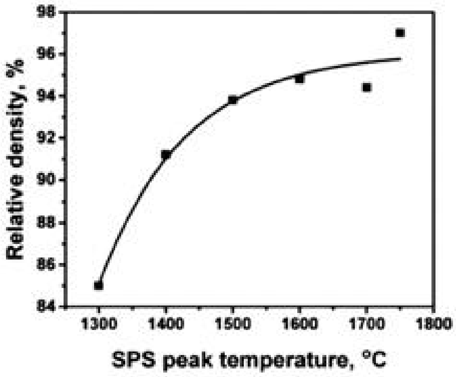


Fig. 1 Variation in relative density of the consolidated composite as a function of SPS temperature

Fig. 2 shows SEM image of the polished and etched surface of the consolidated composite samples. The microstructure is composed of tungsten grains (white), oxide particles (gray) and pores (black). The W grain size and La_2O_3 particle size in the bulk composite are quite uniform, about 10 µm and 3 µm, respectively. From the SEM images we can see that the La_2O_3 particles are homogeneously distributed in the W matrix without visible agglomeration and segregation.

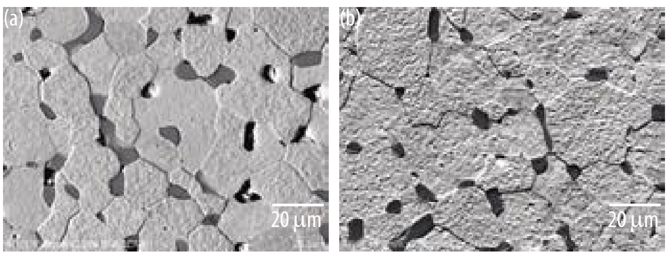


Fig. 2 (a) SEM micrographs of W-La_2O_3 composite sintered at (a) 1400°C, relative density of 92% and (b) 1750°C, relative density of 97%

The sample sintered at 1750°C having a relative density of about 97% exhibited a microhardness of 600 HV with narrow distribution.

Contributors: S B Chandrasekhar, Deepthi, R Vijay and Tata Narasinga Rao

Centre for Engineered Coatings

The specific ability of Centre for Engineered Coatings (CEC) to facilitate a wide variety of industrial application development by means of depositing very different coating material combinations ranging from few nanometer to a couple of millimeter thickness has been contributing significantly to the developments in the field of surface engineering in India. The past accomplishments include the successful transfer and implementation of Detonation Spray Coating, Micro-Arc Oxidation and Electro-Spark Coating technologies, being quite unique in the national context. The Centre has registered yet another year with excellent progress during the period of report encircling the technology development, application development, sponsored and in-house R&D accomplishments as briefed hereunder.

In recognition of consistent quest for enhanced durability of engineering components pertaining to various industry segments, the Detonation Spray Coating (DSC) with increased pulse frequency (6 Hz), and increased throughput, is under final stages of prototype testing. Further, inline with the objectives of "Make in India" concept, the wear-resistant, abradable coatings utilizing the DSC and Plasma Spray technologies were indigenously developed on the aircraft blades and vanes. Concerted focus on the strategic and civilian application of Cold Gas Dynamic Spray (CGDS) has been yielding promising applications. Further, prototype portable CGDS system has been designed and developed; both the DSC and CGDS technologies will be launched soon for technology transfer to Indian industries. With the recent development of fatigue resistant aluminum alloys through Micro Arc Oxidation (MAO) coatings, a major research and application development program were simultaneously initiated to extend the concepts developed for meeting the diverse demands of aerospace industry components including those of landing gear. Having designed and transferred an exclusive academic scale MAO system recently to a university in India, the much focused work to benefit the academic community in the country has also been initiated through simultaneous interactions with many academic institutions in the country.

As a logical extension to various R&D accomplishments registered recently, a well-defined roadmap aimed to transform the in-house R&D accomplishments towards the market sensitization and application development for PED and Cathodic Arc Physical Vapor Deposition (CAPVD) is now in place. Further, in the direction of translating the research into real time applications, a major project pertaining to the indigenous development of thermal barrier coatings for strategic helicopter blades through Electron Beam Physical Vapor Deposition (EBPVD) has been conceived. Further, the Solution Precursor Plasma Spray (SPPS) technique as recently proved at ARCI to deposit a wide array of hybrid coatings is currently being explored for various industrial and strategic applications by means of various sponsored projects.

Finally, as a part of constant efforts to keep the industry and institutions updated about the latest developments, a workshop on Thermal Spray Coating Technologies (TSCOAT) was organized by CEC, which evoked immense interest from various participating institutions. Furthermore, a joint centre entitled "Advanced Nano-Characterization Centre" (ANCC) has been conceptualized in collaboration with Nanomechanics, USA, which is being established to mutually share and strengthen the research outcome in the field of materials development and characterization.

D Srinivasa Rao
raods@arci.res.in

G Sundararajan
gsundar@arci.res.in

Simultaneous Improvement of Fatigue, Wear and Corrosion Resistance of Al Alloys Through MAO Coatings

L Rama Krishna *lrama@arci.res.in*

Although hard anodizing of Al alloys moderately improves the hardness, wear and corrosion resistance; concurrent reduction in fatigue life by ~30-50% drives the need to develop the enabling technology to simultaneously enhance the wear, corrosion and fatigue properties. The fatigue performance of plain Micro Arc Oxidation (MAO) coatings (without any pre-reatment) also exhibits a debit, the extent of debit is significantly lower than that of hard coat anodized coatings. The shot peening treatment is acknowledged to produce sub-surface compressive residual stresses which acts as a barrier to crack propagation and therefore improves fatigue performance. The primary purpose of shot peening is to introduce compressive residual stresses which can be retained even after MAO coating such that the overall fatigue life could be enhanced. Towards realizing such a phenomenon, the dog-bone geometry fatigue samples made out of a 6061-T6 Al alloy were subjected to shot peening operation prior to MAO coating deposition. Fatigue tests were conducted as per ISO 1143 standard with a stress ratio R=-1 (fully reversed) condition.

The overall fatigue performance as improved through a combination of shot peeing (SP) followed by MAO coating (SP+MAO) is clearly shown in Fig. 1 which clearly confers the significant enhancement in overall fatigue life at all stress levels investigated. Multiple dominant cracks initiated and propagated through underlying substrate without any deflection are observed (from Fig. 2) in case of plain MAO coatings.

However, the SP+MAO coatings exhibit single dominant crack that deflects at the maximum shear stress region at an angle of ~45° to its natural propagation direction evident from the Fig. 3. Such a notable crack deflection away from its natural propagating direction is expected to significantly absorb the cyclic energy and therefore leading to the concurrently extended fatigue life, which is quite understandable.

Further, 336 hrs neutral salt spray corrosion tests conducted on 6061-T6 Al alloy coupons clearly indicate the absence of any visible pits in case of both plain MAO and SP+MAO coatings. In addition, MAO coated 6061 Al alloy exhibits superior wear resistance under diverse wear modes such as dry abrasion, sliding and erosion than that of hard anodized coatings. Thus the fatigue, wear and corrosion resistances can be improved simultaneously through the combination of shot peeing and MAO coating which paves the path for conceptualizing numerous applications in the aerospace sector.

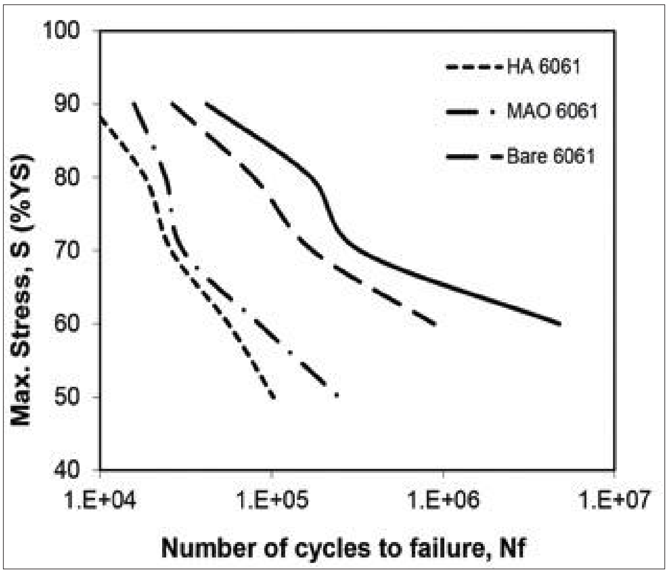


Fig. 1 Comparative fatigue cycles to fail as a function of % of maximum stress

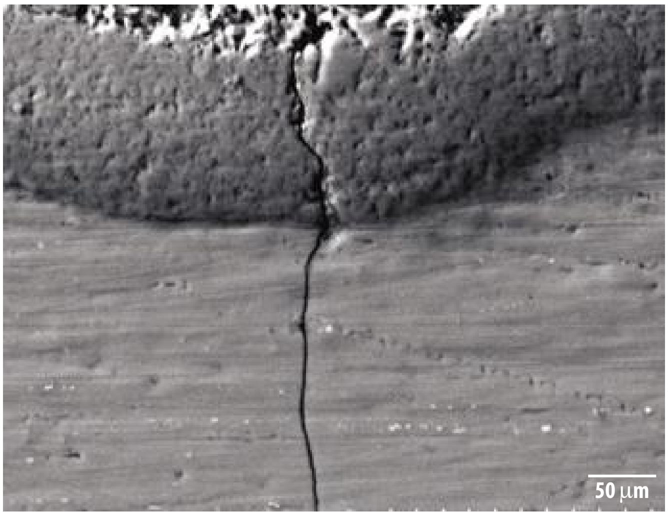


Fig. 2 Fatigue crack propagation of Plain MAO coated 6061 Al alloy

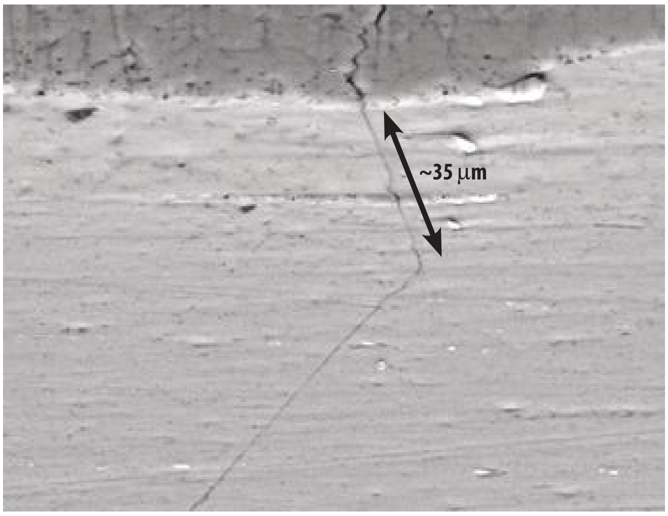


Fig. 3 Fatigue crack propagation of Shot Peened + MAO coated 6061 Al alloy

Contributors: Y Madhavi, T Sahithi, Nitin P Wasekar and D Srinivasa Rao

Fracture Behaviour of nc-TiAlN/a-Si_3N_4 Nanocomposite Coatings during Nanoimpact Test

N Ravi ***nravi@arci.res.in***

Nanolayered nc-TiAlN/a-Si_3N_4 nanocomposite (NC), TiN and multilayered TiN/NC coatings of 2 µm thick were deposited by Cathodic Arc PVD coatings on high speed steel (HSS) substrates with a surface roughness of 0.08 R_a, subjected to cyclic nanoimpact test that simulates interrupted machining operation, such as milling. Hardness values of the coatings are 24 GPa for TiN, 30 GPa for TiN/NC and 40 GPa for nancomposite and their elastic modulii are 450 GPa, 425 GPa and 400 GPa, respectively. Similarly, their indentation fracture toughness values are 7.2, 9.0 and 5.8 MPa.m$^{0.5}$, and brittleness indices 3.3, 3.3 and 6.9 KPa.m$^{-0.5}$, respectively. The impact tests were conducted at a frequency of 0.25 Hz using a Berkovich indenter at 150 mN load for 10 min. duration and the indentation impressions were studied by FIB/SEM to evaluate deformation behavior to rank their eventual performance.

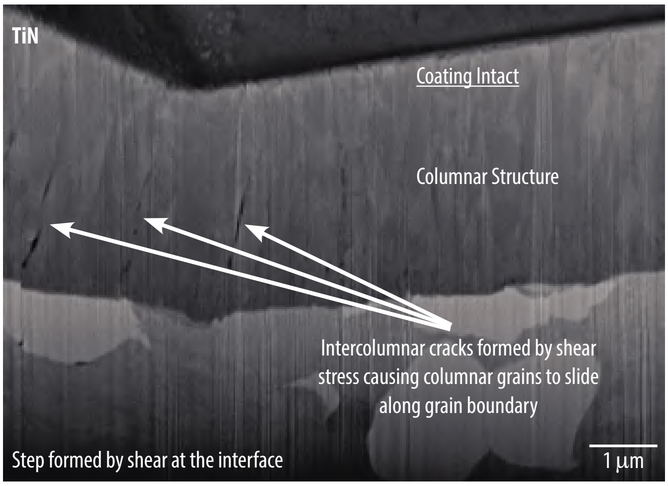


Fig. 1 Cross-sectional FIB image of the indentation made during cyclic imapct test for TiN

Fig. 1-3 shows the representative cross-sectional FIB images of the indentations made during the cyclic impact tests for TiN, nc-TiAlN/a-Si_3N_4 and TiN/NC coatings, respectively. Fig. 1 shows the intercolumnar cracks (typical of columnar TiN coating developed during quasi-static indentation test), formed by shear stress assisted intercolumnar grain sliding. The steps formed at the coating-substrate interface suggest that the intercolumnar shearing extends up to the interface. The constant thickness of TiN even after cyclic indentation impact indicates the coating is intact with the substrate. In the case of nancomposite coatings (Fig. 2), the cracks formed are of transgranular (or edge cracks) type, which are parallel to the coating surface. The cracks are found to occur along the interlayers, possibly due to the tensile and bending stresses caused by difference in plastic behavior between the coating and substrate. The reduction in coating thickness at the centre of the indentation impression signals that the coating has been deformed, but not intact with the substrate. Mixed mode of cracking events are seen in case of TiN/NC coating (Fig. 3), as it exhibits both intercolumnar cracks in TiN layers and transgranular cracks in nanocomposite layers, but the coating is seen to be intact without any deformation. It also can be observed that the coating debris is more in case of nanocomposite coating than the other two coatings pointing that the nanocomposite coating is more brittle than the other two coatings. This is supported by highest brittleness index and lowest toughness of nanocomposite coatings despite their high hardness.

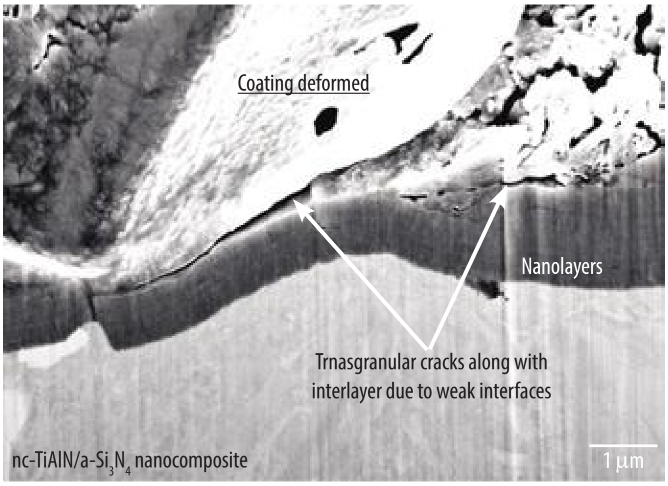


Fig. 2 Cross-sectional FIB image of the indentation made during cyclic imapct test for nc-TiAlN/a-Si_3N_4 nanocomposite coating

Based on the above observations, the performance ranking of coatings is concluded as, TiN > TiN/NC > nc-TiAlN/a-Si_3N_4. Further studies to enhance the properties of multilayered nanocomposite coatings are in progress.

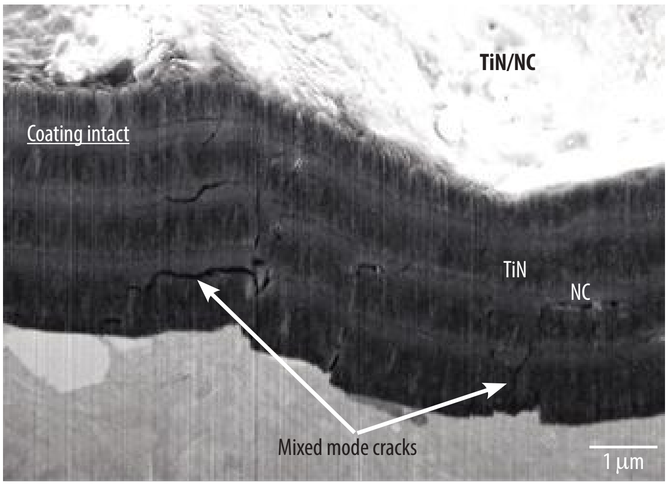


Fig. 3 Cross-sectional FIB image of the indentation made during cyclic imapct test for TiN/NC coatings

Contributors: R Markandeya and Shrikant V Joshi

Efficacy of Thermal Spray Coatings in Blast Furnace Tuyere Applications

G Sivakumar ***gsivakumar@arci.res.in***

Production hardware in an integrated steel plant is always exposed to severe operating environment, which typically involves a combination of high temperature, corrosive gases and erosion conditions. Such harsh environment tends to accelerate the rate of degradation and eventually leads to a decrease in product quality, reduced operating efficiency, invokes greater maintenance cost and, eventually, higher overall downtime. One such important hardware is the copper based tuyere used for injecting hot air (~1100°C) and pulverized coal into the furnace. The service life of a tuyere has a direct influence over the operating cost of the furnace and productivity. A water-cooled tuyere operates at temperatures in the vicinity of around 2000°C and is prone to severe thermal damage, corrosion from S/Cl_2 gases and erosion from splashing of molten metal and slag. The progressive damage is significant in affecting the tuyere efficiency and also, unattended damage cause possibilities of explosion within the blast furnace. Hence, imparting better protection at the 'nose' part of tuyere is of significant interest to the steel industry.

Thermal spray coating has been explored as a potential solution to mitigate above problems through detonation spray coating (DSC) and atmospheric plasma spraying (APS), and five different material systems (Yttria stabilized Zirconia (YSZ), Cr_3C_2-25NiCr (CrC), YSZ + 20% mullite (M-YSZ), mullite (M) and Al_2O_3-ZrO_2 (AZ)) were identified as prospective candidates for protecting the tuyeres. Based on the performance studies, the coatings were ranked and the most promising coating was chosen to be applied on an actual blast furnace tuyere for field evaluation.

Among the different coatings, detonation sprayed coatings showed denser microstructures than the plasma sprayed equivalents for each coating material as shown in Fig. 1. Moreover, the relatively more porous nature of plasma sprayed coatings was responsible for the reduced microhardness values in APS coatings vis-à-vis DSC equivalents. In terms of erosion wear performance, coatings synthesized by the DSC route show much superior erosion resistance compared to the APS coatings. This is to be expected in view of the consistently lower porosity and, in most cases, higher hardness exhibited by the DSC coatings. In addition to the above, it is also well documented in literature that the optimum particle temperature and higher particle velocity enable detonation sprayed coatings to exhibit compressive residual stresses which improve adhesion characteristics and mechanical properties. It is pertinent to note that alumina, zirconia, YSZ and mullite are known for their resistance to hot corrosion by 'S' and 'Cl' species and similar trend was observed for both DSC and APS coating. During the course of exposure to 40 hours, no spallation was observed in the ceramic coatings, whereas CrC exhibited poor hot corrosion properties. Under thermal cyclic tests at 1000°C, most of the DSC sprayed coatings survived for about 1000 cycles whereas, plasma sprayed M and M-YSZ failed within few cycles. APS AZ, YSZ survived for 600 and 1000 cycles, respectively.

Based on the above studies, it was found that Al_2O_3-ZrO_2 (AZ) and YSZ had shown promise against the three modes of failure observed in tuyeres i.e. erosion damage, thermal loading and hot corrosion. This allowed the following material–process combinations for tuyere application to be adopted for actual application namely, APS NiCoCrAlY bond coat - APS YSZ intermediate coat - DSC AZ top coat, and APS NiCoCrAlY bond coat - APS YSZ intermediate coat - APS AZ top coat. The second combination was selected for plant trial due to widespread availability of APS compared to DSC, to address a problem faced by the steel industry worldwide. The coated tuyere showed 90% improvement in service life which was a significant improvement for the industry. The disassembled coated tuyere has shown signs of mixed mode of failure i.e., thermal loading, erosion and corrosive gas attack.

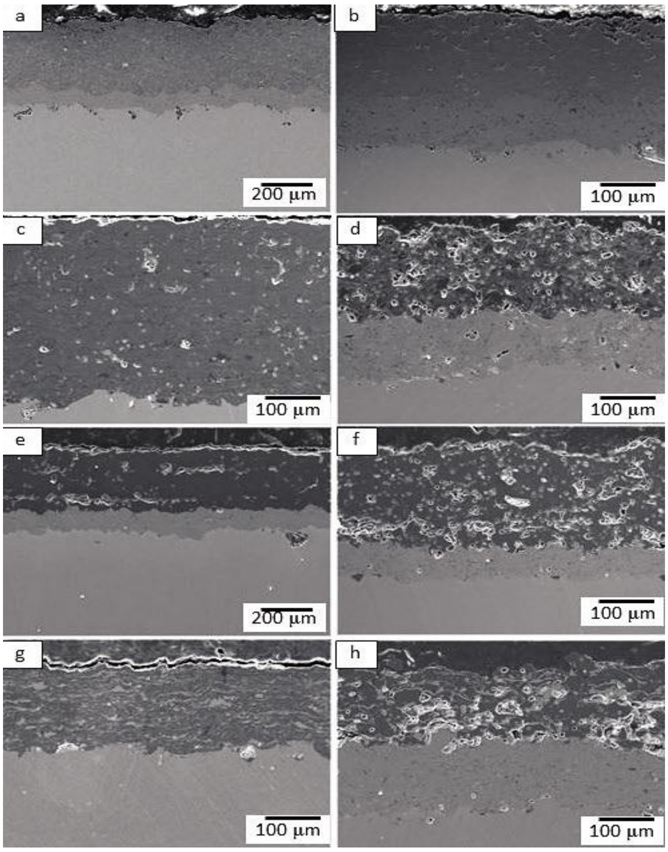


Fig. 1 Cross-sectional microstructures of various candidate coatings a) DSC CrC, b) APS CrC, c) DSC AZ, d) APS AZ, e) DSC M, f) APS M, g) DSC M-YSZ, and h) APS M-YSZ coating

Contributor: Abhishek Pathak

Pulsed Electrodeposition of Bulk Nanocrystalline Nickel Coatings

Nitin P Wasekar *nitin@arci.res.in*

Conventionally in the traditional direct current deposition the properties of electrodeposited coatings depend upon the bath pH, temperature, organic additives and the current density employed during deposition process. Although an important acidic bath gives hard coatings, the disposal of the used bath is main environmental issue. The higher temperatures utilized during process may give higher deposition kinetics due to increased diffusion of ionic species. However, the cost incurred for maintaining higher bath temperatures add cost to the process. The addition of organic additives for obtaining crack free, hard coatings leads to higher impurity content such as sulphur in the final deposit which is responsible for embrittlement related problem in the coatings. Another major concern in direct current deposition is the limiting current density above which deposition ceases due to depletion of ionic species near the cathode surface thereby burning effects and powder formation takes place during the process.

Our immense interest and sincere efforts has resulted in complete alleviation of above issues encountered during conventional direct current deposition and successful synthesis of fully dense coatings on par with the coatings obtained globally. For the first time we have demonstrated control over properties such as grain size and the hardness of the coatings (Fig.1) utilizing a simple bath at moderate temperatures with minimal quantity of additives near to neutral pH at more than 85-96% current efficiency by varying a single pulse parameter. It was traditionally thought that the grain size cannot be controlled in electrodeposited coatings without addition of alloying element. However, the process for deposition of bulk and pure nanocrystalline coatings was established. An implication of this methodology leads to control over hardness of coatings from 200 HV to 550 HV as per Hall-Petch effect. This is evident from Fig. 2 wherein hardness varies over a range in present method (using pulse reverse current) unlike in case of direct and pulsed current deposition.

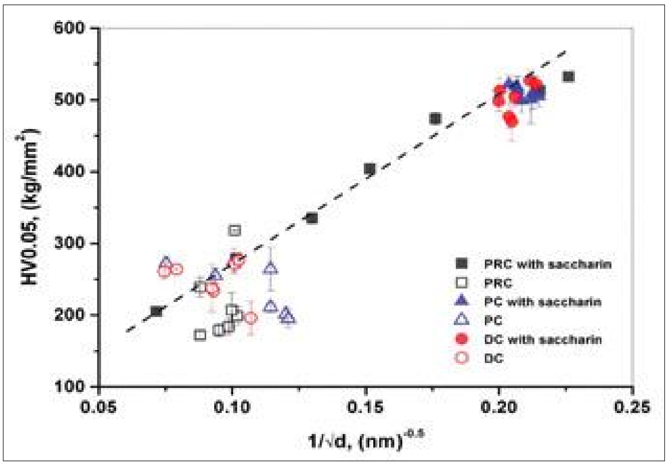


Fig. 2. Hall-Petch plot for Ni coating deposited using various electrodeposition modes

As an extension to the work, the methodology for depositing nanocrystalline layered coating (Fig. 3) was developed, wherein the mechanical property of a layer will be different from the adjacent layer in a single coating was achieved. Thus, utilizing a simple method, the property across the coating cross section could be changed at will depending upon the suitability of application. The suitability of technique resulted in synthesis of bulk nanocrystalline coatings having high toughness thereby improving the wear and corrosion resistance.

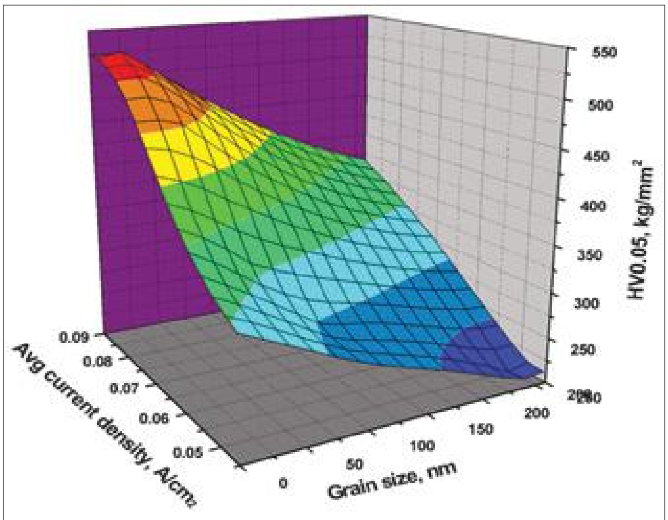


Fig. 1 Influence of current density on grain size and hardness of nanocrystalline nickel coatings

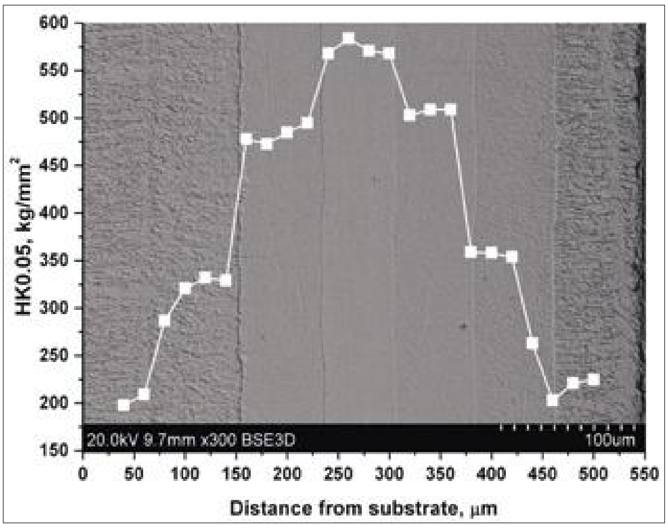


Fig. 3 Variation of hardness across the cross section of electrodeposited Ni coating

Contributor: D Srinivasa Rao

Cr/CrN/AlTiN/AlSiN/AlSiO Tandem Solar Selective Coatings for Solar Thermal Applications

Krishna Valleti ***krishna@arci.res.in***

For more than five decades extensive research has been carried out in order to harness the solar energy for cleaner energy production. Among the various methods, Solar Electric Generating Systems (SEGS), particularly Concentrating Solar Power systems (CSP), that have been designed to convert concentrated solar energy into heat before generating electricity through a photo thermal process have gained a lot of interest. These systems make use of Heat Collection Elements (HCEs) which are generally copper or stainless steel tubes that have low absorption in the solar spectra (α ~ 0.36, ε ~ 0.14) hence they require some kind of surface treatment to enhance their absorption. This is where multi layered solar selective coatings majorly come into play. Several methods such as evaporation, ion plating, pulsed laser deposition and RF/DC magnetron sputtering have been used to deposit these multi-layered coatings. Most of these methods offer good results in terms of optical properties but fail in terms of cost and coating stability. The Cathodic Arc Physical Vapour Deposition (CAPVD) is used to deposit hard coatings for cutting tools. Recent research on the use of this deposition technique for solar selective coatings has gained interest in the development of cost effective coatings. This technique has several advantages such as, noteworthy coating reproducibility, high coating substrate adhesion, density, homogenous coatings, and is nontoxic unlike CVD.

In the present work, solar selective coatings of Cr/CrN/AlTiN/CrN/AlTiN/AlSiN and Cr/CrN/AlTiN/CrN/AlTiN/AlSiN/AlSiO have been developed on SS tubes as shown in schematic (Fig. 1). The optimization of individual layer thicknesses and arrangement of the layers have been done systematically. The optimized coating thickness was found to be approximately 300 nm. Optical characterization was carried out in order to find the absorptivity of the coatings with respect to solar AM 1.5 spectra. It is observed that, the coating which is devoid of the AlSiO layer shows less absorptivity (α ~ 0.91 and ε ~ 0.09) at room temperature than the coating with the AlSiO layer (α ~ 0.96 and ε ~ 0.11) (Fig. 2). This implies that AlSi after annealing forms an oxide which acts as an antireflective layer and this layer is essential to increase the absorption of the coating.

Mechanical testing for adhesion involved scratching the surface of the coating by using a diamond indenter. Compared to coatings deposited by other techniques, the present coatings display good adhesion as they fail at an approximate load of 6 N. Wettability studies performed on these coatings have shown contact angles ranging from 102 to 108° (Fig. 3). The hydrophobic nature of the coatings contributes to its self-cleaning nature and prevents it from dust and corrosion. These observed exceptional properties indicate that the as-developed coatings can perform well even in open atmospheric conditions.

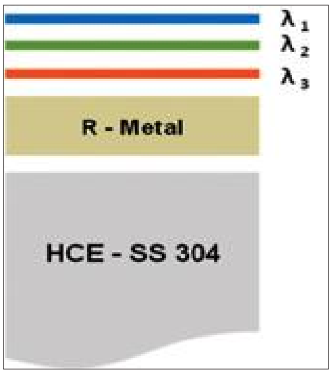


Fig. 1 Schematic of a solar selective coating for CSP applications. Where: λ_1, λ_2 and λ_3 - different functional materials with absorption maxima at different wavelengths, R-Metal– Refractory metal, HCE - Cu, SS 304

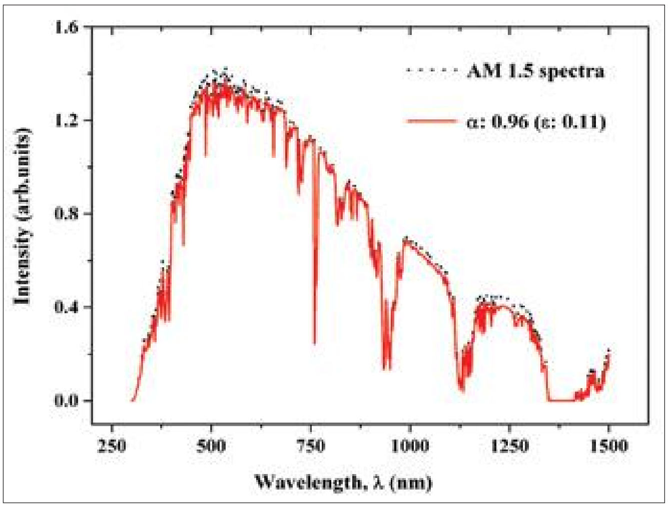


Fig. 2 Optical absorptivity of a tandem Cr/CrN/AlTiN/CrN/AlTiN/AlSiN/AlSiO solar selective coating on SS tube with respect to AM 1.5 solar spectra

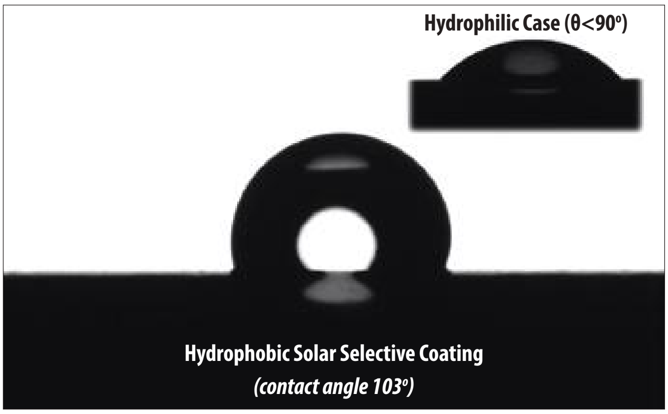


Fig. 3 Surface image of a tandem Cr/CrN/AlTiN/CrN/AlTiN/AlSiN/AlSiO solar selective coating exhibiting hydrophobic nature (a simple hydrophilic surface image is given in insert for reference)

Contributors: Smita G Rao

Wear and Corrosion Performance of Cold Sprayed Ni-B_4C Composite Coatings

S Kumar ***skumar@arci.res.in***

Cold spray coating technique is one among the thermal spray variants in which high velocity micron-sized particles are impacted onto substrate / previously deposited layers to form coating by strain induced adiabatic heating accompanied by shear instability. Due to low processing temperature and high deposition rate, this process is suitable for rapid production of many metallic coatings. Since the bonding / deposition mechanism is influenced by severe plastic deformation induced adiabatic heating of impacting bodies, cold spray cannot be used to deposit materials prone to fracture upon impact. Co-depositing hard particles along with soft metals using cold spray technique can be realized since soft feedstock can be served as a binder.

Metal matrix composites (MMC) are getting increased attention in applied research since they provide superior properties. In this work, different Ni-B_4C composites were deposited using cold spray technique. Since B_4C provides high wear, abrasion resistance, and very low density, it was pot milled with nickel feedstock to get composite feedstock. To achieve the same kinetic energy upon impact, property tailoring was carried out by carefully selecting the size cut. In order to compare the performance of the MMC, pure Ni clad B_4C was also deposited.

Figure.1a shows the SEM microstructure of the coatings deposited using Ni-Ni clad B_4C composite feedstock. It is evident from the figure that the distribution of B_4C particles in the coatings is homogeneous. For the purpose of comparison, the sample was heat treated at 600°C in vacuum. Figure 1b shows the wear performance of the coatings. Ni-Ni clad B_4C coating exhibits the very low wear rate which can be comparable with the coating deposited using Ni clad B_4C. Due to the poor deposition efficiency of Ni clad B_4C, it was decided to carry out wear tests for longer duration. For longer duration, the wear resistance of heat treated Ni-Ni clad B_4C is much superior than pure Ni clad B_4C. Corrosion performance of the heat treated Ni-Ni clad B_4C is superior to other coatings. The results suggest that the heat treated Ni-Ni clad B_4C cold sprayed coatings exhibit superior wear and corrosion performances.

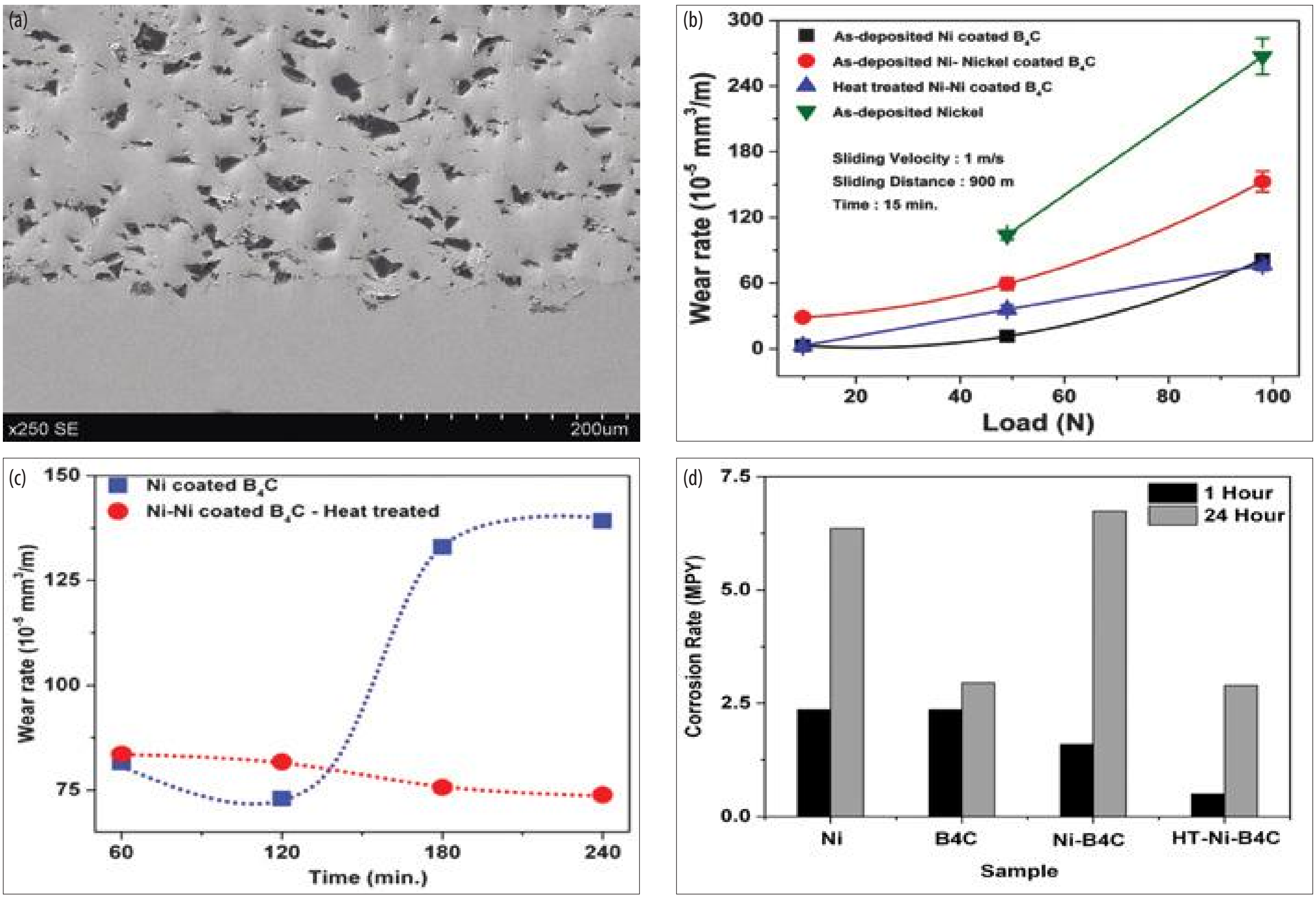


Fig.1 Scanning Electron Microscope images of (a) Ni-B_4C composite coating (b) Wear rate of the coatings at different loads (c) Wear rate of the Ni clad B_4C and Ni-B_4C composite as a function of time, and (d) Corrosion rate of different coatings

Contributor: Sai Kiran Reddy

Deformation Structure in Cold Sprayed Cu, Cu-Al Alloys: Influence of Stacking Fault Energy

Naveen Manhar Chavan ***naveen@arci.res.in***

Cold gas dynamic spray is a coating technique that involves high velocity impact of micron sized metallic/alloy/composite powder particles (10-45 µm) on the substrate in solid state. The coating formation is majorly accepted to be based on adiabatic shear instability induced softening and bonding at localized regions of particle/substrate and particle/particle interfaces. In essence powder particles undergo a high strain rate (~ 10^7-10^{10} s^{-1}) deformation especially at the interface zones. In the present study, the deformation structure post impact within individual copper (Cu) and Cu-Al alloy particles (Cu-2.2Al and Cu7.5Al), termed as "splats" post impact, on SS 304 is studied in great detail with Ion Channel Contrast Imaging. The microstrucutural evolution was studied as a function of the Stacking Fault Energy (SFE) of the impacting powder material.

Ion Channel Contrast Imaging of all the three splats of different materials and deposited at the same mean particle velocity are shown in Fig.1. Focussed Ion beam was used to section the impacted splat into half in order to image the splat cross section. It can be observed that the deformation structure is markedly different for the three alloys owing to the difference in the Stacking Fault Energies [SFE](Cu ~ 80 mJ/m^2, Cu2.2Al ~ 28 mJ/m^2 and Cu7.5Al ~ 6 mJ/m^2). The striking feature is the extent of the deformation induced changes in the microstructure that increases as the SFE decreases. It can also be observed that the extent of deformation twinning increases as the SFE decreases, in fact, twinning is also seen till the top portion of splats in Cu2.2Al (Fig.1b) and Cu7.5Al (Fig.1c) where as their density is very less in the case of copper (Fig.1a) even near the interface. Qualitatively the extent of grain refinement and/or dynamic recrystallization is also more in Cu2.2Al and Cu7.5Al. These observations can be understood based on the fact that as the SFE decreases the cross slip is hindered and hence the materials tend to exhibit higher hardening unlike the high SFE materials that can cross slip and dynamically restore or soften themselves. Also, the fact that the width of stacking faults is much higher in case of low SFE materials promotes deformation twinning. This is because stacking faults act as favorable sites for deformation twin nucleation. Since high strain rates are involved, deformation twinning proceeds even at room temperature cold spray process unlike conventional cold or cryogenic processes needed to develop deformation twins. This is because of the synergistic effect of low SFE and high strain rates. This synergistic effect is brought out because of the fact that as the strain rate increases beyond a certain extent the minimum stress required for deformation by slip exceeds that by deformation twinning paving way for excessive twinning even in slip dominant Face Centred Cubic (FCC) metals and Alloys.

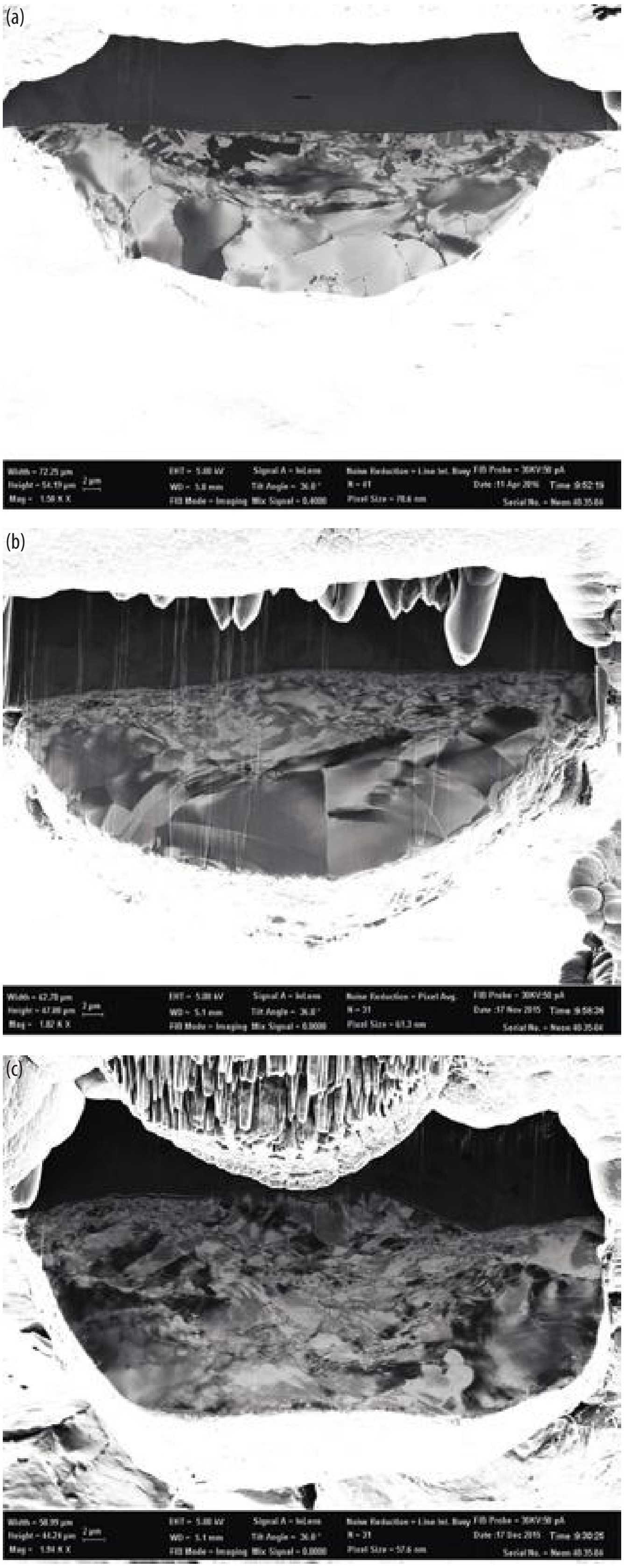


Fig.1 Splats deposited at a Mean Velocity of 517 m/s of (a) Cu (b) Cu-2.2Al and (c) Cu7.5Al

Contributors: L.Venkatesh and G. Sundararajan

Development of Advanced Detonation Spray Coating System (MARK-II)

Debajyoti Sen ***dsen@arci.res.in***

In the past, ARCI had indigenously developed a Detonation Spray Coating (DSC) system in technical collaboration with M/s. IPMS, Kiev, Ukraine. A total of six systems were indigenously fabricated and tested at ARCI. Subsequently, after rigorous R&D and application development efforts, the DSC technology along with indigenously developed equipments was transferred to four Indian entrepreneurs located at different parts of the country. All the technology receivers are thriving on their respective application development and job work activities. They also approach ARCI periodically for various technological inputs necessary to meet the wide-spread nature of application demands of various industry segments and ARCI has been extending its timely support.

Fig.1 DSC gas control system and advanced detonation spray coating system

It is noteworthy that some of the components in the existing DSC system such as graphite seals, flash back arrester elements were imported and there exists many mechanically moving parts such as cam, gears, piston, pusher, bearings etc., which wear out and therefore need periodic replacement for smooth functioning. Besides, excessive heat generation at the piston also needs additional cooling arrangements. In view of the aforementioned limitations, it has been decided to re-design the DSC system and completely eliminate all the moving parts. Accordingly, the first and foremost challenge that was addressed successfully has been the design of new gas mixing chamber and solenoid valves and their integration with the DSC system. A series of experiments were conducted to ensure that the system performance and resulting coating quality are matched with the requirements.

Further, a separate test rig has been fabricated to characterize each critical part that is under design. The shot frequency has been increased from 3 Hz to 6-8 Hz so as to enhance the productivity of the system on par with HVOF system while carefully retaining the preeminent coating quality. Utilizing such reengineered DSC system equipped with manual gas flow controls while the other mechanisms were controlled through LABVIEW software, one of the most popular spray powder namely the Chromium carbide-25Nickel chromium has been deposited at different frequencies (3, 4, 5, 6Hz). While the excessive heat generation was absent in mixing chamber, the metallurgical characteristics of the coatings were ensured to be identical at all the frequencies employed for coating deposition. Enthused by such an observation, subsequent coating trials with aluminum oxide powder are currently in progress.

As a logical extension to the aforementioned success, the manual gas flow controllers are now being replaced with mass flow controls (MFC) operated through a specially designed PLC system so as to demonstrate a precise control over the operational parameters, repeatability, reliability and the overall coating quality. The advanced detonation spray coating system named as MARK-II is expected to be launched soon for benefitting the Indian industry.

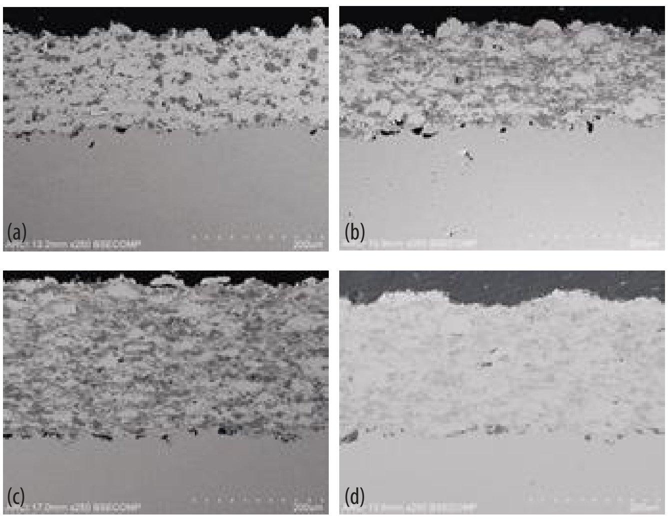


Fig. 2 Microstructure of Cr_3C_2-25NiCr coatings at various frequencies (a) 3Hz (b) 4Hz (c) 5Hz (d) 6Hz

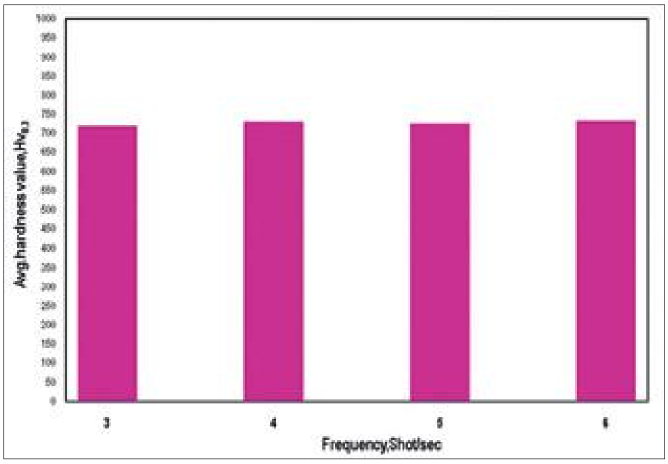


Fig. 3 Hardness value of Cr_3C_2-25NiCr coatings at various frequencies

Contributors: L.Venkatesh and G. Sundararajan

Centre for Ceramic Processing

Centre for Ceramic Processing (CCP), with its proven capabilities in the area of ceramic shaping and engineering the properties for specific applications, has continued developments in the emerging areas. Reliability and long-term durability of ceramics under the given service condition are the prime requirements, which depend on processing route and dictated by the processing parameters. During this period also, the Centre has been successful in its efforts to fulfill the commitments on the technology development and supply of deliverables of the time bound sponsored programs, especially in the area of transparent ceramics. Centre has also undertaken limited production and supply of prototypes as a part of demonstrating the technologies developed. Centre has established a facility and demonstrated single step densification of ceramics through vacuum canning followed by Hot Isostatic Pressing. Additionally, zeta potential measurements with high solid loading, based on acoustic impulse enabled the centre to enhance the homogeneity of casting, a critical factor in achieving the transparency. Centre has also been successful in commercial scale up of the technology established on a laboratory scale in the area of transparent ceramics.

Centre has made significant progress in its core competent area of defect free processing through Pressure Slip Casting of advanced ceramics, Extrusion, Chemical Vapour Deposition (CVD) and Hot Isostatic Pressing (HIP). The first phase of the sponsored programs, on development of porous ceramic tubes in combination with moderate mechanical strength for thermal management and development of complex shaped solid electrolyte parts based on in-house synthesized sodium beta-alumina, has been successfully completed and second phase of developing the actual components is in progress.

In the area of efficient combustion with low emission, reticulated ceramic foam based porous burners are designed and activities are in progress to stabilize the flame within the engineered reticulated pore structure through optimized parameters. Centre has also initiated activities on alumina-graphene/CNT composites synthesized through sol-gel route followed by vacuum sintering for wear resistant seal application. Centre has attempted several job orders such as hot Isostatic pressing of 3-D printed precious metal parts, Nd:YAG transparent laser ceramics and alumina spools for high temperature furnaces through conventional compaction processing.

Roy Johnson
royjohnson@arci.res.in

G Padmanabham
gp@arci.res.in

Pressure Slip Casting of Dense Alumina Complex Shapes

Y Srinivasa Rao ***ysr@arci.res.in***

Pressure slip casting (PSC), due to its inherent advantages compared to the conventional slip casting of ceramic products, has established itself in the last few decades in the manufacturing of table/sanitary ware very well. Major advantages of pressure slip casting are its high productivity, consistency, high green densities (≥60%) and very low rejection rates (≤3% in green stage). Though the parameters have been well established for table ware manufacturing, the technique has not been utilized in the making of advanced ceramic products for industrial applications. In view of this, ARCI has initiated a program to fill the technological gap of developing pressure casting process for advanced ceramics. Initially, Al_2O_3 slip properties and pressure casting machine (PCM) parameters are optimized to cast Al_2O_3 discs of dimensions ∅80 x Th: 5-7 mm and sinter them to obtain densities ≥99% of TD. It is well known that PSC/PCM has a limitation of thickness build-up upto a maximum of 15 mm. Efforts have been made to study and achieve thicknesses of >15 mm by pressure cast complicated shapes using Al_2O_3 slip. In view of the above two products such as grinding balls and spools are experimented and results are presented.

The SS patterns for i) a ∅60 mm solid sphere and ii) a set of spools each having approx dimensions ∅30mm x Th:15 mm have been designed, fabricated for the preparation of polymer moulds. These polymer moulds with their uniform pore size of about 10 µm will aid the thickness build up during the casting process. The Al_2O_3 slip used in these experiments has been prepared with MR01 grade HINDALCO powder, while Darvan 821 was the dispersant in addition to minor other additives. A solid loading of ≥ 75% has been achieved with a very good flowability of the slip.

Initial PSC trials have ended up with ∅60 mm green spheres having hollow cavities at the centre indicating the incomplete filling of the slip after formation of a thickness of about 20-25 mm is achieved. It is quite obvious that the PSC works on the principle of removal of water from the slip through application of external pressure. Further, once the thick casting is formed it will become extremely difficult to drain the water through the pores, irrespective of the magnitude of the applied pressure. By fixing the slip properties like solid loading, specific gravity and the PCM parameters such as feed speed, slip pressure and holding time, the problem of hollow portion at the centre of the sphere has been successfully solved. Fig.1 presents a typical sequence of how the hollow portion volume has been controlled with the slip/PCM parameters. It is evident that the hollow cavity at the centre of the sphere could be eliminated successfully and finally achieving the fully solid green ball of ∅60 mm which upon sintering at 1600°C acquired 98.5-99% density and Fig. 2 shows a picture of such sintered alumina balls of ∅50mm.

Fig.1 Sequential removal of hollow portion to reach full formation in half cut sintered alumina balls

Fig.2 Pressure slip cast alumina grinding balls (∅ 50 mm) sintered at 1600°C to ≅ 99% density

A complicated shape like a set of spools with Al_2O_3 as shown below in Fig.3 has been cast on PCM successfully with the specially designed and fabricated polymer moulds. Upon sintering at about 1600°C we could obtain a solid spool set with 99% density. Experiments are going on to increase the productivity further by way modifying the mould design and slip parameters as well to be suitable for commercial production.

Fig. 3 Pressure cast Al_20_3 spools sintered at 1600°C

Contributor: Roy Johnson

Pore Engineering in Ceramics Through Fugitive Pore Formers

M Buchi Suresh ***suresh@arci.res.in***

There is a great deal of initiative to develop porous materials because of many potential applications. Engineered porosity significantly influences the physico-chemical, thermal and mechanical properties. Therefore, it is required to gain information on controlling the porosity while forming porous ceramic components for specific applications. Properties like chemistry, particle size and distribution of the pore former material and processing technique are critical factors in addition to the properties of the starting ceramic powders. Generation of pores through sacrificial pore former results in negative replica of the template and hence effective tailoring of the pore morphology is possible. Sintering temperature can also contribute to the porosity and pore size distribution. It is well-known that the mechanical properties of ceramics are dictated by the porosity of the material. Hence, it is necessary to optimize these two contradicting factors ie., porosity and strength to achieve the desirable performance for the envisaged application.

In this article, the results of investigations related to the fabrication of porous zirconia ceramics for thermal management application employing polystyrene beads with various sizes are reported. The burn out temperature of the pore former was studied using TG/DSC Simultaneous Thermal Analyzer (Netzsch, Germany) and the weight loss was recorded as a function of temperature, in static air up to 500°C. 100% weight loss of the pore former material is observed at 450°C. Slurries with 0.1wt% of T10 (10micron) and 0.1wt% of T10+T20 were prepared and slip casted into circular green discs. These samples were dried and sintered at different temperatures between 1100°C-1250°C. The porosities were measured using Archimedes principle by calculating the porosity from the weights of the dry sample and the saturated sample.

Figure 1 shows the effect of particle size of the pore former material on the porosity of the sintered ceramic specimen with respect to the sintering temperature. A combination of pore former material with two different particles sizes, namely T10 and T20 has resulted in to larger pores as revealed by SEM studies. Fig. 2 shows the SEM images of dense sample and porous zirconia sample with 50% porosity. It is evident from the SEM image of the porous zirconia sample that the sample with 50% porosity has exhibited uniform pore distribution with isolated pores which are desirable for thermal management application. The effect of porosity on the mechanical strength of porous zirconia samples is shown in Figure 3. Zirconia samples sintered at different temperatures having different porosities were made into 45 x 4 x 3 mm samples as per the ASTM standard and the 3-point bend strength was used to estimate the maximum strength of the samples. The sample with minimum porosity has resulted with the flexural strength of 250 MPa. Porous samples with the porosity of 30% resulted into 100 MPa and sample with 50% porosity has given a flexural strength of 50 MPa. Attempts are in progress to engineer the porosity and pore structure to enhance the mechanical properties of the zirconia components.

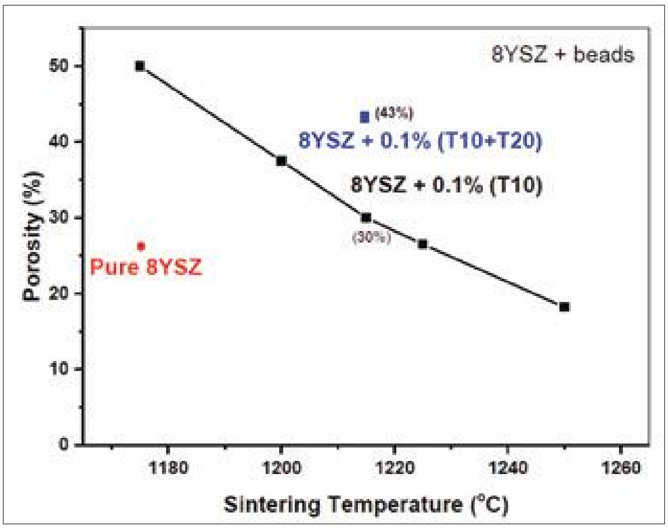


Fig. 1 Porosity variation with sintering temperature and pore former material and its particle size

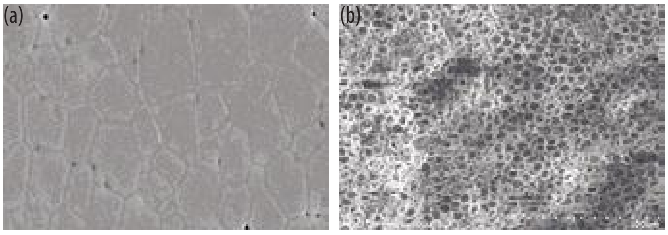


Fig. 2 Microstructure of (a) fully sintered zirconia sample (b) zirconia sample with pore former

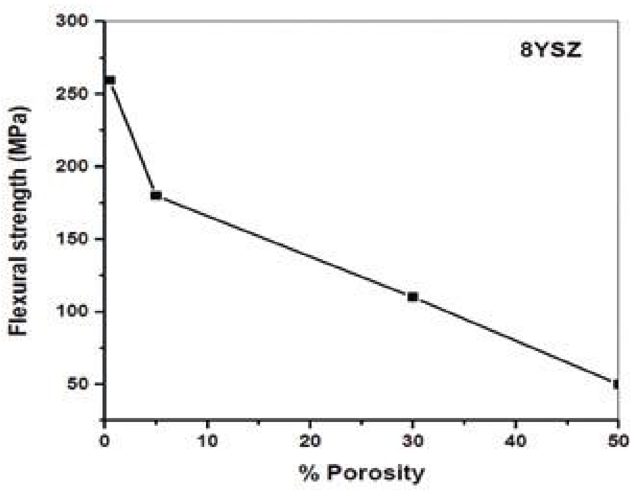


Fig. 3 Flexural strength variation with porosity of porous zirconia samples

Contributors: Roy Johnson

Development of Alumina-Graphene Nano Composites for Wear Resistant Applications

Senthil Kumar ***senthil@arci.res.in***

Advanced alumina based nano composite materials are receiving increased attention due to their improved mechanical and tribological properties and are useful in various applications. Some of the major applications include armor, prostheses, bearings and wear resistant seals. Various reinforcement materials which are currently explored are CNTs, fibers and graphene. Among these reinforcements, graphene has been the material of interest due to its unique physical and structural characteristics. Further, graphene offers high dispersability in the matrix even in larger quantities compared to CNTs and fibers without spring back effect during shaping. In addition, graphene also impart excellent mechanical, electrical, thermal and tribological properties which makes it a suitable candidate to enhance the flexural strength and fracture toughness of the matrix material. Moreover, graphene is a better candidate for solid lubrication, which reduces the frictional force between contact surfaces thereby enhancing the wear resistant properties.

In the present study, alumina-graphene composites were prepared using sol-gel processing. Stable graphene oxide suspension was prepared in-house using chemical exfoliation technique. Boehmite sol was prepared by mixing commercially available boehmite powder with water at 9:1 ratio followed by acid peptization. Stable graphene oxide suspension containing known amount of graphene oxide was dispersed in stable boehmite sol using mechanical stirring. The mixture was stirred, gelled, dried and calcined in vacuum for an hour at 1000°C. The calcined powder was further shaped using uniaxial compaction followed by cold isostatic pressing at 200 MPa. The samples were sintered at 1600°C for an hour in vacuum for achieving densification.

Figure 1 shows the SEM pictures of the fractured surface image of the sintered alumina graphene sample. It can be observed from fig.1 that the graphene layers are uniformly distributed and embedded in the alumina matrix. The average sintered grain size of alumina in the composite is between 600 – 800nm. Figure 2 shows the SEM image of indentation crack propagated through the alumina-graphene ceramics. It can be clearly seen that the crack has been propagated with many deflections in the crack path. This provides the evidence of improved toughness with long crack path for its propagation. In addition, Figure 2 also shows the grain bridging mechanism in the path of crack, where the existence of graphene in the path inhibited the crack expansion by sharing the fracture stress in the composites and further improving the toughness.

Figure 3 shows the initial results of wear test on pure alumina and alumina-graphene composite samples under identical conditions (ball on disc method, WC ball against samples). The pure alumina sample has shown the wear depth up to 40μm for test duration of 1200 seconds. However, no sign of wear has observed in the case of composite material.

Graphene alumina composite exhibited enhancement in strength of 400MPa (average) in comparison to pure dense alumina with 300MPa. A maximum fracture toughness of 5 MPa-m$^{1/2}$ has been observed for composite in comparison to 3.5 MPa-m$^{1/2}$ exhibited by pure alumina samples. Presently developed alumina-graphene composites are being explored for their potential in wear resistance and seal applications.

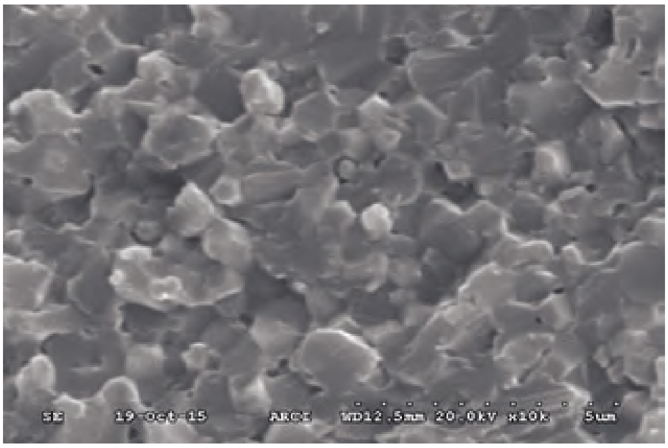


Fig.1 Fractured surface of alumina graphene composites

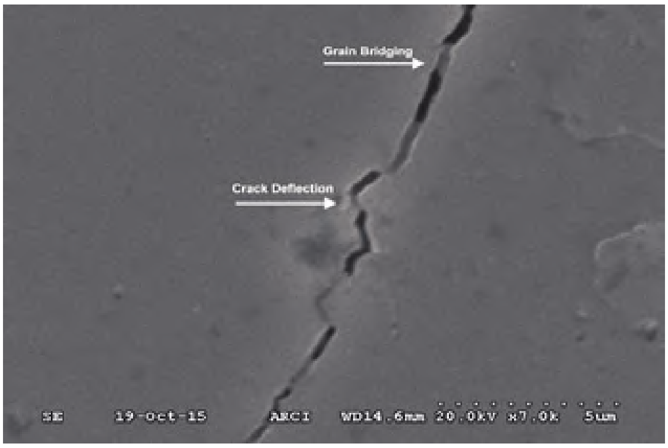


Fig.2 Grain bridging and crack deflection mechanism

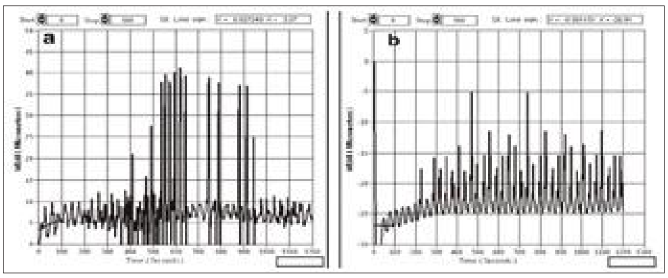


Fig. 3 (a) Wear testing of pure alumina and (b) Alumina graphene composites

Contributors: R. Easwaramoorthi and Roy Johnson

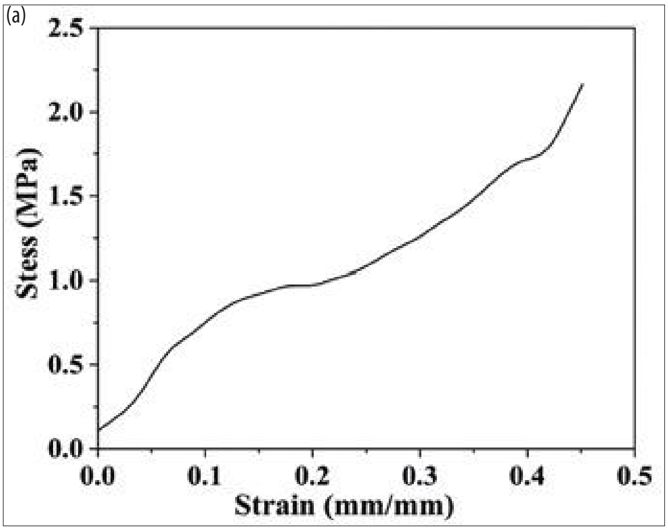
Compressive Deformation Behavior of Polymer Infiltrated Ceramic and Metallic Foams

Papiya Biswas ***papiya@arci.res.in***

Light weight reticulated porous cellular foam structures are recognized as the candidate materials for energy absorption application due to the unique mechanism of failure under impact stresses. These cellular structures are generally composed of solid struts with the air occupying the polyhedral voids as a second phase. During the impact, the struts collapse sacrificially and the air inside the cells reflects the shock waves, when constrained. In an attempt to improve the energy absorption properties while impact, the high viscous polymer has been vacuum infiltrated into aluminum foams with 10 pores per linear inch and cured as per the curing cycles to ensure the interface bonding with the strut surface. The foams with and without infiltration were evaluated for the energy absorption properties under quasi-static compression test at different strain rates.

The foam samples were cut into 15mm cube specimens. A few specimens were subjected to vacuum infiltration with uniformly mixed hardener and resin. Infiltrated specimens were further slowly heated in an oven to ensure the polymerization and interface bonding within the structure. These specimens were compression tested at a ram rate of 0.5mm per minute and the stress-strain behavior was recorded. Specific compression strength of the sample along with the energy absorbed during failure is shown in Table-1. The stress-strain curves for aluminium foam and polymer infiltrated foams are depicted in Fig. 1(a) and (b), respectively. It is evident that in case of aluminium foam an increase in stress is evident from the curve with a steep increase in the final stage due to the collapse of foam structure with struts touching each other. Polymer infiltration resulted in more uniform distribution of load with an initial increase of stress followed by close to plateau regime extending with respect to the strain.

It is evident that there is a significant increase in the compressive strength from 2.17 MPa to 91 MPa as a result of the polymer infiltration; similarly the energy absorption has significantly increased from 0.49 to 29.54 J/mm^3. It was observed that the composite has a solid fraction of 16% fraction with the polymer fraction of 84%. The significant improvement in energy absorption properties can be attributed to the composite effect under compressive load. The metal struts absorb the energy by deformation; however the polymer dissipates energy through densification. This combined effect resulted in almost 42 fold increase in compressive strength and energy absorption properties, with a marginal 3-fold increase in the weight. This indicates that the metal-polymer composite is an efficient shock absorber material that can be further investigated for applications which necessitates properties such as light weight in combination with high energy absorption.



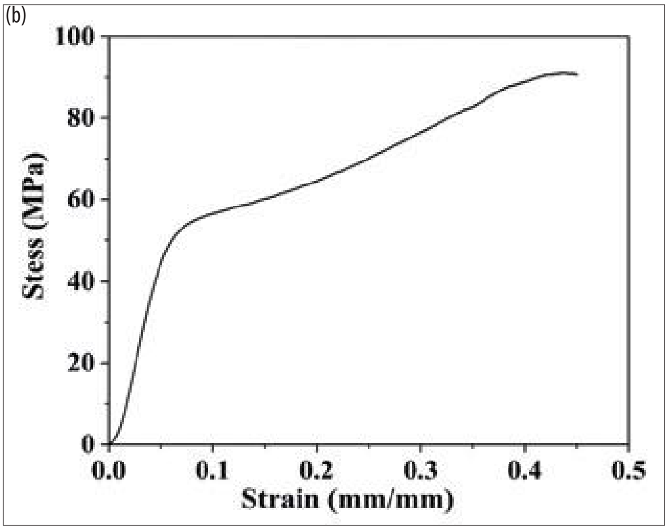


Fig. 1 Stress vs. strain curve of (a) aluminium foam and (b) aluminium + polymer foam

Table 1 Compressive strength and energy absorption data of aluminium and aluminium + polymer foam

Foam Material	Compressive Strength (MPa)	Specific Compressive Strength (MPa)	Total Energy Absorbed (x 10^{-3} J/mm^3)
Al	2.17	13.56	0.49
Al + Polymer	91.00	106.02	29.54

Contributors: B. Dileep and Roy Johnson

Direct Ceramic Powder Consolidation through Vacuum Encapsulation and Hot Isostatic Pressing

Pandu Ramavath **_pandu@arci.res.in_**

Commercially available submicron Al_2O_3 powder procured from M/s. Baikowski, France with a particle size of 300 nanometer and > 99 % alpha phase was encapsulated in a capsule using an encapsulation welder. The capsule was made of SS-316L with dimensions of 52 mm outer diameter, 50 mm inner diameter and a height of 80 mm. The capsule was placed on a vibrator to ensure proper packing and degassed in a furnace at 400°C at a heating rate of 5°C per minute at a vacuum of 10^{-3} Torr. An encapsulation welder and a crimping facility were employed to seal the sample under vacuum. The sealed capsule was helium leak tested and subjected to a heating and pressurizing schedule as shown in Fig 1. The capsule was finally hot iso-statically pressed at 1350°C and 2000 bar pressure under argon atmosphere.

The densified alumina sample was de-encapsulated by conventional machining from the deformed SS capsule after hot iso-static pressing and is shown in Fig. 2. The density of alumina sample was evaluated by ASTM 792 and also samples with dimensions of 45 (l) x 4 (w) x 3 (h) mm were prepared for 3-point bend loading as per ASTM C-1161-02C. The samples were also ground, polished and further thermally etched at 50°C below the peak temperature of processing to evaluate the microstructure. The samples exhibited a density of 3.94 g/cc, very close to theoretical values as a result of the direct consolidation of the powder under simultaneous temperature and pressure in the regime of the high temperature yield value of alumina ceramics. The stress-strain curve of the 3-point bend samples is shown in Fig. 3 attaining a flexural strength of 280 to 312 MPa with an average of 304 MPa.

Microstructure and fractographs of the samples were recorded by Scanning Electron Microscope and are shown in Fig. 4(a) and (b). Microstructure of the thermally etched sample is shown in Fig. 4(a). It is evident that the microstructure indicates well packed grains with average grain size of 3 µm. The fracture behavior and cleave facets in Fig. 4(b) are found to be highly uniform and material is failed under cleavage. The microstructure complements with the density and strength value is at par or better than the sample processed through the sinter + HIP route demonstrating the suitability of direct ceramic powder consolidation through vacuum encapsulation and hot iso-static pressing.

Alumina ceramics are generally prepared by colloidal shaping or compaction processing followed by pressure less sintering at elevated temperature to close all open pores, which is further subjected to Hot Iso-static Pressing for maximum densification. Unlike this conventional process, which is time taking and cost intensive, the present process is rather single step with an advantage of lower processing duration in combination with low cost adaptable for ceramic fabrication. The optimization of the process for the transparent alumina ceramics is in progress.

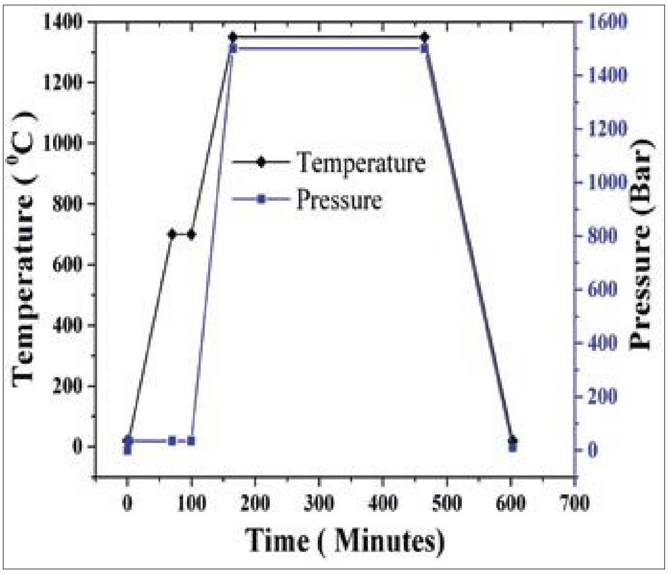


Fig.1 Heating and pressure schedule

Fig. 2 Densified alumina sample after de-encapsulation

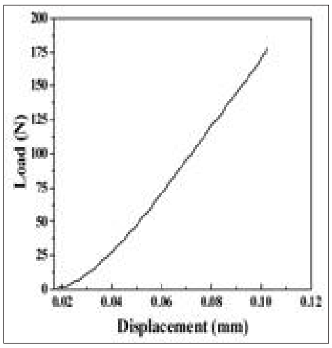


Fig. 3 Load-displacement curves obtained from 3-point bend testing

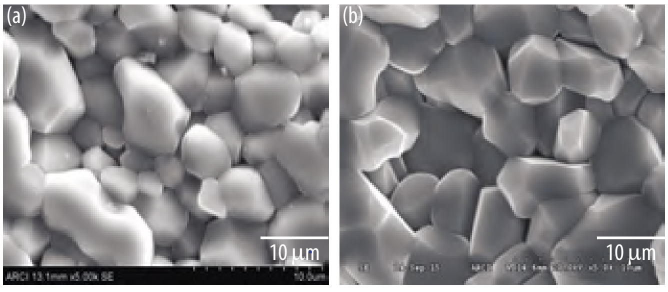


Fig. 4 (a) SEM Micrograph and (b) Fracture surfaces obtained from the failed specimens of 3-point flexural strength

Contributor: Roy Johnson

Centre for Laser Processing of Materials

Laser is a high intensity, precise, flexible and clean heat source. Depending on its intensity and interaction time with the material being processed, a laser beam can heat, melt or vaporize a wide range of materials. Due to its unique properties, laser has been gainfully utilized to carry out manufacturing in several industrial sectors such as automotive, aerospace, energy, electronics and nuclear. Laser based processing can be classified as macro processes (cutting, welding, cladding, alloying, drilling and brazing) and micro processes (micro texturing, scribing, micro drilling etc.) depending on the scale of effects induced during the process.

The Centre for Laser Processing of Materials (CLPM) works towards development and promotion of laser-based manufacturing solutions for the industry. Various laser based processes being pursued include:

- *Laser surface engineering (hardening, cladding, alloying, texturing)*
- *Laser welding and brazing (including laser-arc hybrid)*
- *Micro processing (surface texturing, drilling, scribing)*
- *Laser based repair and refurbishment of components*
- *Metal additive manufacturing*

The activities span from R&D work towards an in-depth understanding of various processes, development of applications and manufacturing solutions followed by know-how transfer to the user industries. Some of the important activities are as follows:

- *In the ultrafast laser processing area, the Centre is actively involved in various microprocessing application development/ demonstration such as laser surface texturing of automotive engine materials for improved tribological performance, laser cutting of liner slits for giant telescope and laser drilling of very fine holes (hole diameter 50 µm) for flash X-ray camera.*
- *Laser hardening method was investigated on various grades of steels used in compressor blades etc.*
- *Laser assisted additive manufacturing of different alloy powders in 3D geometries with diode laser cladding system has been attempted. Repair and refurbishment technologies were pursued. A new inner bore cladding head has been integrated to diode laser for internal cladding of pipes and tubes up to 550 mm depth and inner diameter as small as 65 mm.*
- *Laser brazing and cold metal transfer brazing processes were successfully developed for joining of Aluminium and Steel in different dissimilar combinations under "Multi-Join" consortium project and a few demonstration components were fabricated.*

In order to increase the outreach, the Centre has also organized an International Conference on Applications of Lasers in Manufacturing (CALM 2015), in association with Messes Muenchen India. CALM 2015 was attended by about 200 delegates with speakers from all over the world from academia as well as industry.

G Padmanabham
gp@arci.res.in

Ultrafast Laser Processing of Different Materials and Their Applications

Ravi Bathe ***ravi@arci.res.in***

Ultrafast laser can be used for unique applications that are not possible using other technologies. A number of applications were demonstrated since installation of ARCI's ultrafast laser facility in August 2014. The ultrafast laser micromachining system is equipped with some of the most cutting edge features such as a wide range of pulse duration (ns, ps, fs), broad spectrum of wavelength (UV, visible, NIR), multiple beams at the workstation, precision motion system and fast speed galvo scanner. Compared to conventional lasers, femtosecond laser materials processing can significantly reduce the thermal effect in target materials. This is because femtosecond laser pulses can deposit energy into a target material faster than the electron-phonon-relaxation-time.

Laser micro processing investigations were carried out to indentify wide parameters. The high repetition rate and pulse energy ultrafast laser system facilitate faster processing speeds with minimal thermal damage. Varying the processing conditions can also be used to precisely deposit heat within a microscopic region. Influence of ambient medium as well as the effects of various process parameters are taken into account to develop a reliable ultrafast laser micromachining process. Accordingly, the important parameters considered were pulse duration, pulse energy, pulse repetition rate, focusing optics, laser beam wavelength, polarization and translation speed.

The minimum laser fluence below which ablation cannot be initiated is defined as the ablation threshold or optical breakdown threshold. The fluence above the ablation threshold is necessary for laser micromachining. The ablation properties of SS304 and Nickel sheet were studied for laser pulses of 100 fs duration and centered at 800 nm wavelength. The linear relationship between the square of the crater diameter and the logarithm of the laser fluence in the form of

$$D^2 = 2\omega_0^2 ln\left(\frac{E}{E_{th}}\right)$$

provides the ablation threshold. Figure 1 presents the measured values of the ablation diameter D of craters exposed to different laser fluences. The figure includes two sets of data from experiments performed on SS304 and Nickel. The beam radius focused on the surface can now be determined by estimating the slope of this linear fit to the data points. We obtain a 1/e^2 Gaussian beam radius of ω_0 = 7.66 and 12.11µm for the 50 mm and 100 mm focal length lens, respectively. The results show that ablation of SS304 requires lower threshold fluence than Nickel (~ 0.28 J/cm^2 for SS304 and 0.31 J/cm^2 for Ni).

Similar studies were carried out on different materials and various applications were developed as shown in Table 1.

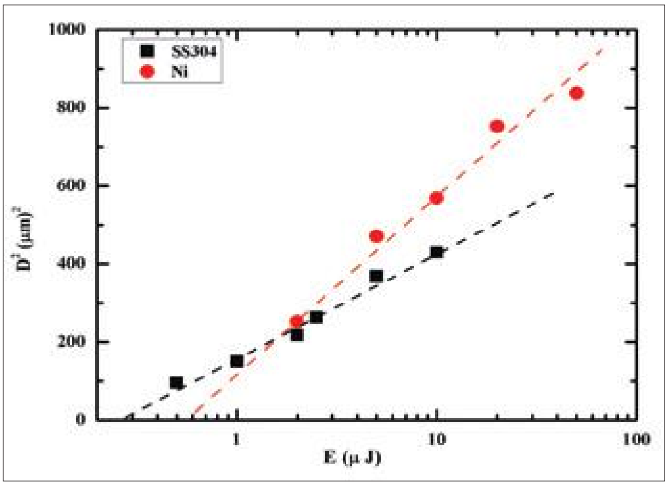
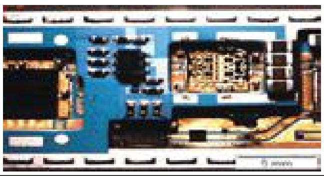
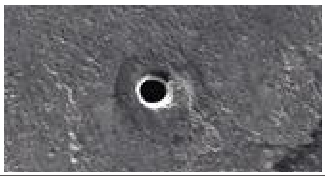
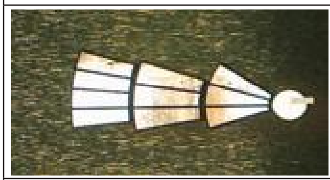
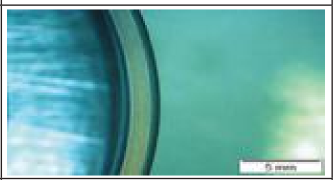
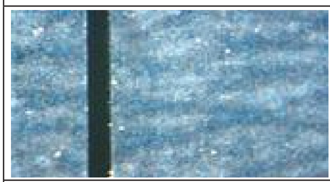
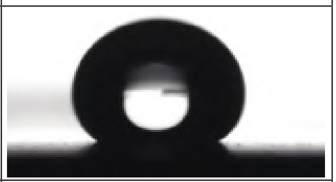


Fig. 1 The ablation threshold measurements of SS304 (50 mm FL) and Ni (100 mm FL) with laser pulses of 100 fs and 800nm. The squared diameter (D^2) of the ablated areas is plotted as a function of the laser pulse energy (E)

Table 1 Applications developed at CLPM, ARCI using ultrafast laser system

	
Precise micromachining of low temperature co-fired ceramic multi-layer module boards: machining of 1mm x 1mm area and 5 layer (600 µm) depth without damaging surrounding components on the board	Aperture for flash X-ray cameras: 50 µm hole diameter in 400 µm thick tungsten stripe, deviation from circularity < 5 µm, Depth non-uniformity < 5 µm
	
Control and shadow grids for pulsed microwave source: 3D profile cutting of grids with width 50-100 µm and high edge quality in molybdenum of 100 µm thick	Laser surface texturing: bearing and piston ring, dimples of 30-40 µm diameter and 5-10 µm depth
	
Liner slit for optical telescope: 50 µm width and 100 mm long slit in SS316l, minimum heat affected zone	Superhydrophobic metallic surfaces: surface micro-nano structures

Contributor: G Padmanabham

Laser Aided Additive Manufacturing

Gururaj Telasang ***gururajst@arci.res.in***

Laser aided additive manufacturing (AM) is one of the most exciting manufacturing processes, which is being projected as synonymous with "Future of Manufacturing". AM enables manufacture of finished parts directly from digital input. It offers a great geometric freedom for rapid manufacturing to either prove new innovative designs or precisely build the parts such as aerospace components, tools and biomedical implants. The same can be extended to repair and refurbish expensive components as well. Classic example is the successful reclamation of bladed disks of aero-engines resulting in considerable cost savings. In AM, as shown in schematics (Fig. 1), the 3D model (CAD file) of component is sliced into thin layers using software and data of these digital layers is given as an input to the additive manufacturing system in order to build the component layer by layer typically using a laser or on electron beam as energy source and alloy material in the form of powder. This helps in generating a final product with less waste, less weight and minimum environmental impact. The process is known by several names, 3D printing, solid free-form fabrication, layered manufacturing etc. It provides an immediate link between the virtual realm and manifest object.

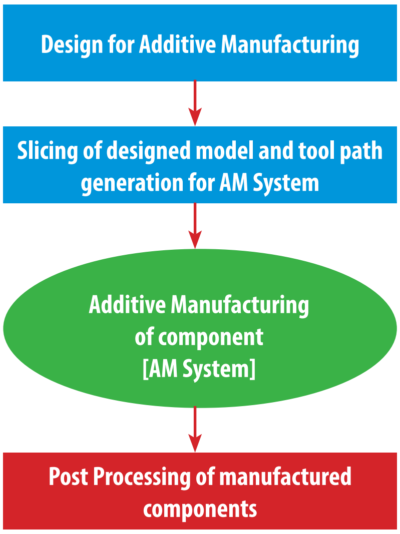


Fig. 1 General methodology for AM

Initial attempts on AM have been made using existing DCAM software to slice CAD model, generate tool path and corresponding program codes for 6-axis robot coupled with diode laser and co-axial powder feeding nozzle (Fig. 2 a-b) using AISI H13 tool steel (Fig. 2c) and Stellite 6 (Fig. 3) powders. The whole concept and features available in the existing robot based system were demonstrated by building selected geometries. The builds were metallurgically and mechanically evaluated for as-processed and post heat treated conditions.

Detailed analysis of AISI H13 tool steel part has been carried out to study the defects and porosity, microstructural anisotropy (Fig. 4a), micro hardness variation across the build. Post processing by vacuum heat treatment could be optimized to achieve uniform martensitic microstructure and fine carbides across the build (Fig. 4b & c). Consequently, uniform hardness (450 HV0.2) and comparatively lower tensile properties were observed compared to conventionally processed H13 tool steel, but can be improved by optimizing the process parameters and post heat treatment.

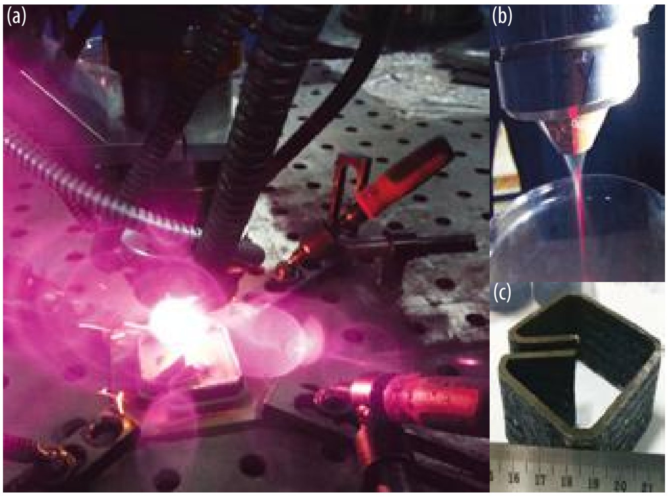


Fig. 2 Photographs showing (a) process arrangement(b) co-axial nozzle and laser beam (c) as build component of AISI H13 tool steel

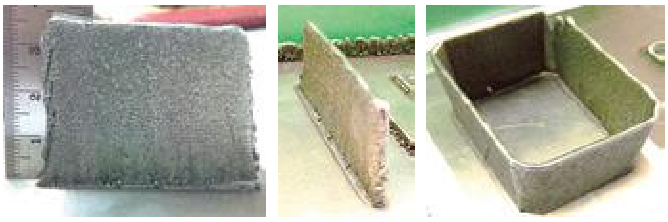


Fig. 3 Photographs showing as-build thin wall and rectangular geometries of satellite 6

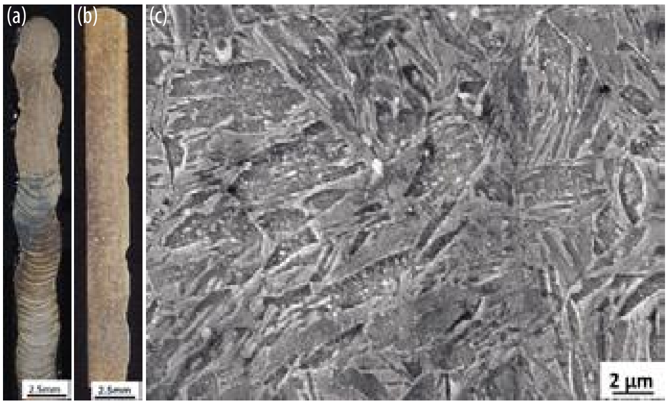


Fig. 4 Cross-sectional optical micrographs of (a) as processed (b) post heat treated and (c) SEM microstructure of post heat treated AISI H13 tool steel part

Contributor: G Padmanabham

Laser Brazing of Aluminum-steel-in-white Application for Automobile Body

SM Shariff *shariff@arci.res.in*

Introduction of high-strength-to-weight materials like Al-alloys in body building components is increasingly tried and tested for light weighting of automobile vehicles. Automotive bodies (car, bus, truck etc.) usually involve joining by resistance spot welding. Technically and economically promising aluminum auto body concepts (requiring large amount of joining) enables not only a significant weight reduction, but also cost efficiency too. As a consequence, properties (tensile strength, shear strength, corrosion resistance etc.) of joints significantly affect the overall properties of the whole structure and its stiffness. Conventional spot welding of aluminum proves to be energy-intensive, unreliable and costly. Although other techniques like patented plasmatron process, cold-metal transfer weld-brazing etc were found to yield improved joint quality requirements, application of high speed laser brazing was found to provide great promise in automotive car body manufacturing.

ARCI in collaboration with Fraunhofer Institutes of Germany is developing laser brazing technology for joining suitable Al-alloys with automotive steels currently used in body fabrication. Figure 1 depicts laser brazing system constituting Scansonic brazing head (Model ALO3) coupled with filler-wire based seam tracking (SCAPACS) integrated to 6-kW fiber coupled diode laser and 6+2 axis Kuka Robot. Joints with lap-fillet and flange configurations (shown in Fig 2) of 1.5-mm thick 5XXX and 6XXX alloys and 0.8-mm thick galvanized IF steel with good static strength were successfully made. Figure 3 illustrates typical cross-sectional micrographs at interface regions (variation of intermetallic compound (IMC) layer formation) of optimized and un-optimized joints. At optimum processing conditions with flux usage, effective uniform continuous interface could be produced at joint with low IMC. Indeed, addition of flux facilitates in cleaning surface and enhance wetting with molten Al pool. SEM/EDS microstructural analysis of interface showed 70-80at.%-Fe rich intermetallic phases towards steel side and 60-65at.%-Al rich phases towards Al-melt side. It is clear that strength (from Fig. 4) increased with brazing speed on account of reduction in IMC thickness at interface. Figure 5 illustrates comparison of strengths obtained with various material-combination produced under optimized processing conditions. The result envisages applicability of laser brazing process with appropriate strength being possible for auto body applications.

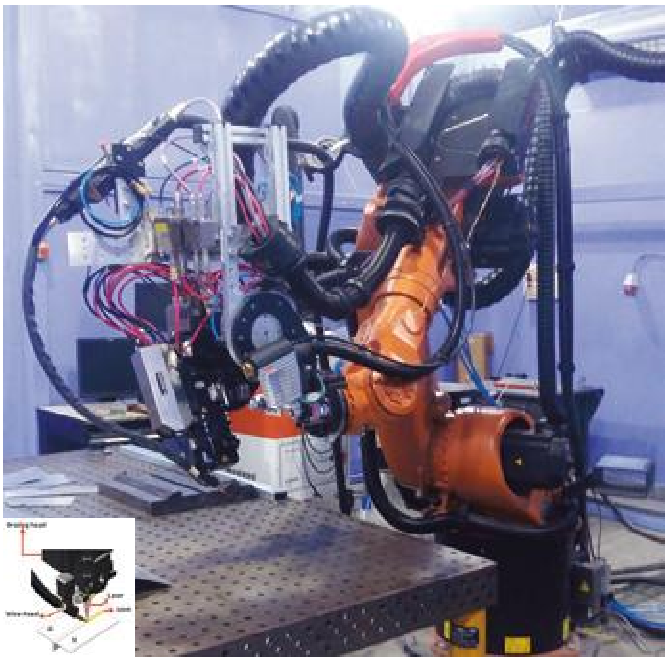


Fig. 1 Seam-tracking based laser brazing system integrated to 8-axis Robot (Inset shows schematic of the process)

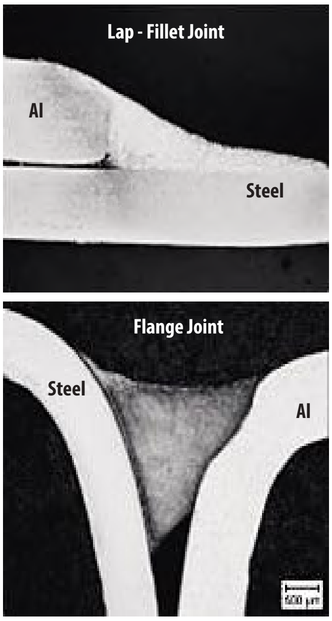
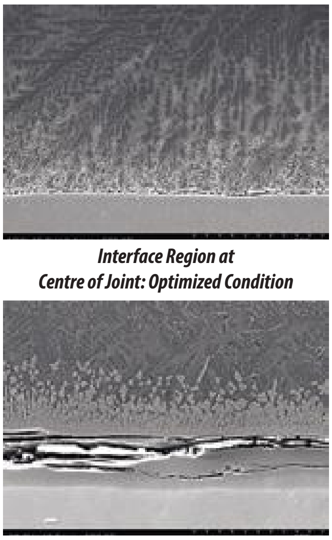


Fig.2 Joint configurations



Interface Region at Centre of Joint: Optimized Condition

Interface Region at Centre of Joint: Unoptimized Condition

Fig.3 Cross-sectional microstructures of joints

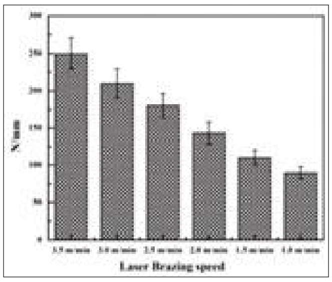


Fig.4 Effect of brazing speed on strength of lap-fillet joint of Al-6082 with IF Steel

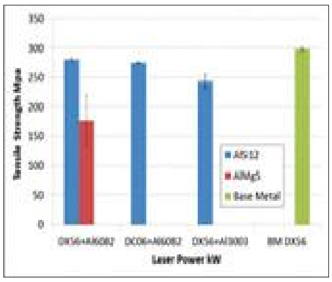


Fig.5 Effect of material combination on strength of brazed joints in comparison with base steel strength

Contributors: G Padmanabham and Dr-Eng Günther Goebel

Laser Cladding of Dissimilar Materials Using Buffer Layer

Manish Tak **manish@arci.res.in**

In applications where components come in contact with each other under high pressure and corrosive environment the surfaces are subjected to wear, galling and self-welding thereby necessitating frequent replacement. One of the remedies to extend their life is by hard-facing with superior anti-galling and wear resistant materials. Hard-facing using conventional methods such as weld-overlay process, plasma transfer arc processes etc., are being used but these techniques are found to have limitations in terms of cracking and distortion. These limitations and shortcomings can be overcome to a greater extent by laser-clad deposition process due to high controllability in heat input with precision. However, the issue related to formation of transverse cracking mainly due to difference in coefficient of thermal expansion (CTE) in substrate and the coating is an issue. A suitable buffer layer between the clad layer and the substrate can reduce these interfacial stresses.

In the present work, laser cladding of a Ni-based alloy (Colmonoy 53) on 316L steel substrate was investigated and effect of the composition of buffer layer on cracking susceptibility was studied. Cladding was carried out using a 6 kW diode laser system with an off-axis nozzle mounted on a 6+2 axes robotic system. In order to understand the effect of the buffer layer composition on the transverse cracking, two layers clads were generated where the first layer was the buffer layer with different composition and the second layer was made of colmonoy 53 alloy (Table 1). The composition of the buffer layer was varied by mixing SS316L powder with the colmonoy 53 powder. Dye penetration test results showed significant reduction in cracking with increase in SS316L powder content in the buffer layer and no cracks were observed with buffer layer composition of 75%SS316L+25% Col 53. It clearly indicates that reason for cracking is due to the CTE difference between the substrate and coating and the addition of SS316L in the buffer layer reduces the interfacial stresses as the CTE mismatch will reduce at the interface.

Cross-sectional micro-hardness profile (Fig. 2) clearly shows that reduction in micro-hardness with increase in the SS316L content in the buffer layer which is a result of more Fe content in the clad layer due to dilution from the buffer layer leading to reduction in the surface hardness. The SEM micrographs of different regions in the clad with buffer layer (75%SS316L+25% Col 53) are shown in Fig 3. It can be observed that the clad region consists of fine γ-Ni dendrites whereas the buffer layer is consisting of γ-Ni(Fe) matrix. More analysis is being carried out in order to understand the effect of buffer layer on cracking and to achieve a crack-free multi-layered clad-coating on a larger area.

Table 1 Buffer layer and clad layer composition details

Sample No.	Layer 1 (Buffer Layer)	Layer 2 (Clad layer)
1	25%SS316L+75% Col 53	100 % Col 53
2	50%SS316L+ 50% Col 53	100 % Col 53
3	75%SS316L+ 25% Col 53	100 % Col 53
4	100%SS316L	100 % Col 53

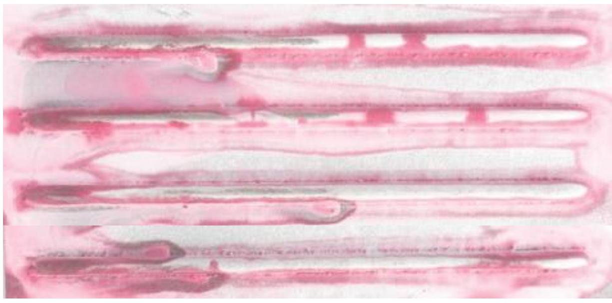


Fig. 1 Dye penetration test on laser clads of different composition of buffer layers

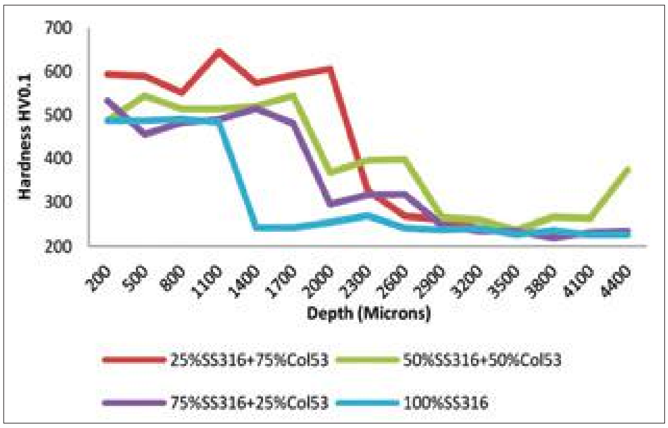


Fig. 2 Cross-sectional micro hardness profiles of two layer clads with various buffer layer compositions

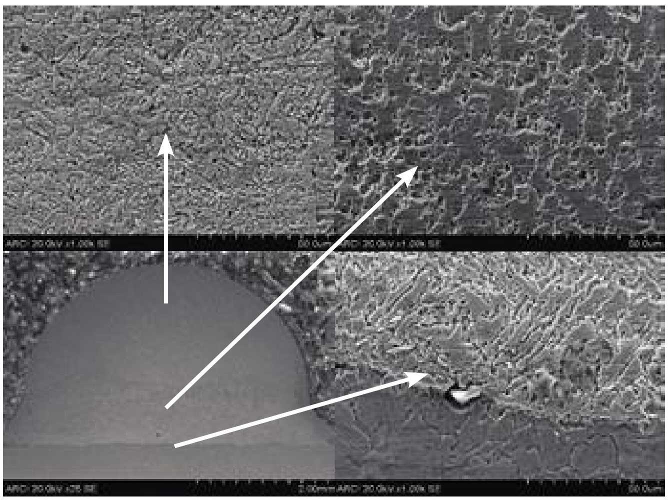


Fig. 3 SEM Micrographs of clad layer, buffer layer and interface for the clad with 75%SS316+25%Col53 as buffer layer and Colmomoy53 as second layer

Contributors: SM Shariff and G Padmanabham

Laser - MIG hybrid Welding Process of Nickel Based Super Alloy Haynes 230

K V Phani Prabhakar *phani@arci.res.in*

The Nickel-Chromium-tungsten-molybdenum solid solution carbide strengthened nickel based superalloy (Haynes-230) owing to its excellent high temperature strength, oxidation resistance, high creep resistance and low thermal expansion is identified as one of the candidate materials in ultra-supercritical (USC) boilers capable of operating with 760°C, 35Mpa steam. The alloy is primarily composed of a face centered cubic (FCC) austenite matrix with tungsten rich precipitates in the matrix and grain boundaries. Weld solidification cracking, liquation cracking and micro fissuring in the fusion zone are the major weldability issues.

The Laser Metal Inert Gas (MIG) hybrid butt welding experiments were carried out using 3.5kW CO_2 slab laser with a focus spot dia of 180μ in Gaussian beam mode along with synergic pulsed MIG process. Filler wire of similar composition was used to weld plates of size 300x150x10mm in single pass, double pass and two independent passes in 'Y' groove configuration. The dye penetrant and X-ray radiographic analysis qualified all the welds. The micro hardness survey revealed that there is hardly any influence of laser hybrid welding cycle on Haynes 230 superalloy.

The hardness variation of single pass, double pass and two independent pass hybrid welds in the vicinity of coarsened precipitate near fusion boundary indicates relatively higher hardness in double pass and two independent pass hybrid welds than in single pass hybrid welds may be due to higher accumulation and stagnation of heat near neck portion in successive weld passes. Macrographs of Single and Double Pass laser hybrid welds (LHW) indicating neck region shown in Figure 1. All the LHW room temperature and elevated temperature tensile specimens fractured in the weld with near 100% joint efficiency along with ductile fracture. The impact energy of single pass weld is higher than double pass and two independent pass welds with ductile fracture may be due to absence of reheat zones. All laser hybrid butt welds cleared face bend test as shown in Figure 2.

Laser hybrid weld microstructure found to be fully austenitic with columnar dendritic solidification, finer at bottom and coarser at top. Heat Affected Zone (HAZ) is almost absent with very narrow zone containing coarsened precipitates and thickened grain boundaries. Staggered liquation cracks indicated in Figure 3, nucleated from the fusion boundary towards base metal and found to be more significant around MIG zone than in the laser zone.

Energy dispersive spectroscopy (EDS) of Single pass hybrid welds indicate micro-segregation near inter-dendritic boundaries as precipitates containing chromium and tungsten in both MIG and laser fusion zone. Further, EDS of double pass hybrid welds indicate presence of inter-dendritic precipitates consisting of tungsten, molybdenum and chromium which are coarser near root pass than in fill pass.

EDS of two independent pass hybrid welds indicate that coarsened precipitates near fusion line are richer in tungsten and less in nickel and chromium than in inter-dendritic precipitates of MIG fusion zone.

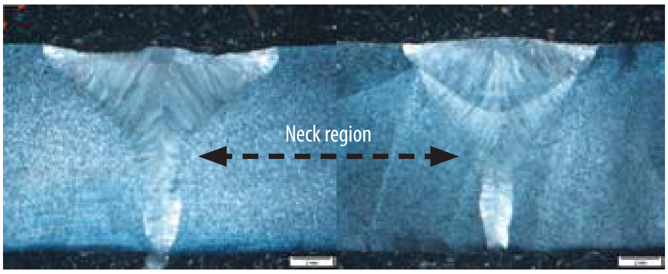


Fig. 1 Macrographs of Single and Double Pass Laser hybrid welds indicating neck region

Fig. 2 Face bend test of hybrid welds

Fig. 3 Liquation crack near neck region of hybrid welds

Contributors: E Anbu Rasu and G Padmanabham

Laser Welding of Automotive Grade Steel DP 780

E Anbu Rasu *anbu@arci.res.in*

High strength with good formability and high crash worthiness are the characteristics of advanced high strength steels (AHSS) qualifying them as popular candidate materials for automotive applications. Among them, dual phase (DP) steels are popularly used for automobile bodies. DP steels are characterized by a microstructure consisting of hard martensite in a soft ductile ferrite matrix. In actual application, there are several parts requiring welding of these steels. Welding heat alters the microstructure and consequently basic characteristic of DP steel. Effect of heat input in laser welding of 1 mm thick dual phase steel having 780 MPa tensile strength (DP 780) on the tensile properties, specifically failure location and formability was evaluated using Erichsen cup test. A 3.5kW CO_2 laser beam in continuous mode with a spot size of 360 μm was used for the experimentation under argon shielding.

From bead-on-plate trials on 150 x 85 x 1 mm thick, inference is drawn that minimum heat input of 30 J/mm is needed to get full penetration with sufficient under bead. Defect free laser butt welds were generated at 3 different heat inputs - 30 J/mm, 40.5 J/mm & 54 J/mm. Macrostructure of laser weld with heat input of 30 J/mm shown in Figure 1. The laser welding process resulted in formation of martenstic structure in the fusion zone and formation of tempered martensite in Head Affected Zone (HAZ) and partial disappearance of martensite near intercritical HAZ (near base metal).

Micro hardness profiles shown in Figure 2 indicate higher hardness value of 402 $HV_{0.2}$ in the fusion zone (FZ) and lower hardness value of 235 $HV_{0.2}$ in HAZ as compared to the base metal hardness of 255 $HV_{0.2}$. Higher hardness in the fusion zone is attributed to high cooling rates in the laser welding process resulting in the formation of mostly martensite. Dip in HAZ hardness indicates formation of soft zone. It is noted that degree of softening is higher in laser welded joints with high input. This is due to tempering of pre-existing martensite.

Stress-elongation curves of laser butt welded DP780 shown in Figure 3 for two sets of specimens indicate that laser welding led to decrease in elongation and decreases significantly with increase in heat input. Welded joints failed in the base metal for low heat input (i.e 30 J/mm) while joints with higher heat input (i.e 40.5 J/mm & 54 J/mm) failed in the HAZ and it is clear that heat input influences failure location.

The Erichsen cup test results indicate that laser welding of DP 780 steel led to loss of formability as shown in Figure 4. The loss in formability is relatively more with welds of highest heat input than with lowest heat input by 19%. Further optimization for minimizing the HAZ softening by post weld heat treatment is being attempted.

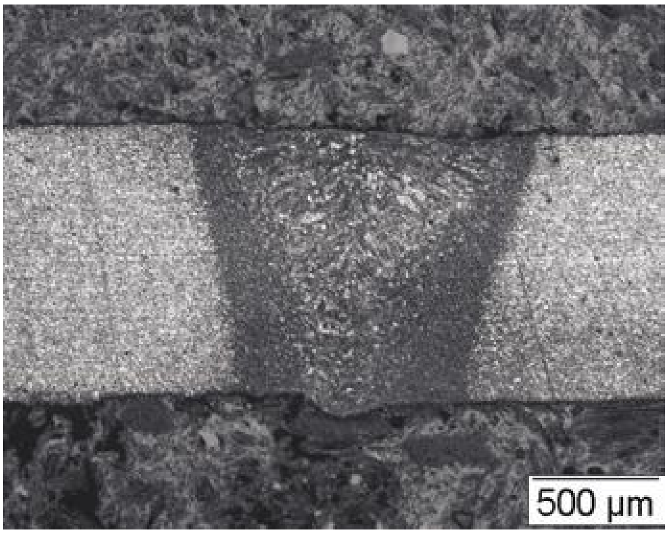


Fig. 1 DP780 steel laser weld (30J/mm) macrostructure

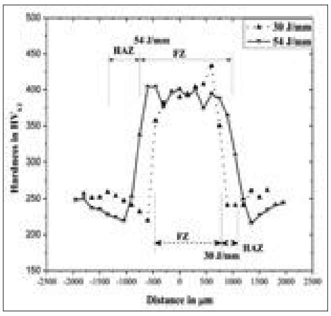


Fig. 2 Micro hardness profile across DP780 steel laser welds

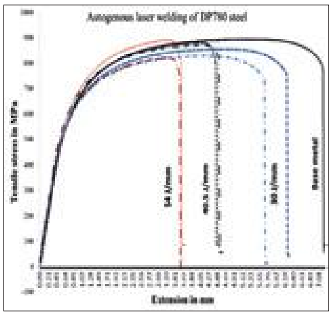


Fig. 3 Stress-Elongation curves of laser welded DP780 steel under different heat input condition

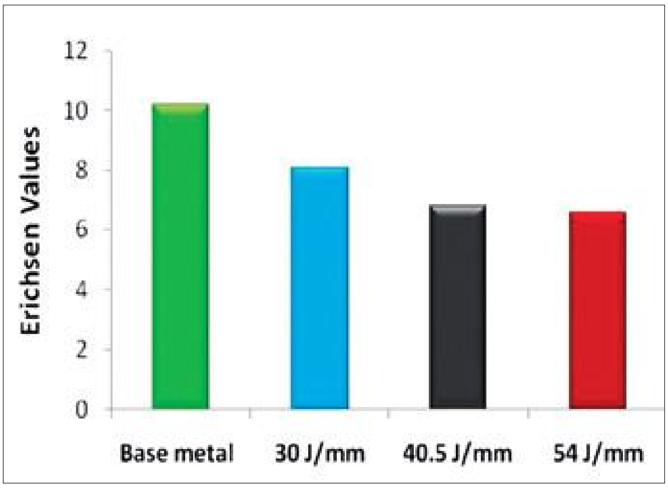


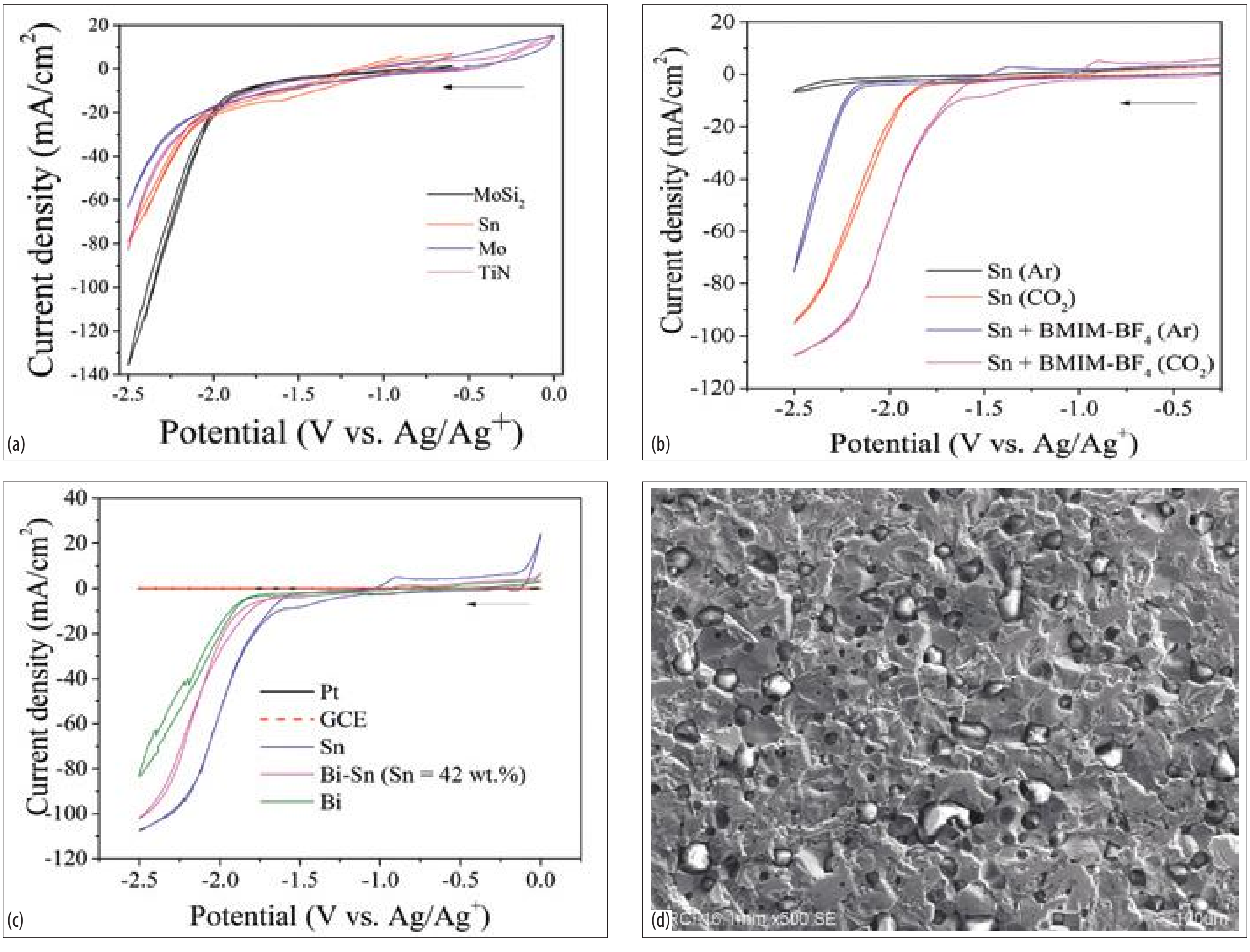
Fig. 4 Erichsen cup test results of DP 780 steel laser welds in different heat input conditions

Contributors: K V Phani Prabhakar and G Padmanabham

Direct Splitting of Carbon dioxide to Carbon monoxide in Electrochemical Cells

I Ganesh ***ibramganesh@arci.res.in***

This article reports the electrochemical reduction of carbon dioxide (CO_2) to carbon monoxide (CO) with a faradaic efficiency of >95% and current density of about 110 mA/cm^2 at an applied potential of about 2.5 V vs. Ag/Ag$^+$ (i.e., at an over-potential of about 1.3 V) obtained in a controlled potential electrolysis (CPE) experiment conducted over certain new materials developed at ARCI. CO_2 is freely available at thermal power plants, cement industry and huge refineries, which produce several million tons of CO_2 everyday, which is being released into atmosphere. ARCI's process has the potential to be a highly economical process. For commercializing any gaseous producing electrochemical process, the minimum current density of product formation should be between 100 and 300 mA/cm^2. As can be seen from cyclic voltammetry curves (CVs) shown here, certain materials exhibited current densities, >110 mA/cm^2, for the reduction of CO_2 to CO (confirmed by gas-chromatography and mass-spectrometry (GC-MS) analysis). During CPE experiments, no drop in the activity was noted for continuous 8 hours over cathodic systems consisting of ARCI developed materials employed in conjunction with BMIM-BF_4 ionic liquid. This process of ARCI can be a substitute to the CO_2 sequestration process to be deployed at thermal power plants, cement industry and gas refineries in India. Furthermore, CO formation from CO_2 is one of the best ways of storing energy available today. Methanol, a product from CO feedstock, can be employed in place of gasoline and diesel being employed in the present existing energy distribution infrastructure to meet the energy needs of the society. Hence, there would not be any severe economical consequences while transforming from fossil fuel energy dependency to non-fossil fuel, renewable and solar energy dependency. In fact, the cost incurred for CO formation from CO_2 can indeed offset the cost to be incurred for CO_2 sequestration process.



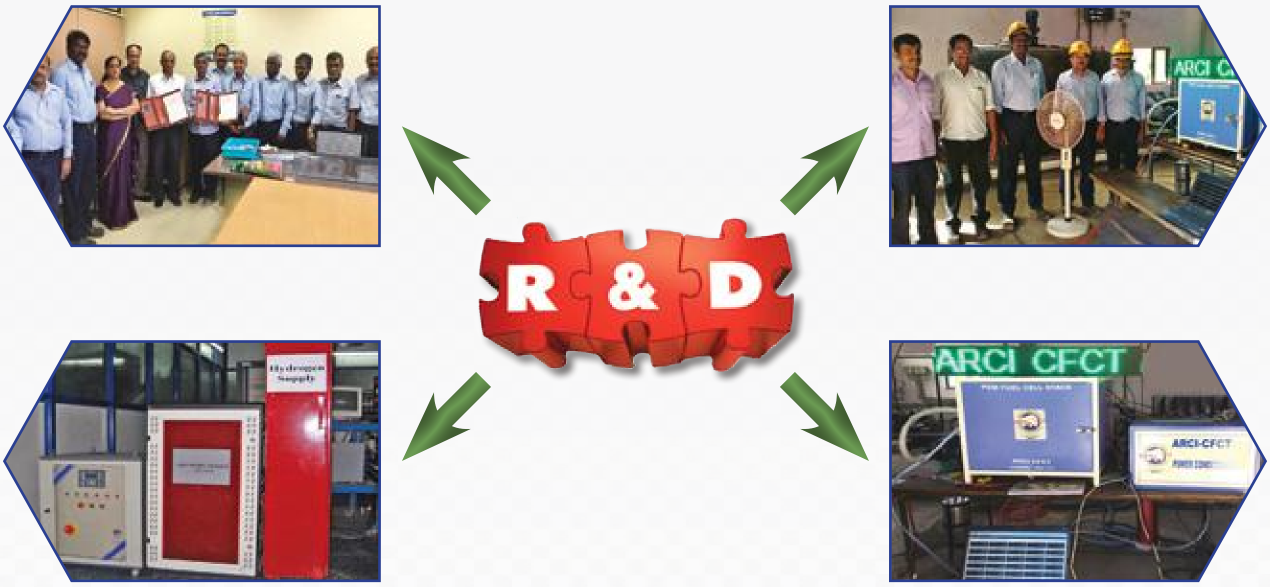
Figs. (a-c) These cyclic voltammetry (CV) curves were recorded using Ni as an anode on a three-electrode based electrochemical work station at a scanning rate of 100 mV/s in an electrolyte consisting an aprotic solvent, supporting electrolyte and BMIM-BF_4 ionic liquid, which was saturated and blanketed with CO_2 gas. (d) SEM micrograph of $MoSi_2$ (Super Kanthal)

Contributor: G Padmanabham

Centre for Fuel Cell Technology

Centre for Fuel Cell Technology (CFCT), established at ARCI, during 2004, has been at the forefront of PEMFC technology development in the country. The centre has established various process know-how for the various components used in the fuel cell stacks and built fuel cell systems of capacity ranging from 1 kW to 10kW. There are many in house demonstrations, and as well many sponsored application oriented demonstration projects, which are handled effectively and a few organisations are already in the pipeline for the demonstration of the system at their sites, where hydrogen is available. Noteworthy is the recent demonstration at Neyveli Lignite Corporation (NLC), Neyveli, where hydrogen is available at their electro chlorination plant in the sodium hypochlorite production. A PEMFC system along with reactant management system (flow controllers, blowers, humidifiers), power management system (Converters, Inverters) various load banks (AC, DC), fuel cell control monitoring system along with data logging facility for current, voltage, temperature, individual cell monitoring provision has been installed at the site and the data has been collected . The system was intermittently operated and generated a power of 100 kWh using the hydrogen available at NLC, Neyveli. Another demonstration initiated is at Gail India, New Delhi, in the coming months.

As part of the hydrogen technology development, the centre has established an energy efficient technology for hydrogen generation by combining reforming and electrolysis. With our recent improved electrodes, catalysts and membrane the cost has been brought down by about 20%. The centre for fuel cell technology consists of a team of scientists from various science and engineering background, working on various aspects of energy conversion devices viz., supercapacitors, electrolytes for Li ion batteries, Zn-Ni alkaline battery, Metal air batteries etc. The fundamental R & D is expected to play a pivotal role for the application research and the prototype development.



K S Dhathathreyan / N.Rajalakshmi
ksdhatha@arci.res.in / rajalakshmi@arci.res.in

Improvement in PEMFC System and Efficiency

N Rajalakshmi ***rajalakshmi@arci.res.in***

In PEMFC, the major challenges are cost, durability and performance. At CFCT, we are trying to improve the performance as well as durability by addressing the oxygen reduction reaction (ORR) kinetics and by developing new catalyst supports. The kinetics of the ORR can be enhanced by improving the catalytic activity, catalyst-support interaction, mass-transfer limitations, water management etc. The interfacial resistance can be reduced by use of catalyst coated membrane (CCM) electrodes with catalyst coating at the cathode side to reduce membrane pinhole formation.

The pore structure and pore size distribution of cathode GDL for the CCMs are controlled by optimising the concentration of pore-formers. The performance of the fuel cell was studied with oxygen as cathode feed. The GDL with 70% pore-former showed a better performance comparatively. The pore size distribution for the GDL was also characterized.

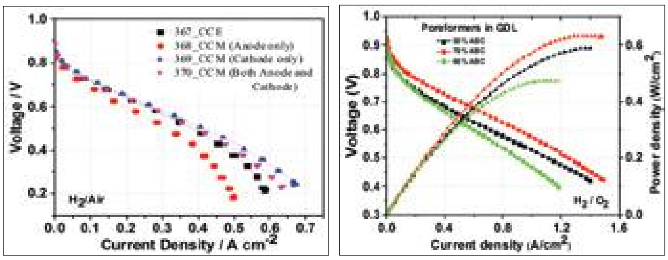


Fig. 1 Performance of the CCMs (H_2/Air) and modified GDL –CCMs(H_2/O_2)

An alternative support material, Nitrogen doped mesoporous carbon (NMC) for platinum was studied for its stability and durability according to DOE protocol. Similar studies are being continued for carbon coated TiO_2 (CCNT) and Zirconium carbide support materials and platinum was deposited by microwave technique. Electrochemical studies showed that Pt/VXc microwave synthesized had higher performance than 20% Pt/C while Pt/CCNT shows comparable performance as commercial 20% Pt/C and Pt/ZrC-VXC had better stability upto 2000 cycles.

At the stack level, the compressive pressure for multiple cells were attempted by relocating the bolts and nuts internal to the stack compared to external positions.

In addition, a thermal management loop to make use of the heat generated from the stack for humidification of both the reactants, that exerts a little back pressure to the system was developed.

This gives rise to a reduced stack volume of 25%, weight by 15% and performance increase by about 20%.

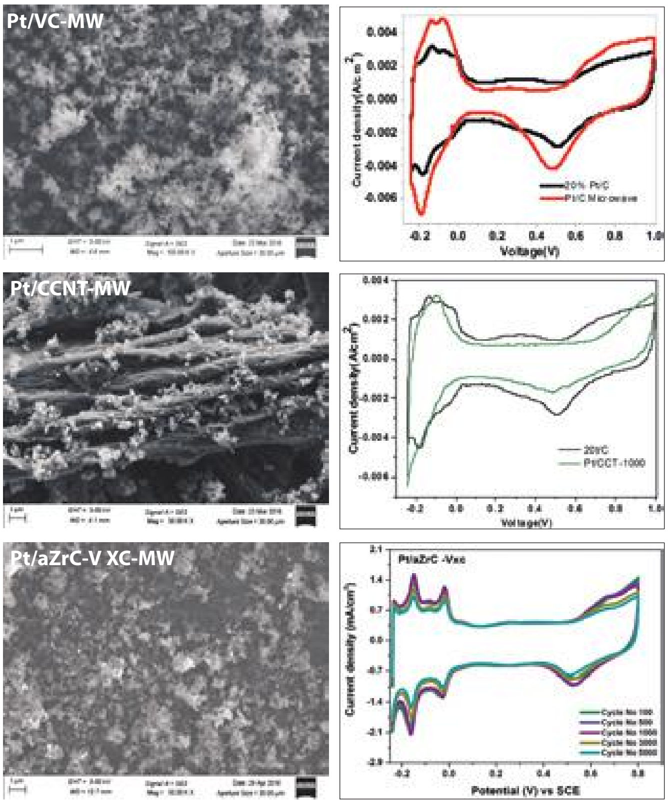


Fig 2 Performance of Catalyst Supports for platinum

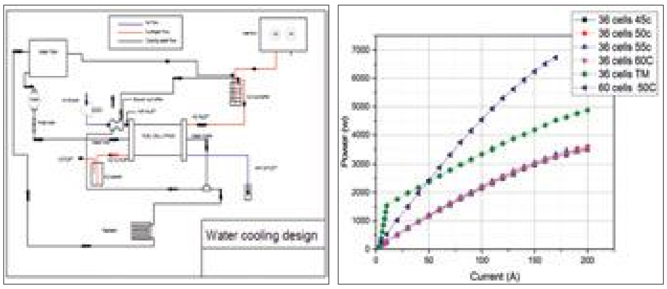


Fig.3 Thermal Management loop and PEMFC stack performance

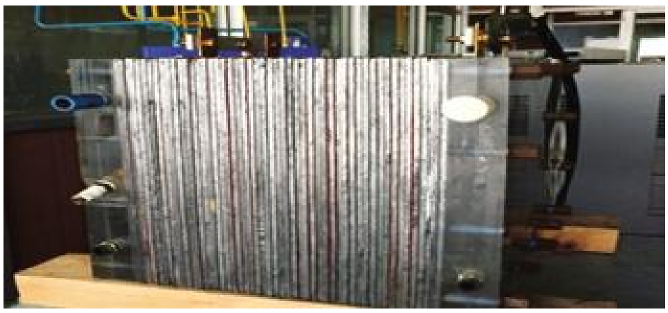


Fig. 4 Improved PEMFC stack

The developed CFCT stacks are compact with combined heat and power and has been tried from 36 cells to 60 cells assembly to accommodate large area electrodes.

Contributors: Anusree Unnikrishnan, Prithi Jayaraj, R Vasudevan, N Kannadasan, N Sudalai, R Parthasarathy, R Balaji and KS Dhathathreyan

Studies on Rechargeable Zinc-Air Systems

K Ramya ***ramya@arci.res.in***

Electricity usage and transportation requires high efficiency energy storage devices to store the energy produced from power plants, renewable energy etc. for use in stationary and mobile applications. Storage devices enable us to store the energy produced in the off peak hours for use in peak hours and help in stabilizing the power of the intermittent renewable energy sources. Alkaline Zn based batteries offer many advantages like high energy density, use of less expensive Zinc, flat discharge voltage, non-flammable and non explosive in nature (as it does not require volatile materials and is environmentally safe). However, rechargeable batteries based on zinc has to overcome the challenges like low cycling stability, high degradation rate, passivation and self discharge posed by the Zinc electrodes. Alkaline Zn-Ni batteries and Zn-air batteries are being developed to capitalize on the advantages of zinc based systems.

Zn/air batteries have a high specific energy of 1300 Wh/kg and are expected to be promising power sources. However, commercialization of the Zn/air batteries have been limited by the complexity of the reactions that take place at the air electrode, i.e, the oxygen reduction reaction (3 phase reaction of catalyst, electrolyte and air) and the oxygen evolution reaction of (2 phase reaction of catalyst and electrolyte). The choice of electrocatalysts to perform the reactions is limited because of irreversibility of the oxygen electrodes and the high overpotentials involved. A three electrode system that separates the oxygen reduction reaction and oxygen evolution reaction is one of the solutions in developing a Zn/air cell. A three electrode Zn/air cell based on gas diffusion electrodes coated with Platinum catalyst has been used for oxygen reduction reaction.

Zinc electroplating reaction has been used for the charging circuit to deposit zinc. The cell is currently being tested and a maximum current density of 15 mAcm^{-2} could be obtained. The cell uses an anion exchange membrane for ion conduction. The membrane further separates the anolyte and catholyte. It was found that the cycling capacity for the cell is very good and stable capacity could be obtained for over 100 cycles. Further the cell could also be cycled between different current densities.

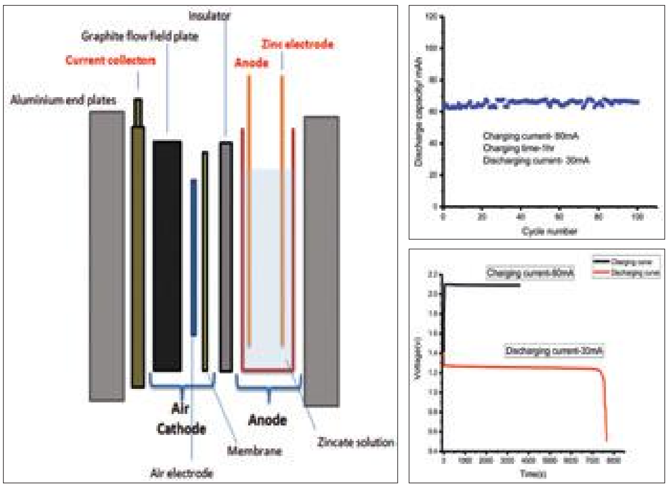


Fig.1 Three electrode system, charge/discharge characteristics, cyclic stability

Transition metal oxide catalysts based on cobalt are one of the promising compounds for use as bifunctional oxygen reduction and evolution catalyst. Co_3O_4 has been shown to have high activity and stability in alkaline media. The other advantages of this catalyst include low cost, thermodynamic stability, low electrical resistance and less environmental impact. The mixed valencies of cobalt in Co_3O_4 provides donor-acceptor sites for chemisorption for oxygen evolution and oxygen reduction reaction (OER and ORR).

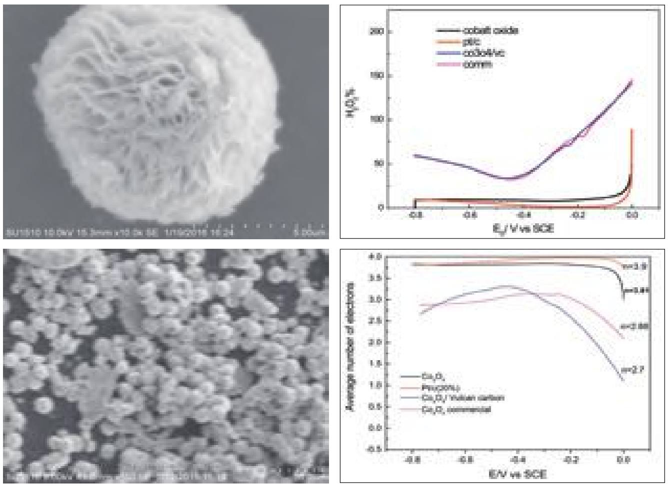


Fig. 2 SEM picture of Co_3O_4 catalyst and electrochemical activity

Co_3O_4 with flower like morphology was prepared by controlling the hydrolysis rate of the cobalt acetate precursor with suitable solvents. The catalyst prepared was characterized by XRD, TGA, SEM, IR etc. ORR characteristics of the prepared compound were compared with commercial Pt/C, Commercial Co_3O_4 and Vulcan Xc added Co_3O_4. ORR characteristics were studied by Cyclic voltammetery (for ORR activity), RDE for ORR kinetics and RRDE (for ORR pathway). It was found that the Co_3O_4 prepared had properties similar to that of Pt/C in the four electron pathway for oxygen reduction it uses and the low amount of H_2O_2 formation. The catalysts are currently being tested for their OER characteristics and their performance in Zn-air batteries. Further, graphene based catalysts and support materials suitable for ORR, anion exchange membranes suitable for use in alkaline electrochemical systems are being developed.

Contributors: I Karajagi, RJ Naik, S Narendran and KS Dhathathreyan

Studies on Development of Rechargeable Alkaline Nickel-Zinc Battery

R Balaji ***rbalaji@arci.res.in***

In CFCT, attempts are being taken for the development of rechargeable alkaline zinc electrode based battery for electric vehicle applications. In the development of metal-air like zinc-air batteries, the high performance electrocatalysts for air cathode is an important issue owing to sluggish reaction nature of oxygen reduction at the cathode. Hence the quest for a low cost, higher reduction rate at the cathode has resulted in the development of alternative redox process. (For ex. $Ni^{2+} \rightarrow Ni^{3+}$)

$$Zn + 2NiOOH + H_2O \leftrightarrow ZnO + 2Ni(OH)_2$$

The widely-used nickel-cadmium batteries with long cycle life are gradually being replaced by other alternative power sources such as nickel-metal hydride, nickel-iron, nickel-zinc, etc. There is a great interest in the nickel-zinc battery which has a superior performance compared with both the lead/acid and the nickel-cadmium batteries. One of the most promising systems, zinc nickel batteries are of high open circuit potential (1.705V) and high energy density (372 Wh/kg). The electrode materials used in the Ni–Zn batteries are abundant, non-toxic and cost-effective. However, widespread commercialization of the Ni/Zn battery using liquid electrolytes has been limited due to the serious problems such as zinc dendrite growth, shape change and high dissolution of the zinc electrode. Many attempts have been made in the literature to overcome the problems and many organic additives have been reported to be effective in suppressing the dendrite growth. With the aforementioned challenges, in mind, we have initiated preliminary studies on development of rechargeable Zinc- Nickel battery using aqueous alkaline electrolyte have been carried out.

Various process optimisation studies were carried out for preparation of high concentration zincate solution and nickel electrode. The single cell of electrode area of 30 cm^2 was developed using steel as cathode substrate and the cyclic behaviour was tested.

The average discharge capacity of 125 mAhr was obtained for 100 cycles at 1.6V. Based on the single cell studies, attempts were also made to develop a battery consisting of 8 cells in parallel connection with the electrolyte volume of about 170ml.

The cyclic behaviour of the battery was tested and the average discharge capacity of 800 mAhr was obtained for 70 cycles at 1.6V. Further development with the view to improve the energy efficiency and cyclic stability tests are ongoing.

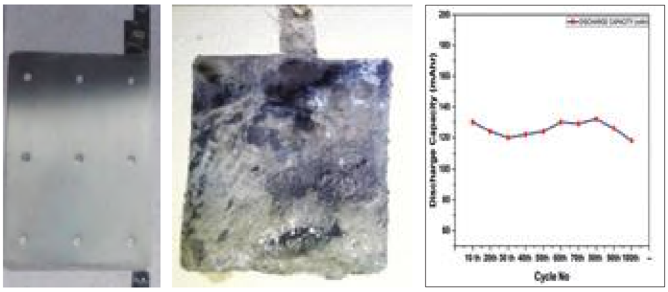


Fig.1 Coated electrodes and cyclic stability

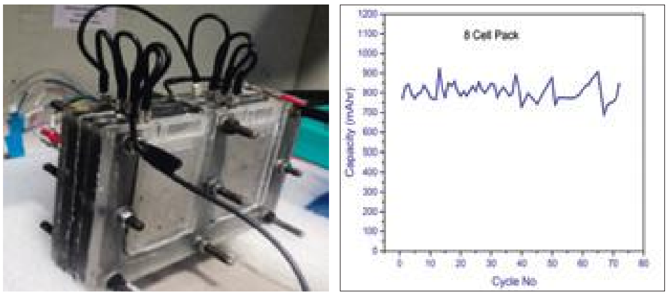


Fig.2 1Ah battery pack and cyclic stability

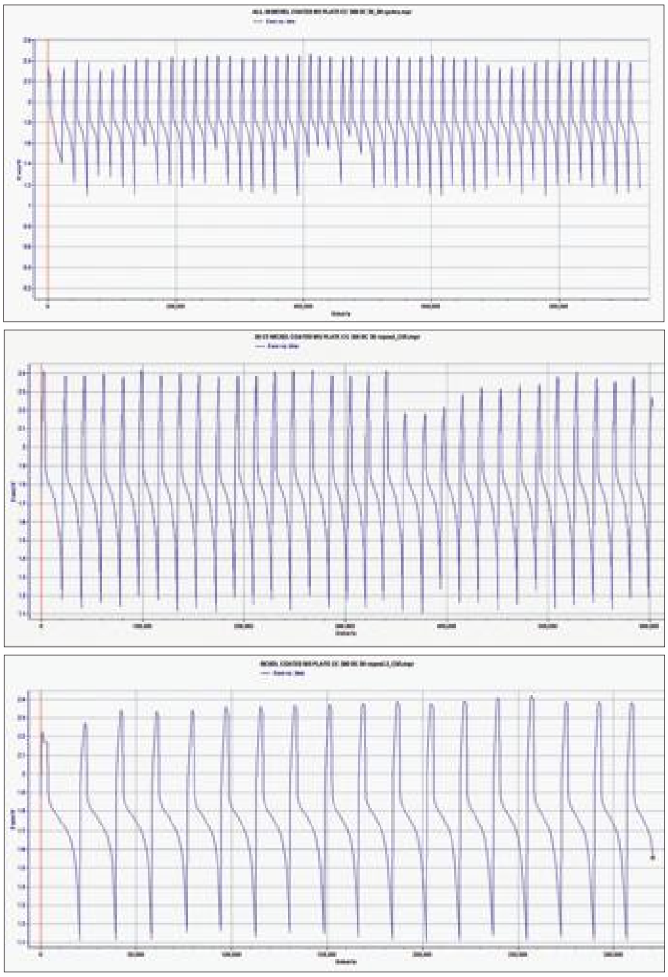


Fig. 3 Charge/discharge characteristics at various c rates

Contributors: M Ayub, Manjula Reddy and KS Dhathathreyan

Activated Carbons from Animal Excreta and Biomass for Supercapacitors

R Imran Jafri ***imraniit@gmail.com***

Supercapacitors also known as electrochemical double layer capacitors (EDLC) which store energy in the form of double layer created between electrode and electrolyte interface has been widely explored as an alternative for high energy density batteries and high power density conventional capacitors. Nano structured, high surface area and highly conductive carbons have been extensively used as electrodes for supercapacitors. However, the synthesis of these nano structured carbon materials (CNT, Graphene, Carbon nanorods etc.) is time consuming and requires sophisticated equipments. Hence synthesis of activated carbons with good electrical conductivity and high surface area from the easily available biomass materials has attracted wide attention for supercapacitors. The present work focuses on the synthesis of high surface area carbons from Cow urine, Jute fibre, Tamarind seeds and Papaya seeds.

Cow urine has been carbonized by heating in Ar atmosphere at 700^{o}C for 6 h (labeled as CCUR-700) and was also activated using KOH to further increase the surface area (labeled as A-CCUR-700). The jute fibres, tamarind seeds and papaya seeds were also carbonized and activated using KOH at 700˚C for 1 h, the samples were labeled as JCF-700, TSC-700 and PSC-700, respectively. The samples have been used as supercapacitor electrodes.

Figure 1(a) shows the photographs of experimental steps involved. The SEM images shown in Figure 1(b) clearly show highly porous structure.

Both CCUR-700 and A-CCUR-700 exhibit 'Type I and Type II' isotherm which indicates the presence of mesoporous structure with slit-shaped pores. The JCF-3-700, TSC-3-700 and PSC-3-600 exhibit 'Type I' isotherms which indicates the presence of microporous structure. The Brunauer-Emmett-Teller (BET) specific surface area of the 2128, 2651, 1224, 1784 and 1356 m^2g^{-1} has been obtained for CCUR-700, A-CCUR-700, JCF-3-700, TSC-3-700 and PSC-3-600, respectively. The results clearly demonstrate the increase in surface area and porous structure after KOH activation.

The materials synthesized have been used as supercapacitor electrodes and has been tested in symmetric two electrode configuration in 6M KOH as electrolyte. A two electrode cell was assembled as follows: Two identical electrodes were taken and were separated with a piece of electrolyte soaked polypropylene membrane; the whole set up was clipped between two Teflon fixtures. Figure 3 (a&b) shows the cyclic voltammograms and galvanostatic charge-discharge curves of all the samples.

A specific capacitance of 135 and 160 F/g^{-1} has been obtained for CCUR-700 and A-CCUR-700, respectively at a potential scan rate of 20 mVs^{-1}. The activated carbon derived from jute fibres, tamarind seeds and papaya seed shows 114 F/g, 131 F/g and 105 F/g at 20 mV s^{-1} respectively. The results demonstrate possibility of using of biomass for supercapacitor application. R & D activity on bulk synthesis of activated carbon from the biomass is undergoing.

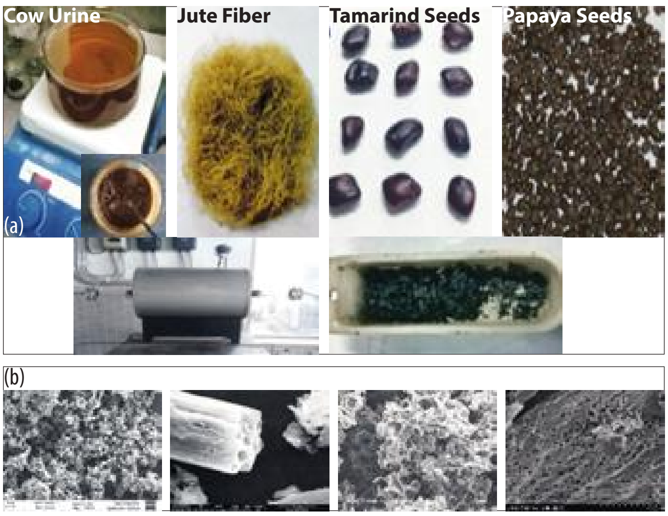


Fig. 1(a) shows the photographs of experimental steps involved. The SEM images shown in Fig. 1(b) clearly show highly porous structure

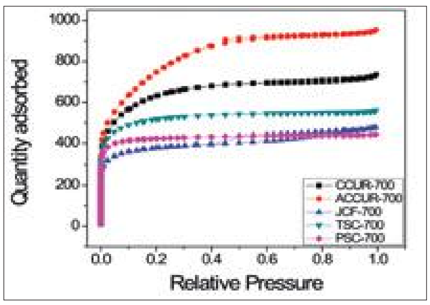


Fig. 2 shows the Nitrogen adsorption/desorption isotherms for biomass derived activated carbon

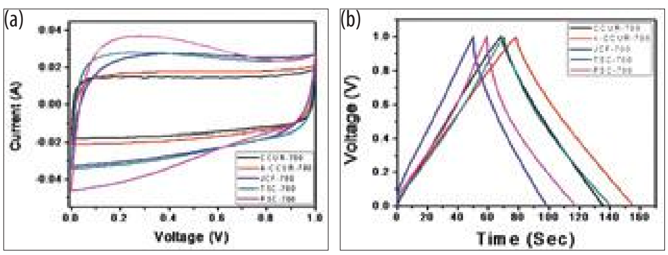


Fig.3 (a &b) respectively shows the cyclic voltammogramsand galvanostatic charge-discharge curves

Contributors: T Ramesh Kumar, N Purushotham Reddy, N Rajalakshmi and KS Dhathathreyan

Study of Solid Electrolyte Interface in Lithium Ion Batteries

Sanju Rani ***sanjuiitd@gmail.com***

Li-ion battery technology is fast emerging as one of the most reliable platform for rechargeable batteries because of several advantages such as higher voltage output (3–5V), higher energy density, and higher charging cycles, lack of memory and pollution and low self-discharge rate. These batteries, however suffer from shorter shelf-life (2-3 years from the date of manufacture) and higher temperature sensitivity that leads to failure upon reaction of the electrolyte with anode and subsequent rise in temperature. Another significant challenge is the solid electrolyte interface (SEI) layer formation which affects the capacity of the batteries. It is a layer that forms on the electrode surface as soon as the battery is assembled and is stabilised after a few early cycles. Although the SEI layer protects the anode from degradation due to electrolyte diffusion and inhibits formation of undesirable lithium compounds in the anode materials, the layer thickness increases over a period of time that prevents the diffusion of Li. At CFCT in collaboration with JAIST, Japan, we are studying the SEI layer formation and its growth on graphene based anode materials with charge discharge cycling. The SEI layer formation with gel electrolyte membrane and two different binders (nafion and PVDF) were investigated. Gel membrane was synthesized and activated with electrolyte LiTFSI. This membrane has been used to assemble the coin cell 2032 with graphene coated copper foil as anode and lithium foil as cathode. The formation of SEI on the graphene anode was monitored by stair-case potential electrochemical impedance spectroscopy (SPEIS) shown in fig 1.

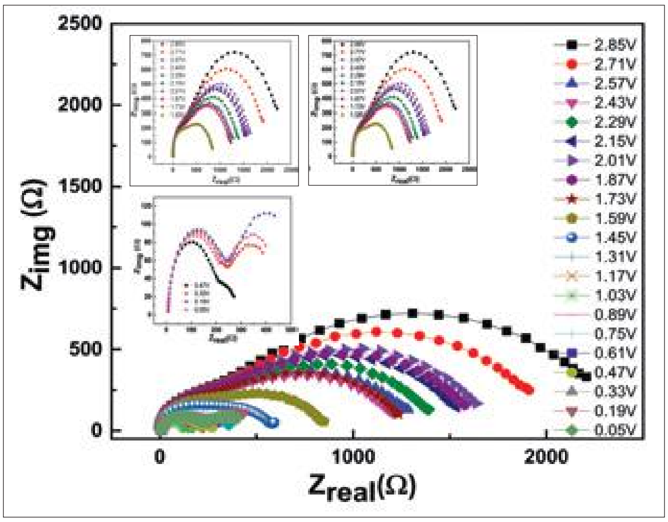


Fig.1 Dynamic Electrochemical Impedance spectroscopy of the cell with gel electrolyte

The thickness of the SEI layer with charge and discharge cycles was also monitored with electrochemical impedance spectroscopy. It was observed that in the applied voltage between 2.85 to 1.59 V all the lithium ion was consumed by SEI layer. Further, the intercalation of Li ions into graphene anode occurred in 1.47 to 0.61 V and finally, in the range of 0.61 to 0.05 V, thickening of the SEI layer takes place. The variation in SEI resistance and charge transfer resistance with applied potential are shown in the following Figure.

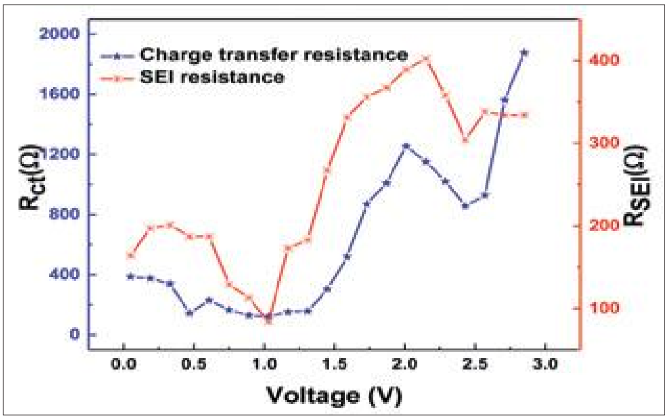


Fig.2 Variation of SEI resistance and charge transfer resistance with applied potential

On the other hand, to study the effect of binder on SEI layer, Nafion and PVDF were explored. The PVDF and Nafion both were mixed in same ratio with graphene powder to form slurry and were coated on Cu foil. Both of these electrodes were analysed with XRD, Raman spectroscopy and SEM before and after charge-discharge cycling. It was found the PVDF binder results in good stability with 400 cycles; however, the Nafion binder yields higher capacity as compared to the PVDF binder sample. SEM images revealed that the Nafion binder SEI layer with pin holes and discontinuities, which may be attributed for poor cycling life in these samples.

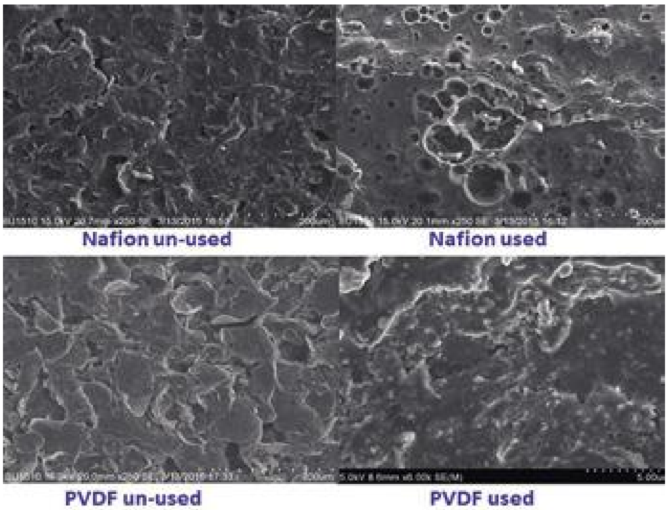


Fig. 3 SEM micrographs of the anode samples prior and after use with diferent binders

Contributors: N Rajalakshmi, Prerna Joshi, V Raman and Noriyoshi Matsum

Centre for Non-Oxide Ceramics

Centre for Non-Oxide Ceramics (CNOC) has been actively pursuing R&D activities in the area of various carbides, nitrides, and borides, their coatings and composites for wide range of applications. The centre has established various processing equipment including large size cold isostatic press (CIP), vacuum hot press, extrusion press, atmosphere controlled high temperature sintering furnace, chemical vapour deposition (CVD) system and CNC machining facilities for production of large size high performance ceramic components for critical applications.

The centre has already developed silicon carbide based light-weighted substrates up to the diameter of 730 mm for space optics application under a sponsored program right from raw material to developing the final mirror. The Centre has also developed large area CVD coated SiC parts for many applications due to their relatively low co-efficient of thermal expansion and extremely smooth surface that can be achieved upon polishing. A high level of surface finish (< 1 nm RMS roughness) has been achieved on the in-house produced mirror blanks by adopting a specialized coating and subsequent polishing. The centre is constantly engaged in development of mirror substrates of specific configurations. The other ongoing major sponsored program in the centre includes the development of non-oxide ceramics for ballistic applications. In order to develop indigenous technologies and to explore the potential of exporting them, ARCI has established state-of-the-art processing facilities for developing large size ceramic protective components.

The centre has developed near-net shape porous SiC parts which find applications in hot gas and molten metal filtrations, heat exchangers, and volumetric solar radiation absorbers etc. SiC foams with wide range of porosity have been produced through optimization of various gelcasting parameters including dispersant concentration, slurry viscosity and solid loading. Ongoing R&D activities of the centre also include development of reticulated SiC foams, ready to press SiC powder through proper selection of additives and binders, carbon nano fibre and nano tube reinforced silicon carbide composites either by using nano powder as primary phase or incorporating them in the matrix as a secondary phase. Recently, the centre has adopted a superior powder processing technique namely spray freeze drying to produce granules of various sizes containing submicron and nano powder. The centre is also actively working on development of extrusion based warpage free long SiC receiver tubes and joining the same for generation of solar thermal powers, nitride based ceramics with low dielectric constant with excellent mechanical properties to protect antenna systems for hypersonic space vehicles. In addition, the centre has successfully developed the technologies for range of products such as reaction bonded and pressureless sintered silicon carbide for mechanical seals, wear resistant parts etc.

Bhaskar Prasad Saha
saha@arci.res.in

Tata Narasinga Rao
tata@arci.res.in

Effect of Porosity on Structure of Silicon Carbide (SiC) Foams Processed by Direct Foaming and Gelcasting

Dulal Chandra Jana ***janad@arci.res.in***

The unique properties of silicon carbide (SiC) foams such as light-weight, high permeability, superior mechanical and thermal properties makes them suitable for wide range of applications including hot gas/molten metal filtration, heat exchangers, volumetric solar radiation absorbers, catalyst supports, ion exchange, metal-ceramic composites etc. Direct foaming of SiC slurries followed by gelcasting is a promising method for producing SiC foams as the process does not require any template, it is easy to tailor the porosity and achieve higher green strength. However, the structure of gelcast foams is largely influenced by content and nature of porosity which significantly affects the properties and final application of foams. The study highlights the effect of porosity on sub-structure e.g. pore size, shape and interconnectivity of gelcast and sintered SiC foams with the help of X-ray tomography and mercury porosimetry.

3D rendering of foams by X-ray tomography is shown in Fig. 1. It shows various size voids distributed in the specimen.

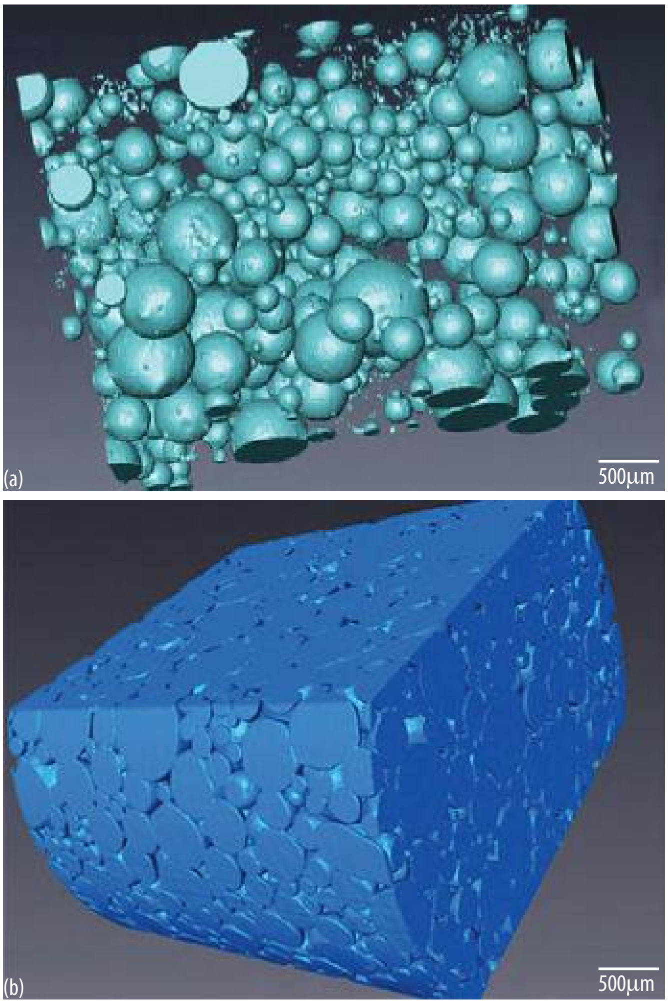


Fig. 1 3D rendering of SiC foams with RD (a) 56 vol.% and (b) 88 vol.%

The foams with porosity 56 vol.% [Fig. 1 (a)] exhibited spherical voids compared to significant proportion of elongated voids in 88 vol.% porosity foam [Fig. 1 (b)]. Also the elongated voids are found to be larger compared to spherical voids. Therefore, it can be predicted that larger voids are formed through coalescence of spherical pores due to the drainage of thin liquid film between the gas bubbles during foaming of SiC slurries in higher porosity foams.

The proportion of open/closed porosity of foams are estimated with the help of apparent density measured by mercury porosimeter and total porosity from weight and dimensions of the specimen. The estimates of open/closed cell struts are assumed to be theoretically dense and the results are shown in Table 1. As seen from Table 1, the increase of total porosity also increases interconnected porosity but lowers the closed porosity, in agreement with X-ray tomography results. The ratio of interconnected and closed porosity increased from 0.33 to 7.80 as the total porosity in the specimen in increased from 56 vol.% to 88 vol.% indicating that high porosity foams are mainly consist of interconnected cells. Attemps to determine cell size distribution (CSD) by use of mercury porosimetry data (cumulative pore volume versus pore dimeter) did not show satisfactory results as the estimates of size by this method is limited by the diameter of interconnecting channels rather than actual size of the voids. However, CSD by X-ray tomography shows that the cell size in 56 vol.% foams ranges between 100 to 200 µm with 50 cumulative volume percentage of cells less than (D_{50}) of about 125 µm and D_{90} of 190 µm. In contrast, the foam with 88 vol.% porosity exhibited very small volume fraction of cells below 100 µm size and D_{90} of 1.7 mm.

Table 1 Estimates of open and closed porosity in different RD S-SiC foams

Total Porosity (P, Vol.%)	Apparent density (%AD)	Open Porosity (% PO=100-AD)	Closed Porosity (%PC=P-PO)	Open to closed porosity ratio
56	86	14	42	0.33
75	46	54	21	2.57
88	22	78	10	7.80

Contributor: G Sundararajan

Effect of Nanocrystalline SiC Content on the Viscosity of Slurries and Average Size of Spray-freeze-dried Granules

Prasenjit Barick ***prasenjit@arci.res.in***

Spray-freeze-drying (SFD) is a promising technique to produce spherical, free flowable granules containing submicron or nanosized ceramic particles. In SFD technique, rheological behaviour of ceramics like nano-silicon carbide (SiC) (D50 ~ 40nm) based slurry play important role to obtain the desired granules. Thus, slurry should be in good workable condition during SFD. In view of the above, experiments were carried out to investigate the effect of solid loading on: (i) viscosity of SiC slurries, and (ii) granule size.

Viscosity of nano-SiC slurries was observed to increase with the increase in solid loading from 5 to 18 vol%, as illustrated in Fig.1. The viscosity increases progressively with increase in SiC content upto 15 vol% in the slurry, whereas significant further increase in viscosity is observed when the solid loading (SiC) is increased to 18 vol% slurry. The slurries containing 5,10 and 15 vol% nano-SiC powder, are found to exhibit more or less Newtonian behaviour over the entire shear rate range, whereas the slurry with 18 vol% solid loading shows shear thinning characteristics approaching a plateau at higher shear rates. Higher solid loaded slurry (>18vol%) exhibits poor dispersion. Thus, freeze granulation was carried out with 5, 10, 15 and 18 vol% solid loaded slurries. Further, with the increase in solid loading, the mean size of granules increases as shown in Table 1.

The increase in viscosity of slurries with concomitant increase in solid loading is caused due to enhanced particle interaction and reduction of free water as the interparticles spacing decreases. Both decrease in inter-particle spacing as well as high surface area of the SiC powder (~ 80 m^2/g) lead to increase in attractive forces between particles in case of higher solid-loading. As a result, the formation of a network of weakly bonded particles occurs to give a local structure to the slurry in the form of flocs. Flocs may link with each other to form a continuous structure throughout the slurry causing increase in viscosity. As the slurry is sheared, the structure breaks down and at high shear rates the viscosity approaches η_∞ i.e. the viscosity limit for infinite shear stress. The shear thinning behaviour of SFD-18 slurry with a drop in viscosity by about three times on changing from relatively low to high shear rates may be attributed to breaking of the internal floc structure. In slurries having relatively lower solid content, the interparticles attractive force is probably not high enough to retain the floc structure, and therefore Newtonian behaviour is observed at all shear rates under 500 s^{-1}.

The rheological behaviour depicted in Fig.1 shows that, with the increase in solid loading, the corresponding viscosity of slurry increases. It is intuitive that smaller number of droplets would form by disintegration of a slurry with higher viscosity as higher amount of resistance will be exerted by such slurry to air in comparison to that of lower viscous slurry under given SFD parametric conditions. Thus, as viscosity of SFD-5, SFD-10, SFD-15, and SFD-18 slurries increase, number of granules decreases and mean granule size increases accordingly.

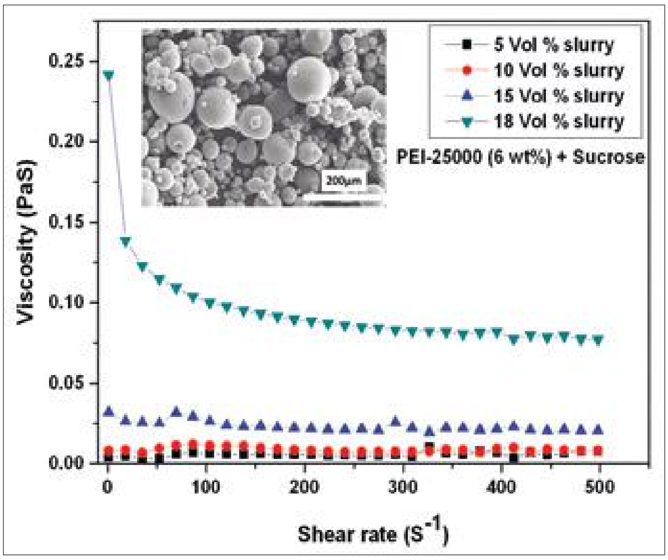


Fig.1 Solid content of slurry vs. viscosity; (a) inset shows representative SEM image of granules

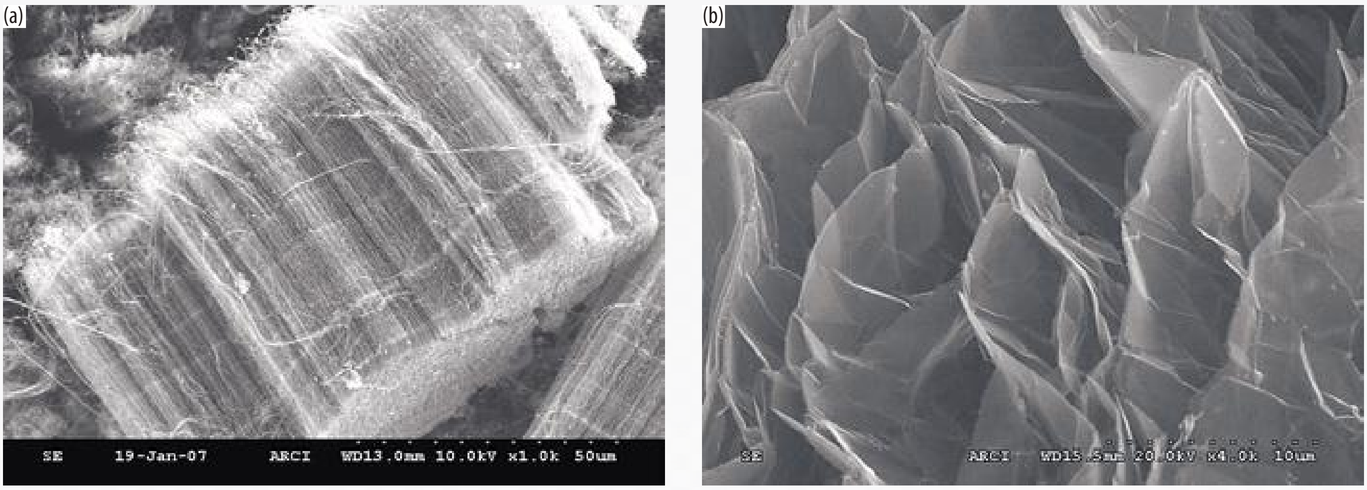
Table 1 Mean granule size

Slurry loading of slurry (D50)	Mean granule size (μm)
5 vol%	3.65
10 vol%	13.97
15 vol%	46.87
18 vol%	53.23

Contributor: Bhaskar Prasad Saha

Centre for Carbon Materials

Carbon nanomaterials are considered as one of the most promising materials owing to their unique thermal, mechanical and electronics properties. Carbon nanotubes (CNTs) and other carbon nanomaterials such as graphene, nanoplates carbon onions, carbon spheres and other low dimensional carbon nanostructures etc., have become one of the most promising emerging materials for novel applications. Carbon nanotubes due to their tubular geometry and covalent SP^2 bonds between individual carbon atoms, exhibit properties such as elastic modulus of approximately 1 TPa, tensile strength of 100 GPa and capacity to carry current density around 10^9 Amp cm^{-2}. These unique properties have resulted in many potential applications for carbon nanotubes for niche areas. Keeping this in view, the Centre for Carbon Materials (CCM) has initiated efforts for development of multiwall carbon nanotubes (MWCNTs) and other carbon nanomaterials for super-capacitor applications. Composite electrodes that synergistically integrate electric double layer capacitance of MWCNTs with fast and highly reversible pseudo capacitance properties of transition metal oxides or conductive polymers are essential to achieve high energy density and power density in super-capacitors. Porous and high surface area using CNTs and graphene are emerging electrode designs that are pushing forward the development of thin and flexible advanced super capacitors. MWCNTs also find applications in lithium ion batteries as they increase the reversible capacity, enhance the rate capability and improve the cyclability. Carbon nanomaterials are highly anisotropic in nature and the properties are dependent on processing route as well as the processing conditions. Optimization of processing parameters and controlling the structure are the key factors for such application, therefore efforts in the Centre to get better carbon nanomaterials are ongoing. The Centre has also initiated efforts in the electrode development for supercapacitor applications.



(a) Vertically Aligned Carbon Nanotubes (b) Graphene Nanosheets

P K Jain
pkjain@arci.res.in

G Padmanabham
gp@arci.res.in

Development of Electroactive Carbon Sphere–Nickel Rich Cobaltite Nanoelectrode for Supercapacitor

Balaji Padya ***balaji@arci.res.in***

World wide, the demand for green energy storage and conversion appliances is exponentially increasing. During the past decades supercapacitors have attracted enormous interest due to their high power density, fast recharge capability and long cycle life combined with moderate energy density. Nanoscaled-carbon based electrodes are appropriate candidates. High surface area, tailored pore size distribution, high electrical conductivity and chemical inertness render them suitable as nanoelectrodes. These carbon nanostructures possess electrochemical double layer capacitance and is hard to increase beyond 500 F/g. In general, transition metal oxides and conducting polymers are added to the carbon based nanoelectrode to increase the specific capacitance as they exhibit redox reactions. An innovative electrode material based on nano-structured materials to mitigate the current electrode limitation has gained paramount importance to solve the energy storage related critical issues.

Carbon sphere-nickel cobaltite (CS-NC) hybrid was synthesized by two-stage one-pot hydrothermal method. Optimization of various parameters (growth temperature, growth time and precursor concentration) is carried out to grow the carbon sphere (CS) with uniform size and distribution. The radius of CS is in the range of 100-1100 nm as illustrated in Fig.1a. NC dandelion-like structures are grown by solvothermal method by controlling the concentrations of nickel and cobalt based precursors as shown in Fig.1b. These NC based nanostructures are uniformly anchored and coated on CS as depicted in Fig.1c and 1d.

The capacitive property of CS-NC was evaluated by cyclic voltammetry in a three electrode system. Fig.2a illustrates the CV curves with variant scanning rates ranging from 10 to 100 mV/s. NC anchored CS composite electrode exhibited redox couples indicating the pseudocapacitance which means it can store the energy through the adsorption of ions on the surfaces of electrode (for CS) and fast redox reactions occurs between the active material and electrolyte (for NC) as illustrated in Fig.2a. Addition of NC on CS increased the specific capacitance due to the redox peaks generated by NC and is associated with M-O/M-O-OH (M=Ni or Co ions). The specific capacitance of CS-NC decreases with increase in scan rate as is ascribed to insufficient diffusion of OH-ions into the pores required for the fast reaction as depicted in Fig.2b. CS, NC and CS-NC composite exhibited gravimetric specific capacitance of 301, 400 and 920 F/g, respectively at scan rate of 10 mV/s. The conductive CS facilitated the electron transport and effectively prevents the agglomeration of NC nanoparticles and ensures the full utilization of electroactive material for superior properties.

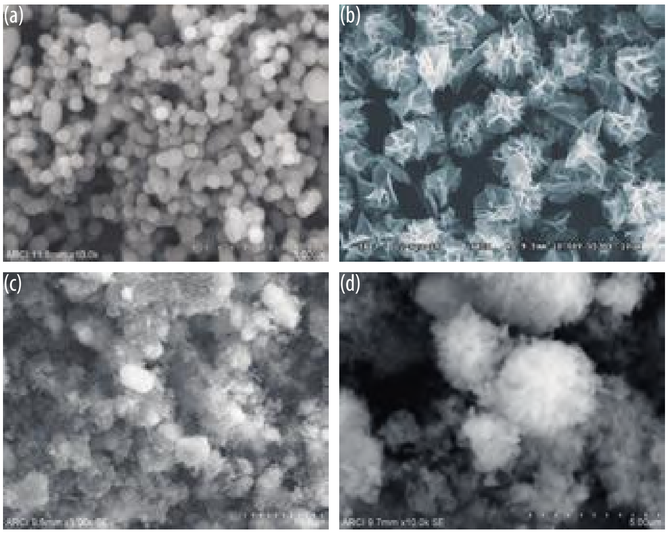


Fig.1 Morphology of nanostructures: carbon spheres (a), nickel cobaltite (b), and CS-NC composite at low and high magnifications (c,d)

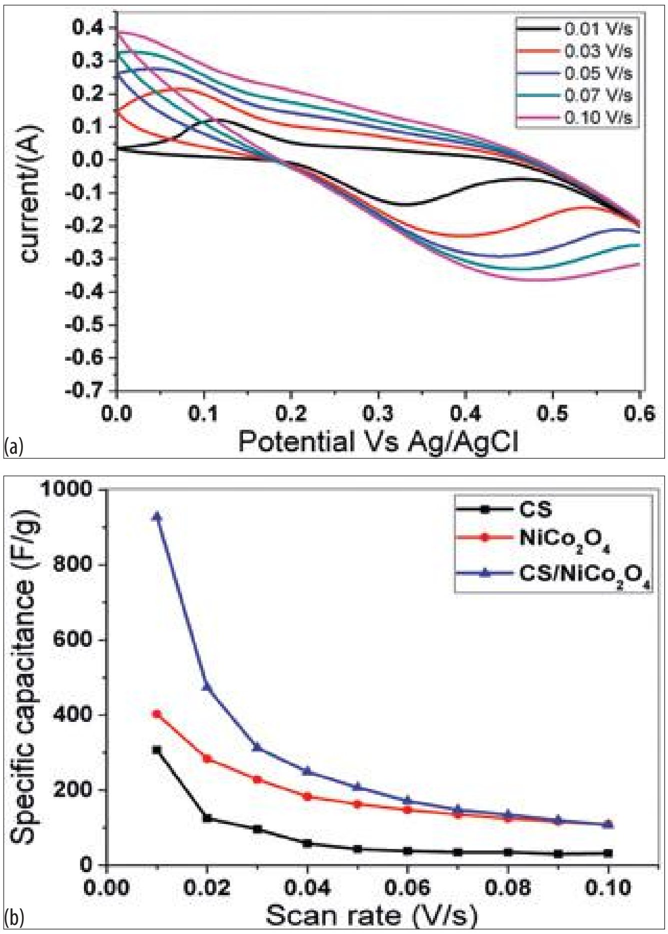


Fig.2 Electrochemical properties of CS-NC

Contributor: P K Jain

Centre for Sol-gel Coatings

Centre for Sol-Gel Coatings (CSOL) has been working with industrial partners for commercialization of the sol-based nanocomposite coatings for a wide variety of applications on different substrates. The most distinct advantage when used on metals/alloys is that a direct-to-metal coating is possible thus obviating the need for the use of any primers or adhesion promoters. The Centre has been focusing on the following applications:

- *Chrome-free, self-healing, corrosion protection coatings on aluminum and its alloys for automotive and aerospace applications*
- *Anti-tarnish coatings on noble metals*
- *Ultrahydrophobic coatings through a combination of laser texturing and sol-gel coatings*
- *Eco-friendly, halogen-free flame retardant coatings on textiles*
- *Sol-gel derived membranes for opto-electronics applications*

The development of hexavalent chrome-free, self-healing coatings on aluminum and magnesium alloys using organic/inorganic encapsulation materials like polymeric microcapsules, and layered materials for containing the corrosion inhibitor is ongoing. In addition, investigations were carried out to evaluate the efficiency of sol-gel coatings for sealing of the porosity in microarc oxidized layers. Promising results have been obtained in all aspects and has resulted in filing of nearly five invention disclosures. Further work is underway to demonstrate the scale-up feasibility of such coatings.

Development of anti-tarnish coatings is ongoing. Consistency in obtaining good and uniform coatings on silver and gold coupons/articles possessing anti-tarnish property and perspiration resistance has been achieved after persistent efforts.

A combination of laser texturing using femtosecond laser and sol-gel coating deposition on stainless steel substrates was explored for generating ultrahydrophobic surfaces, which could be used in biomedical applications. Preliminary tests showed that such kind of ultrahydrophobic surfaces could inhibit up to 90% of the bacterial growth within a short time of 30 minutes. Further investigations are underway to improve the mechanical properties of such surfaces.

The in-house developed halogen-free, water-based flame retardant formulation has been investigated on cotton, nylon and polyester and found to be promising. Limiting oxygen index measurements carried out on treated and untreated cotton showed that the value for untreated cotton is <21% vis-à-vis 37. 5% for the flame retardant treated cotton.

R Subasri
subasri@arci.res.in

G Padmanabham
gp@arci.res.in

Scanning Vibrating Electrode Technique Measurements on Self-Healing, Corrosion Protection Coatings on Al and Mg Alloys

R Subasri ***subasri@arci.res.in***

Aluminum and magnesium alloys have several applications in automobile and aerospace industries due to their high strength-to-weight ratio and low cost. During their usage, the surfaces constantly get exposed to extreme atmospheric conditions and may get corroded or oxidized, resulting in the loss of material with the time. Chromate conversion coatings have been the most widely used self-healing, anti-corrosion treatments for aluminum and magnesium alloys. However, there is an increasing demand for the development of environmentally friendly and cost-effective methods for corrosion protection, due to the toxicity involved in use of hexavalent chromium. Use of sol-gel based coatings for corrosion protection can increase materials' lifetime, reduce replacement costs, and improve product safety. In addition, corrosion inhibitors when added to a sol-gel matrix can generate coatings with further improved corrosion resistance. However, direct addition of inhibitors is found to be deleterious to the barrier properties of the coating and hence, encapsulation inside nanocontainers before addition to a sol-gel matrix is expected to provide a controlled release of the inhibitor. In this context, nanoclay containers encapsulating corrosion inhibitors were introduced into a hybrid sol-gel matrix and coatings deposited on Al and Mg alloys. In order to confirm the self-healing activity, scanning vibrating electrode technique (SVET) measurements were carried out on bare, matrix sol and self-healing sol coated Al and Mg alloy substrates after introducing an artificial scribe on the substrates having an area ranging from 0.1 to 0.3 mm^2 and exposing them to 3.5 wt % NaCl. The frequency of vibrating electrode used was 100 Hz. The current density maps were plotted in 3D format over the scan area, with positive and negative current densities representing anodic and cathodic regions, respectively. The measurements were made at the open circuit potential.

The local current maps over the surface of bare and coated aluminum substrates, recorded immediately and after specified times of exposure to 3.5% NaCl are shown in Fig 1. A steep anodic current flow in the flaw area of the bare aluminum indicated the occurrence of accelerated corrosion due to small anode, large cathode configuration at the defect area. This result indicated the absence of any definite self-healing activity in the bare aluminum surface. The current density map for matrix sol coated aluminum (second row) after initial exposure to 3.5 wt % NaCl during which the anodic current flow area increases dramatically at the coated area. After 24 hours of immersion, there is small sign of corrosion activity. This confirmed the presence in barrier property of matrix sol coated aluminum. The current density map for self-healing sol coated aluminum showed that after initial immersion, the anodic current flow area decreased dramatically at the defect area. After 12-48 hours of immersion, there is small sign of corrosion activity, which is completely suppressed. This confirmed the initiation of passivation due to release of corrosion inhibitors from the nanocontainers. The self-healing coating offers both barrier protection, contributed from matrix sol and self-healing action from loaded nanoclay. Whenever the barrier property is lost due to any defect or scratch, the inhibitors released from the nanocontainers are able to provide a self-healing effect, i.e., mainly by formation of a passive layer due to localized increase in pH during corrosion initiation at the scribed area.

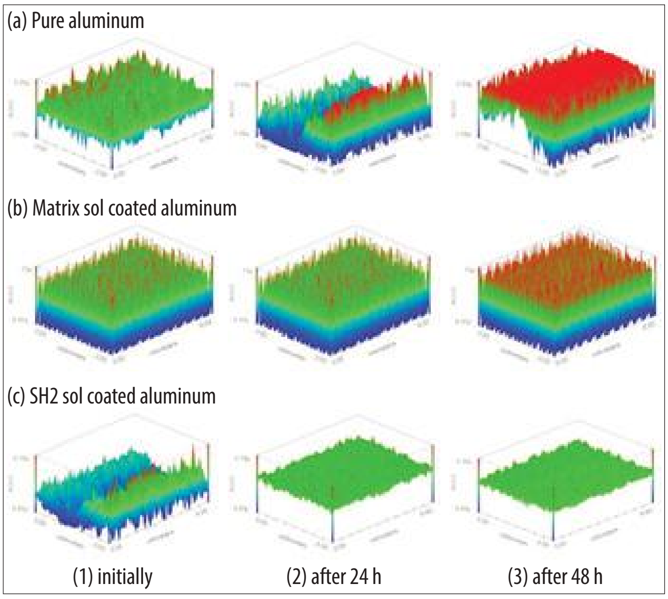


Fig. 1 Current density maps for the uncoated and coated Al substrates for different times of exposure to 3.5 % NaCl solution

Similar experiments carried out on Mg alloy AZ91 as shown in Fig. 2, confirmed the promising nature of the developed self-healing coatings.

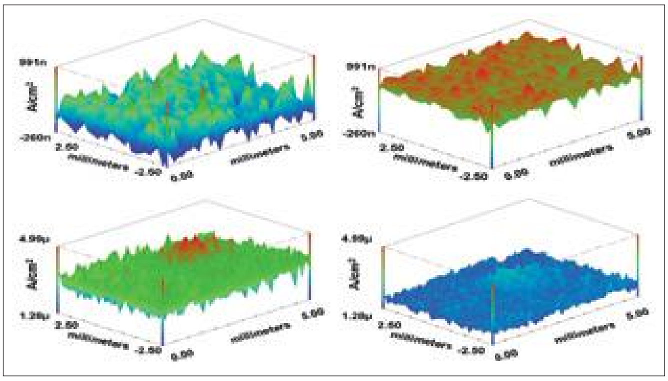


Fig. 2 Current density maps for bare (top) and self-healing sol coated (bottom) AZ91 substrates, after exposure to 3.5 wt % NaCl

Contributors: S Manasa, Swapnil H Adsul (ARCI) and T Siva, S Sathiyanarayanan (CECRI, Karaikudi)

Microscopic Galvanic Corrosion of Silver and Copper Alloy under an Artificial Sweat Solution

K Murugan **murugan@arci.res.in**

When two dissimilar metals are electrically connected and exposed to an electrolyte, one metal acts as an anode and the other as cathode. The electropotential difference between the dissimilar metals is the driving force for an accelerated attack on the anode member, and thus the metal at higher position in the electrochemical series undergoes higher corrosion rates. This type of corrosion is called galvanic corrosion. Such corrosion related damages lead to unacceptable deterioration of appearance, leaking of tubes or failure of fasteners that can drastically reduce the service life of the component and lead to costly premature component replacement. The degradation of various materials by the contact of human sweat is one of the important requirements in the field of fabrics and metallic materials. Corrosion of metals caused by human body contact is an issue in the field of fashion jewellery making particularly where copper and silver alloys play a major role. In general, without proper consideration given to micro scale phenomenon, the existing corrosion management strategies have constantly been subjected to unexpected problems. This study deals with the galvanic corrosion of copper and silver alloys on a microscopic level due to the presence of inhomogeneous second phase.

In this study a synthetic sweat solution of pH4 that comprise of sodium chloride, ammonium chloride and lactic acid as major components was synthesized. The perspiration environment was simulated in a closed transparent container using a synthetic sweat solution at 40°C. The perspiration resistance of pure silver, sterling silver and α/β brass was evaluated by visual inspection. Further, the surface morphology and chemical composition of the metals and corrosion products were analyzed using SEM attached with EDS facility.

Upon 24 hrs exposure of pure silver and copper in the above accelerated perspiration chamber, there was no change in color or lustere as observed by visual inspection. However, within 4 hrs of exposure, the sterling silver and brass adversely lost their originality. Fig. 1(a-d) shows the visual appearance of the sterling silver and brass coupons before and after perspiration resistance test. It clearly indicates that within 4 hrs of accelerated perspiration test, the silver coupons completely turn black in colour, whereas, brass coupons significantly loose their originality and appear similar to copper. It has been proved that such a failure is due to the microstructural in-homogeneity which leads to the galvanic corrosion. In the case of sterling silver, copper rich phase is more anodic compared to silver, whereas in the case of brass, zinc is more anodic compared to copper. In both the cases, the failure is due to anodic dissolution (or leaching) confirmed by SEM and EDS analysis. Fig. 2 shows the SEM image of the corrosion affected and unaffected interface regions. The unaffected region shows 7 wt.% of copper confirming the sterling silver composition, whereas corrosion affected region shows more than 20 wt.% of copper along with the presence of chlorine indicating copper chloride formation. This indicates that the failure starts at copper rich zone and it spreads throughout the area. Similar type of corrosion due to chemical in- homogeneity was also observed in brass. This type of failure can be avoided by providing invisible sol-gel coating on brass or silver articles. Fig. 3 shows the effective protection of a part of brass by sol-gel coating.

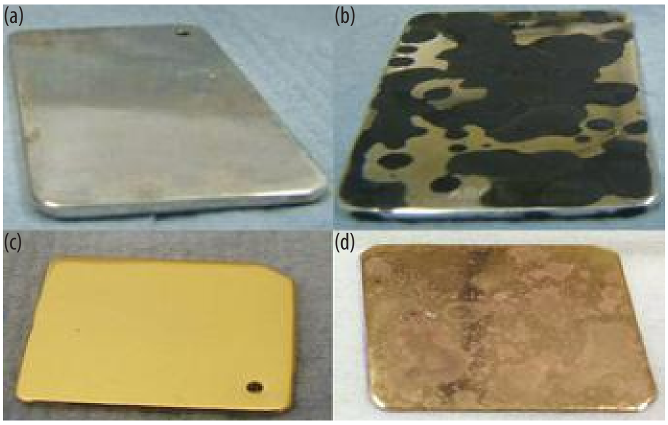


Fig. 1 Visual appearance of (a) sterling silver (b) sterling silver after 4 hrs exposure (c) brass and (d) brass after 4 hrs of exposure

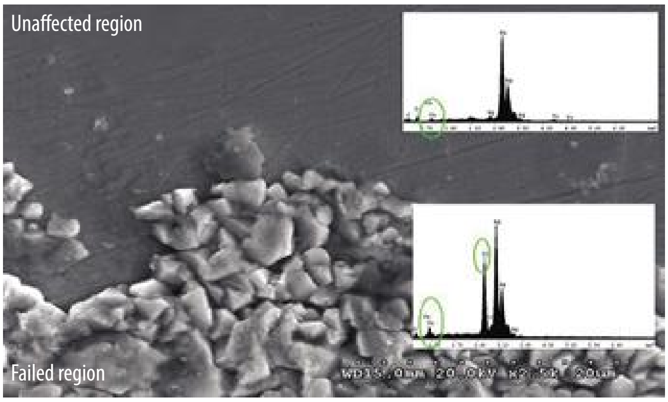


Fig. 2 SEM and EDS analysis on the perspiration affected and un-affected interface

Fig. 3 Indicating the coated regions looking brand new while the uncoated region has faded

Contributors: N Siddarth Srinivasan and G Padmanabham

Corrosion Protection by Sol-Gel Based Duplex Coating on Anodized and Micro Arc Oxidized Aluminium

K R C Soma Raju *somarajuk@arci.res.in*

Aluminium and its alloys require surface modification to impart weather resistance in corrosive environment. Although hexavalent-chromium based conversion coating exhibits excellent corrosion resistance and promote adhesion with paints, but being carcinogenic, it is being preferably phased out in many application segments. Organic paints alone do not exhibit good adhesion and cannot protect the aluminium substrates in demanding conditions. Hybrid sol-gel coatings are gaining importance due to ability to cure at low temperature, excellent corrosion resistance, good pencil scratch resistance of 5H and promote adhesion.

Investigations at Centre for Sol-Gel Coatings were carried out to assess the corrosion resistance of optimally thick sol-gel coating vis-à-vis equivalently thick anodized and duplex sol-gel coatings. Potentiodynamic polarization and impedance studies of the anodized aluminum substrate showed that corrosion resistance was found to be superior than the bare aluminum substrate during short term exposure to corrosive medium, i.e. 1 hr , but found to fail in long term i.e. 120 hr exposure studies. One of the possible ways of improving long term corrosion resistance is to apply a suitable sol-gel composition as a top coat. Moreover, micro arc oxidation which falls in the same electrolytic oxidation family and has excellent mechanical properties was also selected for investigations, as it could be industrially relevant for a wide spectrum of applications.

A new low temperature curable hybrid silica matrix sol composition was developed to further enhance the corrosion resistance of not only sol-gel coating, but also duplex anodizing and micro arc oxidation coatings. The three coatings with identical coating thickness were deposited on commercially pure aluminium substrates as single layers as well as duplex coatings and were thermally cured in an air circulating drying oven at 130°C for 1 h. Individual and duplex coating layer thicknesses were maintained identical at 8.5 µm and 10.5 µm, respectively. The corrosion resistance of uncoated aluminium alloy, sol-gel, anodized, micro arc oxidized, and duplex coating of anodizing+sol-gel and micro arc oxidation + sol-gel coatings was assessed by potentiodynamic polarization in 3.5 wt% NaCl solution for 1 hr and 120 hr exposure.

The experimental results presented in Fig. 1 and Fig. 2 reveal that the corrosion resistance of only sol-gel coating was marginally better in short term test but has shown significant improvement in long term test. Uncoated substrate has corroded extensively but shows reduced corrosion current density due to the presence of extensive corrosion products as a passive layer. Anodizing on the other hand has exhibited excellent corrosion resistance in short-term exposure, but it could not retain the same when subjected to long-term exposure. Such a degradation behavior is due to the presence of open surface porosity in anodized layer which typically extends to the substrate-coating interface. Micro arc oxidation has shown consistent corrosion resistance in both short and long term tests. However, an enhanced corrosion resistance was observed when sol-gel coating is employed as a duplex coating system in both short term and long term polarization measurements with both anodized and micro arc oxidized substrates. Effective sealing of the open surface porosity of anodizing and micro arc oxidation with sol-gel coating resulted in synergetic beneficial effect of enhanced corrosion resistance by physical blocking of passage of corrosive Cl^- ion entering the pores.

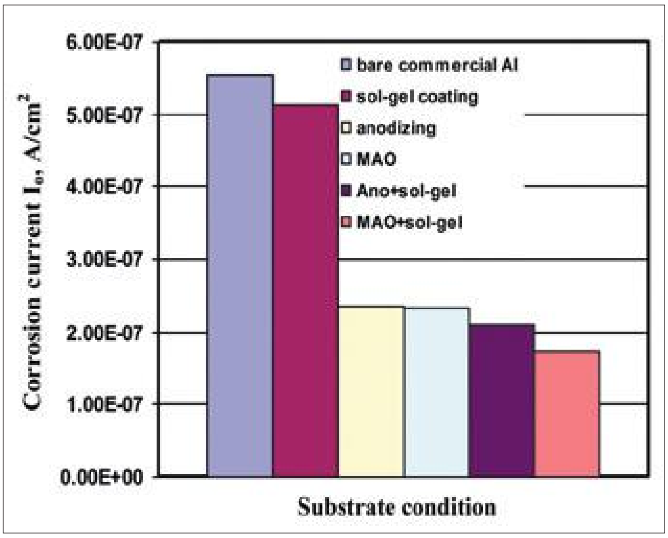


Fig. 1 Corrosion current density of samples exposed to 3.5wt% NaCl solution for 1 hr

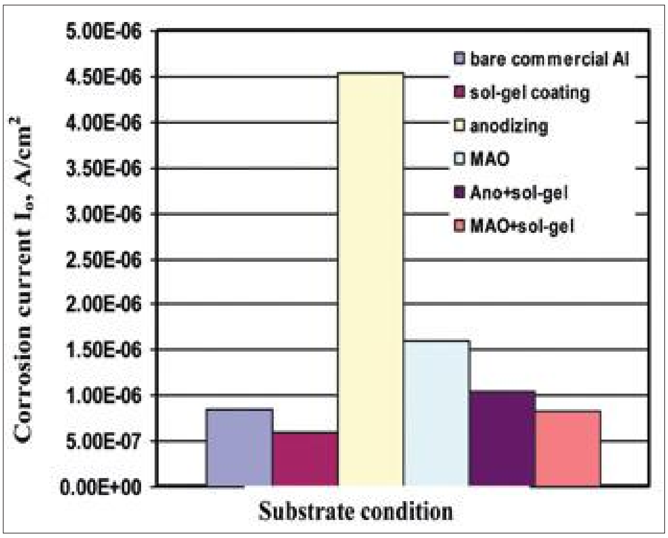


Fig. 2 Corrosion current density of samples exposed to 3.5wt% NaCl solution for 120 hr

Contributors: A Jyothirmayi and L Rama Krishna

Automation of Flow Coating Process

V Uma ***uma@arci.res.in***

Instrumentation plays an important role in realizing the process technology for use by industry. Flow coating is one of the methodologies of coating deposition. The main objective of flow coating is to give a controlled flow of the liquid to provide uniform coating and the required instruments are generally built in-house to suit the process based on the application. For example, in continuous flow coatings on rolls and tapes for use in solar panels, the angle of inclination of the distribution blade plays an important role, and in capillary coatings used to coat Liquid Crystal Display (LCD), speed of the linear drive mechanism is an important parameter. Preliminary tests were carried out to optimize parameters for a flow coating equipment.

The instrument shown in the Fig. 1 has a high torque DC servo driver controlling the servo motor. The shaft of the motor is connected to dual cassette flow head which has molybdenum disulphide based rollers (4 numbers) fixed on the motor shaft, which pushes the liquid through the silicone pipe connected to its head. The flow precision is directly proportional to the number of rollers while the flow rate depends on the tube diameter. With suitable range of the motor speeds, and flow rate, the required limits can be set. This can be carried out while designing the equipment. The instrument uses peristaltic pump for dosing the liquid, which is more economical than the mass flow meter, which uses thermal sensor to measure the flow rate and corrects dynamically. The peristaltic pump uses servo drive to precisely give angular movement to the motor. This can be programmed manually using the keys displayed on the control panel and also be accessed remotely using the X-bee (Fig. 2) serial interface module programmed to operate and edit the changes set by the user over 100 meter range. The unit has three modes of operation

1. Continuous mode
2. One shot mode
3. Pulse mode

In the continuous mode, up to 6 schedules can be programmed as required by the user. In one shot mode, time and rpm are to be given as input parameters and in pulse mode, on/off cycles are to be mentioned. The timing for all the modes can be provided as input in hr/min/sec.

Experiment result as in the graph (Fig. 3), shows correlation between the two parameters and this gives an understanding between the flow-rate on the y-axis vs rpm on x-axis. The flow rate has linearity for higher rpms of the motor. The fixed parameters during the experiment are the pump head which has four rollers and the tube through output feed which is 3 mm in diameter.

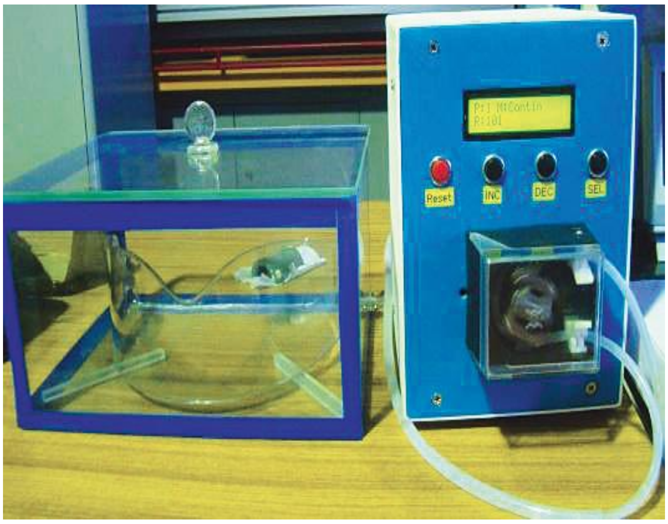


Fig. 1 Instrument showing the high torque DC servo driver controlling the servo motor

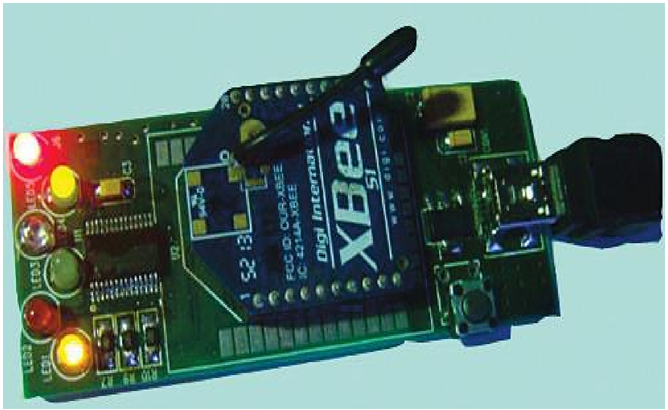


Fig. 2 The X-Bee serial interface module

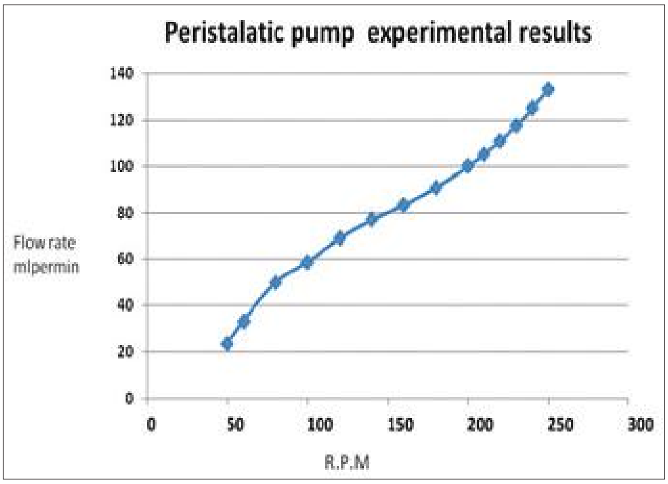


Fig. 3 Graph showing the correlation between flow rate and RPM

Multilayered Solar Selective Sol-gel Coatings on SS 321

D Sreenivas Reddy *dsreddy@arci.res.in*

Solar thermal devices convert solar radiation into heat, which is subsequently converted into electricity. Functional coatings on components of solar device, especially in heat collection element (HCE), can substantially improve the efficiency of the solar to thermal energy conversion. The absorber tube in the HCE has a solar selective coating (SSC) to realize high solar to thermal conversion efficiency. In the past, hexavalent chrome-based coatings were used as SSC. Due to toxic and carcinogenic nature of hexavalent chrome, its use has been strictly banned across the world. Sol-gel coatings are eco-friendly, possess good adhesion of coating to a wide variety of substrates and are amenable to deposit on large areas. Due to these characteristics, sol-gel derived coatings seem to be promising and viable for use as spectrally selective surfaces.

Nanocermet based coatings show promise for use as SSC, since they exhibit high absorbance of the solar spectrum in the visible wavelength range. Accordingly, a multi-layered coating stack comprising an infrared (IR) reflective material applied as first layer on the substrate followed by an absorber layer (cermet, Ag-TiO_2) and an anti-reflective coating (SiO_2) as the topmost layer was generated.

All layers were generated at room temperature on SS 321 plates of dimensions 100 mm x 100 mm and thermal cured at 923 K for one hour under vacuum. The thickness of each layer was measured by spectroscopic ellipsometer and the phase constitution of the films was measured by X-Ray diffraction and scanning electron microscope for microstructural analysis. The UV-Vis-NIR spectrum of the multilayered coating stack as shown in Fig. 1 showed an average absorbance of 94 ± 1% over 300-1500 nm and emissivity of 0.13 as measured by the emissometer. Thermal emissivity as shown in Fig. 2 was measured at temperatures from 100-400°C. It was seen that the emissivity does not vary much with temperature.

Due to the promising nature of the performance of the coating stack, 1 m long tubes with 75 mm OD and wall thickness 1.5 mm were coated with the multi-layered solar selective coatings. Photograph of a coated tube is shown in Fig. 3.

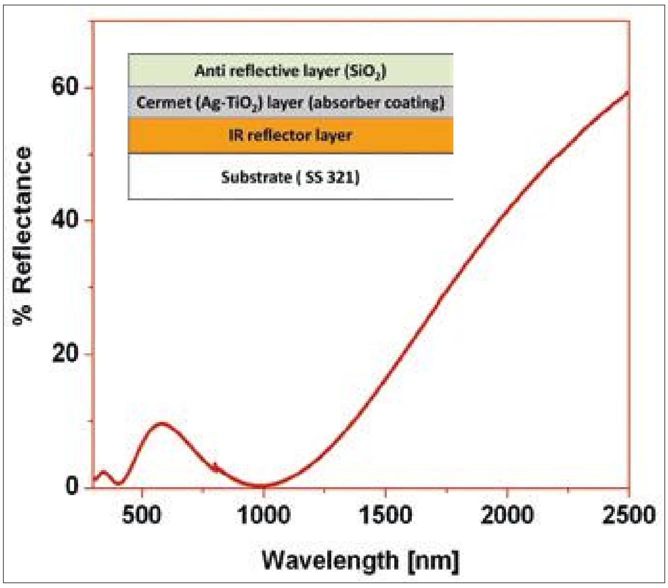


Fig. 1 UV–Vis-NIR spectrum of multi layered SSC

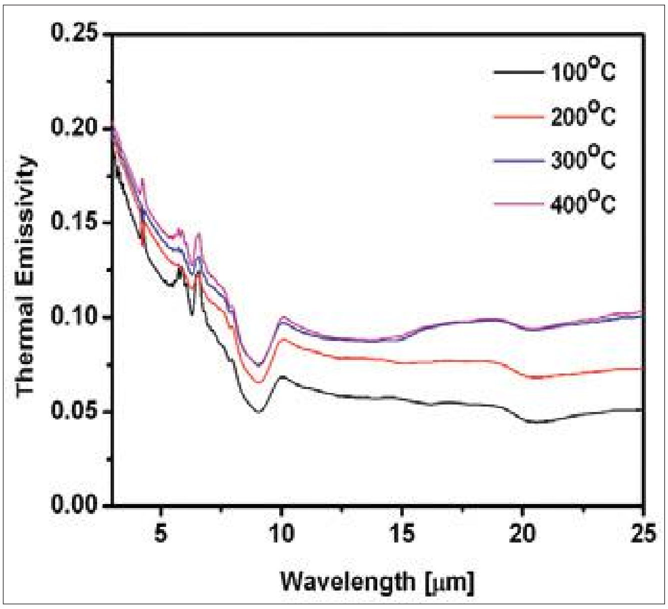


Fig. 2 Thermal emissivity of the multi layered SSC as a function of temperature

Fig. 3 Photograph of solar selective coated 1 m long SS tube

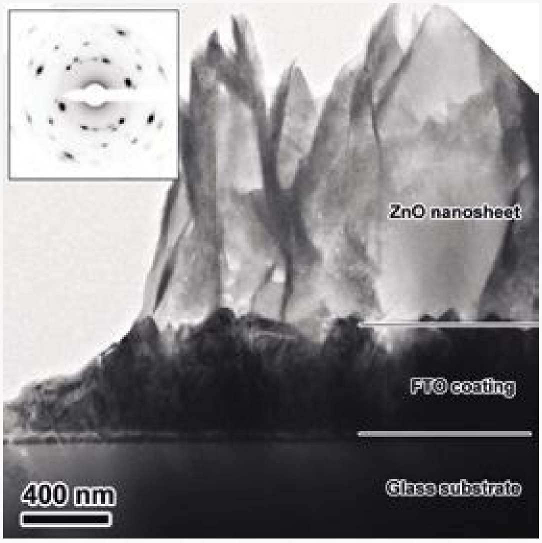
Contributors: K R C Soma Raju and R Subasri

Centre for Materials Characterization and Testing

The Centre for Materials Characterization and Testing (CMCT) continues to perform the dual roles of supporting ARCI's technology development programmes and carrying out basic research. The focus of the work at the Centre is on obtaining a good understanding of microstructure and correlating the same with materials properties.

In recent years, there has been an increased emphasis on research in nanoscience and nanotechnology. Nanostructuring enhances materials properties and this aspect is being used at ARCI to enhance the performance of coatings. Fine oxide dispersoids of the size of a few nanometres enhance the functionality of steels. In these examples as in many other cases, a thorough comprehension of the microstructure is always helpful, indeed necessary, to tune and enhance the functionality of materials and performance of devices. The facilities at the Centre such as the field emission scanning electron microscope, focused ion beam milling unit, transmission electron microscope and the small angle x-ray scattering facility are all geared to characterize materials in the sub-micron to nanometre length scales. Where structural analysis is needed, conventional x-ray diffraction and the microfocus x-ray diffraction facilities available with the Centre are utilized. The study of corrosion is an important aspect and work in this area is in progress. Mechanical testing of small volumes of the material is being carried out using the instrumented indentation facility established last year and preliminary creep data is being obtained from the recently installed units.

Two of the writeups from the Centre present the microstructural and thermomechanical aspects of oxide-dispersed strengthened steels, while three more discuss a microstructural investigation on mesoporous SnO_2 beads, an enhancement of corrosion performance of niobium coatings and the use of the instrumented indentation technique to study solid particle erosion.



Cross-section TEM BF image of ZnO nano-sheets grown on fluroine doped tin oxide (FTO) coated glass substrate
Inset to figure shows selected area diffraction fromt he nano-sheet exhibits crystalline nature

G Ravi Chandra
ravi.gundakaram@arci.res.in

Tata Narasinga Rao
tata@arci.res.in

Investigation of Microstructure of Primary Particles in Mesoporous SnO_2 Beads using SAXS

K Suresh *sureshkopppoju@arci.res.in*

Mesoporous metal oxide beads such as TiO_2 and SnO_2 with high internal surface area and interconnected pore structure have received significant attention due to their potential applications in various energy conversion and storage devices. For example, sub-micron sized SnO_2 beads with custom designed microstructures have recently achieved > 10% solar to electric energy conversion efficiency in dye-sensitized solar cells (DSSCs) with higher dye loading and improved electron diffusion coefficient. Such beads are usually made up of SnO_2 nanoparticles assembled in a random network.

Mesoporous SnO_2 beads have been synthesized by the hydrothermal (HT) method, wherein densely packed primary crystalline SnO_2 particles with definite size (~5nm), which is determined by the temperature during the HT process, are arranged in a specific assembly leading to sub-micron beads. Post heat treatment around 500°C, the trapped organic compound in the beads is removed, which creates mesoporous structure in beads. The formation of crystalline primary particles and their assembly is an established mechanism. However, no systematic work has been carried out to investigate the microstructure of the primary particles at every stage of synthesis of mesoporous SnO_2 beads. Usually, transmission electron microscopy is employed to investigate the microstructure at the length scale of a few nanometers. As the size of the beads is too thick for electron transmission, TEM could not be applied effectively to study the microstructure of the primary particles in these beads. It is very important to understand the size of primary particles, which determines the effective surface area of primary particles and mesoporous structure in SnO_2 micro-beads. Therefore, we have employed the small angle X-ray scattering (SAXS) technique to investigate the microstructure of the primary particles and x-ray diffraction (XRD) to study the crystalinity and crystal structure in mesoporous SnO_2 beads at different stages of synthesis.

XRD studies (Fig.1a) reveal that the as-prepared SnO_2 beads by the HT method at 160°C, exhibit amorphous nature. Further, SAXS investigation of the as-prepared micro-beads showed a strong scattering above q=1 nm^{-1} (Fig.1b) and the estimated size of the scatterers is 1.3±0.4nm. Combining XRD and SAXS studies, these scatterers are found to be amorphous Sn-O nanoclusters that are existing in the as-prepared micro-beads. Upon heat treatment (400°C and above for 1 hour), these nanoclusters crystallize and also grow to larger particles (inset to Fig. 1b) as presented in schematic (Fig. 2). By employing SAXS, owing to the high transmission of X-rays, we have overcome the limitations of TEM to investigate the microstructure of primary particles in SnO_2 micro-beads from nucleation to growth. This has enabled the study of powder particles that have thickness ranging from a few tens of micron to several hundred micron.

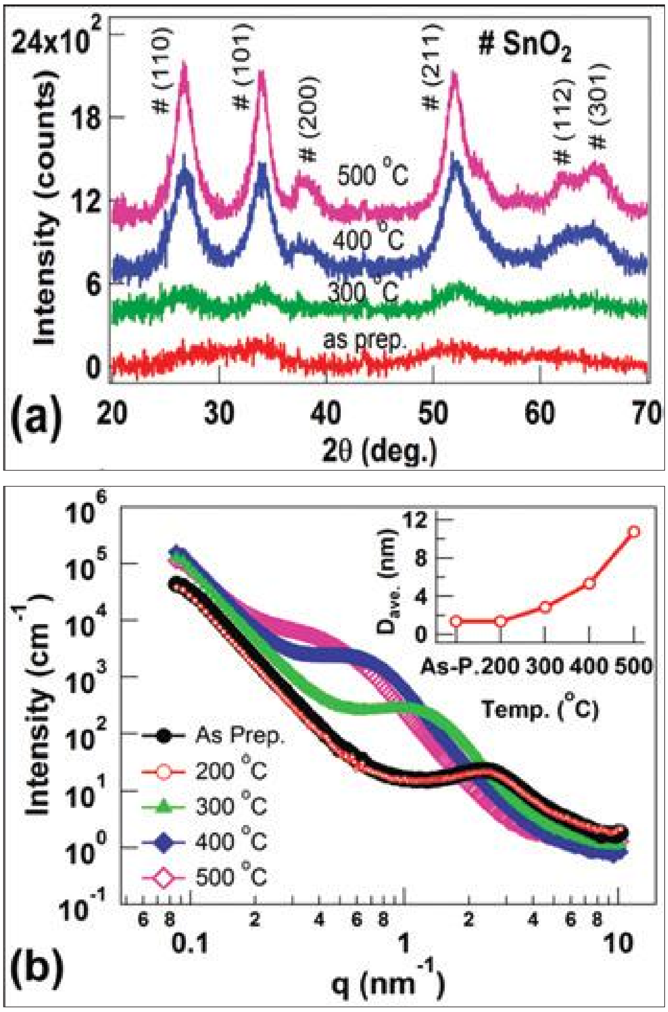


Fig. 1 (a) XRD and (b) SAXS profiles of the SnO_2 beads as prepared at 160°C and heat treated at 200 - 500°C.
Inset to Fig.1b shows average primary particle diameter with heat treatment temperature

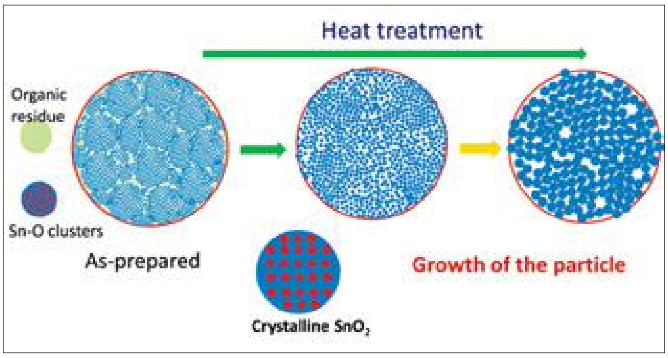


Fig. 2 Schematic depicting the formation stages of mesoporous SnO_2 micro-beads

Contributor: R. Easwaramoorthi

Study of High Temperature Creep Behaviour of ODS-18Cr Ferritic Steels

P Suresh Babu ***pitchuka@arci.res.in***

The use of conventional ferritic/martensitic and ferrtic steels for high temperature applications is limited to less than 550˚C due to the very low tensile and creep strength beyond this temperature. The high temperature strength of these steels above 550°C can be improved by dispersing stable nano-sized oxide particles (Y_2O_3, TiO_2 etc.) uniformly in the steel matrix. The performance of oxide dispersion strengthened (ODS) steels depends on the composition, stability, concentration, size, spacing and distribution of dispersoids in the matrix. The nano-sized oxide particles (1-5 nm) in the matrix improve the high temperature mechanical properties (strength and creep) by suppressing the grain growth, acting as obstacles to dislocation motion and stopping grain boundary sliding. Properties of ODS steels can be further enhanced by the presence of coherent complex oxides ($Y_2Ti_2O_7$/ Y_2TiO_5) produced by interaction of Y_2O_3 with Ti as well as excess oxygen.

ODS-9Cr ferritic-martensitic steels exhibit nearly isotropic mechanical properties after final heat treatment, producing an equiaxed grain structure. But the application of these ferritic-martensitic steels is limited due to poor oxidation/corrosion resistance. In order to improve the oxidation/corrosion resistance and temperature capability, ODS ferritic (12-18Cr) steels are considered. ARCI has embarked on a major program for the development and demonstration of technology for the manufacture of ODS-18Cr steels. Understanding of deformation behaviour of ODS steels at high temperatures when exposed to longer times (creep) is very essential before they can be used in real applications. This article presents creep studies carried out on ODS-18Cr steels at ARCI.

Pre-alloyed 18Cr steel (Fe-18Cr-2.3W-0.3Ti) powder was milled with nano Yttria powder (30-50 nm) in a high energy ball mill (Simoloyer CM20) for 6h under argon atmosphere. The milled powder was filled in cans, degassed and sealed, after which the sealed cans were upset forged at 1050°C and extruded at 1150°C. The extruded rods were annealed at 900°C for 1h and water quenched. Creep tests were carried out on these samples at 650°C at different stress levels. The creep data at 650°C recorded at various stresses are shown in Fig. 1. It is found that the tertiary stage is absent at low stress levels and the creep rate increased with increasing stress. The fractured surface of samples tested at 300 and 350 MPa stresses showed mixed mode of failure (secondary cracks and dimples), whereas samples tested at higher stresses exhibited dimple type fracture. The creep exponent calculated from the minimum creep rate and stress data is 16. Such a high creep exponent is typical for ODS steels and indicates that dislocation creep is responsible for the deformation. TEM analysis near the fractured surface of the sample tested at 650°C and 400MPa stress showed pinning of dislocations at oxide particles (Fig.2). Moreover, there is no change in the grain and precipitate size after creep tests at 650°C. Using the total time to failure, creep rate and strain data, the modified Monkman-Grant constant (C_{MMG}) was calculated. C_{MMG} varies from 0.028 to 0.048 in the present study, which indicates that at a certain strain rate, high creep stress or temperature is required for the sample to fail. Creep tests at higher temperatures (>650°C) are in progress to study the creep performance of ODS 18Cr steels.

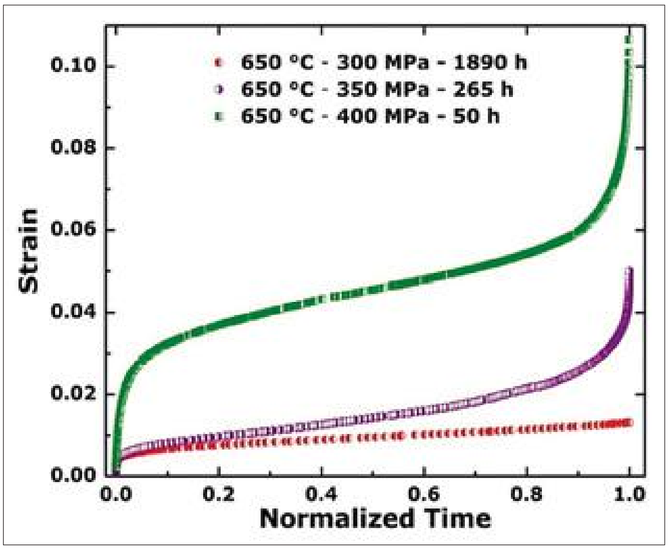


Fig.1 Creep curves of 18Cr ODS steel tested at 650°C temperature and different stress levels

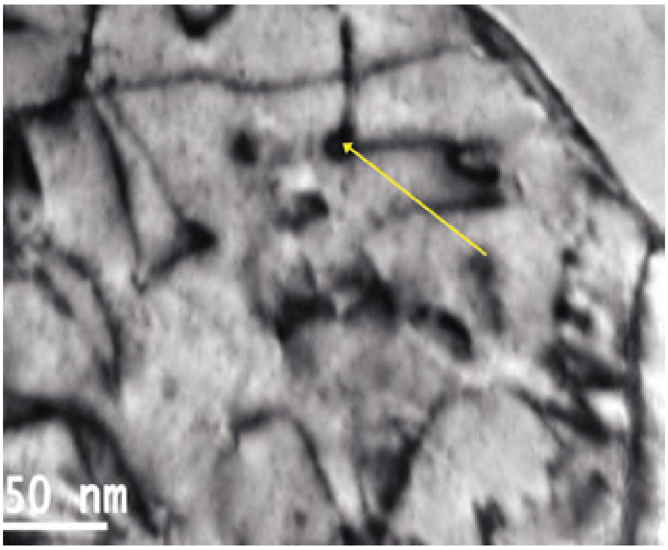


Fig.2 TEM images near fracture surface of ODS 18Cr- steels tested at 650°C and 400 MPa stress. Arrow indicates pinned dislocation at the departure side of the precipitate

Contributor: R Vijay

High Resolution (HR) Electron Microscopy of 18Cr ODS steel

M Ramakrishna ***ramakrishna@arci.res.in***

ODS steels with high chromium content, which are developed for nuclear fuel clad applications, are processed using a powder metallurgy route that involves milling of blended pre-alloyed steel and Yittria powders for a pre-determined time, followed by hot consolidation using extrusion. Reports suggest that the Yittria powder gets fragmented during milling and, after a certain period it gets dissociated into Y and O. During hot consolidation, Y and O associate with Ti and form Y-Ti-O based dispersoids with an average size around 5 nm. As part of the ODS project at ARCI, 18Cr ODS steel alloy was processed using the above-mentioned process. Pre-alloyed powders of composition Fe-18Cr-2.33W-0.34Ti were mixed with Yittria powder, milled using a Simoloyer mill for 1 hr and 6 hrs and finally consolidated using a combination of upset forging and extrusion. Electron microscopy of the as-milled powders was carried out using the Tecnai G2 transmission electron microscope (TEM) at ARCI and bulk ODS steel samples in both annealed and extruded conditions were studied using the Tecnai F30 TEM at IISc, Bangalore. Preparation of powder samples for transmission studies in the TEM is an elaborate procedure. First, the powder is mixed thoroughly in an epoxy-resin mix and is subjected to vacuum so that the particles get wet by the mix properly. This mix is filled in a brass tube having 3 mm diameter and is set at a temperature of around 110°C. Finally, a thin disc is cut from the tube and is thinned as in the case of a bulk sample. Bulk ODS samples for TEM observation were prepared using the twin jet electro-polishing technique. Fischione-make polisher, loaded with mixed acids electrolyte and maintained at -30°C, was used for thinning bulk samples.

Fig. 1a shows observations on the 1hr milled powder sample. The dark field image captured using a reflection from yttria shows that fragmented yttria particles have got distributed along the weld interfaces of the iron powder particles. Fig.1b shows the HR image of the yttria particle circled in Fig. 1a. Attempts were made to find the presence of yttria in 6hr milled powder sample using SAED, but probably due to further fragmentation or dissociation of yttria, no evidence of Y_2O_3 was found. Fig.1c shows a high magnification image captured using the Tecnai G2 microscope at ARCI, shows dispersoids with cuboid shape. Presence of Moiré fringes due to interference between the [110] of Fe and 222 of $Y_2Ti_2O_7$ can be seen within the dispersoid. Fig.1d shows a similar dispersoid imaged using the F30 microscope. It can be seen that the image offers much better resolution, the reason being F30 works at 300kV so a more intense electron beam with lower wavelength is employed. A more pertinent feature of F30 that causes improved resolution is that the specimen position is much closer to the objective lens.

The inset of Fig. 1c shows fast Fourier transform of the HR image shown in Fig. 1c which clearly shows diffraction spots pertaining to both matrix and dispersoid. It can be seen that the dispersoids present a specific orientation relationship (OR) with respect to matrix. But after observing many such dispersoids, it was found that OR between the dispersoids and matrix is not unique unlike the OR between precipitates and matrix in a typical age-hardenable alloy. Figs. 1e and 1f show HR images of both matrix and dispersoid created by carrying out inverse fast fourier transform (IFFT) using the diffraction spots of diffraction pattern from Fig. 1b. HR imaging of 18Cr ODS steel has thus helped in resolving the dispersoids and understanding their OR with matrix.

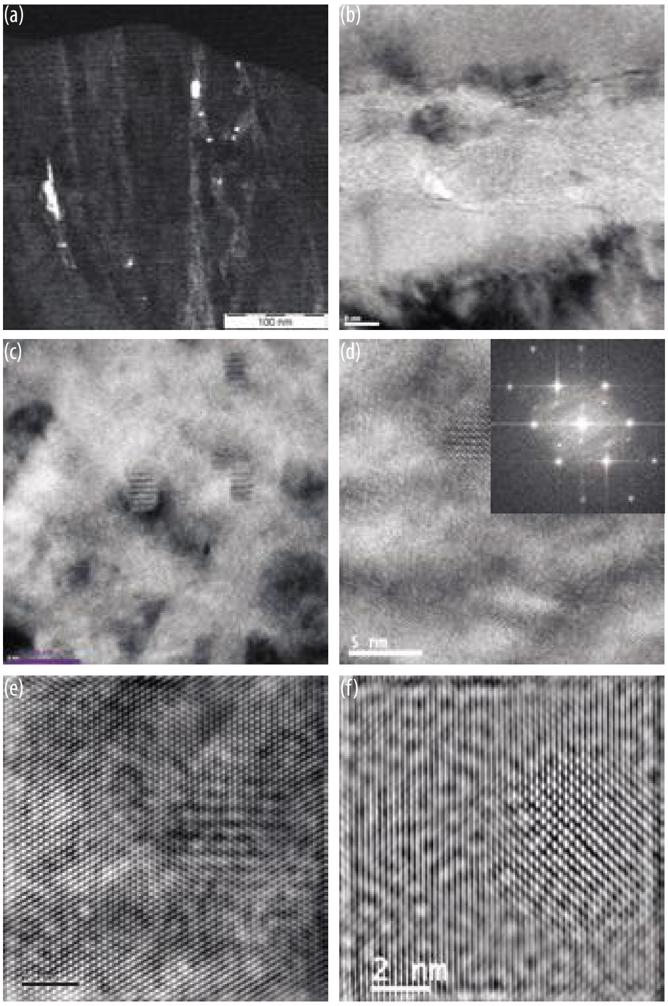


Fig1. (a) DF image showing presence of yttria, (b) SAED pattern from corresponding area (c) TEM BF image showing cuboid shaped dispersoids filled with moiré fringes taken at ARCI (d) TEM BF image showing cuboid shaped dispersoids filled with moiré fringes taken using FEGTEM. Inset shows FFT of the image B (e) Processed IFFT image of dispersoid (f) Processed IFFT image of matrix

Collaborators: K S Prasad and R Vijay

Effect of Heat Treatment on Corrosion Performance of Cold Sprayed Niobium Coatings

A Jyothirmayi

ajyothi@arci.res.in

Niobium forms a rapid stable passive film in aqueous solutions of most organic and mineral acids, which makes it an attractive corrosion protective coating for steels. Since the passivated niobium is cathodic to the underlying steel, rapid preferential attack of the substrate occurs through the porosity in the coating. By using Cold spray technique, dense metallic coatings with fewer defects are obtained. These defects can be further eliminated by heat treatment due to improved inter-splat bonding.

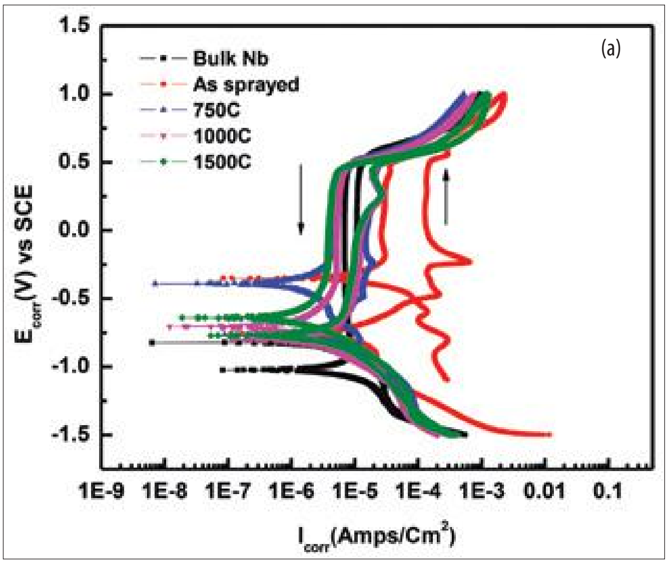
Niobium coatings with thickness up to ~ 300µm deposited on mild steel were separated from the substrate and heated at different temperatures for two hours in order to study the effect of heat treatment on the corrosion properties. Potentiodynamic polarization reverse scans and impedance tests were carried out using SI 1260 impedance analyzer with SI 1287 electrochemical interface for as-coated, heat-treated and bulk Nb samples after one hour exposure to 1M KOH (a more aggressive environment).

The polarization reverse plots recorded are shown in Fig.1 (a), and the analyzed data of corrosion potentials (E_{corr}) and current densities (I_{corr}) are given in Table1. The forward and reverse scans are indicated by up and down arrows respectively in the figures. All the graphs showed negative hysteresis indicating the repassivation of damaged film. The E_{rp} (reverse potential) is more positive than E_{corr} for as-coated and heat-treated coatings, which demonstrates superior re-passivation behavior and better performance of all cold sprayed Nb coatings as compared to bulk Nb. The corrosion currents for coatings heat treated at 1000°C and 1500ºC are lower than that of bulk. Even the sample heat treated at 750°C exhibits lower corrosion current density, which is close to the bulk (Table 1). The defects in the as-coated samples prevent formation of a uniform passive film. Closing of pores and defects in the cold-sprayed coatings, with reduction in grain boundaries on account of heat treatment, is responsible for increased corrosion resistance.

Bode plots from impedance data of all the coatings are shown in Fig. 1(b). The R_{ct} and R_{pore} values obtained by circuit fit of the plots are shown in Table1. The R_{ct} value is very low for the as-coated sample and it is improved for heat-treated samples at 750ºC. Samples heat-treated at 1000ºC and 1500ºC show very high R_{ct}. However the coatings show some pore resistance, which is improved with heat treatment from 750ºC to 1500ºC. The total resistance increases with heat treatment and coatings heat treated at 1000ºC and 1500ºC showed better results than that of bulk tantalum samples.

Table 1 E_{corr}, I_{corr} and corrosion rate from polarization plots shown in Fig. 1(a), R_{ct} and R_{pore} from circuit fit of Bode plots shown in Fig. 1(b)

Sample ID	E_{corr} (mV) vs SCE	I_{corr} [µA/cm²]	Corrosion rate (MPY)	Data from impedance analysis	
				R_{ct} [Ω.cm²]	R_{pore} [Ω.cm²]
Nb- Bulk	-773	1.78	0.498	45735	1.38
As coated	-755	4.71	1.326	6066	47.8
HT at 750ºC	-761	1.86	0.524	8354	322.6
HT at 1000ºC	-800	1.63	0.459	61679	387.4
HT at 1500ºC	-769	1.58	0.443	94880	303.3



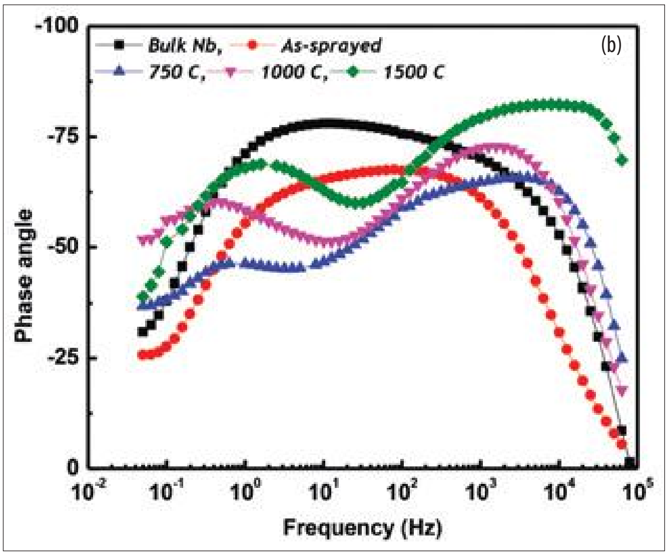


Fig 1 (a) Potentiodynamic polarization reverse scans and (b) Bode plots of bulk, as-coated and heat-treated Nb coatings after 1hr exposure to 1M KOH

Contributors: S Kumar and V Vidyasagar

An Alternate Instrumented Testing Method for Solid Particle Erosion Testing

L Venkatesh ***venkatesh@arci.res.in***

It is well known that conventional mechanical properties like hardness, tensile strength etc. are poor indicators of erosion performance. Hence the only known method to rank erosion rate of different materials is by solid particle erosion testing. Of late, there has been a growing interest for measurement techniques that can study erosion performance. Nano impact tests using an instrumented indentation system under dynamic loading conditions have been found to simulate the response of thin films and coatings under erosion testing. In this study, solid particle erosion performance of three coatings will be compared with their performance under nano impact testing. Chromium carbide-NiCrMoNb metal matrix composite coatings were generated using laser cladding, detonation spraying and plasma spraying. Erosion rate was measured using a standard solid particle erosion tester and instrumented impact test was carried out using a pendulum-based depth sensing system capable of impacting precisely at the same location repeatedly at regular intervals.

Erosion rate of the coatings in terms of mass loss of the coatings is shown in Fig.1. The plasma sprayed coating showed highest erosion rate whereas detonation sprayed coating showed least erosion rate while that of laser clad coating was in between that of the two thermally sprayed coatings. The poor performance of the plasma sprayed coating was attributed to the brittleness of the coating and weak bonding of the splats.

The average of the final impact depth after cube corner impact tests on the coatings is shown in Fig. 2. The ranking of the coatings by nano impact testing is same as that determined through erosion testing. The ratios of erosion wear rate (1:1.2:1.6) and average impact depth (1:1.1:1.4) of the coatings too were similar. Secondary electron imaging of the impact sites showed similar failure features that were observed after erosion testing. Fig. 3 shows impact curves for plasma sprayed coating with the corresponding secondary electron images as insets. Splat spalling and brittle fragmentation, which are responsible for its poor erosion performance, are simulated during impact testing. As is clearly observed, nano impact testing results appear to reflect erosion performance in a better way. With its dynamic loading, nano impact testing also simulates the micostructural response of the coatings to solid particle erosion.

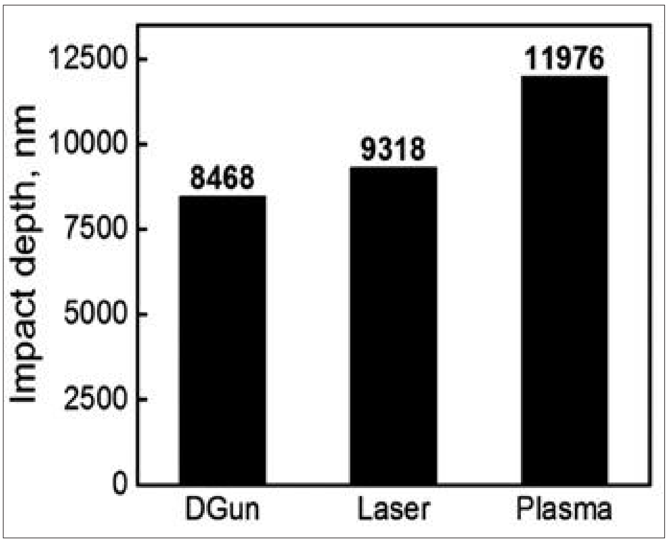


Fig.2 Average impact depth of the coatings

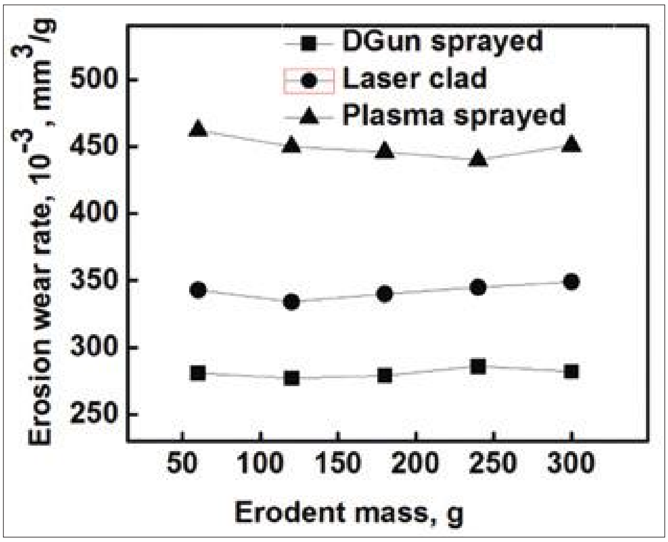


Fig.1 Erosion wear rate of the coatings

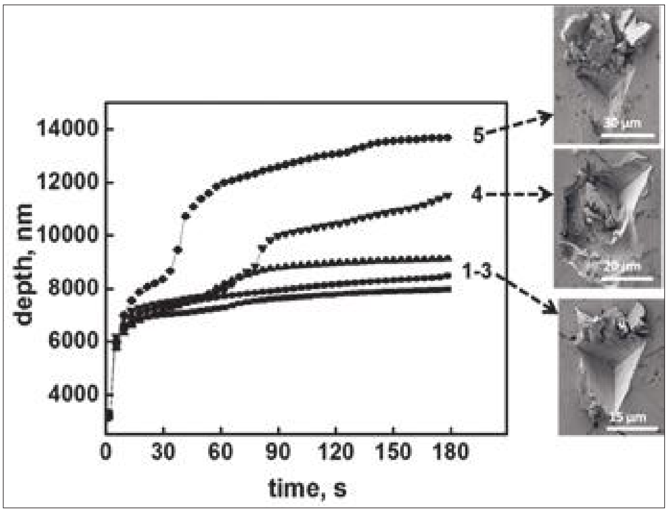


Fig.3 Impact curves with corresponding secondary electron images for the plasma sprayed coating

Collaborators: P Suresh Babu, G Siva Kumar and Manish Tak

Centre for Knowledge Management of Nanoscience and Technology

Sanjay Bhardwaj ***sanjay@arci.res.in***

Centre for Knowledge Management of Nanoscience & Technology (CKMNT) was set up at ARCI, Hyderabad under the aegis of National Nano Mission in the year 2009. The mandate of the CKMNT is to continuously search & monitor the literature and patents emerging in the area of nanoscience and technology, analyze, categorize and disseminate information among the stakeholders. In the process, the Centre also maintains knowledge databases. During this first phase of the project (2009 - 2016), the Centre developed human resources required for such a unique activity and successfully fulfilled its mandate. Some of the highlights of this phase are as follows:

(a) Provided strategic inputs to the Nano Mission on the following:
- Regulatory Framework for Nanotechnology - A Global Perspective
- Nanotechnology Funding and Investment: A Global Perspective
- A Compendium on Scenario of Nano-Enabled Sensors in India
- Guidelines and Best Practices for Safe Handling of Nanomaterials in R&D Labs and Industry (published on Nanomission website inviting comments)
- Yearly update on Global and Indian Scenario of Nanoscience and Technology Publications

(b) Participated as Knowledge Partner in Nano Mission sponsored conferences :
- Bangalore Nano (5th edition (2012), 6th edition (2013), 7th edition (2014) & 8th edition (2016)) – As a knowledge partner.
- International Conference on Nanoscience and Technology (ICONSAT), 2012, Hydeabad- CKMNT assisted ARCI in organizing the event.

(c) Knowledge partner, for the event 'Global Green Nanotechnology Conclave (GiGaNTiC 2015)' organized by CII during 6th - 7th August, 2015, at Ahmedabad. CKMNT has contributed a short compilation entitled "Nanotechnology Applications in Healthcare - Potpourri".

(d) Valuable insights to various organizations for their R&D/ technology development efforts through technological and techno-business analytics reports.

(e) Repository of nanotechnologies (also included in Nanotechnology Directory) available for licensing and transfer.

(f) Compilation of sector-wise Indian Patent database, which contains detailed patent portfolio of various organizations and information of various patented technologies.

(g) Freedom to Operate (FTO) analysis on "Improved process for producing silica aerogel thermal insulation product having titanium dioxide nanoparticle formed in-situ" for an R & D organization.

(h) Prepared a report on the market potential of sol-gel coatings for automotive applications as a prelude to generation of a technology development and transfer road-map for an R & D organization.

(i) Prepared a Compendium on Nano-Enabled Sensors in India on behalf of Nano Mission under the guidance of National Manufacturing Competitiveness Council (NMCC), Govt. of India.

(j) CKMNT has been publishing Nanotech Insights, a quarterly newsletter dedicated to the field of nanoscience and technology from the year 2010. Several newsletter articles republished in Nanowerk website were ranked among most popular articles in the Top 10 Spotlights.

During the last year, work on the following themes/application areas has been carried out for different client organizations:

(1) Patentability report for a antimicrobial chemical composition for cosmetics and personal care

(2) Report for heterocyclic compounds in polymers and other materials. Report covers comprehensive patent landscaping, white space analysis, technological trend analysis, citation analysis, claims and technology overview of the most cited patents, Indian scenario and building block patents

(3) Patent landscape report on Diethylamino hydroxybenzoyl hexyl benzoate (Uvinul A Plus) and Avobenzone for cosmetics and personal care application. The report identified bibliometric analysis, white space analysis, technological trend analysis and competitors' analysis.

(4) Techno-commercial report on the applications and market opportunities of MWCNTs in various industries such as plastics, composites, energy, coatings, wire and cable, and nanofluids.

(5) Work to prepare the techno-business reports related to (a) ceramics and (b) nanotechnology in upstream oil and gas industry is ongoing for interested client companies.

Contributor: G Padmanabham

Centre for Technology Acquisition, Transfer and International Cooperation

Centre for Technology Acquisition, Transfer and International Co-operation (CTATIC) works towards bridging the gap between the R & D activities at ARCI and the need of industrial organizations.

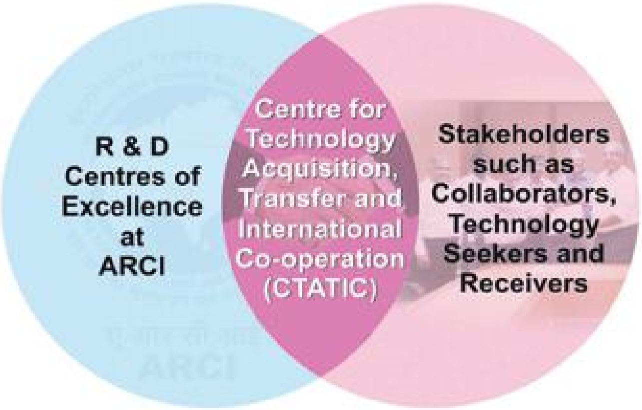


Fig.1 Interfacing role of CTATIC

Last year, recently developed 'Intellectual Property Development Indices (IPDIs)' were applied for ongoing R & D projects. Need of technologies for collaborations and readiness of technologies for transfers were assessed using IPDIs. Discussions were initiated to identify potential partners for possible collaborations and technology transfer. Nearly 30 prospective collaborators /technology seekers expressed interest in leveraging ARCI's knowledge-base and capability. Following major Agreements have been signed during the year:

- Know-how Transfer Agreement with private sector companies for manufacturing the aerogel flexible sheet.
- Sponsored R & D Agreements in the areas of nanomaterials, sol-gel coatings, engineered coatings and fuel cells with companies from India and abroad.
- Option Agreement with a private company for laser cladding technology.
- Another Agreement was signed with a leading public sector undertaking for cooperation in mutually identified R & D areas.

Stakeholders from industry, academia and R & D were sensitized about ARCI's knowledge-base and capabilities through different means such as delivering invited lectures, presentations in conferences, workshops and seminars. ARCI had also put up stall in the Laser World of Photonics India 2015 during September 2015 and in the 8th Bangalore India Nano (BIN) 2016 Conference during March 2016. ARCI received "Best Exhibitor" Award in "Creative Design" category in the BIN 2016. Enquiries received from prospective collaborators and technology seekers due to above efforts are being addressed. Costing of more than 40 projects / technologies was conducted. Patent analysis was conducted for over 20 cases to either ascertain the patentability of R & D outputs, to provide inputs for the R & D programmes being initiated or to scout for possible technology seekers. Other activities of the CTATIC include reporting of ARCI output to different government departments and monitoring agencies.

Role of the CTATIC at different levels of the IPDIs for ARCI's R & D programmes is shown below:

Fig. 2 Schematic showing IPDIs and role of the CTATIC

IPDI →	1	2	3	4	5	6	7	8	9	10
Activities →	Basic concepts and understanding of underlying scientific principles	Shortlisting possible applications	Research to prove technical feasibility for targeted application	Coupon level testing in simulated conditions	Check repeatability/ consistency	Prototype testing in real-life conditions	Check repeatability/ consistency	Reassessing feasibility (IP, competition technology, commercial)	Initiate technology transfer	Support in stabilizing production
IP Chain Milestone(s) →	Exploratory studies		Laboratory testing			Field demonstration			Technology transfer	
Role of CTATIC →	• Competitive intelligence • Identification of possible collaborators • Selecting appropriate engagement model (decision variables: IPDIs, collaborators, IP ownership & licensing methodology, deliverables, milestones, financials etc.) • Preparing/finalizing contratual agreement • Patent analysis and filing					• Activities mentioned from IPDI 1 to 5 • Preparing status reports on onoging R&D projects and using them for IP/Technology Marketing efforts • Feasibility assessment • Costing of technologies and projects			• Activities mentioned from IPDI 1 to 8 • Receivables management (collection of technology transfer fees/royalties) even beyond IPDI 10	

Sanjay Bhardwaj
sanjay@arci.res.in

G Padmanabham
gp@arci.res.in

Portfolio of ARCI Technologies

Technology Transfers Undertaken

Based on the perceived market size of products/ services based on ARCI technologies, ARCI has adopted exclusive and non-exclusive modes of technology transfer to facilitate healthy competition in the market. So far, ARCI has successfully transferred 15 technologies to 27 receivers and few other technologies are under transfer. The following tables depict the completed/ongoing technology transfers and technologies available for adaptation/transfer:

Sr. No	Technology	Technology Recipient	Status
1-8.	Electro Spark Coating (ESC) equipment	Hard, wear resistant coatings	Transferred to 8 companies on non-exclusive basis
9.	Magnesia Aluminate Spinel (MAS)	Steel, cement and power plants	Transferred on exclusive basis
10.	Ceramic crucibles	Carbon and Sulphur analysis	Transferred on exclusive basis
11.	Energy efficient air heaters from ceramic honeycombs	Industrial heating	Transferred on exclusive basis
12-15	Detonation Spray Coating (DSC)	Wear and corrosion resistant coating for various components	Transferred to 4 companies on region-exclusive basis
16.	Reinforced graphite sheets and seals	Automotive sector	Transferred on exclusive basis
17.	Heat pipes heat sinks	Waste heat recovery systems, solar energy applications, power electronics	Transferred on exclusive basis
18.	Evaporation boats	Metallization	Transferred on exclusive basis
19.	Ceramic honeycomb molten metal filters	Molten metal filtration	Transferred on exclusive basis
20.	Calcium aluminate cements and furnace sealants	Refractory castables	Transferred on exclusive basis
21-23.	Micro Arc Oxidation (MAO)	Hard (1800 VHN) wear resistant coatings on aluminum and titanium alloys	Transferred to 3 companies on region-exclusive basis.
24.	ESC equipment manufacturing	Diverse segments	Transferred on non-exclusive basis
25.	Nanosilver impregnated ceramic water filter candles to impart anti-bacterial function	Water purification	Transferred on non-exclusive basis
26.	Nano silver based textile finishes for anti-bacterial applications	Anti-bacterial applications	Transferred on exclusive basis
27.	Nanotitaniumdioxide based textile finishes for self cleaning applications	Self-cleaning applications	Transferred on exclusive basis
28.	Decorative coatings on glass substrates	Aesthetic applications	Ongoing
29.	Aerogel Flexible Sheet Technology	Thermal Insulation applications	Ongoing

Technologies Available for Adaptation/Transfer

S. No	Technology and Related Issues	Key Features and Applications	
1.	**Decorative, Corrosion Resistant, Easy-To-Clean (ETC) Coatings on Metals** (Indian Patent Application Number 620/DEL/2010 filed on 17/03/2010) Level of Maturity: In-house testing completed	***Key Features:*** - Water contact angle $95^0 \pm 5^0$ - Can be directly applied on Aluminium/Stainless steel/mild steel substrates without need for primer - Can be transparent or decorative - High scratch hardness and abrasion resistance - Good corrosion resistance > 720 hrs Salt Spray Test (for Aluminium) - Good adhesion - Can be made anti-bacterial	***Possible Applications:*** - On Aluminum for use of chromate-free, decorative multi-functional coatings for blades of ceiling fans - On SS sheets as decorative, abrasion resistant coatings for modular kitchens
2.	**Hard Coatings on Plastics like Polycarbonate, PMMA, Carbon Epoxy Composites etc.** (Indian Patent Application Numbers 2427/ DEL/2010 dtd. 12/10/2010 and 1278/ DEL/ 2011 dtd. 02/05/11) Level of Maturity: In-house testing completed	***Key Features:*** - High scratch hardness and abrasion resistance - Long life - Good adhesion - Coloured coatings possible - Can be made easy-to-clean with low surface free energy	***Possible Applications:*** - Helicopter and automobiles windshields and windows - Aircraft canopies - Helmet visors - Road markers - Bi-aspheric lenses used in indirect ophthalmoscopy

<table>
<tr><th>S. No</th><th>Technology and Related Issues</th><th colspan="2">Key Features and Applications</th></tr>
<tr><td>3.</td><td>Decorative Coatings on Glass and Ceramics
(Indian Patent Application Number 2427/DEL/2010 filed on 12/10/2010)

Level of Maturity: Technology transfer ongoing with one company on non-exclusive basis. Available for transfer.</td><td>Key Features:
- Adjustable transmission and refractive index of the coatings
- Colour of the coating can be controlled by suitable choice of dopants
- UV temperature stable and weather proof
- Recyclability of glass due to complete degradation of organic constituents at high temperatures
- Opaque coatings possible with high temperature durability</td><td>Possible Applications:
- Coloured glasses for aesthetics or decoration
- Scratch resistant coloured coatings for glass bottles used in various industries such as perfume and fashion fields
- Architectural Applications</td></tr>
<tr><td>4.</td><td>Durable Single Layer Anti-Reflective Coating on Glass
(Indian Patent Application No.: 2330/DEL/2013 dated: 05/08/2013)

Level of Maturity: In-house testing completed</td><td>Key Features:
- Economical possibility of large area applications
- Low temperature curability
- Developed and demonstrated sol-gel based antireflective coatings on 1 m long, borosilicate glass cover tube of 120-130 mm diameter to maximize visible light transmission to 97%</td><td>Possible Applications:
- Showroom display glass
- Ophthalmic lenses
- Solar thermal plants
- Automobile</td></tr>
<tr><td>5.</td><td>Nanocrystalline Zinc Oxide (ZnO) based Varistors
(Indian Patent Application Number 1669/DEL/2006 dtd. 20/07/2006)

Level of Maturity: In-house testing completed</td><td>Key Features:
- Higher Breakdown voltage (5 times); Higher Coefficient of non-linearity (3 to 4 times); Lower leakage current compared to that of commercial varistors</td><td>Possible Applications:
- Surge voltage protection in electrical and electronics industry</td></tr>
<tr><td>6.</td><td>Nano Silver Impregnated Ceramic Candle Filter
(Indian Patent Application Number 2786/DEL/2005 dtd. 19/10/2005)

Level of Maturity: Small scale production Technology transferred to one company and is available for transfer on non-exclusive basis.</td><td>Key Features:
- Successfully field tested at various villages in Andhra Pradesh with a Non-Governmental Organization
- No electrical power and pressurized water required:
- Ease in maintenance
- Commercially attractive {very low amount of silver used (0.2 wt %), Cost increase : candle (30-50%) and filter assembly (3-5%)}
- Replacement needed once in six months</td><td>Application:
Ceramic candles for drinking water purification</td></tr>
<tr><td>7.</td><td>Silica Aerogels
(Indian Patent Application Number 2406/DEL/2010 dtd. 08/10/2010)

Level of Maturity: In-house testing completed. Transfer of know-how for aerogel flexible sheet is ongoing on exclusive basis.</td><td>Key Features:
- Stable from cryo (-50^0C) to 1000^0C
- Thermal conductivity (0.03 W/mK)
- Fire resistant
- Chemically inert
- Easily cut
- Hydrophobic
- Thickness range from 5-25 mm can be produced</td><td>Possible Applications:
- Thermal insulation in automotives
- Heating/cold storage
- Thermal clothing
- Aerospace etc.</td></tr>
<tr><td>8.</td><td>Laser Welding and Laser-MIG Hybrid Welding

Level of Maturity: Testing on some actual components as per users' requirements done successfully</td><td>Key Features:
- High power density
- Single pass welding of thick sections
- Controlled heat input welding with precision
- No vacuum requirement</td><td>Possible Applications:
- Tailor welded blanks for automotive applications etc.
- Can weld a wide variety of materials and thicknesses
- Can weld magnetic materials unlike Electron Beam Welding
- Steel plates, thick section welds, ship building etc.</td></tr>
<tr><td>9.</td><td>Laser Surface Hardening Treatment

Level of Maturity: Testing on some actual components as per users' requirements done successfully</td><td>Key Features:
- Selective localized area hardening with minimal heat input
- No quenchant requirement
- No surface damage
- Excellent reproducibility with ease of automation
- Negligible post process machining requirement
- Controlled case depth
- Refined homogenous microstructures
- Minimal distortion
- Chemical cleanliness</td><td>Possible Applications:
- Suited to wide range of steels, cast irons and profiles
- The process can be developed for hardening of a variety of components such as crankshafts, camshafts, piston rings, tooling and dies, bearing steels, steam turbine blades, sheet metal etc.</td></tr>
</table>

S. No	Technology and Related Issues	Key Features and Applications	
10.	**Laser Surface Coating (Alloying and Cladding)** Level of Maturity: Testing on actual components done successfully	*Key Features:* - Material to be coated is fused using a laser beam and deposited on a substrate with good metallurgical bonding but with minimal base metal dilution - Low heat input resulting in fine microstructures - Provides crack-free clad layers without porosity	*Possible Applications:* - Wear plates for different applications - Component repair and refurbishment
11.	**Laser Drilling** Level of Maturity: Testing on actual components done successfully	*Key Features:* - Non-contact drilling method - Holes of large aspect ratio and very small diameter (0.3 mm) can be drilled - Precise control of heat input - Holes can be drilled at shallow angles to the surface	*Possible Applications:* - A wide variety of materials such as metals, ceramics and composites etc., can be drilled - The process can be used for specific applications such as drilling of fine holes on high pressure nozzle guided vanes and combustion liners for aero-engine applications.
12.	**Micro Arc Oxidation** (Indian Patent Number 209817 granted on 06/09/2007; US Patent Number 6893551 granted on: 17/05/2005) Level of Maturity: Small scale production Technology transferred to 3 entrepreneurs and is available for export and for states in India other than Andhra Pradesh, Tamilnadu and Karnataka.	*Key Features:* - Ability to coat Al, Ti, Mg and Zr metals and their alloys - Ease to coat complex shapes and difficult to access regions - Uniform, dense, hard and thick coatings - Superior coating properties and performance compared to other conventional acid based processes like anodizing and hard anodizing - Excellent tribological properties and corrosion resistance - Eco friendly - 5 to 40 times service life enhancement	*Possible Applications:* - For a wide array of applications in industries such as textile, automobile etc.
13.	**Detonation Spray Coating (DSC) Technology** Level of Maturity: Small scale production Technology transferred to 4 entrepreneurs and is available for all Indian states (except for Delhi, Haryana, Punjab, U.P., Uttaranchal, Bihar, Jammu & Kashmir, and H.P.) and for export.	*Key Features:* - Attractively priced compared to imported HVOF units - Extreme versatility - Capable of depositing a vast range of metals, alloys, cermet, ceramic and composite coatings for varied functional applications	*Possible Applications:* - Coatings for applications such as wear and corrosion resistance etc., for various industries
14.	**Electro Spark Coating (ESC) Equipment Manufacturing Technology** (Indian Patent Application Number 1610/ DEL/2005 dtd. 21/06/2005) Level of Maturity: Small scale production Technology transferred to one company and is available for transfer to all Indian states on non-exclusive basis.	*Key Features:* - Simple and cost-effective - Metallurgical bonded coatings with low heat input to the substrate - Any electrically conductive material available in electrode form can be coated on any conductive substrate - Equipment is portable and lends itself easily to automation for ensuring reproducibility - Capable of providing coating thickness in the range of 10-130 µm	*Possible Applications:* - Component refurbishment and to combat severe conditions of wear - Can be used for enhancing life of cutting tools such as end mills, taps and lathe bits
15.	**Exfoliated Graphite and its Value Added Products** (Indian Patent Number 187654 granted on 07/06/1995) Level of Maturity: Commercial Scale Technology transferred to one company and is available for transfer to all Indian states on non-exclusive basis.	*Key Features:* - Impermeable to fluids - Leak proof sealing under low turning torque - Easily cut and punched - Can withstand temperature range from -200^0 to $+500^0$C in oxidizing and up to 3000^0C in inert atmosphere - Excellent thermal shock resistance - Does not age or creep - Cannot get wetted by molten glass, metal etc., self-lubricating, and resistant to all chemicals	*Possible Applications:* - Fuel Cells - Automotive - Oil refineries - Petrochemical industries etc.
16.	**Ultrafast Laser Micromachining** Level of Maturity: Testing on actual components done successfully	*Key Features:* - High machining quality - Heat sensitive material machining - No wavelength dependence so any material can be machined with the same laser - Greater flexibility and very well defined ablation threshold (down to 100 nm) - More predictable outcome with higher yield	*Possible Applications:* - Refurbishment of piston rings - Machining inside glass - Can be used on ceramics, metal tubes, and silicon.

Support Groups

Development of a PLC Based System for Detonation Spray Coating System

S Nirmala, Electronics and Instumentation Group ***nirmala@arci.res.in***

The denotation of depositing coatings relies on gaseous explosion. In short, the Detonation Spray Coating (DSC) system consists of an explosion chamber which is coaxially mounted with a gun barrel. Measured quantities of fuel gases are ignited in the explosion chamber so as to generate a shock wave. Powder particles of the desired coating material are injected into this wave. As they travel along the gun barrel, they gain energy from the shock wave and bombard the substrate at high temperature and velocity to form a dense and strong coating on its surface. This process is repeated at a desired rate. DSC process has been implemented by means of a Programmable Logic Controller (PLC), as it has proven itself in harsh industrial environments. Human Machine Interface (HMI) allows the operator to enter process parameters like shot frequency and total number of shots to be fired to form the desired coating thickness. A driver circuit is used to drive the solenoid valves connected in respective gas lines (Fig.1).

The complete sequence of operation is as follows:-

Phase-1: Inert Nitrogen gas is let in to purge the barrel after each detonation.

Phase-2: Fuel gases i.e. Oxygen and Acetylene are simultaneously introduced.

Phase-3: Nitrogen is let in again as back fill to cover Oxy-Acetylene ports.

Phase-4: The gas mixture is ignited by a spark and powder is injected into the barrel.

The sequence described above is implemented by opening and closing a series of solenoid valves that control the flow of different gases and the ignition. A PLC program using a Siemens micro PLC has been developed and tested by conducting experiments on existing DSC system. Figure 2 shows a part of the PLC ladder program that has been developed.

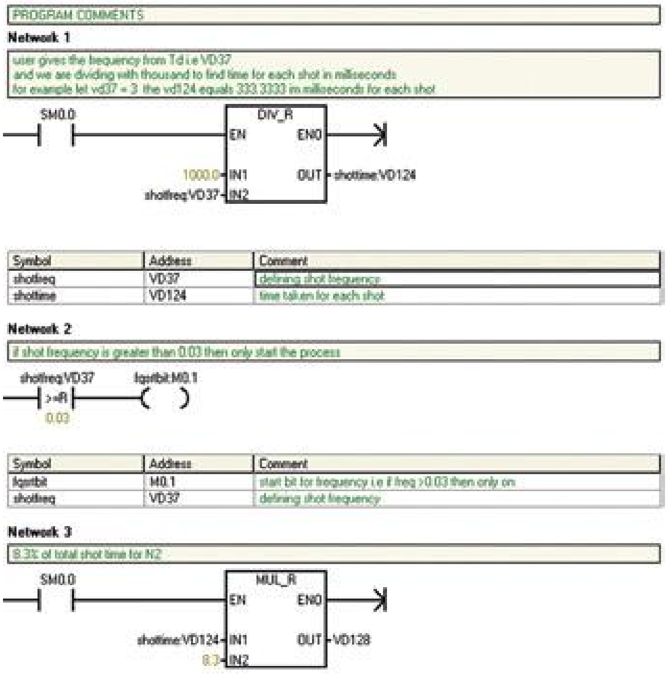


Fig.2 Portion of ladder logic

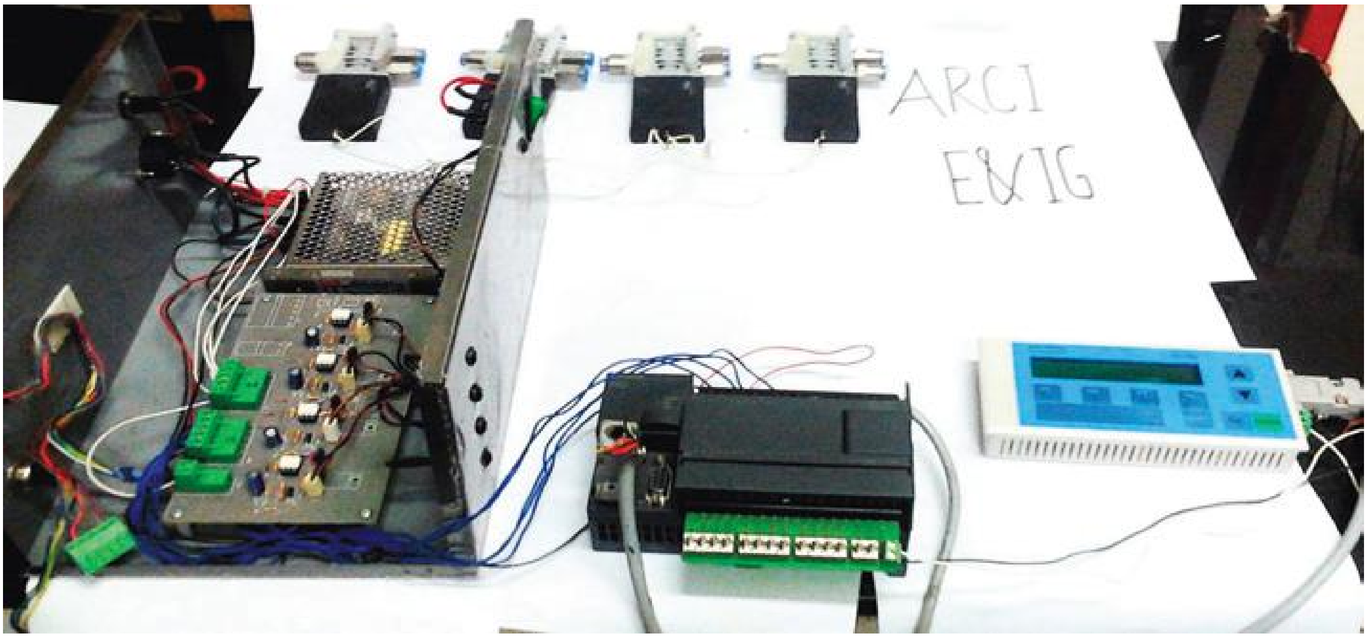


Fig.1 PLC, HMI & Driver Circuit

Contributors: N Aruna and A S Joshi

Automation of Arc Discharge Setup for Synthesis of Carbon Nanotubes

Ch Sambasiva Rao, Electronics and Instumentation Group *csrao@arci.res.in*

A DC Arc Discharge setup is employed at ARCI for the production of carbon nanotubes. An arc is produced between two carbon rods arranged vertically inside a double walled stainless chamber of about 200 litre capacity. The upper rod, which is the anode, is moved by a motor and gear mechanism towards or away from the lower carbon cathode. The cathode deposits that are produced during the arcing contain multi walled carbon nanotubes.

This production set up has been automated using a PLC and touch screen type HMI panel as shown in Fig.1 and 2.

The features of this automation are given below:

- Operating parameters are controlled and displayed on a touch screen in real time.
- All Data can be logged in files for post processing / studies
- Selector switch permits both auto and manual operation
- Safety interlocks monitor the status of vacuum, water flow, over-temperature, etc and prevent any malfunctioning of the system.
- In auto mode, the sequence of operation, illustrated in the chart below in Fig.3 is automatically invoked without operator intervention.

Fig.2 PLC Controlled HMI Control Panel

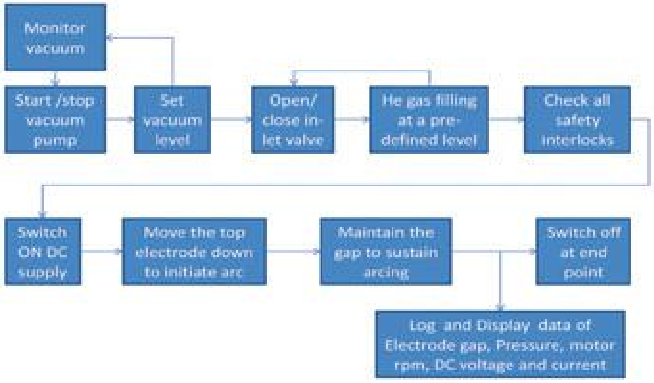


Fig.3 Sequence of operation

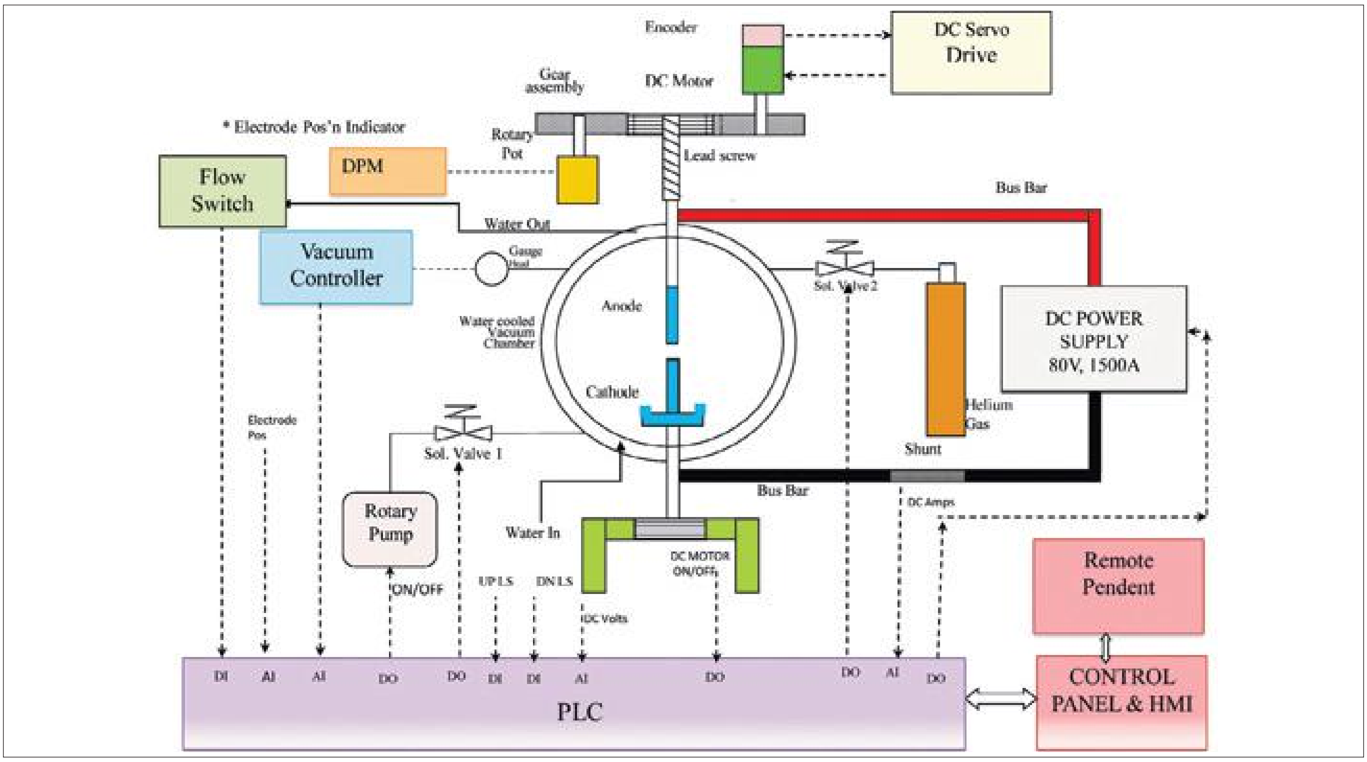


Fig.1 Schematic diagram

Contributors: S Nirmala and A S Joshi

Development of a General Purpose Data Logger using Arduino Microcontroller

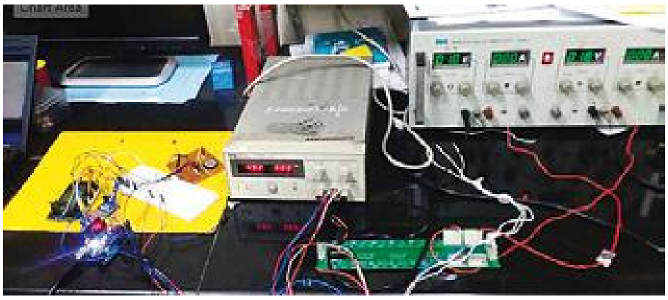
N Aruna, Electronics and Instumentation Group ***aruna@arci.res.in***

An inexpensive data logger has been developed which can be used for any general purpose application. The Data logger uses an Arduino micro-controller, a multiplexer and two power supplies for its operation. A LCD screen is used to display the monitored values and a storage data (SD) card can be used to store the data. This can be retrieved by a personal computer in Excel compatible files. All data storage is done in real time with recording of date and time using a DS1307 IC.

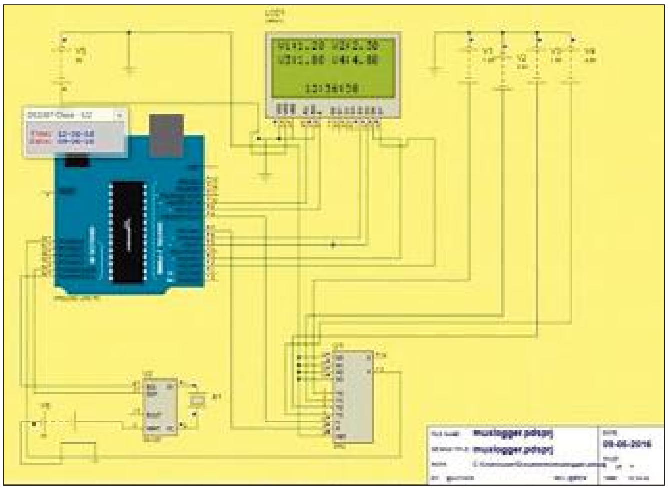
The program is developed with Arduino Integrated Development Environment loaded in a PC. The initial program was developed for testing 4 input data signals with a fixed sampling interval This is converted to an executable *.exe file and loaded in the micro-controller which can then function independently without a PC.

The integrated setup has been tested for its functionality and accuracy by monitoring 4 analog input signals, which are generated from a second power supply whose output is variable from 0 to 5 Volts DC. The set values of the power supply have been compared with the logged data and found to be in excellent agreement.

As in any data logging system, additional sensors are required to convert physical parameters like pressure, flow, temperature, speed, etc to voltage signals compatible with the developed data logger.



Physical arrangement of the test setup



Schematic of the data logger circuit

Table shows the logged data for 2 analog inputs

Date	Time	Actual v1	Acquired v1	Actual v2	Acquired v2
15/2/2016	12:12:06	0.5	0.48	0.08	0.061
15/2/2016	12:12:07	0.52	0.51	0.12	0.11
15/2/2016	12:12:08	0.51	0.51	0	0
15/2/2016	12:12:09	1.22	1.21	0.1	0.08
15/2/2016	12:12:10	1.22	1.23	0.15	0.16
15/2/2016	12:12:11	1.99	2.01	2.81	2.8
15/2/2016	12:12:12	2.26	2.25	3.22	3.21
15/2/2016	12:12:13	2.53	0.15	0.48	0.46
15/2/2016	12:12:14	2.59	2.59	0.5	0.49
15/2/2016	12:12:15	2.64	2.65	0.62	0.62
15/2/2016	12:12:16	4.81	4.8	1.23	1.24

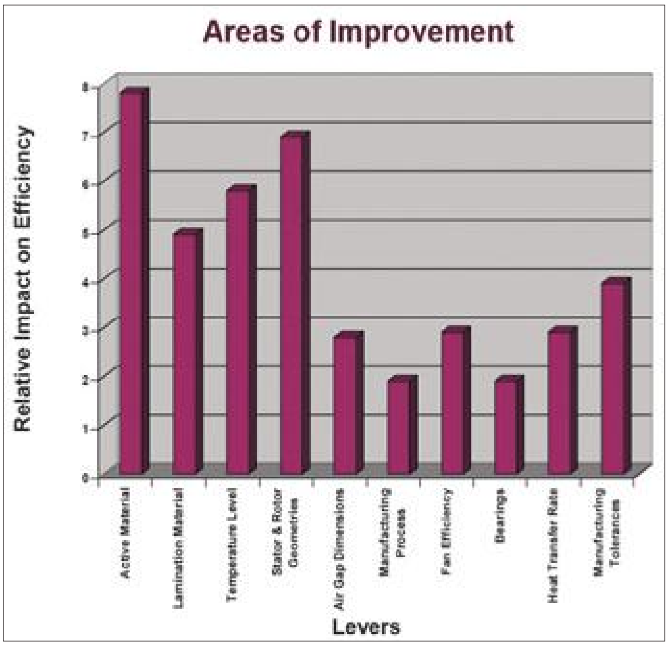
Contributors: S Nirmala and A Krishna

The Next Generation Motor - Design

V Balaji Rao, Electrical and Civil Maintenance ***vbalajirao@arci.res.in***

For many years, the efficiency of three-phase induction motors has been the subject of numerous investigations aimed at increasing efficiency values by minimizing losses during the operation. The losses are ~57% of the generated electric energy in the industry consumed by motors. The sources of losses in electric motors are many and need to be looked at separately in detail, considering their origin, level, influence, and possibility to be measured rather than just determined. Induction motor design principles have not changed dramatically over the years, whereas the tools and the knowledge of engineers have improved considerably.

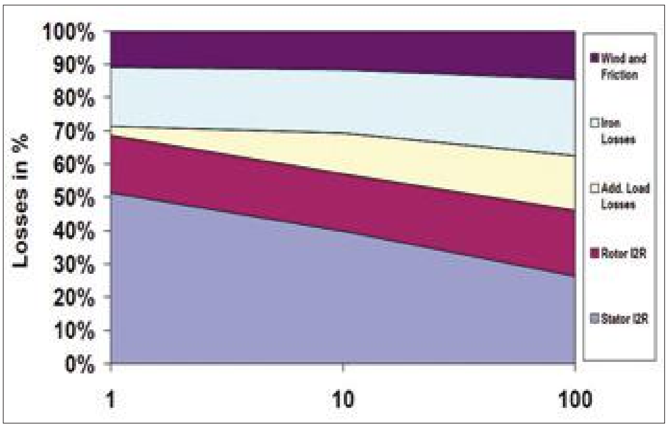
Induction motors generally have only a few parts that actively influence their performance. The components are differentiated into active parts and nonactive parts. Active parts are the rotor and stator assembly. The cores are manufactured from laminated steel. The rotor cage is mostly made of die-cast aluminum. The stator winding is made of insulated copper wires. The nonactive components are the housing or frame, bearing-end shields, fan, fan cover, terminal box, and shaft. The ability to improve performance is proportional to the active volume of the motor. Because of the defined frame assignments for each horsepower rating and speed set by NEMA MG1, the freedom to move within a dimensional envelope is limited to certain well-defined maximum dimensions in each direction (mostly shaft height and mounting dimensions). Increasing the performance of a motor, improving efficiency, requires an increase of the active volume or an improvement in technology.



Impact of the possible areas of improvement for the performance of induction motors

Typical efficiency levels over time

	Efficiency	
Perpetual Motion	100%	
Super Conducting Motor	98.5 – 99.5%	
Amorphous Steel Laminations	98 – 98.5%	
Potential Cooper Rotor	96.5 – 97.5%	
Today's Premium Efficiency	96.2%	
EPACT	95%	
1975	<94%	
200, HP Motor – Past, Present, and Future		



Typical loss distribution

Factors for Improving Efficiency

The factors for improving efficiency are as follows:

1. Increase the amount of active material
2. Utilize high-performance lamination materials
3. Lower the temperature level of the motors
4. Optimize the stator/rotor geometries
5. Optimize the air gap dimensions
6. Optimize the lamination punching and stacking process to prevent cross currents and harmonics causing stray-load losses, and minimize burrs that can short out lamination, thereby increasing core loss.
7. Improve the efficiency of fan assembly
8. Use high-efficiency bearings
9. Increase the rate of heat transfer between active parts and housing
10. Limit the manufacturing tolerances by optimizing processes

It is felt that ARCI could take up R&D on some of the materials aspects.

Source: IEEE Industry Applications Magazine

Preventing Plagiarism in R&D Institutions

R Vijaya Chandar, Technical Information Centre ***vijay_ravula@arci.res.in***

Plagiarism may be defined as the use of another person's words and/or ideas without due acknowledgement to the original source. Unfortunately, in the past few years, the instances of plagiarism in scientific research have been quite significant. The availability of materials in electronic form via internet has made it easier to copy portions of already published text. The scientific community considers plagiarism as a serious offence both in research and in academics. Allegations of plagiarism can harm the reputation of institutions as also the academic careers of students and researchers. Most young researchers become victims unknowingly because they are not very clear on what constitutes plagiarism and often youngsters are unaware of the consequences.

Plagiarism can be classified into two types: Intentional and Unintentional.

Intentional plagiarism: An author copies already published work intentionally.
Unintentional plagiarism: Though the author does not have the intention of copying, he/she has not provided proper references of the published work, and sometimes the paraphrasing is improper.

Plagiarism Detection Tools:

In order to combat plagiarism in R&D institutions, a systematic approach has to be taken up. Students and researchers should be educated about the adverse consequences of plagiarism during their research careers. Workshops may be conducted periodically for middle and senior level staff, and orientation programs on scientific writing and research ethics could be made mandatory for all the students and researchers who are beginning their careers.

In addition to creating awareness among researchers, R&D institutions can make use of plagiarism detection tools which

- help in detecting incidents of plagiarism and suggest appropriate remedial action
- help researchers cite proper references
- filter duplicate content
- create awareness of plagiarism among researchers

At present, there are several plagiarism detection tools that are available either free of cost or commercially. Some of the popular tools that are available online are mentioned in the following table and researchers can make use of these tools:

Tool	Web address
Duplichecker	http:/www.duplichecker.com
Plagiarism Checker	http://www.plagiarismchecker.com/
Viper	http://www.scanmyessay.com/
Plagiarism Detect	http://plagiarism-detect.com/
ETBLAST	http://etest.vbi.vt.edu/etblast3
Plag Scan	http://www.plagscan.com/seesources/plagiate.php
Article Checker	http://www.articelchecker.com
Copyscape	http://www.copyscape.com
Plagtracker	https://www.plagtracker.com

However, these free tools have several limitations and restrictions, some of which are given below:

- The uploaded document should not exceed a certain number of words as specified by the developer of the software
- It is sometimes possible to upload only text files
- It may not be possible to upload files at all
- The software does not work on PDF and HTML files
- In many cases the document has to be broken into many parts and only a couple of paragraphs can be uploaded each time for checking.

Understanding the importance of having a proper tool to combat plagiarism within ARCI, TIC has subscribed to iThenticate, a product developed by iParadigms LLC, USA. All the manuscripts that are to be submitted to journals for publication are checked in advance using this tool and a 'similarity report' is prepared for every manuscript. All the portions that match with published literature are identified and authors are briefed so that these portions may be reviewed and suitable modifications be made in the revised manuscript. Though the process was initiated only for journal articles, now other documents such as student thesis and project reports are also being checked. TIC helps students and researchers to avoid unintentional plagiarism by providing proper guidance to them. Students are also trained in the beginning so that they are aware of issues and potential problems are avoided.

High Definition Video Conference Solution using Telepresence

S Sankar Ganesh, Computer Centre ***sankar@arci.res.in***

Telepresence (TP) is a set of technologies which uses video and audio conferencing components as well as other "arts and sciences" to create a two-way immersive communication experience that simulates an in-person and interactive encounter. The technologies are integrated into a high-bandwidth system to support real-time, seamless presentation in a dedicated telepresence space.

Telepresence Advantages over Video Conferencing

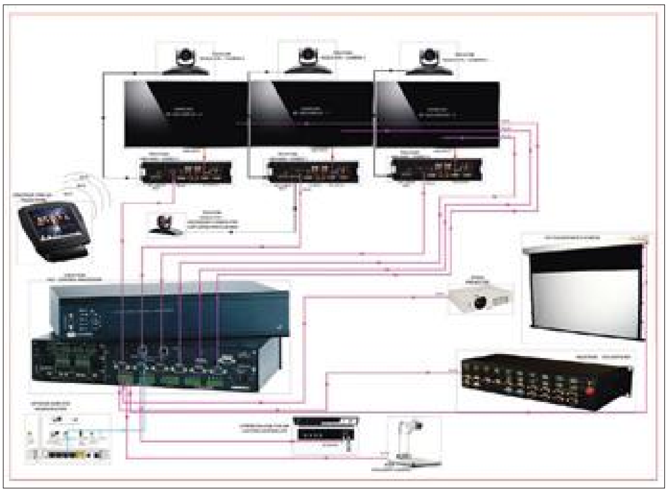
- High-quality audio and video
  - Video: Clear, life size and high definition videos
  - Audio: Speech clarity, intelligible, high fidelity, spatially accurate, echo-free and of sufficient volume
- Simplicity
  - One of the major complaints with traditional videoconferencing is that video calls are too complex to set-up and operate
  - Video conferencing typically include not-so-user-friendly-settings (call speed, camera pan-tilt-zoom) or multiple hand-held remotes to confuse audience.
  - TelePresence overcomes the above limitations of videoconferencing by using a touch panel.
- Excellent ambience
  - Entire interiors comprising of lighting, furniture and fixtures, even the wall paint colors provide an ambience at all sites involved in the call to be identical which further enhance the simulation - allowing participants to imagine sharing a single table.

Telepresence Suites in ARCI

- Telepresence Suites have been successfully implemented and are being utilized between ARCI-Hyderabad and ARCI-Chennai as an integrated solution including the entire Furniture & Interiors that are natively embedded with complete Hardware, Software, Networking, Lighting, Electrical, Audio Visual, Conferencing, Control systems, Air conditioning, Smoke detection and Uninterrupted Power Supply.
- The suites are capable of collaboration in local meetings, collaboration over audio teleconferences, face to face collaboration in media rich group and TelePresence video and any combination of above simultaneously. It is possible to add any legacy video conference studio and desktop video participant or any other R&D labs, Institutes or suppliers in a video meeting over ARCI's Public IP just like two videoconferencing studios have a video meeting experience or higher without compromising the experience of participants from the suite locations. It is also possible to include PSTN subscriber for those who cannot attend the meeting.
- High definition cameras, LED displays, mic systems, codecs, content monitors, document camera, white board with secondary camera, projection system, VGA switcher, lighting controller & Wireless Touch panel together enable the entire suite for all collaboration purpose.

The Telepresence Suite has been extensively used as board room for various internal meetings of Centres in ARCI-Hyderabad and ARCI-Chennai, as Telepresence unit between ARCI-Hyderabad & ARCI-Chennai offices during project reviews, recruitment interviews (both domestic and international) thus eliminating the cost and time of travelling. It is also used as Video Conferencing unit with government & private organizations for all official purposes.

Telepresence Suite of ARCI-Hyderabad



Control schematic of Telepresence Room

Contributors: K Naresh Kumar, MR Renju and R Vijay Kumar

Implementation of NKN with the Multi-Protocol Label Switch-Virtual Private Network Service

K Naresh Kumar, Computer Centre ***naresh@arci.res.in***

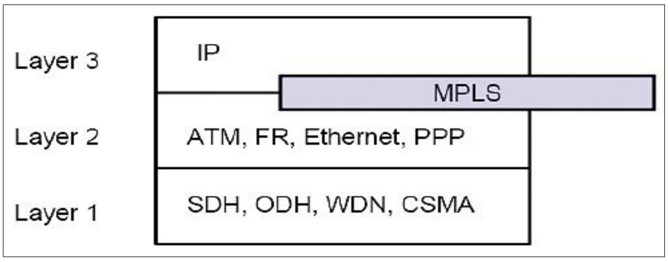
National Knowledge Network (NKN) project is aimed at establishing a strong and robust Indian network capable of providing secure and reliable connectivity with ultra-high speed core, starting with multiple 10G and progressively moving towards 40/100 Gigabits per Second (Gbps). Using NKN, all prestigious Government universities, research institutions, libraries, laboratories, healthcare and agricultural institutions across the country with vision and passion will be able to transcend space and time limitations in accessing information and knowledge and derive the associated benefits for themselves and for the society. NKN provides international connectivity to its users for global collaborative research. Presently, NKN is connected to TransEurasia Information Network (TEIN4) and to GLORIAD network. National Informatics Centre (NIC) is the designated implementing agency for NKN.

Initially, NKN connectivity was established at ARCI-Hyderabad with 1Gbps. Later it has been extended to the Chennai and Gurgaon offices with 100Mbps. ARCI has been using a greater bandwidth of Internet Services provided through NKN in the head office and branch offices. Apart from Internet Services, ARCI has the Multi-Protocol Label Switch – Virtual Private Network (MPLS-VPN) service established between the Office in Hyderabad and the offices at Chennai and Gurgaon. MPLS-VPN, is an IP network infrastructure delivering private network services over a public infrastructure.

Applications of MPLS-VPN:

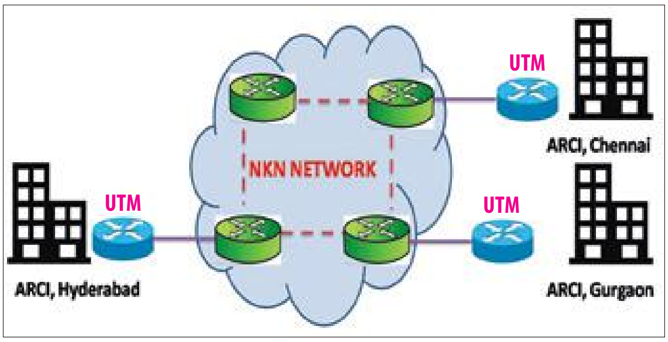
- The MPLS-VPN services enable Users across different locations to share their folders and files.
- The 'Common Application', which is the most important and critical module of Enterprise Resource Planning (ERP) applications of ARCI, is accessible for employees at the Chennai and Gurgaon offices also.
- Critical Servers' data are being copied between the Network Attached Storage (NAS) box of ARCI-Hyderabad and NAS box of ARCI-Chennai on regular basis.
- ARCI has Telepresence system (a High-Definition Video Conferencing System) at Hyderabad and Chennai Offices. The Point-to-point call requires a higher bandwidth which is being provided through the MPLS-VPN between these offices.

MPLS is a new forwarding mechanism in which packets are forwarded as labels. Labels correspond to the IP destination networks. Labels can also correspond to other parameters, such as quality of service (QoS) or source address. MPLS was designed to support forwarding of other protocols as well. MPLS is arranged between Layer 2 and Layer 3. It is scalable and provides easy solution to provision controlled access.



MPLS mechanism

ARCI has two types of Networks, wherein one is used for Internet access and the other for internal communication and access of ERP applications. The internet and the intranet have been configured in the Unified Threat Management (UTM) devices at all three locations. UTM offers comprehensive network, web & content, application and email security while providing secure remote access and data leakage prevention. UTM's centralized management enables organizations to implement high levels of security with visibility across multiple locations.



NKN setup at ARCI

Initially, a Closed User Group (CUG) within the NKN Network with the Virtual Routing and Forwarding (VRF) name as ARCI on the respective routers of NIC has been created for configuring the MPLS-VPN. UTMs were connected in the defined router interface with given IP details and defined routing in all three ARCI locations for internal communications. LAN segments of Hyderabad, Chennai and Gurgaon offices are shared to NIC team to propagate in their network for ARCI-VRF. The MPLS-VPN of ARCI is configured with no access to any other network/internet. The data and video traffic requires certain ports to be opened in the network, which was also configured in the UTMs and in the NKN routers.

ARCI has been using NKN's Internet and MPLS-VPN service effectively for its data and video traffic, which is peaked at 131 Mbps at Hyderabad and 93 Mbps at Chennai site during the last year.

Contributors: M R Renju, S Sankar Ganesh and R Vijay Kumar

Income Tax Savings Declaration – Employee Self-Service

M R Renju, Computer Centre **renju@arci.res.in**

Enterprise Resource Planning (ERP) software developed using Sybase and PowerBuilder is operational in ARCI since 1999 to manage and automate many back office functions related to stores and purchase, finance and accounts and human resources, etc. Employees of ARCI have been using an application named "Common Application", a workflow module that enables the users to raise various requisitions viz. Leave, Leave Travel Concession, Temporary Duty, etc., and has been instrumental in obtaining the approvals in digital form. As an extension to these services, new applications have been incorporated to the module, important among them being the Income Tax Savings Declaration. The Income Tax Savings Declaration module enables the employees of ARCI to submit their details of savings and other income tax related declarations online through the Common Application. The Payroll system collects these inputs, uses them for the calculation of income tax and also recovers the Tax Deduction at Source (TDS). The process and workflow involved in the new applications are given below:

- **Request creation and approval:** Using this module, the employees can create request through the common application in the ERP system. Upon creation of request, the system initiates the workflow and the end user has to forward request to the next level for approval. The concerned approvers in the workflow receive the notification about the request in their "TO_DO" list and perform the required action on it. At the time of creation of the request, the employees may provide the proposed data for the financial year and the Payroll system calculates income tax on the provided data. During the final calculation of the income tax at the end of the financial year, the Payroll User can return the request to the end user for submitting the actual data along with proofs. At this point of time the users can submit the actual data for final calculation of the income tax.
- **Types of Savings:** Employees can declare the data on the following:

o Chapter VI A: *The data provided here can be considered by the employer for pre-tax deductions from the Gross Taxable Income as per the income tax rules. The declarations under Section 80 such as savings, donations, medical treatment, education loan interest, etc., can be declared here.*

o House Rent: *The data provided here are considered to get pre-tax deductions from the Gross Total Income as per the income tax rules.*

o Loss on House Property: *Based on the data provided in the Housing property, the system computes the exemption and perquisites applicable to the housing benefit.*

o Other Income: *Employee can furnish the details of income that he/she earns from other sources, that include any income earned apart from employment and it can be entered under - Income from House Property; - Income from other sources*

o Updating in Payroll System: *The system is developed in such a way that it automatically updates the records for the approved requests in the Payroll system.*

o Payroll Calculations: *During payroll process, the system calculates the tax deduction after verifying the entries in the payroll system.*

o Validations: *Major validations applied to the system are given below.*

(i) Employee can raise only one requisition for an assessment year.

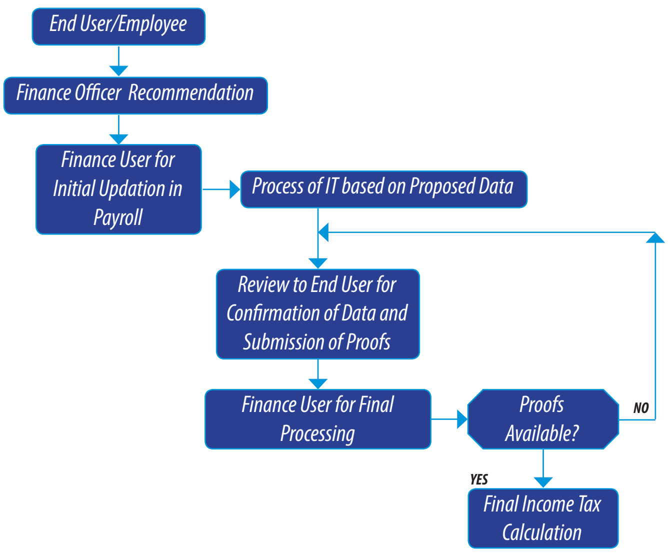
(ii) If house rent provided is more than Rs.1 lakh (at present), Permanent Account Number (PAN) of house owner is mandatory during declaration.

(iii) If aggregate amount under Chapter VI A declarations exceeds Rs.1.5 lakh, it will be limited to Rs.1.5 lakh (at present) during the income tax calculation.

(iv) Loss on self-occupied house property is limited to Rs. 2 lakh (at present).

(v) If proofs are not submitted before the final calculation of income tax, the system will not update the data into the payroll system.

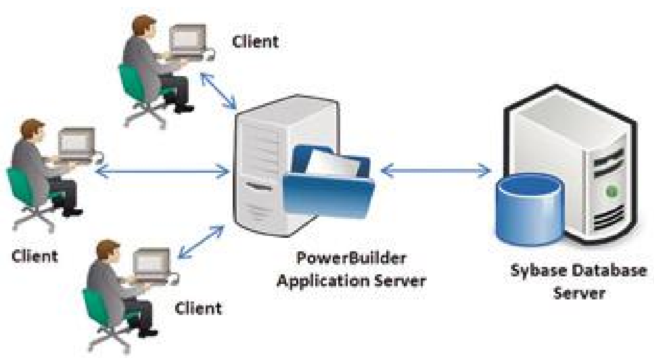
o Workflow



o Reports: *The system provides the following reports to the employees after successful creation of the request and IT calculations:*

- *Report of the declarations made by the employee*
- *Income tax calculation Sheet.*

These applications are effectively being utilized facilitating speedy processing in an environment free of hassle or errors.



Schematic of process and work flow

Contributors: S Sankar Ganesh, K Naresh Kumar and R Vijay Kumar

Events, Data and Statistics

Major Events

DST Conclave 2015

ARCI organized the "DST Conclave-2015" during July 6-7, 2015 at Hyderabad. During the event, Directors from various Institutes under Department of Science and Technology (DST), few IITs and IISc, participated and made presentations highlighting the major R&D activities of their respective institutes. Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences; and Shri Y. S. Choudhary, Hon'ble Minister of State for Science & Technology and Earth Sciences deliberated upon the presentations and discussed the future plan for their respective institutes with the Directors.

Dr. G Sundararajan presenting a bouquet to Dr. Harsh Vardhan at the DST Conclave 2015

Dr. G Sundararajan presenting a bouquet to Shri Y S Choudhary at the DST Conclave 2015

Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences; and
Shri Y S Choudhary, Hon'ble Minister of State for Science & Technology and Earth Sciences with Directors of DST Institutes, few IITs and IISc., at the DST Conclave 2015

Jayanthi Celebrations

ARCI celebrated Dr. B. R. Ambedkar Jayanthi and Dr. Babu Jagjivan Ram Jayanthi on April 14, 2015.

Independence Day

ARCI celebrated Independence Day on August 15, 2015. Dr. G. Sundararajan, Director, ARCI hoisted the National Flag and addressed the gathering. Associate Directors, Dr. G. Padmanabham and Dr. Tata Narasinga Rao, also delivered their messages to the audience.

Annual Medical Check-up and Health Talk

Annual Medical Check-up programme for ARCI employees for the year 2015 was carried out during September 09-10, 2015. Medical tests were carried-out for employees categorized under two age groups i.e. below and above 45 years of age. Special tests such as TMT test etc., were carried out for employees above 45 years of age. Vitamin D-3 test was also carried out to benefit various women employees of ARCI.

Visit of Hon'ble Union Minister for Science & Technology and Earth Sciences to ARCI

Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences, visited ARCI, Hyderabad on October 11, 2015. During the course of his visit, the Minister visited various Centres of Excellence (CoEs) related to Nanomaterials, Engineered Coatings, Ceramic Processing, Non-Oxide Ceramics, Sol-Gel Coatings, Laser Processing of Materials and Solar Energy Materials. He interacted with Scientists and Technical Officers involved in development of various materials based technologies. He appreciated their efforts in actively working towards transfer of few technologies developed at ARCI to Indian organizations. The Hon’ble Minister spent substantial time in witnessing several technical demonstrations such as easy-to-clean coatings on solar panels, detonation spray coating process, laser surface treatment of automotive components and also noted that nanomaterials are finding several applications. While appreciating the efforts made by Scientists, he also complimented them for keeping the cost factor in mind, which will facilitate commercialization and wider usage. Subsequent to the lab visit, he addressed all the Scientists, Technical Officers and young Research Fellows of the Centre and motivated them to work with a specific dream and time frame towards its fulfilment. He also opinioned that ARCI is already working in the lines of Make in India campaign, and with minor directional changes it can contribute substantially towards the goals of the Government. During the interaction, he remarked that the Scientists, Technical Officers, Technicians and other staff who are working with highly sophisticated equipment are able to maintain them with in-house capabilities and also placed on record that the efforts of ARCI are highly impressive.

Prof. P Rama Rao welcoming the Hon'ble Minister to ARCI with a bouquet

Tree plantation by the Hon'ble Minister

Dr. Roy Johnson explaining the activities at Centre for Ceramic Processing

Dr. BP Saha explaining the activities at Centre for Non Oxide Ceramics

The Hon'ble Minister interacting with Prof. P Rama Rao, Chairman, Governing Council-ARCI, Associate Directors & Team Leaders of ARCI and Dr. M Prithviraj, Scientist G-DST

Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences and Prof. P Rama Rao, Chairman, Governing Council-ARCI along with Associate Directors, Scientists and Technical Officers of ARCI

Dr. G Padmanabham explaining the activities at Centre for Laser Processing of Materials to the Hon'ble Minister

Dr. Tata Narasinga Rao explaining the activities at Centre for Nanomaterials to the Hon'ble Minister

Dr. R Subasri explaining the activities at Centre for Sol-gel Coatings to the Hon'ble Minister

Hon'ble Minister addressing all the Scientists and Technical Officers of ARCI

Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences with Prof. P Rama Rao, Chairman, Governing Council-ARCI Associate Directors and Research Fellows of ARCI

Dr. G Sundararajan with Research Fellows, Trainees and Students of ARCI on the occasion of Dr. APJ Abdul Kalam's Birth Anniversary Celebrations

Late Dr. APJ Abdul Kalam's 84th Birth Anniversary Celebrations

Late Dr. APJ Abdul Kalam, Former President of India was also the former Co-Chairman of ARCI's Governing Council during the initial years. On his 84th Birth Anniversary on October 15, 2015, Dr. G. Sundararajan, Director, Dr. G. Padmanabham and Dr. Tata Narasinga Rao, Associate Directors paid rich floral tributes to him at ARCI. Dr. G Sundararajan shared his association and experience with Dr. Kalam. Dr. G Padmanabham and Dr. Tata Narasinga Rao also shared their knowledge on him with the research fellows, trainees and students of ARCI who attended the celebrations. They also emphasized the importance of taking up career in research for the development of the country.

Official Language (Hindi) Implementation at ARCI

The Official Language Implementation Committee (OLIC) under the chairmanship of Dr. G. Sundararajan, Director-ARCI has been successful in the implementation and progressive use of Hindi at ARCI. During the year 2015-16, ARCI issued more than 3000 letters in bilingual form and surpassed the target set by the Department of Official Language (D.O.L), Ministry of Home Affairs, Govt. of India. The Department of Science and Technology (DST), in its review, has appreciated the achievement of ARCI in this regard. To propagate the use of Hindi in a better manner, ARCI conducted Hindi workshops on a quarterly basis for its employees. ARCI has also been imparting Training in Hindi to its Employees under the Hindi Teaching Scheme and has trained many employees in Prabodh, Praveen and Pragya levels. Merit employees were also provided cash awards as per rules.

ARCI conducted internal OLIC meetings on a quarterly basis to review the progressive use of Hindi at ARCI. The minutes of the meeting were sent to DST as well as D. O. L. for review. ARCI celebrated Hindi Week during September 07 to 11, 2015. The programme concluded on September 15, 2015. On this occasion, Dr. G Sundararajan, Director, ARCI inaugurated, the Digital Board. Digital Boards are installed in selected Centres of Excellences at ARCI and are useful to display information such as Aaj ka Vichar, Aaj ka Shabd, daily events, activities and programs at ARCI. During Hindi Week celebrations, various programmes and competitions such as Antakshari, Elocution, Noting and Drafting in Hindi, Essay Competition were conducted, and prizes were distributed to the winners. A lecture on 'Noting & Drafting' was delivered by Shri. Shriram Singh Shekhawat, Lecturer, Hindi Teaching Scheme, Hyderabad.

Inauguration of Digital Board by Dr. G Sundararajan, Director-ARCI

Dr. G Padmanabham, Shri Shriram Singh Shekhawat with the participants at the Hindi Workshop

Dr. Tata Narasinga Rao, Associate Director administered the vigilance awareness pledge at the Administration Building

Mr. AYV Krishna, IPS, DIG, CBI-Chennai giving a lecture on 'Vigilance Awareness' during Vigilance Awareness Week

Vigilance Awareness Week

Vigilance awareness week was observed at ARCI from October 26-31, 2015. The theme of Vigilance Awareness Week for the year 2015-16 was "Preventive Vigilance as a Tool of Good Governance". An exhibition showing the posters, photographs etc., on Vigilance Awareness was also arranged in the Administration Building on this occasion. All the Team Leaders administered the pledge to the employees working in their respective Centres and the messages by the President, the Prime Minister and the Central Vigilance Commissioner (CVC) on October 26, 2015. An elocution competition was organised for students (SRF/JRF/PGTP/GTP/Project Students) on October 27, 2015. A lecture on "Vigilance Awareness" by Mr. A. Y. V. Krishna, IPS, DIG, CBI, Chennai was organised on October 29, 2015 at ARCI.

Annual Day

ARCI celebrated its 19th Annual Day on December 31, 2015. On this occasion, Dr. Tata Narasinga Rao, Convenor, Annual Day Committee and Associate Director welcomed the gathering. Dr. G. Sundararajan, Director, ARCI in his address detailed about various activities and emphasized on the major achievements of ARCI during the year. Dr. G. Padmanabham, Associate Director also addressed the gathering. Various cultural events were organized as part of the celebrations and prizes were distributed to the participants. Some of the employees and their children also actively participated in the cultural events. The celebrations concluded with vote of thanks by Dr. P. K. Jain, Scientist "F".

On the occasion of superannuation of Dr. G. Sundararajan, Director ARCI, on December 31, 2015 a thanksgiving function was also organized along with the Annual Day Celebrations. Prof. P. Rama Rao, Chairman, ARCI Governing Council appreciated the efforts of Dr. G. Sundararajan, during the past two decades, in steering ARCI from project phase to implementation phase and also successfully transformed ARCI into a globally reputed R&D institute. Dr. G. Padmanabham, Associate Director, Shri R. Vijay Kumar, Chief Finance & Accounts Officer and respective Team Leaders also shared their experiences.

Prof. P. Rama Rao and Dr. G Sundararajan planted Epiphyllum Oxypetalum (Brahma Kamal) sapling on the occasion.

Dr. G Sundararajan, Director-ARCI addressing the gathering

Prof. P Rama Rao felicitating Dr. G Sundararajan

Prof. P Rama Rao and Dr. G Sundararajan planting the Brahma Kamal sapling

August gathering of Employees with their families at the Annual Day Celebrations of ARCI

Republic Day

ARCI celebrated Republic Day on January 26, 2016. Dr. G Padmanabham, Director-in-Charge hoisted the National Flag and addressed the gathering on the occasion. Dr. Tata Narasinga Rao, Associate Director also addressed the gathering.

Sports

ARCI constituted a sports committee to conduct sports and games for the year 2015-16. Sports and games was inaugurated on February 05, 2016 by Dr. G Padmanabham, Director (I/C). In all, more than 20 events were conducted and more than 100 employees actively participated in games such as Volleyball, Cricket, Badminton, Tennikoit, Football, Carom, Athletics etc. Prizes were distributed to the winners and runners-up during the Sports Day celebrations on March 31, 2016 by Dr. G Padmanabham, Director-in-charge and Dr. Roy Johnson, Scientist 'G'. This year the prizes also included T-Shirts with ARCI logo printed on them.

Tennikoit and volley ball games in progress

Rolling Shield being presented to the Winners Team for the year 2015-16 by Dr. G Padmanabham and Dr. Roy Johnson on the occasion of Sports Day

National Science Day

National Science Day (NSD) was celebrated on February 29, 2016 at ARCI. Dr. G. Padmanabham, Director-in-Charge welcomed the audience comprising of Scientists, Officers, Research Fellows, Project Students, Trainees and briefed about the importance of National Science Day Celebrations.

Prof. K. S. Ratnakar, Director-Global Medical Education & Research, Global Hospitals, Hyderabad, the Chief Guest on the occasion, delivered a lecture on "Science and Conscience".

Prof. K S Ratnakar delivering a talk on 'Science and Conscience' on the occasion of National Science Day celebrations at ARCI

National Safety Week

ARCI observed National Safety Day/Week with effect from March 04, 2016, on the occasion of 45th National Safety Day. Safety and Health Pledge was administered to the employees followed by two days in-plant Training Program

Shri S Kalyanaraman, Security, Fire and Safety Officer administering the Safety and Health pledge on the occasion of National Safety Week celebrations

Prof. K S Ratnakar with Dr. G Padmanabham, Dr. Tata Narasinga Rao and audience on the occasion of National Science Day celebrations at ARCI

Experts from National Safety Council, Mumbai with safety coordinators, on the occasion of National Safety Week celebrations at ARCI

on "Safety in Storage, Handling of Hazardous Gases and Chemicals" conducted by experts from National Safety Council, Mumbai during March 8-9, 2016. 50 participants including Scientists, Technical Officers, and Technicians etc., attended the program and certificates were also issued. Further, a general talk on Safety was also organized in which all the employees & students participated and various issues, doubts related to Safety norms at work place were addressed by the experts. An exhibition on Personal Protective Equipments (PPEs) was also organizedm, wherein reputed firms dealing with PPEs displayed their products and further the representatives from the firms and experts from National Safety Council explained their uses.

ARCI Internal Complaints Committee (AICC)

The ARCI International Complaints Committee (AICC) has been actively involved in promoting awareness regarding Sexual Harassment of Women at Workplace. During this year, additional bilingual awareness posters were placed at prominent locations in the campus. ARCI celebrated International Women's Day on March 10, 2016. Ms. Padma Pothukuchi, Behaviour Analyst, Educationist and International Corporate Coach was the Chief Guest on the occasion. She delivered a motivational lecture titled "Bhramari...Positive Transformation from the Inside Out". She also participated in the activities conducted specifically for women on the occasion.

Expert from National Safety Council, Mumbai delivering a talk on 'Safety' on the occasion of National Safety Day celebrations at ARCI

Ms. Padma Pothukuchi delivering a talk on the occasion of International Women's Day celebrations at ARCI (Inset: Felicitation of Ms. Padma Pothukuchi)

Ms. Padma Pothukuchi with the audience on the occasion of International Women's Day celebrations at ARCI

Dr. B V Pattabhiram with Batch 1 participants during the Workshop on 'Motivation'

Conference/Workshops/Symposia Organized by ARCI

- **Workshop on Motivation**

ARCI organized a one day in-house workshop on 'Motivation' for the benefit of all the employees on May 15, 2015. The workshop was conducted by Dr. B V Pattabhiram, leading trainer of self management skills, in two batches. All the employees were highly benefitted by the Workshop.

Dr. B V Pattabhiram conducting the one day workshop on 'Motivation'

- **Indo-Belarus Bilateral Workshop on Nanomaterials and Technologies**

ARCI organized a bilateral Indo-Belarus Workshop on "Nanomaterials and Technologies" during November 16-17, 2015, supported by the Department of Science and Technology (DST), Govt. of India and Govt. of Belarus at Hotel IBIS, Gurgaon NCR Delhi. The workshop was attended by more than 25 experts from India and Belarus. The aim of this joint workshop was to exchange information and identify mutual areas of interest for initiating collaboration between Indian and Belarussian Scientists. Dr. G. Padmanabham, Associate Director-ARCI, Hyderabad, India and Prof. A. Ph. Ilyuschenko, Director-Powder Metallurgy Institute, Minsk, Belarus chaired the program. Dr. P.K. Jain, Sc. 'F'-ARCI, Hyderabad was the Convener for the workshop.

Participants at the Indo-Belarus Bilateral Workshop

- **7th Indo-Korean Joint Workshop on "Green Mobility and Energy Materials"**

ARCI organized the 7th Indo-Korean Joint Workshop on "Green Mobility and Energy Materials" at Hyderabad during November 26-27, 2015. The workshop was funded by DST and was co-chaired by Dr. Tata Narasinga Rao, Associate Director. There were about 50 delegates from India and Korea who attended the workshop. The workshop focussed on areas such as 'Future transportation systems', 'Li-ion batteries for EVs', 'Thermoelectric materials', 'Fuel cells' and

Dr. B V Pattabhiram withBatch 2 participants during the Workshop on 'Motivation'

Dr. Tata Narasinga Rao addressing the gathering during the Workshop

'Light Weight Materials for Automotive Application'. A total of 20 lectures were presented by the distinguished scientists from both the countries. In addition, a poster session was also held on November 27, 2015 in which participants, mostly research students, presented their research work. The joint workshop was aimed to improve the relations in the field of Science and Technology between both the countries. The workshop brought out the importance of joint collaboration between the two countries in the field of green mobility and energy storage devices covering both fundamental and application aspects. After two days of technical presentations and discussions, clear ideas on strengths of each side and possible complimentary collaboration emerged. At the end of technical sessions, there was a session for panel discussion, where the panel members and researchers from both countries presented their views about how to further consolidate the collaboration between India and Korea.

- **Workshop on "High Performance and Future Cement"**

ARCI in association with Zoz GmbH, Germany established a Zoz-ARCI centre at ARCI to demonstrate the technologies developed by Zoz GmbH and eventually transfer them to Indian Organizatons. A two day workshop was organized during December 12-13, 2015 to propogate the efficacy of High Performance and Future cement being developed by Zoz GmbH, Germany to Indian organizations. Dr. R. Vijay, convener, welcomed the delgates, Dr. G. Sundararajan, Director ARCI, inaugurated the workshop. Prof. Henning Zoz, inventor of the Simoloyer Technology and Director, Zoz GmbH and Dr. Deniz Yigit, Head, R&D, Zoz GmbH delivered talks on advanced processing of nanostructured materials, with particular emphasis on production of high-performance cement having fast curing time and strength. Performance of high performance cement was also demonstrated during the Workshop. About 35 delegates from cement industries, R&D and academic institutes attended the workshop.

- **Workshop on "Hydrogen Energy Technology"**

A workshop on “Hydrogen Energy Technology” was organised to felicitate the superannuation of Dr. K. S. Dhathathreyan, Head, Centre for Fuel Cell Technology (CFCT) and Associate Director, ARCI, honouring his contribution to Hydrogen Energy Technology on January 27, 2016 at IC & SR (Hall 2), IIT-Madras, Chennai. Renowned fuel cell scientists from academic Institutes such as IIT-Madras (Prof. B Viswanathan, Prof. Raghuram Chetty), IIT Delhi (Prof. S Basu), Research laboratories such as CECRI (Dr. S Ravichandran and Dr. Santhosh Kumar Bhat), and from Industrial organizations such as Mahindra & Mahindra (Dr. Mathew Abraham), Mesha Solutions (Dr. P Sridhar) presented talks on various topics including Sustainable Energy from Hydrogen, Hydrogen Development in Automotive Vehicles-Future Challenges for Commercialization, Hybrid Ultracapacitors, CO_2 Reduction to Chemical Fuel: Photo Chemical Pathways, Shape Controlled Palladium Nanostructures for Fuel Cell Applications, Challenges in Water Electrolysis, and New Polymer membranes for LT and HT PEMFC. All CFCT students presented posters during the Workshop.

Dr. K S Dhathatreyan with the participants at the Workshop

Dr. G. Sundararajan and Prof. Henning Zoz with the participants at the workshop

Human Resource Development

ARCI-IIT Fellowship Programme

ARCI continues to sponsor fellowship programmes at Indian Institute of Technology (IIT) – Bombay, IIT-Hyderabad and IIT-Madras. As a part of these ARCI–IIT Fellowships, ARCI supports the doctoral study of talented students, selected as ARCI Fellows, to work in areas of immediate interest to ARCI under the expert guidance of an identified faculty member. ARCI's support includes stipend, procurement of consumables and essential equipment. After successful completion of the programme, the ARCI Fellow is awarded a Ph.D. degree by the respective academic institution.

The status of projects being undertaken is as follows:

Project	Collaborating Institute	Name of the Fellow	Date of admission	Status
Study of Multicentric Composite Thin Films	IIT - Bombay	Tarun Garg	16.07.2009	Completed
Molybdenum Oxide and Tin Oxide/Sulfide Nanostructured Materials for Anodes in Lithium Ion Batteries	IIT- Hyderabad	A Bhaskar	01.08.2010	Completed
Study and Design of Stable and Highly Efficient Copper Zinc Tin Sulphide (CZTS) Thin Film Photovoltaics prepared by DC Magnetron Sputtering	IIT - Madras	Deepak Kumar	01.08.2012	Ongoing

Post Doctoral Fellows, Research Scholars, Senior/Junior Research Fellows, Post Graduate/ Graduate Trainees and M.Tech/B.Tech./M.Sc. Project Students joined during the year at ARCI

DST-Inspire Faculty	01
Post-Doctoral Fellows	02
Senior Research Fellows	03
Junior Research Fellows	02
Post Graduate Trainees	08
Graduate Trainees	29
M.Tech Project Students	32
B.Tech./M.Sc./Diploma Project Students	20
Trainees under Summer Research Programme	59

Recognition of ARCI as an External Centre for Carrying Out Ph.D. Research

The following academic institutes recognized ARCI as an External Centre for carrying out Ph.D. Research. Accordingly, interested ARCI employees, Project Scientists and Research Fellows can register for Ph.D. (as per university norms) at the University.

01. Indian Institute of Technology – Bombay
02. Indian Institute of Technology – Kharagpur
03. Indian Institute of Technology – Kanpur
04. Indian Institute of Technology – Hyderabad
05. Indian Institute of Technology – Madras
06. National Institute of Technology – Warangal
07. National Institute of Technology – Tiruchirappalli
08. Visvesvaraya National Institute of Technology – Nagpur
09. University of Hyderabad (Central University) – Hyderabad
10. Andhra University – Visakhapatnam

(A) LIST OF RESEARCH FELLOWS WHO COMPLETED Ph.D.

Sl. No.	Name of the Student (Mr./Ms.)	Topic	Registered at	Status
01.	Y. Krishna Priya	Studies on joining of aluminum alloy and steel by fusion joining process	University of Hyderabad	Completed
02.	Ch. Leela Pydi Pavithra	Structure - property correlations in pure copper and copper nanocomposite foils prepared by electro deposition	University of Hyderabad	Completed
03.	M. S. Archana	Development of TiCN - metal/intermetallic based nanocomposites for cutting tool applications	University of Hyderabad	Completed
04.	P. Sai V Pramod Kumar	Study of mechanical properties of cathodic arc deposited Ti-Al-N and Ti-Al-Cr-Si-N multi-layered coatings	University of Hyderabad	Completed
05.	K.H. Anulekha	Electrospun nanostructured metal oxides based electrode materials for high performance lithium Ion Batteries	Indian Institute of Technology, Hyderabad	Completed
06.	Alka Pareek	Investigation on stability and efficiency improvement of modified Cd-chalcogenide nanostructures for photoelectrochemical H_2 generation	University of Hyderabad	Completed

(B) LIST OF RESEARCH FELLOWS WHOSE Ph.D. IS ONGOING

Sl. No.	Name of the Student (Mr./Ms.)	Topic	Registered at
01.	M. Nagini	Effect of milling on microstructural evolution in nano ODS-18Cr ferritic steel and the resultant mechanical, corrosion and oxidation properties	University of Hyderabad
02.	N. S. Anas	The effect of carbon nanotubes and graphene dispersion on the microstructural and mechanical properties of Al alloys	University of Hyderabad
03.	L. Subashini	Laser-arc hybrid welding of special steels	University of Hyderabad
04.	Bolla Reddy	Spherical indentation behaviour of porous Copper and PED multilayered Nickel coating	Indian Institute of Technology, Hyderabad
05.	Anusree Unnikrishnan	Polymer electrolyte membrane fuel cells impurity studies experimental and modelling Investigations	Indian Institute of Technology, Hyderabad
06.	Mitravinda Tadepalli	Synthesis, characterization and electrochemical performance of nano porous synthetic carbon materials as electrodes for supercapacitor application.	Indian Institute of Technology, Hyderabad
07.	Brijesh Singh Yadav	Development and detail investigation on chalcopyrite $CuI_{nx}Ga_{1-x}Se_2$ (Copper Indium Gallium Diselenide) solar absorber layer	Indian Institute of Technology, Hyderabad
08.	J. A. Prithi	Cathode materials for improved PEMFC performance and impurity tolerance	Indian Institute of Technology, Madras
09.	K. Nanaji	Development of mesoporous metal oxides/mesoporous carbon electrode materials for energy storage applications	Indian Institute of Technology, Madras
10.	S. Bhuvaneswari	Structure, morphology and electrochemical performance correlation in metal doped spinel ($Li M_x Mn_{2-x} O_4$) (M = transition metals) as Li ion battery cathode materials	Indian Institute of Technology, Madras
11.	Ravi Gautam	Microstructure – magnetic property correlation of advanced soft magnetic material.	Indian Institute of Technology, Madras
12.	Sumit Ranjan Sahu	Carbon nanohorns based anode material for lithium ion battery	Indian Institute of Technology, Madras
13.	N. Sasikala	Structure and electrochemical property correlation of $LiNiO_2$ based cathode materials.	Indian Institute of Technology, Madras
14.	S. Harish	Design, development, performance evaluation & optimization of engineering parameters of thermoelectric generator system for automotive exhaust applications.	Indian Institute of Technology, Madras
15.	S. Vasu	Structure and electrochemical property correlation of lithium rich layered oxide and layered oxide of lithium ion batteries for electric vehicle applications	Indian Institute of Technology, Madras
16.	Ramavath Janraj Naik	Studies on material chemistry aspects of alkaline electrochemical cells	Indian Institute of Technology, Madras
17.	Amol C. Badgujar	Development of copper indium gallium selenide solar cells	Indian Institute of Technology, Bombay
18.	Vallabharao Rikka	Investigation on ageing mechanism of lithium ion cell ($LiFePO_4$ / graphite)	Indian Institute of Technology, Bombay
19.	Kumari Konda	Importance of coating, mixing and calendaring in Li-ion batteries	Indian Institute of Technology, Bombay
20.	B. Jayachandran	Interface engineering of high temperature thermoelectric materials and its effect on the thermoelectric device performance.	Indian Institute of Technology, Bombay
21.	Imran Karajagi	Studies on the development of materials for metal-air batteries	Indian Institute of Technology, Bombay
22.	Puneet Chandran	Design and development of hard protective coatings for cutting tools used in machining of advanced materials	National Institute of Technology, Warangal
23.	P. Tejassvi	Electrospun inorganic materials for battery applications	National Institute of Technology, Warangal
24.	E. Hari Mohan	Development of high capacity nanostructured anode and sulphur cathode for lithium sulphur battery applications	National Institute of Technology, Warangal
25.	V.V.N. Phani Kumar	Synthesis, characterization & doping of olivine/ spinel based materials and its effective binding nature for lithium ion batteries.	National Institute of Technology, Warangal
26.	N. Manjula	Studies on the aspects of depolarized electrolysis for hydrogen generation	National Institute of Technology, Warangal
27.	T. Ramesh	Activated carbons for energy storage	National Institute of Technology, Warangal
28.	P. M. Pratheeksha	Development of nanostructured electrodes for high energy density lithium ion battery applications	National Institute of Technology, Warangal
29.	S. Manasa	Nanoclay based self-healing, corrosion protection coatings on aluminum alloys	National Institute of Technology, Warangal
30.	Boosagulla Divya	Fabrication of solar cell photovoltaic energy system using pulsed-electrodeposited $CuI_{nx}Ga1-xSe_2$ (CIGS) Absorber layer under n-type CdS semiconductor film window.	National Institute of Technology, Warangal
31.	M. Shiva Prasad	Development of solar selective absorber coatings for concentrating solar power applications	National Institute of Technology, Warangal

Sl. No.	Name of the Student (Mr./Ms.)	Topic	Registered at
32.	V. V. Ramakrishna	Microstructure – magnetic property investigation of MnBi alloy to develop rare earth free permanent magnets	National Institute of Technology, Thiruchirappalli
33.	B. Priyadarshini	Development and optimisation of thermoelectric materials for automotive waste heat recovery application	National Institute of Technology, Thiruchirappalli

Appointments

ARCI has added the following employees in its fold to take up varied responsibilities:

Employee Name	Designation	Date of Joining
Dr. K. Suresh	Scientist "E"	February 18, 2016
Ms. K. Divya	Scientist "B"	March 11, 2016
Mr. Sreekanth Vallabhaneni	Assistant "A"	March 18, 2016
Mr. Boorgu Venkatesham	Assistant "A"	March 18, 2016
Mr. Ramavathu Ranga Naik	Assistant "A"	March 18, 2016
Mr. Pokalkar Sai Kishore	Assistant "A"	March 28, 2016

Promotions

ARCI has been following its existing assessment and promotion policy since the year 2000-01. As per the policy, assessments were carried out for all eligible employees and the following were promoted during the year 2015-16:

Name of the Promotees	Effective Date	Post	
		From	To
Mr. J. Shyam Rao	June 29, 2015	Technician "B"	Technical Assistant "A"
Mr. Y. Krishna Sarma	July 22, 2015	Officer "A"	Officer "B"
Mr. G. Ramesh Reddy	July 22, 2015	Officer "A"	Officer "B"
Mr. P. Dharma Rao	August 4, 2015	Assistant "B"	Officer "A"
Mr. G. Gopal Rao	August 4, 2015	Assistant "B"	Officer "A"
Dr. Roy Johnson	October 1, 2015	Scientist "F"	Scientist "G"
Dr. L. Rama Krishna	October 1, 2015	Scientist "E"	Scientist "F"
Dr. Y. Srinivasa Rao	October 1, 2015	Scientist "E"	Scientist "F"
Dr. Neha Yeshwanta Hebalkar	October 1, 2015	Scientist "D"	Scientist "E"
Dr. R. Easwaramoorthi	October 1, 2015	Scientist "C"	Scientist "D'
Dr. S. Kumar	October 1, 2015	Scientist "C"	Scientist "D'
Ms. Priya Anish Mathews	October 1, 2015	Scientist "C"	Scientist "D'
Mr. Prasenjit Barick	October 1, 2015	Scientist "C"	Scientist "D'
Mr. Manish Tak	October 1, 2015	Scientist "C"	Scientist "D'
Mr. Naveen Manhar Chavan	October 1, 2015	Scientist "C"	Scientist "D'
Mr. M. Ramakrishna	October 1, 2015	Scientist "C"	Scientist "D'
Mr. Balaji Padya	October 1, 2015	Scientist "C"	Scientist "D'
Ms. Papiya Biswas	October 1, 2015	Scientist "C"	Scientist "D'
Dr. Gururaj Telasang	October 1, 2015	Scientist "C"	Scientist "D'
Ms. V. Uma	October 1, 2015	Technical Officer "C"	Technical Officer "D"
Mr. Ch. Sambasiva Rao	October 1, 2015	Technical Officer "B"	Technical Officer "C"
Mr. A.R. Srinivas	October 1, 2015	Technical Officer "A"	Technical Officer "B"
Mr. M.R. Renju	October 1, 2015	Technical Assistant "A"	Technical Officer "A"
Mr. Narendra Kumar Bhakta	October 1, 2015	Assistant "A"	Assistant "B"
Ms. K. Madhura Vani	October 1, 2015	Assistant "A"	Assistant "B"
Mr. E. Konda	October 1, 2015	Technician "C"	Technician "D"
Mr. A. Sathyanarayana	October 1, 2015	Technician "C"	Technician "D"

Name of the Promotees	Effective Date	Promotion for the post	
		From	To
Mr. B. Venkanna	October 1, 2015	Technician "C"	Technician "D"
Mr. A. Jagan	October 1, 2015	Technician "B"	Technician "C"
Mr. Sushanta Mukhopadhyay	October 1, 2015	Technician "B"	Technician "C"
Mr. Aan Singh	November 26, 2015	Lab. Assistant "D"	Technician "A" (LDCE)

Superannuation

Employee Name	Designation Held	Date of Superannuation
Mr. R. Prabhakara Rao	Chief Admin. & Personnel Officer	June 30, 2015
Dr. G. Sundararajan	Director	December 31, 2015
Dr. K. S. Dhathathreyan	Associate Director	January 29, 2016*

** As 30th & 31st January, 2016 were holidays.*

Resignations

Employee Name	Designation Held	Date of Relieving
Dr. Shrikant V. Joshi	Additional Director	July 31, 2015
Dr. K. Suresh	Scientist (Contract)	January 09, 2016 #

 # completed contract tenure

Visit by Students, Faculty etc., to ARCI

01. 41 M.Sc (Physics) students and faculty members from Kakatiya University, Warangal visited ARCI on April 08, 2015.
02. 40 M.Tech (Nano Technology) students and faculty members from Vellore Institute of Technology, Vellore visited ARCI on April 28, 2015.
03. 17 Scientists and Engineers from various DRDO laboratories, who participated in "Management Development Programme" conducted by Administrative Staff College of India (ASCI), visited ARCI on July 16, 2015.
04. 20 Scientists and Engineers from various DRDO laboratories who participated in "Management Development Programme" conducted by Administrative Staff College of India (ASCI), visited ARCI on September 23, 2015.
05. 21 M.Sc (Physics) students and faculty members from Osmania University, Hyderabad visited ARCI on October 09, 2015.
06. 28 Engineers from various Government Organizations who participated in "Creativity & Innovation Management in Research" conducted by Engineering Staff College of India (ESCI) visited ARCI on October 27, 2015.
07. 21 Scientists and Engineers from various DRDO laboratories who participated in "Management Development Programme" conducted by Administrative Staff College of India (ASCI), visited ARCI on December 10, 2015.
08. 30 B.Sc (Physics) students and faculty members from Bhavans' Vivekananda College of Science, Humanities & Commerce, Secunderabad visited ARCI on January 06, 2016.
09. 50 M.Tech (Nano Technology) students and faculty members from Jawaharlal Nehru Technological University, Hyderabad visited ARCI on January 20, 2016.
10. 27 M.Sc. (Organic Chemistry) students and faculty members from Loyola Academy Degree and PG College, Secunderabad visited ARCI on January 22, 2016.
11. 20 M.Sc. (Chemistry) students and faculty members from ACS College Chandrapur, Maharashtra visited ARCI on February 03, 2016.

Summer Research Programme

Students from IITs, NITs, Banaras Hindu University, IIITs, Central Universities and various other state and private universities from all over the country were short-listed for availing Summer Research Programme (SRP) at ARCI for the year 2015. 59 students were selected for the programme, for a period of 45 – 60 days. The programme started on 11th May, 2015. The selected students initially underwent a week long orientation course so as to get familiar with the activities being carried out at ARCI. Each student was guided by a scientist to carry out a mini project. The students were issued certificates on successful completion of the programme.

Dr. S V Joshi, Additional Director with Summer Trainees

Reservations and Concessions

The Reservations and Concessions for Scheduled Castes (SC)/Scheduled Tribes (ST)/Other Backward Castes (OBC) and persons with disabilities are followed as per Government of India orders from time to time. At ARCI, the overall representation of employees under SC is 17.17%, S.T is 4.29%, OBC is 25.15% and that of persons with disabilities is 1.84% as on March 31, 2016.

Seminars by Indian and Foreign Visitors

1. Dr. Suresh R. Sriram, Staff Scientist, Nalco-An Ecolab Company, USA delivered a lecture on "Development of Self Healing Polymer Composites and Photoinduced Ring Opening Metathesis Polymerization" on April 01, 2015.
2. Dr. T. A. Parthasarathy, UES Inc., U.S.A delivered a lecture on "Modeling Environmental Behavior of Ultra High Temperature Ceramics" on April 13, 2015.
3. Dr. K. V. Raghavan, INAE Distinguished Professor, Indian Institute of Chemical Technology (IICT), Hyderabad delivered a lecture on "Discovery, Development and Assessment: Vital Links in R&D Chain" on May 11, 2015.
4. Prof. Yuki Nagao, Associate Professor, Japan Advanced Institute of Science and Technology (JAIST), Japan delivered a lecture on "Proton transport at Nafion-Pt Interface" on June 11, 2015.
5. Dr. Ramana Chintalapalle, US Air Force Research Laboratory, University of Texas, USA delivered a lecture on "Functional Mixed Oxide Thin Films for Energy Related Applications" on June 15, 2015.
6. Dr. Masahiro Miyauchi, Associate Professor, Tokyo Institute of Technology, Japan delivered a lecture on "Development of Visible-Light-Active Photocatalyst for Environmental and Energy Issues" on June 17, 2015.
7. Prof. Arvind Agarwal, Professor and Director (Advanced Materials Engineering Research Institute) Florida International University, USA delivered a lecture on "Graphene Nanoplatelets Reinforced Tantalum Carbide Consolidated by Spark Plasma Sintering" on June 18, 2015.
8. Dr. Akkisetty Bhaskar, Indian Institute of Technology (IIT), Hyderabad delivered a lecture on "Molybdenum Oxide and Tin Oxide/Sulfide Nanostructured Materials for Anodes in Li-Ion Batteries" on July 21, 2015.
9. Prof. T. Venkataraman, University of Calgary, Canada delivered a lecture on "Advanced Ceramics for Next Generation Solid Oxide Fuel Cells and All-Solid-State Li Ion Batteries" on August 11, 2015.
10. Dr. K. Madhav Reddy Post Doctoral Fellow, Johns Hopkins University, USA delivered a lecture on "Advanced Studies on the Development of Advanced Ceramics" on August 12, 2015.
11. Dr.Ramaiyan Kannan, Marie Curie fellow, University of Birmingham, UK delivered a lecture on "Electrolyte and Electrode Materials for Fuel Cells" on September 22, 2015.
12. Prof. Paul Rometsch, Monash University, Australia delivered a lecture on "Additive Manufacturing" on October 16, 2015.
13. Dr. Anil K. Sachdev, General Motors Global Research and Development, USA delivered a lecture on "The Intersection of Materials, Processing and Design with Light Weight Materials" on November 23, 2015.
14. Dr. Rupak Banerjee, Assistant Professor, IIT, Gandhinagar delivered a lecture on "Growth and Characterization of Advanced Functional Nanomaterials" on December 08, 2015.
15. Prof. C. Suryanarayana, University of Central Florida, USA delivered a lecture on "Nanocomposites by Mechanical Alloying" on January 05, 2016.
16. Dr.Andrey V Ragulya, Deputy Director, Institute of Problems in Materials Science (IPMS), National Academy of Sciences of Ukraine, Ukraine delivered a lecture on "Activities on Advanced Materials at IPMS – An Overview" on January 06, 2016.
17. Dr. John V. Kennedy, Ion Beam Physics Research Scientist, National Isotope Centre, New Zealand delivered a lecture on "Nanostructured Oxides for Sensor Applications" on January 08, 2016.
18. Prof. S.R.P. Silva, Director-Advanced Technology Institute, University of Surrey, UK delivered a lecture on "Future Solar Energy Materials and Devices" on January 12, 2016.
19. Prof. B. Viswanathan, IIT Madras, Chennai delivered a lecture on "Sustainable Energy from Hydrogen" on January 27, 2016.
20. Dr. Mathew Abraham, Retd. General Manager, Alternative Fuel, Mahindra & Mahindra, Chennai delivered a lecture on "Hydrogen Development in Automotive Vehicle- Future Challenges for Commercialization" on January 297, 2016
21. Dr. P. Sridhar, Chief Scientist, Mesha Energy Solutions (P Ltd.), Bengaluru delivered a lecture on "Hybrid Ultra Capacitors" on January 27, 2016
22. Prof. S Basu, IIT Delhi delivered a lecture on "CO_2 Reduction to Chemical Fuel: Photo Chemical Pathways" on January 27, 2016.
23. Prof. Raghuram Chetty, IITM, Chennai delivered a lecture on "Shape Controlled Palladium Nanostructures for Fuel Cell Applications" on January 27, 2016.
24. Dr. S Ravichandran, Scientist F, CSIR-CECRI, Karaikudi delivered a lecture on "Challenges in Water Electrolysis" on January 27, 2016.
25. Dr. Santhosh Kumar Bhatt, Scientist D, CSIR-CECRI, Chennai delivered a lecture on "New Polymer Membranes for LT and HT PEMFC" on January 27, 2016.
26. Prof. K.S. Ratnakar, Director- Global Medical Education and Research, Global Hospitals, Hyderabad delivered a lecture on "Science and Conscience" on February 29, 2016.
27. Dr. Amit Kumar Roy, Research Scientist, BASF SE, Germany delivered a lecture on "Atomic Layer Deposition (ALD) of Functional Coatings on Soft and Delicate Materials" on February 29, 2016.
28. Dr. Rajeev Kumar, Inspire Fellow, National Physical Laboratory, New Delhi delivered a lecture on "Studies on Light Weight Carbon Foam and its Applications in Various Fields" on March 02, 2016.
29. Prof. Horst Hahn, Director, Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Germany delivered a lecture on "Reversible Electrochemistry Controlled Magnetic Phase Transitions" on March 09, 2016.
30. Dr. Robert Schwarzer, Professor (Retd.), University of Technology, Clausthal, Germany delivered a lecture on

"EBSD: Texture Analysis and Orientation Stereology" on March 11, 2016.

Indian and Foreign Visitors for Technical Discussion

1. Prof. Noriyosshi Matsumi, Prof. Yuki Nagaor and Dr. Vedarajan Raman, Assistant Professor, JAIST, Japan visited during June 03-05, 2015.
2. Dr.-Ing. Thomas Seefeld and Mr. Rolf Tietjen, Bremer Institut Für Angewandte Strahltechnik GmbH, Germany visited during September 05-07, 2015.
3. Dr. Suwas Nikumb, Senior Research Officer, National Research Council, Canada visited during September 12-16, 2015.
4. Dr. Sasangan Ramanathan, Dean of Engineering and Dr. S. Thirumalini, Chairperson, Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham University, Coimbatore visited during September 21, 2015.
5. Ms. Cladia Sixl, Group Director, Messe Munchen GmbH, Germany visited on October 09, 2015.
6. Mr. Shyam Ragupathy, Deputy General Manager-Business Strategy, Indo National Limited, Nippo Batteries, Chennai visited on October 15, 2015.
7. Dr.Frank Riedel and Mr. Patrick Urbanek, Fraunhofer Institute for Machine Tools and Forming Technology (IWU), Germany visited during November 05-06, 2015.
8. Dr. Henning Zoz, President and Dr. Deniz Yigit, Head, R&D, Zoz GmbH, Germany visited during December 12-13, 2015.
9. Dr.Fumihiro Haga, Manager, EV System Laboratory, Nissan Motor Company, Japan and Mr.K.Balaji, Deputy Manager, R&AE Technology Research, Renault Nissan, Chennai visited on December 18, 2015.
10. Dr.Pratab Baskar Principal Researcher Materials Modeling and Product Design, Tata steels Jamshedpur and Dr. Mahesh Murthy, Principal Researcher Materials Modeling and Product Design, Group Technology Tata Office, Bengaluru visited on December 28, 2015.
11. Dr.Gaurav Varshney, Scientist, Bhabha Atomic Research Centre (BARC), Mumbai visited on December 28, 2015.
12. Dr. Andrey V. Ragulya, Deputy Director and Ms. Margarita Iakovleva, Chief Technologist, Institute of Problems in Materials Science (IPMS), Ukraine visited January 02-08, 2016.
13. Mr.N.DakshinaMoorthi , Senior Manager Design and Development, Sree Vishnu Magnetics (p) Ltd., Chennai visited on January 21, 2016.
14. Dr. B. Simhachalam, Senior General Manager, Corporate Technology Centre, Tube Investments of India Ltd., Chennai visited on February 01, 2016.
15. Mr. Santosh Tawari, Director, LAS Engineers and Consultants (P) Ltd, Mumbai and Dr. Amita Bitrla , Director, Act Life Sciences P Ltd, Mumbai visited on February 10, 2016.
16. Mr. Vikas Dwivedi, Group Captain and Mr. Bipin Patil, Wing Commander, 3 Base Repair Depot, Air Force Chandigarh visited on February 24, 2016.
17. G. Krishna Kumar, Group Captain, HQ maintenance command, Air Force station, Nagpur visited on February 24, 2016.
18. Dr.Lane P Ballard, Vice President- Materials & Manufacturing Technology, Boeing Research and Technology (BRT), USA., Dr. Javaheri Masoud Amin, Director- Advanced Production Systems, Materials & Manufacturing Technology, BRT, USA., Dr. C. Mahender Reddy, Senior Manager- NDE & Inspection Integration, Materials & Manufacturing Technology, BRT., Dr. Seraphine N Wang, Senior Manager - Production Support, Manufacturing Technology Integration, BRT, USA visited on March 03, 2016.
19. Dr.Cortney K Mittelstadt, Vice President-Technology, Giner Inc., USA visited on March 10, 2016.
20. Mr.K.Karthikeyan, Senior Engineering Manager, L& T Ltd, Chennai visited on March 21, 2016.
21. Dr.M.Venkateswaralu, Assistant General Manager, Amara Raja Batteries, Tirupati visited on March 24, 2016.
22. Mr. PM Puranik, Air Commodore, Air Officer Commanding, 3 Base Repair Depot, Air Force, Chandigarh visited on March 24, 2016.

Visits Abroad

1. Ms. Alka Pareek (Dr. T.N. Rao), Senior ARCI Fellow, visited USA during April 05-12, 2015 to participate in the '2015 MRS Spring Meeting' and presented a paper on "Role of Transition Metal-Hydroxide (M-OHx, M=Mn, Fe, Ni, Co, Cu) Co-Catalyst Loading: Efficiency and Stability Studies of CdS Photoanodes".
2. Dr. Krishna Valleti visited USA during April 18-26, 2015 to participate in the 'International Conference on Metallurgical Coatings and Thin Films (ICMCTF)' and presented a paper on "An Endeavour to Examine Erosion Failure Mechanisms in TiCrN Coatings".
3. Dr. K. S. Dhathathreyan visited Taiwan during April 19-23, 2015 to participate in the '2015 International Conference and Workshop on Ecology, Environment and Energy (3E)- Pursue as First Steps on the Road to Sustainability'.
4. Dr. G. Sundararajan visited Nice, France during May 29-June 02, 2015 to participate in the Industrial Research Committee meetings of CEFIPRA.
5. Dr. Sanjay Dhage visited USA during June 12-22, 2015 to participate in the SERIIUS annual meeting and also to present a paper on "Non-Vacuum Route for CIGS Thin Film Absorber on Flexible Glass Substrate" at the '42nd IEEE Photovoltaic Specialist Conference'.
6. Dr. Tata N. Rao visited USA during June 13-26, 2015 a) to participate in the 'Advanced Automotive and Industrial/ Stationary Battery Conference (AABC)' held at Detroit and made a poster presentation on "Nanostructured Pure and SnO_2 mixed $Li_4Ti_5O_{12}$ as High Performance Anode

Materials for Lithium Ion Batteries" and b) for technical discussions at Clemson University.

7. Dr. R. Subasri visited The Netherlands during June 21-27, 2015 to participate in the 'Coatings Science International (COSI) 2015' and presented a paper on "Effect of Heat Treatment on the Optical Properties of Sol-Gel derived Dielectric Solar Control Coatings on Glass".

8. Mr. Balaji Padya visited Singapore during June 26-July 04, 2015 to participate in the 'International Conference on Materials for Advanced Technologies (ICMAT-15)' and presented a paper on "Enhanced Electron Emission Properties of Carbon Nanotube Microislands Generated by Femtosecond Ultrafast Laser Patterning for Electron Gun Application".

9. Dr. Sanju Rani Chandaroy (DST Women Scientist) visited Japan during June 26-July 12, 2015 to carryout DST-JSPC project work on 'Development of Gel Electrolytes based on Organic –Inorganic Hybrids'.

10. Mr. Pandu Ramavath visited Ohio, USA during August 15-25, 2015 for pre-dispatch inspection and equipment training programme on 'Encapsulation Facility for Hot Isostatic Press'.

11. Ms. Papiya Biswas visited USA during August 15-28, 2015 for pre-dispatch inspection and equipment training programme on 'Encapsulation Facility for Hot Isostatic Press' at Ohio and 'Zeta Potential' at Florida.

12. Dr. Nitin P. Wasekar visited Poland during September 19-26, 2015 to participate in the 'European Congress And Exhibition on Advanced Materials and Processes (EUROMAT 2015)' and presented a paper on "Dry Sliding Wear Behaviour of Pulsed Electrodeposited Ni-W-SiC Nanocomposite as an Alternative for Hard Chrome Replacement".

13. Dr. N. Rajalakshmi visited Japan during September 28-October 04, 2015 to participate and to deliver a lecture on "PEMFC Electrodes-Operation on Impure Fuel and Air" at the Annual meeting of the DST-JSPS collaborative project on 'Organoboron Organic-Inorganic Hybrids as Solid Electrolyte for Li Batteries with Graphene based Anodes'.

14. Dr. G. Sundararajan visited USA during September 30-October 12, 2015 a) for technical discussion with Clemson University and Florida International University and b) to deliver invited lectures on "Enhancement of the Fatigue Performance of Micro Arc Oxidation (MAO) Coated Aluminium Alloys" and "Solid Particle Erosion Behaviour of Electrodeposited Nanocrystalline Nickel Coating" at the 'Technical Meeting of Materials Science and Technology (MS&T15)' held at Columbus.

15. Dr. G. Padmanabham visited Limburg, Germany October 27-November 01, 2015 to attend meeting of International Institute of Welding Special Group on Research and Collaboration.

16. Dr. M. Sathiya delivered an invited lecture on "Fundamental Advances Boosting the Development of High Capacity Lithium Rich Layered Oxides" at the 'BASF-Volkswagen Science Award Electrochemistry' held at Tokyo, Japan on October 29, 2015.

17. Dr. S. Sakthivel visited South Korea during November 06-13, 2015 to participate in the 'International Solar Energy Society (ISES) Solar World Congress 2015' and presented a paper on "Design and Fabrication of Highly Environmentally Stable Cr-Fe-Ni/ZrO_2-SiO_2 Composite Oxide based Tandem Absorber for Solar Thermal Power Generation Applications".

18. Dr. P. Suresh Babu visited Sweden during November 10-14, 2015 to participate in the 'Micro Materials Ltd's 15th Annual User Meeting and Conference' and delivered an invited lecture on "Cube-Corner Impact Behavior of CAPVD Monolithic and Multilayer TiAlN Coatings".

19. Dr. G. Sivakumar visited Montreal, Canada during November 28-December 06, 2015 to a) participate and deliver an invited lecture on "Realizing Solution Precursor Plasma Spray Technique Towards Deposition of Functional Coatings" at the 'Thermal Spray of Suspension and Solution Symposium (TS4)' and b) to attend a programme on the 'Demonstration of Axial III Suspension Plasma Spray System' at National Research Council, Montreal.

20. Dr. S. Kumar visited France during December 08-13, 2015 to participate in the 'Les Recontres Internationales sur la Projection Thermique (RIPT-7th Edition)' and presented a paper on "Microsctructure and Performance of Cold Sprayed Al-SiC Composite Coatings with High Fraction of Particulates".

21. Dr. D. Prabhu visited San Diego, USA during January 09-18, 2016 to participate in the '2016 Joint MMM-Intermag Conference' and presented a paper on "A New Soft Magnetic Fe-P (Si) Alloy with Low Core Loss and High Magnetic Induction".

22. Dr. R. Vijay visited Germany during March 05–13, 2016 to participate in the '9th International Symposium on Nanostructures' and delivered a lecture on "Development of Nanostructured Materials using Simoloyer Technology at Zoz-ARCI Centre".

Lectures by ARCI Personnel in India

1. Dr. R. Gopalan delivered an invited lecture on "Investigation on Magnetic Properties-Process Correlation in Rare Earth Permanent Magnets using 3D Atom Probe" at the 'Nano Probe Techniques Workshop' held at Kanpur on April 10, 2015.

2. Dr. R. Subasri delivered the keynote lecture on "Commercialization Prospects of Sol-Gel Coatings: Global Scenario" at the 'National Conference on Sol-Gel Coatings' held at Chennai on April 10, 2015.

3. Dr.K.Ramya delivered an invited lecture on "Polymer Electrolyte Membrane Based Electrochemical Conversion of Carbon-dioxide from Aqueous Solutions" at the '4th International Conference on Natural Polymers, Bio-Polymers, Bio-Materials, their Composites, Nanocomposites, Blends, IPNs,

Polyelectrolytes and Gels: Macro to Nano Scales (ICNP – 2015)' held at Kottayam during April 10-12, 2015.

4. Dr. R. Gopalan delivered an invited lecture on "Rare-Earths: Resources and Challenges for Green Energy Technology" at the 'International Conference on Science, Technology and Applications of Rare Earths (STAR 2015)' held at Thiruvananthapuram during April 23-25 2015.

5. Dr. M. Sathiya delivered an invited lecture on "Sodium Ion Batteries" at the 'Power Sources Technologies Pertaining to Defence, Aero and Spin-off to Civil Applications (PoSDAC) Workshop' held at Hyderabad on April 28, 2015.

6. Dr. R. Prakash delivered an invited lecture on "Lithium Ion Battery Technology for Electric Vehicle Application" at the 'PoSDAC Workshop' held at Hyderabad on April 28, 2015.

7. Dr. R. Easwaramoorthi delivered an invited lecture on "Atmospheric Processing of Perovskite Solar Cells" at the 'Brainstorming Session on Hybrid Perovskite Materials' held at Mumbai during May 05-06, 2015.

8. Dr. G. Sundararajan delivered an invited lecture on "Advanced Manufacturing Technologies for Strategic Sectors: ARCI's Experience" at the 'International Conference on Advanced Materials and Manufacturing Processes for Strategic Sectors (ICAMPS-2015)' held at Thiruvananthapuram during May 13-15, 2015.

9. Dr. R. Subasri delivered invited lectures on "Sol-Gel Nanocomposite Coating Technology: Development and Demonstration for Diverse Applications" and "Multifunctional Nanocomposite Coatings for Strategic Sector" at the 'International Conference and Technology Meet on Military and Marine Applications' held at Pune during May 23-24, 2015.

10. Dr. Gururaj Telasang delivered a lecture on "Laser Surface Engineering for Life Extension of Pressure Die Casting Tools (AISI H13)" at the 'International Conference on Fatigue, Durability and Fracture Mechanics (Fatigue Durability India 2015)' held at Bengaluru during May 28-30, 2015.

11. Dr R. Subasri delivered a lecture on "Organic-Inorganic Hybrid Nanocomposite Coatings for Corrosion Protection of Metals and Alloys" at CSIR-Central Electrochemical Research Institute, Karaikudi on June 12, 2015.

12. Dr. R. Gopalan delivered an invited lecture on "Materials Processing, Applications Research and Technology" at the 'International Conference on Frontiers in Materials Processing, Applications Research and Technology (FIMPART-2015)' held at Hyderabad during June 12-15, 2015.

13. Dr. B.P. Saha delivered an invited lecture on "Silicon Carbide: A Novel Ceramic Materials for Advanced Applications" at the 'Workshop on Indian Innovations in Materials Research: New Materials and Process (IIMR -15)' held at Kolkata during June 25-27, 2015.

14. Dr. N.Rajalakshmi delivered an invited lecture on "Alternative Vehicle Technologies – Electric Vehicles and Hybrids- Make in India" at the 'Conference on Advanced Manufacturing Technologies for Engineering Sector: Theme- Make in India - Rise with Technology, Enhance your Competitiveness' held at Chennai on June 26, 2015.

15. Dr. N.Rajalakshmi delivered an invited lecture on "Materials for Energy Storage and Conversion – Carbon Based" at the 'National Symposium on Energy Materials' held at Chennai on June 29, 2015.

16. Dr. G. Ravichandra delivered an invited lecture on "Electron Microscopy in the Development of Materials for Industrial Applications" at the 'International Conference on Electron Microscopy' held at Mumbai during July 08-10, 2015.

17. Mr. L. Venkatesh delivered a lecture on "Electron Microscopy Study of Laser Clad Chromium Carbide-NiCrMoNb" at the 'International Conference on Electron Microscopy' held at Mumbai during July 08-10, 2015.

18. Dr. G. Sundararajan delivered the 'Dr. Kondal Rao Memorial Lecture-2015' on "Non Oxide Dispersion Strengthened Steels : Recent Developments at ARCI" at Nuclear Fuel Complex, Hyderabad during July 15, 2015.

19. Dr.N.Rajalakshmi delivered an invited lecture on "Electric Vehicles and Fuel Cells-Make in India" at the '7th National Level Technical Symposium' held at Chennai on July 29, 2015.

20. Dr. S. M. Shariff delivered a lecture on "Influence of Pre and Post-Clad Heat Treatment on Quality (Cracking Susceptibility and Microstructure) of Laser-Clad Hardfaced NiCr Coatings on SS-316L" at the '2nd International Conference on Advances in Cutting, Welding and Surfacing (CWS)' held at Coimbatore during August 05-07, 2015.

21. Dr. Sanjay Bhardwaj delivered an invited lecture on "Competitive Intelligence for Nanotechnology-Based Businesses" at the 'Plenary Session of the Global Green Nanotechnology Conclave (GiGaNTiC 2015)' held at Ahmedabad during August 06 - 07, 2015.

22. Dr. G. Sundararajan delivered an invited lecture on "Conversion of Powders to Product @ ARCI" at the 'Workshop on Powder Metallurgy: Technology and Applications' held at Chennai on August 07, 2015.

23. Dr. Sanjay Bhardwaj delivered invited lectures on "Identifying Innovation Opportunities" and "Leveraging Knowledge-Base of Research and Technology Organizations (RTOs) for Entrepreneurship" at Sreenidhi Institute of Science and Technology, Hyderabad on August 21, 2015.

24. Dr. G. Sundararajan delivered the 'Prof. Atma Ram Memorial Lecture' on "Advanced Ceramics: Research and Technology Development at ARCI" at Central Glass and Ceramic Research Institute (CGCRI), Kolkata on August 26, 2015.

25. Dr. Sanjay Bhardwaj delivered a lecture on "Utilizing Intellectual Property Development Indices (IPDIs) in R&D Organizations" at the Indian Oil Corporation Ltd - R&D Centre, Faridabad on August 28, 2015
26. Dr. Gururaj Telasang delivered an invited lecture on "Post Processing for Metal Additive Manufacturing" at the 'Training Programme on Design for Additive Manufacturing (DFAM)' held at Hyderabad during August 31-September 01, 2015.
27. Dr. P.K. Jain delivered an invited lecture on "Advanced Functional Materials" at KL University, Guntur on September 02, 2015.
28. Dr. G. Padmanabham delivered an invited lecture on "Laser Based Materials Joining Technologies-An Overview" at the 'International Conference on Application of Lasers in Manufacturing (CALM2015)' held at New Delhi during September 09-11, 2015.
29. Dr. Ravi Bathe, delivered a lecture on "Ultrafast Laser Surface Texturing of Automotive Components for Friction Control" at 'CALM 2015' held at New Delhi during September 09-11, 2015.
30. Dr. S. M. Shariff delivered a lecture on "Laser Surface Alloying/Cladding Applications in Energy and Automotive Sectors" at 'CALM2015' held at New Delhi during September 09-11, 2015.
31. Dr. Gururaj Telasang delivered contributory lecture on "Laser Assisted Direct Metal Deposition of Hot Die Steel - AISI H13" at 'CALM2015' held at New Delhi during September 09-11, 2015.
32. Mr. Manish Tak delivered contributory lecture on "Techno-Economics of Laser Based Surface Engineering Processes" at 'CALM2015' held at New Delhi during September 09-11, 2015.
33. Dr. R. Gopalan delivered an invited lecture on "Single Crystal of Functional Materials and their Application" at the 'SERC- School on Single Crystal of Functional Materials and their Application' held at Chennai on September 12, 2015.
34. Dr. Sanjay Bhardwaj delivered lectures on "Generating Value from Knowledge-Base of Research and Technology Organizations (RTOs)" and "Managing Innovation Process in R&D Organizations" at the 'Management Development Programme for the Scientists/Engineers of Indian Space Research Organization (ISRO)' organized by Administrative Staff College of India (ASCI) at Hyderabad on September 23, 2015.
35. Dr. G. Ravichandra delivered an invited lecture on "Microstructural, Mechanical and Chemical Characterisation of Coatings" at the 'Workshop on Thermal Spray Coating Technologies (TSCOAT)' held at Hyderabad on September 23, 2015.
36. Dr. S. Kumar delivered an invited lecture on "Cold Spray Fundamentals" at 'TSCOAT' held at Hyderabad on September 23, 2015.
37. Mr. Naveen M. Chavan delivered an invited lecture on "Cold Spray-Technology and Applications" at 'TSCOAT' held at Hyderabad on September 23, 2015.
38. Dr. Sanjay Bhardwaj delivered a lecture on "Generating Value using Intellectual Property Development Indices (IPDIs) in R&D Organizations" at Thomson Reuters IP and Science, Hyderabad on October 08, 2015.
39. Dr. G. Ravichandra delivered an invited lecture on "Applications of Electron Backscatter Diffraction (EBSD) in Materials Science" at the 'World Congress on Microscopy' held at Kottayam during October 09-11, 2015.
40. Dr. P.K. Jain delivered an invited lecture on "Carbon Nanomaterials and their Application in Energy Storage" at the 'National Conference on Application of Carbon Materials in Energy' held at New Delhi during October 14, 2015.
41. Dr. Sanjay Bhardwaj delivered a lecture on "Intellectual Property Value Chain in Research and Technology Organizations (RTOs)" at the 'DST Programme on Creativity and Innovation Management in Research' organized by Engineering Staff College of India (ESCI) at Hyderabad on October 27, 2015.
42. Dr. S. M. Shariff delivered an invited lecture on "Application of Diode Laser Based Cladding Process as a Viable Tool for Repair and Refurbishment" at the 'Symposium on Advanced Repair Technologies 2015' held at Bengaluru during October 27-28, 2015.
43. Dr. G. Ravichandra delivered a guest lecture on "Characterization of Coatings and Films" at the Birla Institute of Technology and Science Pilani, Hyderabad on October 30, 2015.
44. Dr. S. M. Shariff delivered a lecture on "Influence of Plasticity Factor on Tribological Performance of Laser Surface Modified Rail Steels" at the 'Conference on Advanced Materials and Processing' held at Jaipur during November 02-04, 2015.
45. Dr. R. Gopalan delivered a general lecture on "Critical Functional Materials for Automotive Energy Applications" at the 'National Metallurgists Day-Annual Technical Meeting' held at Coimbatore during the November13-16, 2015.
46. Dr. P.K. Jain delivered an invited lecture on "Vertically Aligned Carbon Nanotubes and their Field Emission Applications" at the 'Indo-Belarus Joint Workshop on Nanomaterials and Technologies' held at Gurgaon during November 16-17, 2015.
47. Dr. R. Subasri delivered an invited lecture on "Sol-gel Nanocomposite Coatings for Diverse Applications" at the 'Indo-Belarus Joint Workshop on Nanomaterials and Technologies' held at Gurgaon during November 16-17, 2015.
48. Dr.D. Prabhu delivered an invited lecture on "Nanomaterials and Technologies" at the 'Indo-Belarus Joint Workshop on Nanomaterials and Technologies' held at Gurgaon during November 16-17, 2015.

49. Dr. P.K. Jain delivered an invited lecture on “Advances and Applications of Nano-Composites” at the ‘Faculty Development Programme’ organized by Aditya Institute of Technology and Engineering, Andhra Pradesh on November 18, 2015.

50. Dr. G. Ravichandra delivered a guest lecture on “Mechanical Properties of Materials at the Sub-Micron Scale” at the Birla Institute of Technology and Science Pilani, Hyderabad on November 19, 2015.

51. Dr. Sanjay Bhardwaj delivered a lecture on “Implementing Intellectual Property Development Indices (IPDIs) for Materials Related R&D” at ARCI, Hyderabad on November 19, 2015.

52. Dr. R. Subasri delivered an invited lecture on "Sol-gel Derived Hybrid Nanocomposite Coatings for Corrosion Protection of Metals and Alloys" at the ‘Seminar on Nanomaterials for Energy Sector’ held at BHEL R&D Centre, Hyderabad on November 20, 2015.

53. Mr. L. Venkatesh delivered a lecture on “Solidification Microstructure of Laser Clad Chromium Carbide-NiCrMoNb” at the ‘International Conference on Solidification Science and Processing’ held at Hyderabad during November 24-27, 2015.

54. Dr. Malobika Karanjai delivered an invited lecture on “Friction Materials and Composites” at the ‘Powder Metallurgy Short Course (PMSC 2016)’ held at Pune on November 26, 2015.

55. Dr. Sanjay Bhardwaj delivered a lecture on “ARCI Technologies for Collaborations and Transfer” during the ‘STEM Annual Summit 2015’ held at Hyderabad on November 26, 2015.

56. Dr. R. Gopalan delivered an invited lecture on “Materials and Components for Sustainable Transportation and Energy Saving” at the ‘7th Indo-Korean Joint Workshop on Green Mobility and Energy Materials’ held at Hyderabad during November 26-27, 2015.

57. Dr. N.Rajalakshmi delivered an invited lecture on “Making Fuel Cells Work-Challenges” at the “7th Indo-Korean Joint Workshop on Green Mobility and Energy Materials’ held at Hyderabad during November 26-27, 2015.

58. Dr. R. Prakash delivered an invited lecture on “Large Format Lithium Ion Fabrication Process and Challenges” at the ‘7th Indo-Korean Joint Workshop on Green Mobility and Energy Materials’ held at Hyderabad during November 26-27, 2015.

59. Dr. D. Sivaprahasam delivered an invited lecture “Thermoelectrics for Exhaust Waste Heat Recovery: The Challenges in Materials Technology and Device Fabrication” at the ‘7th Indo-Korean Joint Workshop on Green Mobility and Energy Materials’ held at Hyderabad during November 26-27, 2015.

60. Dr. S. Sakthivel delivered an invited lecture on “Role of Nanofunctional Coatings for PV and Solar Thermal Application” at the ‘International Conference on Nanomaterials and Nanotechnology’ held at Tiruchengode, Tamil Nadu during December 07-11, 2015.

61. Dr. Sanjay Bhardwaj delivered invited lectures on "Key Facets for Effective Management of an Innovation Process: A Case Study" and "Innovative Projects and Intellectual Property Development Indices (IPDIs)" at the ‘Management Development Programme (MDP) for Scientists/Engineers from ISRO’ organized by ASCI at Hyderabad on December 10, 2015.

62. Dr. Manjusha Battabyal delivered an invited lecture on “Enhancement of Thermoelectric Properties in Ni doped Co4Sb12Te0.1 Skutterudites” at the ‘International Conference on Frontiers in Materials Science and Technology (ICFMST-2015)’ held at Orissa during December 10-12, 2015.

63. Dr. P.K. Jain delivered an invited lecture on “Synthesis of Carbon Nano Composites and their Application” at Hindustan College of Engineering, Mathura on December 11, 2015.

64. Dr. Roy Johnson delivered an invited lecture on “Cellular Ceramics of Energy and Environmental Applications” at the ‘International Conference on Ceramics and Advanced Materials for Energy and Environment (CAMEE 2015)’ held at Bengaluru during December 14-17, 2015.

65. Dr. Ravi Bathe delivered an invited lecture on “Applications of Laser in Ceramic Machining” at ‘CAMEE 2015’ held at Bengaluru during December 14-17, 2015.

66. Dr. P.K. Jain delivered an invited lecture on “Multifunctional Application of Carbon Nano Materials” at the ‘National Workshop on Nano Materials’ held at Hyderabad on December 15, 2015.

67. Dr. R. Gopalan delivered an invited lecture on “Functional Materials for Automotive Applications” at the ‘3rd International Workshop on Advanced Functional Nanomaterials (TIWAN-2015)’ held at Chennai on December 16-18, 2015.

68. Dr. S. M. Shariff delivered an invited lecture on “An Overview of Laser Surface Modification Technologies Developed at ARCI” at Jamshedpur on December 28, 2015.

69. Dr. Sanjay Bhardwaj delivered invited lectures on “Technology Development, Demonstration and Transfer : A Case Study”, “Role of Intellectual Property Development Indices (IPDIs) in R & D Projects” and “IP Competitive Intelligence for R&D Planning” at the Institute of Nano Science and Technology (INST), Mohali during January 01-02, 2016.

70. Dr. R. Balaji delivered a guest lecture on “Hydrogen Fuel Cell Technology-An Introduction” at the ‘Seminar on Renewable Energy’, held at Gandhigramam, Tamilnadu on January 18, 2016.

71. Dr. J. Joardar delivered an invited lecture on “Rietveld Method in Quantitative XRD” at the ‘Workshop on Advanced Techniques in Materials Characterization (ATMC-2016)’ held at Raipur during January 22-23, 2016.

72. Dr. Sanjay Bhardwaj delivered an invited lecture on "ARCI's Technology Portfolio for Collaborations and Transfer" at the 'Technology Meet' organized by EEPC India (Ministry of Commerce and Industry) at Coimbatore on January 28, 2016.
73. Dr. B. V. Sarada delivered an invited lecture on "Electrochemical Technologies for the Synthesis of Solar Energy Materials" at the 'National Conference on Frontiers in Chemical Sciences and Technologies' held at Warangal during January 28 –29, 2016.
74. Dr. G. Padmanabham delivered an invited lecture on "Innovative Materials Processing for Energy and Environment Applications" at the 'AP Science Congress' held at Tirupati on January 29, 2016.
75. Dr. S. Sakthivel delivered an invited lecture on "Important Role of Nanomaterials in Functional Coatings for Solar and Other Applications" at the 'National Conference on Innovations in Chemical Sciences (NCIC2016)' held at Chennai on January 29, 2016.
76. Dr. Srinivasan Anandan delivered an invited lecture on "Application of Nanotechnology in Self-Cleaning and Battery Materials" at the 'Seminar on Nanoscience Technological Applications' held at Hyderabad on January 30, 2016.
77. Dr. K. Ramya delivered an invited lecture on "HTPEMFC Stack Development and Analysis using AC Impedance Spectroscopy" at the 'International Conference on Advancements in Polymeric Materials (APM 2016)' held at Ahmedabad during February 12-14, 2016.
78. Dr. P. H. Borse delivered an invited lecture on "Efficiency and Stability Aspects of CdS Photoanode for Solar Hydrogen Generation Technology" at the 'International Conference on Recent Trends in Physics (ICRTP2016)' held at Indore during February 13-14, 2016.
79. Dr. Malobika Karanjai delivered a plenary session lecture on "Soft Magnetic Composites for Automotive Applications: Promises and Challenges" at the 'International Conference on Paticulate Technology and Automotive Components (PM16)' held at Pune on February 18-20, 2016.
80. Dr. R. Balaji delivered an invited lecture on "Hydrogen-Fuel of Future" at the 'National Conference on Recent Development in Chemistry' held at Tirupattur, Tamilnadu on February 24, 2016.
81. Dr. Neha Hebalkar delivered an invited lecture on "Performing Supercritical Drying in HEL's High Pressure Vessel to Produce Aerogels which are the World's Best Thermal Insulators" at the 'User Conference of HEL, UK' held at Goa during February 25-26, 2016.
82. Dr. Sanjay Bhardwaj delivered an invited lecture on "Commercializing R&D: Role of Knowledge Management" at the 'International Conference on Emerging Trends in Biosynthesis of Nano Particles in Agri Biotechnology - Research and Commercialization' at Hyderabad during February 25-27, 2016.
83. Dr. R. Easwaramoorthi delivered an invited lecture on "Science for All" at the 'National Science Day Celebration' held at Government City College, Hyderabad on February 27, 2016.
84. Dr. S. Sakthivel delivered an invited lecture on "Role of Nanomaterials and Functional Coatings for Solar Thermal and PV Applications" at the 'National Workshop on Nanomaterials and Thin Film Based Applications' held at Vellore on March 18, 2016.
85. Mr. R. Vallabha Rao delivered an invited lecture on "Lithium Ion Battery: Sustainable Energy Systems for EV and Grid Applications" at the 'Workshop on Advanced Automotive Materials' held at Chennai on March 19, 2016.
86. Dr. Manjusha Battabyal delivered an invited lecture on "Advanced Automotive Energy Materials" at the 'Workshop on Advanced Automotive Materials' held at Chennai on March 19, 2016.
87. Dr. P. K. Jain delivered a guest lecture on "Carbon Nanomaterials and their Various Applications" at the National Geophysical Research Institute (NGRI), Hyderabad on March 29, 2016.
88. Dr. P. K. Jain delivered an invited lecture on "Multifunctional Materials and their Applications" at the 'National Seminar on Multifunctional Materials and their Applications (NSSMA 2016)" held at Hyderabad during March 29-30, 2016.

Papers Presented at Indian Conference/ Symposia

1. Dr. P. H. Borse presented a paper on "Comparison of Water Photosplitting Properties of Nanocrystalline Zinc Ferrite Prepared by Polymerized Complex and Solid State Reaction Method" at the 'National Conference on Engineering Materials, Energy and Environment' held at Hyderabad during April 24-25, 2015.
2. Ms. N. Manjula (Dr. R. Balaji) presented a paper on "Methanol-Water Electrolysis using TNT based Composite Membrane for Hydrogen Gas Generation" at the 'National Conference on Advanced Functional Materials (NCAFM- 15)' held at Chennai on May 08-09, 2015.
3. Mr. E. Anbu Rasu made a poster presentation on "Laser Micro Welding for Hermetic Sealing of Solenoid Valves" at the 'Workshop on Advances in Materials Joining Technologies 2015 (AMJT 2015)' held at Hyderabad on May 29, 2015.
4. Ms. L Subashini (Dr. G. Padmanabham) made a poster presentation on "Laser-MIG Hybrid Welding of 12mm Thick Reduced Activation Ferritic Martensitic Steel [RAFMS] at the 'AMJT 2015' held at Hyderabad on May 29, 2015 .
5. Mr. N.S. Anas (Dr. R. Vijay) presented a paper on "Optimization of Solution Heat Treatment Temperature for Aluminum alloy-CNT/Graphene Composites" at the 'National Conference on Materials Science and Technology (NCMST 2015)" held at Thiruvananthapuram during July 06-08 2015.

6. Dr. M. B. Sahana presented a paper on "Evidence for Composite Nature of Li1.15Mn0.54Ni0.23Co0.08O2 from High Resolution Transmission Electron Microscopy" at the 'XXXVI Annual Meeting of EMSI' held at Mumbai during July 08-10, 2015.
7. Dr. I. Ganesh made a poster presentation on "Fuel Chemicals Production from Waste-Stream Greenhouse CO2: Effect of Water Oxidation Catalysis on Electrochemical CO2 Reduction over Metal-Ionic Liquid based Cathodic Systems" at the 'National Symposium on Electrochemical Science and Technology (NSEST-2015)' held at Benguluru during the July 24-25, 2015.
8. Dr. Gururaj Telasang presented paper on "Post Processing for Metal Additive Manufacturing" at a 'Training Programme on Design for Additive Manufacturing (DFAM)' held at Hyderabad during August 31- September 01, 2015.
9. Dr. Sanjay Dhage presented a paper on "Pulsed Nanosecond Laser Scribing of Bilayer Molybdenum Back Contact for CIGS Thin Film Solar Cell Applications" at the 'International Conference on Application of Lasers in Manufacturing (CALM 2015)' held at New Delhi during September 09-11, 2015.
10. Mr. D. Nazeer Basha (Dr. Ravi Bathe) presented a paper on "Laser Surface Micro Texturing of Cast Iron" at 'CALM 2015' held at New Delhi during September 09-11, 2015.
11. Ms. E. Anusha, (Dr. S.M. Shariff) made a poster presentation on "Diode Laser Surface Treatment of Bearing Steel for Improved Mechanical and Tribological Properties" at 'CALM 2015' held at New Delhi during September 09-11, 2015.
12. Ms. T. Ragini (Dr. S.M. Shariff) made a poster presentation on "Refurbishment of Cast Iron Components using Laser-Clad Deposition Process: Effect of Preheating on Porosity and Cracking Susceptibility" at 'CALM 2015' held at New Delhi during September 09-11, 2015.
13. Ms. L. Subashini, (Dr. G. Padmanabham) made a poster presentation on "Preliminary Investigation on Laser MIG Hybrid Welding of Ferritic Martensitic Steels" at 'CALM 2015' held at New Delhi during September 09-11, 2015.
14. Ms. A. Geethika Mudiraj (Dr. Gururaj Telasang) made a poster presentation on "Investigation of Laser Aided Additive Manufacturing of AISI H13 Hot Die Steel" at 'CALM 2015' held at New Delhi during September 09-11, 2015.
15. Dr.Malobika Karanjai presented a paper on 'PM Friction Materials in Clutches and Brakes" at the 'Powder Metallurgy Short Course (PMSC15)' held at Pune during September 24-27, 2015.
16. Dr. Krishna Valleti presented a paper on "Functionally Multi-Layered Thin Films for High Temperature Solar Selective Application" at the 'National Conference on Andhra Pradesh Science Congress (APSC- 2015)' held at Guntur during the November 07-09, 2015.
17. Mr. R. Senthil Kumar presented a paper on "CNT Reinforced Alumina CNT Composites for Wear Resistant Applications" at 'National Metallurgists Day-Annual Technical Meeting' held at Coimbatore during the November 13-16, 2015.
18. Ms. B. Priyadarshini (Dr. D. Sivaprahasam) presented a paper on "Effect of Doping on the Thermoelectric Properties of Powder Metallurgy Processed Zn4Sb3" at the 'National Metallurgists Day-Annual Technical Meeting' held at Coimbatore during November 13-16, 2015.
19. Ms. K. Tanuja (R. Gopalan) presented a paper on "Investigation on $LiFePO_4$/C Cathode Prepared by Eco-Friendly Polyvinyl Alcohol (PVA) Binder for LIB" at the 'National Metallurgists Day-Annual Technical Meeting' held at Coimbatore during November 13-16, 2015.
20. Ms. N. Sasikala (Dr. M. B. Sahana) presented a paper on "Effect of Precursors on the Morphological and Electrochemical Property of $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$" at the 'National Metallurgists Day-Annual Technical Meeting' held at Coimbatore during November 13-16, 2015.
21. Mr. Ravi Gautam (Dr. G. Sundararajan) presented a paper on "Effect of Silicon Additions upon the Magnetic Properties of Fe-P Based Soft Magnetic Alloy" at the 'National Metallurgists Day-Annual Technical Meeting' held at Coimbatore during November 13-16, 2015.
22. Dr. D. Prabhu presented a paper on "High Performance Hard Magnetic Materials" at the 'Indo-Belarus Workshop on Nanomaterials and Nanotechnologies' held at NCR Delhi during November 16-17, 2015.
23. Mr. K.R.C. Soma Raju presented a paper on "Corrosion Behaviour of Anodized and Sol-Gel Duplex Coatings on Aluminum" at the 'International Conference and Exhibition on Corrosion (CORCON 2015)' held at Chennai during November 19-21, 2015.
24. Ms. J. Revathi made a poster presentation on "Wood Derived Cellulose Templated Carbon - SnOx Anode Material for Lithium Ion Battery Applications" at the '7th Indo-Korean Joint Workshop on Green Mobility and Energy Materials' held at Hyderabad during November 26-27, 2015.
25. Mr. B. Jayachandran (Dr.D.Sivaprahasam) made a poster presentation on "Interface Engineering of Thermoelectric Generators for Automotive Exhaust Heat Recovery" at the 'Indo - Korean Workshop on Green Mobility and Energy Materials' held at Hyderabad during November 26-27, 2015.
26. Mr. R. Vallabha Rao (Dr. G. Sundararajan) made a poster presentation on "Large Scale Lithium Ion Battery Fabrication for EV Applications" at the 'Indo - Korean Workshop on Green Mobility and Energy Materials' held at Hyderabad during November 26-27, 2015.
27. Ms. P.M. Pratheeksha (Dr. S. Anandan) made a poster presentation on "$LiFePO_4$, a Promising High-Efficient Cathode Material for Rechargeable Lithium Ion Battery Application" at the '7th Indo Korean Joint Workshop on Green Mobility and Energy Materials' held at Hyderabad during November 26-27, 2015.

28. Ms. K. Nanji (Dr. S. Anandan) made a poster presentation on "A Hierarchical Porous Carbon as an Efficient Anode Material for High Power Lithium-Ion Battery" at the '7th Indo Korean Joint Workshop on Green Mobility and Energy Materials' held at Hyderabad during November 26-27, 2015.
29. Mr. N.S. Anas (Dr. R. Vijay) made a poster presentation on "Evaluation of Mechanical Properties of Al Alloy-CNT Composites" at the '7th Indo-Korean Joint Workshop on Green Mobility and Energy Materials' held at Hyderabad during November 26-27, 2015.
30. Mr. Balaji Padya presented a paper on "Densely-Packed Nitrogen Doped 1-D Carbon Nanostructures as Nanoemitter: Stability Issues and Failure Mechanism" at the 'National Conference on Carbon Materials (NCCM 2015)' held at New Delhi during November 26-28, 2015.
31. Mr. Md Younus (Mr. P. Balaji) presented a paper on "Areal Site Density-Controlled Growth of Nitrogen-Enriched Highly Organised One-Dimensional Carbon Nanostructures by Acetonitrile Pyrolysis" at 'NCCM 2015' held at New Delhi during November 26-28, 2015.
32. Ms. P.M. Pratheeksha (Dr. S. Anandan) made a poster presentation on "Investigation of In-Situ Carbon Coated LiFePO4 as a Superior Cathode Material for Lithium Ion Batteries" at 'NCCM 2015' held at New Delhi during November 26-28, 2015.
33. Mr. K. Nanaji (Dr. S. Anandan) presented a paper on "Ordered Mesoporous Carbon as an Efficient Anode Material for Lithium Ion Battery Application" at 'NCCM 2015' held at New Delhi during November 26-28, 2015.
34. Ms. Eesha Andharia (Dr. D. Prabhu) presented a paper on "Structural and Magnetic Studies of Low Concentration Mn-Substituted Strontium Hexaferrite Prepared via Solid State Route" at the 'International Conference on Magnetic Materials And Applications (ICMAGMA 2015)' held at Vellore during December 02-04, 2015.
35. Mr. Ravi Gautam (Dr. G. Sundararajan) presented a paper on "Structural, Mossbauer and Magnetic Studies of Mn-Substituted Strontium Hexaferrite Prepared via Solid State Route" at 'ICMAGMA-2015' held at Vellore during December 02-04, 2015.
36. Dr. Sanjay Bhardwaj made a poster presentation on "Role of Patent Analysis in Innovation Process: A Case Study" at the 'Conference on Patinformatics for Technological Competitive Intelligence and Licensing' held at Pune during December 07-09, 2015.
37. Dr. Y.S. Rao made a poster presentation on "Synthesis and Characterization of Sodium Beta Alumina" at the "International Conference on Ceramics and Advanced Materials for Energy and Environment (CAMEE 2015)' held at Bengaluru during December 14-17, 2015.
38. Dr. M. Buchi Suresh made a poster presentation on "Processing and Development of High Power Laser Ceramics" at 'CAMEE 2015' held at Bengaluru during December 14-17, 2015.
39. Ms. Papiya Biswas made a poster presentation on "Room Temperature Compressive Deformation Behaviour of NiO and Ni foams Filters Prepared through Polymeric Sponge Replication Process" at 'CAMEE 2015' held at Bengaluru during December 14-17, 2015.
40. Mr. Pandu Ramavath made a poster presentation on "Microstructure and Mechanical Properties of Spinel Compacts Densified through HIPing and Sintering Routes" at 'CAMEE 2015' held at Bengaluru during December 14-17, 2015.
41. Mr.K. Varaprasad (Dr. Roy Johnson) made a poster presentation on "Fabrication and Thermo-Mechanical Property Evaluation of Codierite and Cordierite: Zirconia Composites" at 'CAMEE 2015' held at Bengaluru during December 14-17, 2015.
42. Mr. N. Ravi presented a paper on "Cyclic Nanoimpact Behavior of nc-TiAlN/a-Si3N4 Nanocomposite Coatings Deposited by CAPVD Process" at the 'International Conference on Nanoscience, Nanotechnology and Advanced Materials (NANOS 2015)' held at Vizag during December 14-17, 2015.
43. Mr. Balaji Padya presented a paper on "Controllable Chemical Oxidative Polymerization Synthesis of Electroactive Polyaniline Supramolecules Decorated Chemically Modified Nanostructured-Graphene for Electrochemical Capacitive Energy Storage" at the 'NANOS 2015' held at Vizag during December 14-17, 2015.
44. Mr. Puneet Chandran (Dr. Krishna Valleti) presented a paper on "Development of CrAlN-Si3N4/DLC Based Cathodic Arc PVD Coatings for High Speed/Dry Machining Applications" at the 'NANOS 2015' held at Vizag during December 14-17, 2015.
45. Mr. E. Hari Mohan (Dr. TN Rao) presented a paper on "Carboxymethylcellulose Derived Microporous Carbon as a Matrix for Sulfur Cathode in High Performance Lithium-Sulfur Battery" at the 'NANOS 2015' held at Vizag during December 14-17, 2015.
46. Ms. P. Tejassvi (Dr. TN Rao) presented a paper on "Graphene Coated Si Nanofibers as Binder-Free Anode Materials for Lithium Ion Battery Application" at the 'NANOS 2015' held at Vizag during December 14-17, 2015.
47. Mr. Puneet Chandran (Dr. Krishna Valleti) presented a paper on "CrAlSiN Nanocomposite Thin Films for Cutting Tool Applications" at the 'National Conference on Advances in Materials Processing and Characterization (NCAMPC-2016)' held at Warangal during January 04-06, 2016.
48. R. Imran Jafri (Dr.N. Rajalakshmi) presented a paper on "Supercapacitors – Test Cell to Device Fabrication" at the 'Workshop on Hydrogen Energy Technology -2016' held at Chennai on January 22, 2016.
49. Mr. Akhilesh B. Nair (Dr. N. Rajalakshmi) made a poster presentation on "Metallic Bipolar Plates" at the 'Workshop on Hydrogen Energy Technology' organized on the occasion of Dr. K. S. Dathathreyan, Associate

Director-ARCI's retirement felicitation held at Chennai on January 27, 2016.

50. Mr. Md Ayub Shareef (Dr. R Balaji) presented a paper on "Studies on Development of Secondary Alkaline Zinc Batteries" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
51. Mr. Imran Karajagi (Dr.K Ramya) presented a paper on "Studies on Development of Secondary Alkaline Zinc-air Battery" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
52. Mr. R. Janraj Naik (Dr. R. Balaji) presented a paper on "Development of Polymer Electrolyte Membrane for Electrochemical Applications" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
53. Ms. N. Manjula (Dr. R. Balaji) presented a paper on "Electrochemical Methanol Reforming for Hydrogen Production using TNT based Composite Membrane" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
54. Ms. Anusree Unnikrishnan (Dr.N.Rajalakshmi) presented a paper on "Recovery of Chlorine Contaminated Low Temperature PEMFC under Dynamic Conditions" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
55. Ms. J. A. Prithi (Dr.N.Rajalakshmi) presented a paper on "Studies on Sulfur Dioxide as a Contaminant on the Cathode Side of PEMFC" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
56. Mr. T. Ramesh, (Dr.N.Rajalakshmi) presented a paper on "Development of Energy Storage Materials from Agricultural Materials" at the 'Workshop on Hydrogen Energy Technology' held at Chennai on January 27, 2016.
57. Mr. N. Ravi presented a paper on "Effect of Nitrogen Pressure on Mechanical Properties of nc-TiAlN/a-Si_3N_4 Nanocomposite Coatings Deposited in Rotating Electrode Cathodic Arc PVD" at 'National Conference on Advances in Refractory and Reactive Metals and Alloys (ARRMA 2016)' held at Mumbai during January 27-29, 2016.
58. Ms. P. M. Pratheeksha (Dr. S. Anandan) presented a paper on"Development of Conductive Carbon-Nitride (CN) Network on $LiFePO_4$ by a Novel Polymerization Process for Li-Ion Battery Application" at the 'National Conference on Frontiers in Chemical Science and Technology (FCST)' held at Warangal during January 28-29, 2016.
59. Ms. S. Manasa (Dr.R.Subasri) made a poster presentation on "Montmorillonite Nanoclay-Based, Self-Healing, Corrosion Protection Coatings on Aluminum Alloys A356.0 and AA2024-T4" at 'FCST' held at Warangal during January 28-29, 2016.
60. Mr. E. Harimohan (Dr. TN Rao) presented a paper on "Silicon/Graphite Composite as High Performance Anode for Lithium-Sulfur Battery Application" at 'FCST' held at Warangal during January 28-29, 2016.
61. Mr. A. Das (Dr. Malobika Karanjai) presented a paper on "Experimental Investigation of the Compressibility and Mechanical properties of Cp-Ti Powder Metallurgy Components" at the 'International Conference on Particulate Technology and Automotive Components (PM16)' held at Pune on February 18-20, 2016.
62. Mr. K. R. C. Soma Raju presented a paper on "Investigations on Corrosion Resistance of Sol-Gel Derived Nanocomposite Coatings on Stainless Steel" at the '18th National Congress on Corrosion Control' held at Chennai during February 24-26, 2016.
63. Dr. P. K. Jain presented papers on "Carbon Nanomaterials and their Composites" and "Jan Gan Evam Man ki Bhasha – Rajbhasha" at the 'Rajbhasha (Hindi) Joint Seminar' held at Hyderabad during February 25-26, 2016.
64. Mr. Nanaji Islavath (Dr. R. Easwaramoorthi) made a poster presentation on "Efficiency Enhancement of ZnO Nanowire Based Perovskite Solar Cells By Low-temperature $TiCl_4$ Treatment" at the International Conference on Nanoscience and Technology (ICONSAT-2016) held at Pune during February 29-March 02, 2016.
65. Ms A. Yamini (Dr. Neha Hebalkar) made a poster presentation on "Titania Microspheres for Self Cleaning Textile Applications: One More Step Towards Make-in-India" at the '8th Bangalore Nano Conference' held at Bengaluru during March 03-04, 2016.
66. Ms S. Keerthi (Dr Neha Hebalkar) made a poster presentation on "Aerogels: New Generation Thermal Insulation Technology" at the '8th Bangalore Nano Conference' held at Bengaluru during March 03-04, 2016.
67. Mr. E. Hari Mohan (Dr. T.N. Rao) made a poster presentation on "Carbon Based Membranes as an Effective Interlayer for High Performance Lithium-Sulfur Batteries" at the '8th Bangalore Nano Conference" held at Bengaluru during the March 03-04, 2016.
68. Dr. Akkisetty Bhaskar (Dr. T.N. Rao) made a poster presentation on "Effect of Nanostructure on Electrochemical Performance on Sn-Based Anodes for Li-Ion Battery" at the '8th Bangalore Nano Conference" held at Bengaluru during the March 03-04, 2016.
69. Mr. Amol C. Badgujar (Dr. Sanjay R. Dhage) presented a paper on "Bilayer Molybdenum Back Contact on 300 x 300 mm^2 Area for CIGS Thin Film Solar Cell Application" at the '2nd National Conference on Materials on Energy Conversion and Storage (MECS-2016)' held at Puducherry during March 11-13, 2016.
70. Dr. Veerappan Ganapathy presented a paper on "Nanostructured Metal Oxide Photoanodes for Next Generation Solar Cells" at the 'MECS-2016' held at Puducherry during March 11-13, 2016.
71. R. Imran Jafri (Dr. N. Rajalakshmi) presented papers on "Cotton Derived Porous Activated Carbons for High

Power Supercapacitor Applications" and "Carbonized Cow Urine for Supercapacitor Applications" at the 'National Conference on Advanced Functional Materials (NCAFM-2016)' held at Tirupati during March 23-24, 2016.

Participation in Indian Conferences/Symposia/ Seminars/ Workshops/Exhibitions

1. Mr. L. Venkatesh, attended a 'Workshop on Electron Back Scatter Diffraction of Materials (EBSD)' held at Bengaluru on April 15, 2015.
2. Dr. K. Murugan and Dr. Nitin P. Wasekar attended the 'National Seminar on Dr. B.R. Ambedkar and Babu Jagjivan Ram's View on Promoting Science and Technology and Implementation of Reservation Policies' held at Hyderabad on May 08-09, 2015.
3. Dr. Tata N Rao, Dr. P. K. Jain, Dr. G. Ravichandra, Mr. D. Srinivasa Rao, Mr. V. Balaji Rao, Dr. B.P. Saha, Dr. R. Vijay, Dr. Pramod H. Borse, Dr. L. Ramakrishna, Dr. Malobika Karanjai, Dr. Joydip Joardar, Mr. K.V. Phani Prabhakar, Dr. Sanjay Bhardwaj , Dr. G. Sivakumar, Dr. I. Ganesh, Dr. S.M. Shariff, Dr. B.V. Sarada, Dr. Neha Y. Hebalkar, Dr. K. Suresh, Mr. S. Sudhakara Sarma, Mr. Kaliyan Hembram, Dr. K. Murugan, Dr. Dulal Chandra Jana, Dr. Dibyendu Chakravarty, Dr. P. Suresh Babu, Dr. Krishna Valleti, Dr. Sanjay R. Dhage, Dr. Srinivasan Anandan, Dr. Easwaramoorthi Ramasamy, Ms. Priya Anish Mathews, Mr. P. Barick, Mr. Manish Tak, Mr. M. Ramakrishna, Mr. Balaji Padya, Dr. Gururaj Telasang, Mr. S. Arun, Mr. R. Vijay Chandar, Mr. L. Venkatesh, Mr. Debajyoti Sen, Mr. K.R.C. Somaraju, Ms. V. Uma, Mr. P. Rama Krishna Reddy, Mr. G. Venkata Ramana Reddy, Mr. Ch. Sambasiva Rao, Mr. Ch. Karunakar, Ms. B.V. Shalini, Mr. J. Nagabushana Chary, Mr. D. Sreenivas Reddy, Mr. M. Srihari, Mr. A. R. Srinivas, Mr. E. Anbu Rasu, Mr. S. Sankar Ganesh, Mr. K. Naresh Kumar, Mr. K. Ramesh Reddy, Mr. P.V.V. Srinivas, Mr. M.R. Renju, Mr. R. Anbarasu, Mr. J. Shyam Rao, Mr. R. Vijay Kumar, Mr. R. Prabhakara Rao, Mr. P. Nagendra Rao, Mr. S. Kalyanaraman, Mr. A. Srinivas, Mr. Anirban Bhattacharjee, Mr. G.M. Rajkumar, Ms. N. Aparna Rao, Mr. G. Ramesh Reddy, Mr. Y. Krishna Sarma, Mr. P. Venkata Ramana, Mr. P. Venugopal, Ms. P. Kamal Vaishali, Mr. G. Gopal Rao, Ms. K. Shakunthala, Mr. T. Venu, Mr. Ravi Singh, Ms. K. Madhura Vani, Mr. D Krishna Sagar, Mr. A. Satyanarayana, Mr. K.V.B. Vasanth Rayudu, Mr. G. Venkat Rao, Mr. K. Subba Rao, Mr. B. Subramanyeswara Rao, Mr. P. Anjaiah, Mr. Govinda Kumar, Mr. A. Janga Reddy, Mr. Jayakumaran Thampi, Mr. E. Konda, Mr. A. Ramesh, Mr. M. Satyanand, Mr. K. Satyanarayana Reddy, Mr. K. Venkata Ramana, Mr. Ch. Venkateswara Rao, Mr. B. Hemanth Kumar, Mr. Sushanta Mukhopadhyay, Mr. G. Venkat Reddy, Mr. A. Jagan, Mr. D. Manikya Prabhu, Mr. S. Narsing Rao, Mr. P.K. Mukhopadhyay, Mr. Shaik Ahmed, Mr. G. Anjan Babu, Mr. K. Ashok, Mr. E. Yadagiri, Mr. M. Lingaiah, Mr. M.A. Fazal Hussain, Dr. P. Uday Bhaskar, Mr. Amol C. Badgujar and Mr. P. Sai Karthik attended the 'One Day Workshop on Motivation' held at ARCI, Hyderabad on May 15, 2015.
4. Mr. K.V.Phani Prabhakar attended the 'Workshop on Advances in Materials Joining Technologies (AMJT 2015)' held at Hyderabad on May 29, 2015.
5. Mr. Anirban Bhattarjee and Mr. G.M. Rajkumar attended the 'National Seminar on Service Tax' held at Hyderabad on June 11, 2015.
6. Dr. N. Rajalakshmi attended the 'Workshop on Infrared Thermography: Basics, Applications and Recent Advances' held at Chennai on July 11 2015.
7. Mr. K. V. Phani Prabhakar and Mr. E. Anbu Rasu attended the 'Workshop on Infrared Thermography : Basics, Applications and Recent Advances' held at Chennai on July 11, 2015.
8. Dr. R. Vijay and Mr. K. V. Phani Prabhakar attended a 'Workshop on the use of Physical Simulations in Materials Research' held at Chennai during July 17-18, 2015.
9. Dr. G. Padmanabham attended the 'Conference on Make in India-Transformational Driver for Aerospace and Defence Industry' organized by SAE India at Bengaluru on July 29, 2015.
10. Dr. Sanjay Bhardwaj participated in panel discussion on "Nanotechnology for Providing Market Leadership and Achieving Sustainable Market Growth: Opportunities, Challenges, Policies and the Way Forward" at the 'Global Green Nanotechnology Conclave (GiGaNTiC 2015)' held at Ahmedabad during August 06-07, 2015.
11. Ms. Priya Anish Mathews and Dr. K. Samba Sivudu attended the 'IPEX-2015 Conference: Think Local Global: Interfacing IP in a Globalized World' held at Chennai during September 25-26 2015.
12. Dr. Sanjay Bhardwaj participated in the 'R&D Round Table Meeting of Central/Defence Labs, Academia and IT Industry to Create a More Vibrant and Productive Technology Innovation Ecosystem, to Utilize R & D Capability of Labs to Help Forge Partnerships between R & D Labs and Academic Institutions' held at Hyderabad on November 01, 2015.
13. Dr. Manjusha Battabyal, Dr. M.B. Sahana and Mr. Sumit R. Sahu, attended the 'Workshop on Bringing the Nanoworld Together' held Chennai during November 03-04, 2015.
14. Mr. Ravi Gautam attended the 'National Workshop on Orientation Microscopy in SEM and TEM' held at Hyderabad during November 05-06, 2015.
15. Mr. Md Shakeel Iqbal attended the 'Advanced Workshop on Identifying, Capturing, Protecting, Managing and Commercializing Innovations' held at New Delhi during November 16-18, 2015.
16. Dr. Gururaj Telasang and Mr. E. Anbu Rasu attended the pre-conference tutorials on 'NDT for MSMEs' held at Hyderabad during November 24-25, 2015.
17. Mr. V. Balaji Rao and Mr. V.C. Sajeev attended the "Workshop on Smart Grid and Renewable Energy' held at Bengaluru during November 26-27, 2015.
18. Dr. S.M. Shariff attended the 'Conference on Advanced

Materials and Processing' held at Jaipur during December 02-04, 2015.

19. Mr. Vivek Patel, Mr. Ratnesh Kumar Gaur, Mr. Md Shakeel Iqbal, Dr. K. Samba Sivudu and Ms.Vinaya attended the 'BioAsia 2016 Conference' held at Hyderabad during February 08-10, 2016.

20. Dr. J. Joardar attended a Workshop on "Rheo Tribology for Tribological Measurements with access to Rheology" organized by Anton-Parr at Hyderabad on February 12, 2016.

21. Dr. Sanjay Bhardwaj participated in the 'R&D Round Table Meeting on Innovation, IPR and Entrepreneurship in Telangana: Present Status and Way Forward' at Hyderabad on February 19, 2016.

22. Dr. K. Samba Sivudu and Mr. Vivek Patel attended the '8th Bangalore India Nano' held at Bengaluru during March 03-04, 2016.

23. Mr. D. Srinivasa Rao attended the 'Industry Meet on Opportunities and Challenges for SMEs in the Defence Sector' held at Hyderabad during March 07-08, 2016.

Participation in Training Programmes in India

1. Mr. Anirban Battacharjee attended the training programme on 'MDP on Public Procurement' held at Faridabad during July 06-11, 2015.

2. Mr. G. M. Rajkumar, Mr. A. Srinivas, Ms. N. Aparna Rao attended the training programme on 'MDP on Public Procurement' held at Faridabad during July 20-25, 2015.

3. Dr. S. M. Shariff, Mr. K. V. Phani Prabhakar, Dr. T. Gururaj, Mr. Manish Tak, Mr. E. Anbu Rasu and Mr. J. Shyam Rao attended the training on 'KUKA Robot Programming' held at Pune during July 27-31, 2015.

4. Mr. Y. Krishna Sarma and Ms. Kamal Vaishali attended the training programme on 'MDP on Public Procurement' held at Faridabad during August 03-08, 2015.

5. Mr. B. Uday Kumar, Mr. P. Venkata Ramana and Mr. G. Ramesh Reddy attended the training programme on 'MDP on Public Procurement' held at Faridabad during August 17-22, 2015.

6. Dr. Neha Hebalkar attended the international training programme on 'Leadership and Career Development for Women Scientist and Technologists' held at Pune during August 28-September 01, 2015.

7. Mr. P. Sai Karthik attended the training programme on 'Powder Metallurgy Study Course (PMSC-2015)' held at College of Engineering, Pune during September 24-27, 2015.

8. Mr. G. Gopal Rao attended the training programme on 'MDP on Public Procurement' held at Faridabad during October 12-17, 2015.

9. Mr. P. Dharma Rao and Mr. Narendra K. Bhakta attended the 'Basic Training Programme for use of Hindi on Computer' held at Secunderabad during November 02-06, 2015.

10. Ms. K. Shakunthala attended the 'Basic Training Programme for use of Hindi on Computer' held at Secunderabad during December 07-11, 2015.

11. Ms. S. Nirmala, Mr. S. Sudhakara Sarma, Dr. Nitin P. Wasekar, Dr. K. Murugan, Dr. Dulal Chandra Jana, Dr. Dibyendu Chakravarty, Dr. P. Suresh Babu, Mr. R. Senthil Kumar, Ms. Priya Anish Mathews, Mr. Prasenjit Barick, Mr. Manish Tak, Mr. Naveen Manhar Chavan, Mr. M. Ramakrishna, Mr. Balaji Padya, Ms. Papiya Biswas, Dr. Gururaj Telasang, Dr. Krishna Valleti, Dr. S. Kumar, Dr. Sanjay R. Dhage, Dr. Easwaramoorhi Ramasamy, Dr. Srinivasan Anandan, Mr. Vijaya Chandar, Mr. Pandu Ramavath, Ms. J. Revathi, Mr. L. Venkatesh, Dr. P. Uday Bhaskar and Mr. P. Sai Karthik attended the training programme on '7 Habits of Highly Effective People' held at ARCI, Hyderabad on February 12, 2016.

12. Mr. V. Balaji Rao and Mr. V.C. Sajeev attended the training programme on 'ELECRAME 2016' held at Bengaluru during February 13-17, 2016.

13. Mr. J. Bansilal and Ms. K. Madhura Vani attended the training programme 'Basic Training Programme for use of Hindi on Computer' held at Secunderabad during February 15-19, 2016.

14. Ms. S. Nirmala attended the training programme on 'Digital Design using Arduino' held at Hyderabad on February 20, 2016.

15. Mr. P. Sai Karthik attended training programme on 'GIAN Course on Synthesis, Characterization, Processing and Applications of Nano Materials' held at Warangal during March 07-11, 2016.

16. Dr. Roy Johnson, Dr. Y. Srinivasa Rao, Mr. K.V.P Prabhakar, Dr. D. Siva Prahasam, Dr. Ravi N. Bathe, Dr. B.V. Sarada, Dr. Sanjay R. Dhage, Dr. Nitin P. Wasekar, Mr. Dulal Chandra Jana, Ms. S. Nirmala, Dr. M. Buchi Suresh, Mr. Prasenjit Barick, Dr. Gururaj Telasang, Mr. Balaji Padya, Dr. Easwaramoorthi Ramasamy, Dr. Srinivasan Anandan, Mr. Pandu Ramavath, Mr. S. Arun, Mr. L. Venkatesh, Dr. R. Balaji, Mr. K.R.C. Somaraju, Ms. A. Jyothirmayee, Mr. V. Mahender, Mr. K. Srinivasa Rao, Mr. D. Srieenivas Reddy, Mr. A.R. Srinivas, Mr. A. Raja Shekar Reddy, Mr. M. Ilayaraja, Mr. P.V.V. Srinivas, Mr. R. Anbarasu, Mr. J. Shyam Rao, Mr. N. Srinivas, Mr. S. Kalyanaraman, Mr. B. Venkanna, Mr. K.V.B. Vasantha Rayudu, Mr. A. Satyanarayana, Mr. G. Venkata Rao, Mr. A. Praveen Kumar, Mr. B. Subramanyeshwara Rao, Mr. P. Anjaiah, Mr. K. Vigneswara Rao, Mr. Govinda Kumar, Mr. M. Satyanand, Mr. D. Kutumba Rao, Mr. B. Hemanth Kumar, Mr. A. Ramesh, Mr. Shaik Ahmed, Mr. E. Yadagiri, Mr. K. Satyanarayana Reddy and Mr. G. Venkat Reddy attended the two days 'In Plant Training Programme on Safety in Storage and Handling of Hazardous Gases and Chemicals' held at ARCI, Hyderabad during March 08-09, 2016.

Patents' Portfolio

Indian Patents Granted

Title of Patent	Patent Application Number	Date of Filing	Patent Number	Date of Grant
A Solar Drier	487/ MAS/1994	08/06/1994	184674	23/09/2000
A Process for Preparation of Reaction Bonded Silicon Carbide Components	1886/ MAS/1996	28/10/1996	195429	31/08/2006
New Composite Material Having Good Shock Attenuating Properties and a process for the Preparation of Said Material	976/ MAS/1998	06/05/1998	194524	02/01/2006
Improved Process for the Preparation of Magnesium Aluminate Spinel Grains	29/MAS/1999	07/01/1999	200272	02/05/2006
Ceramic Honey Comb Based Energy Efficient Air Heater	30/MAS/1999	07/01/1999	200787	02/06/2006
A Method and a Device for Applying a Protective Carbon Coating on Metallic Surfaces	719/ MAS/1999	08/07/1999	211922	13/11/2007
A Process for the Preparation of Improved Alumina Based Abrasive Material, an Additive Composition and a Process for the Preparation of the Composition	122/ MAS/2000	18/02/2000	198068	16/02/2006
A Process for the Production of Dense Magnesium Aluminate Spinel Grains	520/ MAS/2000	06/07/2000	198208	16/02/2006
A Process for Preparing Ceramic Crucibles	806/ MAS/2000	26/09/2000	207700	20/06/2007
An Improved Method for Making Honeycomb Extrusion Die and a Process for Producing Ceramic Honeycomb Structure using the Said Die	538/ MAS/2001	03/07/2001	198045	13/01/2006
Device for Gas Dynamic Deposition of Powder Materials	944/ MAS/2001	22/11/2001	198651	25/01/2006
A Process for Forming Coatings on Metallic Bodies and an Apparatus for Carrying out the Process	945/ MAS/2001	22/11/2001	209817	06/09/2007
An Improved Boronizing Composition	289/ MAS/2001	03/04/2001	220370	27/05/2008
Process for Carbothermic Reduction of Iron Oxide in an Immiscible Flow with Constant Descent in Vertical Retort of Silicon Carbide	546/ CHE/2003	01/07/2003	205728	16/04/2007
An Evaporation Boat useful for Metallization and a Process for the Preparation of Such Boats	882/ CHE/2003	31/10/2003	201511	01/03/2007
A Device for Controlling the On & Off Time of the Metal Oxide Semi Conductor Field Effect Transistor (MOSFET), A Device for Spark Coating the Surfaces of Metal Workpiece Incorporating the said Control Device and a Method of Coating Metal Surfaces using the said Device	1610/ DEL/2005	21/06/2005	262189	05/08/2014
Titanium Based Biocomposite Material useful for Orthopaedic and other Implants and a Process for its Preparation	2490/ DEL/2005	14/09/2005	228353	03/02/2009
An Improved Method of Forming Holes on a Substrate using Laser Beams	3205/ DEL/2005	29/11/2005	239647	29/03/2010
An Improved Process for the Preparation of Doped Zinc Oxide Nanopowder useful for the Preparation of Varistors	1669/ DEL/2006	20/07/2006	254913	03/01/2013
A Method of and an Apparatus for Continuous Humidification of Hydrogen Delivered to Fuel Cells	670/ CHE/2007	30/03/2007	247547	19/04/2011

Indian Patents Filed

Title of Patent	Patent Application No.	Date of Filing
A Process for the Preparation of Nanosilver and Nanosilver-Coated Ceramic Powders	2786/DEL/2005	19/10/2005
Novel Ceramic Materials Having Improved Mechanical Properties and Process for their Preparation	3396/DEL/2005	19/12/2005
An Improved Process for the Preparation of Exfoliated Graphite Separator Plates useful in Fuel Cells, the Plates Prepared by the Process and a Fuel Cell Incorporating the said Plates	1206/DEL/2006	17/05/2006
An Improved Hydrophilic Membrane useful for Humidification of Gases in Fuel Cells and a Process for its Preparation	1207/DEL/2006	17/05/2006
An Improved Process for Preparing Nanotungsten Carbide Powder useful for Fuel Cells	81/DEL/2007	12/01/2007
A Hydrophilic Membrane Based Humidifier useful for Fuel Cells	95/DEL/2007	16/01/2007
Improved Fuel Cell having Enhanced Performance	606/DEL/2007	21/03/2007
An Improved Method for the Generation of Hydrogen from a Metal Borohydride and a Device Therfor	1106/DEL/2007	23/05/2007
Improved Cylindrical Magnetron Cathode and a Process for Depositing Thin Films on Surfaces using the said Cathode	21/DEL/2008	03/01/2008
Improved Electrode Membrane Assembly and a Method of Making the Assembly	631/DEL/2008	13/03/2008
An Improved Catalyst Ink useful for Preparing Gas Diffusion Electrode and an Improved PEM Fuel Cell	680/DEL/2008	18/03/2008
A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	1829/DEL/2008	01/08/2008
An Improved Gas Flow Field Plate for use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	2339/DEL/2008	13/10/2008
Improved Method of Producing Highly Stable Aqueous Nano Titania Suspension	730/DEL/2009	09/04/2009
Novel Copper Foils having High Hardness and Conductivity and a Pulse Reverse Electrodeposition Method for their Preparation	1028/DEL/2009	20/05/2009
An Improved Method for Preparing Nickel Electrodeposited having Predetermined Hardness Gradient	1455/DEL/2009	15/07/2009
An Improved Composition for Coating Metallic Surfaces, and a Process for Coating Such Surfaces using the Composition	620/DEL/2010	17/03/2010
An Improved Gas and Coolant Flow Field Plate for use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	1449/DEL/2010	22/06/2010
Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity	1835/DEL/2010	04/08/2010
Improved Method for Producing Carbon Containing Silica Aerogel Granules	2406/DEL/2010	08/10/2010
Improved Scratch and Abrasion Resistant Compositions for Coating Plastic Surfaces, a Process for their Preparation and a Process for Coating using the Compositions	2427/DEL/2010	12/10/2010
An Improved Method for Producing ZnO Nanorods	2759/DEL/2010	19/11/2010
Improved Process for the Preparation of Bi-Functional Silica Particles useful for Antibacterial and Self Cleaning Surfaces	3071/DEL/2010	22/12/2010
An Improved Method of Preparing Porous Silicon Compacts	912/DEL/2011	31/03/2011

Title of Patent	Patent Application No.	Date of Filing
An Improved Process for Preparation of Nanosilver Coated Ceramic Candle Filter	1249/DEL/2011	28/04/2011
An Improved Abrasion Resistant and Hydrophobic Composition for Coating Plastic Surfaces and a Process for its Preparation	1278/DEL/2011	02/05/2011
An Improved Method for Making Sintered Polycrystalline Transparent Sub-Micron Alumina Article	1358/DEL/2011	10/05/2011
An Improved Hybrid Methodology for Producing Composite Multilayered and Graded Coatings by Plasma Spraying Utilizing Powder and Solution Precursor Feedstock	2965/DEL/2011	17/10/2011
An Improved Composition for Solar Selective Coatings on Metallic Surfaces and a Process for its Preparation and a Process for Coating using the Composition	3324/DEL/2011	22/11/ 2011
A Process and a Multi-Piston Hot Press for Producing Powder Metallurgy Component, such as Cerametallic Friction Composite	3844/DEL/2011	28/12/ 2011
A novel Process for Produced IR Transparent Polycrystalline Alumina Article and the Article so Produced	365/DEL/2012	08/02/2012
A Process for Preparing Nanocrystalline Olivine Structure Transition Metal Phosphate Material	405/DEL/2012	14/02/2012
An Improved Aqueous Method for Producing Transparent Aluminium Oxy Nitride (ALON) Articles	1408/DEL/2012	08/05/2012
A Device for and A Method of Cooling Fuel Cells	1409/DEL/2012	08/05/2012
An Improved Solar Selective Multilayer Coating and a Method of Depositing the same	1567/DEL/2012	22/05/2012
A Novel Method for the Synthesis of Tungsten Disulphide Nanosheets	1703/DEL/2012	04/06/2012
Enhanced Thermal Management Systems for Fuel Cell Applications Using Nanofluid Coolant	1745/DEL/2012	07/06/2012
Process for Producing Anti-Reflective Coatings with Scratch Resistance Property	1777/DEL/2012	11/06/2012
Improved Method of Manufacturing Copper-Indium-Gallium Diselenide Thin Films by Laser Treatment	2084/DEL/2012	05/07/2012
Electronically and Ionically Conducting Multi-Layer Fuel Cell Electrode and a Method for Making the Same	2198/DEL/2012	17/07/2012
Fuel Cell System Equipped with Oxygen Enrichment System Using Magnet	2985/DEL/2012	25/09/2012
A High Thermal Stable Selective Solar Absorber layer with Low Emissive Barrier Coating over a Substrate and a Process of Producing the Same	3312/DEL/2012	29/10/2012
A Polymer Electrolyte Membrane (PEM) Cell and a Method of Producing Hydrogen from Aqueous Organic Solutions	3313/DEL/2012	29/10/2012
An Improved Test Control System useful For Fuel Cell Stack Monitoring and Controlling	269/DEL/2013	31/01/2013
A Novel Laser Surface Modification Technique for Hardening Steel	337/DEL/2013	06/02/2013
An Improved Solar Selective Absorber Coating with Excellent Optical Absorptance, Low Thermal Emissivity and Excellent Corrosion Resistance Property and a Process of Producing the Same	337/DEL/2013	06/02/2013
An Improved Composition for Coating Anodizable Metal Surfaces and a Process of Coating the Same	1310/DEL/2013	03/05/2013
A Method of Preparation of Supported Platinum Nano Particle Catalyst in Tubular Flow Reactor Via Polycol Process	1571/DEL/2013	24/05/2013

Title of Patent	Patent Application No.	Date of Filing
An Improved Composition for Antireflective Coating with Improved Mechanical Properties and a Process of Coating the Same	2330/DEL/2013	05/08/2013
Process for Producing Anti-Reflective Coatings With Anti-Fogging (Super Hydrophilic), UV, Weather and Scratch Resistance Properties	2919/DEL/2013	03/10/2013
An Improved Process for Obtaining a Transparent, Protective Coating on Bi-Aspheric/ Plano-Convex Lenses made of Optical Grade Plastics for use in Indirect Ophthalmoscopy	3072/DEL/2013	17/10/2013
Exfoliated Graphite Separator based Electrolyzer for Hydrogen Generation	3073/DEL/2013	17/10/2013
Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	1411/KOL/2013	13/12/2013
A Super Hydrophobic Coating with High Optical Properties having Easy to Clean Property, UV and Corrosion Resistance Properties, a Process of Preparation and Application of the Same	402/DEL/2014	12/02/2014
High Temperature Polymer Electrolyte Membrane Fuel Cells with Exfoliated Graphite based Bipolar Plates	494/DEL/2014	20/02/2014
Method of Deposition of Double Perovskite of Sr-Fe Niobium Oxide Film on a Substrate by Spray Coating Technique and the Coated Substrate Thereof	1151/DEL/2014	29/04/2014
An Improved Process to Make Coating Compositions for Transparent, UV Blocking on Glass and a Process of Coating the Same	1152/DEL/2014	29/04/2014
Method of Producing Multifunctional Self Assembled Mixed Phase Titania Spheres	3777/DEL/2014	19/12/2014
Method of Producing Porous MgF_2 Nanoparticles, Antireflection Coating Suspension and Coatings for Solar Optical UV and IR Transparent Window Applications	4041/DEL/2014	31/12/2014
A Novel Electrochemical Method for Manufacturing CIGS Thin Film Containing Nanomesh Like Structure	426/DEL/2015	16/02/2015
An Improved Performance of Nanocomposite Oxide Selective Absorber Coating with Excellent Optical and Thermal Resistant Properties and Method of Manufacturing the Same	1111/DEL/2015	22/04/ 2015
Process and Apparatus for Protection of Structural Members from Wear, Corrosion and Fatigue Damage	1839/DEL/2015	22/06/ 2015
A Method of Preparing of Anti Tarnishing Organic-Inorganic Hybrid Sol-Gel and Coating The Same	2049/DEL/2015	07/07/2015
An Improved Process for Producing Silica Aerogel Thermal Insulation Product with Increased Efficiency	2049/DEL/2015	15/07/ 2015
Solar Selective Coating For Soar Energy Collector / Absorber Tubes with Improved Performance and a Method of Producing the Same	2142/DEL/2015	15/07/ 2015
Method of Producing High Performance Visible-Light-Active Photocatalytic Materials for Self-Cleaning Applications	2625/DEL/2015	25/08/ 2015
Production of Graphene-Based Materials by Thermal Spray	2626/DEL/2015	25/08/ 2015
Method of Preparation of High Performance ZnO Varistors and Improved Compositions	2765/DEL/2015	03/09/ 2015
An Improved Coating Composition to Provide Prolonged Corrosion Protection to Anodizable Metal Surfaces and Process of Preparing the Same	3082/DEL/2015	28/09/ 2015
A Method and an Apparatus for Preparing Nickel Tungsten based Nanocomposite Coating Deposition	201611001190	13/01/2016
A Process for In-Situ Carbon Coating on Alkali Transition Metal Oxides	201611007461	03/03/2016

International Patents Filed and Granted

Title of Patent	Country	Patent Number	Date of Grant	Date of Filing	Indian Patent Details
Process for Forming Coatings on Metallic Bodies and an Apparatus for Carrying out the Process	USA	US6893551B2	17/05/2005	02/08/2002	209817
A Device for Controlling the On & Off Time of the Metal Oxide Semi Conductor Field Effect Transistor (MOSFET), A Device for Spark Coating the Surfaces of Metal Workpiece Incorporating the said Control Device and a Method of Coating Metal Surfaces using the said Device	USA	US8143550B2	27/03/2012	20/03/2006	1610/ DEL/2005
A Process for the Preparation of Nano Silver and Nano Silver-Coated Ceramic Powders	South Africa	2006/8591	30/04/2008	13/10/2006	2786/ DEL/2005
	Sri Lanka	14258	02/11/2011	17/10/2006	
	Indonesia	P-00200600616	---	18/10/2006	
	Bangladesh	233/2006	---	18/10/2006	
A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	South Africa	2009/06786	26/05/2010	30/09/2009	1829/ DEL/2008
	UK	2464378	15/05/2013	02/10/2009	
	USA	8486237	16/07/2013	14/10/2009	
	Japan	2009-237921	27/12/2013	15/10/2009	
	France	2937342	18/12/ 2015	12/10/2009	
	Germany	DE102009044256.1	---	15/10/2009	
	Brazil	PI0904232-6	---	15/10/2009	
Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity	United Kingdom	GB2496089	18/06/2014	19/07/2011	1835/ DEL/2010
	Hong Kong	13107076.7	---	18/06/2013	
An Improved Hybrid Methodology for Producing Composite, Multilayered and Graded Coatings by Plasma Spraying Utilizing Powder and Solution Precursor Feedstock	South Africa	2012/02480	---	05/04/2012	2965/ DEL/2011
	United Kingdom	1206843	---	18/04/2012	
	Canada	2784395	16/09/2014	31/07/2012	
	Brazil	102120221209	---	31/08/2012	
	Germany	102012218448.1	---	10/10/2012	
	France	1259820	---	15/10/2012	
Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	USA	15/103343	---	10/12/2014	1411/ KOL/2013
	Australia	AU2014362928A		10/12/2014	

Discontinued Indian Patents

Title	Patent Number with Date of Grant	Remarks
A Solar Cooker	184675 -25/05/2001	Discontinued from 11th Year
An Indirect Heated Catalytic Converter for use with Vehicles	185433-10/08/2001	Discontinued from 9th Year
A Process for the Preparation of Short Ceramic Fibres	186751-07/06/2002	Discontinued from 11th Year
A Process of Producing Chemically Treated Expanded Graphite and a Device having Such Graphite	187654 -05/12/2002	Discontinued from 11th Year

Journal Publications

1. L. Venkatesh, I. Samajdar, M. Tak, R.D. Doherty, G. Ravi Chandra, K.S. Prasad and S.V. Joshi, "Microstructure and Phase Evolution in Laser Clad Chromium Carbide-NiCrMoNb", Applied Surface Science, Vol. 357, p 2391-2401, 2015.
2. A. Bhaskar, M. Deepa and T.N. Rao, "Tin Disulfide Nanoflowers Versus Nanosheets as Anodes in Lithium-Ion Batteries: How the Nanostructure Controls Performance", Electrochimica Acta, Vol. 184, p 239-249, 2015.
3. A. Pathak, G. Sivakumar, D. Prusty, J. Shalini, M. Dutta, and S.V. Joshi, "Thermal Spray Coatings for Blast Furnace Tuyere Application", Journal of Thermal Spray Technology, Vol. 24(8), p 1429-1440, 2015.
4. M. Kumar, H. Singh, N. Singh, N.M Chavan, S. Kumar and S.V. Joshi, "Development of Erosion-Corrosion-Resistant Cold-Spray Nanostructured Ni-20Cr Coating for Coal-Fired Boiler Applications", Journal of Thermal Spray Technology, Vol. 24(8), p 1441-1449, 2015.
5. J.A. Sekhar, A.S. Mantri, S. Yamjala, S. Saha, R. Balamuralikrishnan and P. Rama Rao, "Ancient Metal Mirror Alloy Revisited: Quasicrystalline Nanoparticles Observed", JOM, Vol. 67, p 2976-2983, 2015.
6. K. Suresh, "A Multi-Functional Dual-Energy Laboratory Mo-Cr-SAXS System", Journal of Applied Crystallography, Vol. 48, p 2040-2043, 2015.
7. P. Karthika, N. Rajalakshmi, K.S. Dhathathreyan and D. Arivuoli, "Synthesis and Electro-Catalytic Properties of Platinum Supported on Graphene for Methanol Oxidation", Journal of Nanoscience and Nanotechnology, Vol. 15 (12), p 9746-9753, 2015.
8. M. Battabyal, B. Priyadarshini, D. Sivaprahasam, N.S. Karthiselva and R. Gopalan, "The Effect of Cu_2O Nanoparticle Dispersion on the Thermoelectric Properties of n-type Skutterudites", Journal of Physics D-Applied Physics, Vol. 48 (45), Article No. 455309, 2015.
9. K. Latha, B. Umamaheswari, K. Chaitanya, N. Rajalakshmi and K.S. Dhathathreyan, "A Novel Reconfigurable Hybrid System for Fuel Cell System", International Journal of Hydrogen Energy, Vol. 40 (43), p 14963-14977, 2015.
10. N.P. Wasekar and G. Sundararajan, "Sliding Wear Behavior of Electrodeposited Ni-W Alloy and Hard Chrome Coatings", Wear, Vol. 342, p 340-348, 2015.
11. R.Dom, P.H. Borse, K.S. Hong, S. Choi, B.S. Lee, M.G. Ha, J.P. Kim, E.D. Jeong and H.G. Kim, "Nanocrystalline Magnesium Ferrite Prepared for Photocatalytic Applications by using the Polymerized Complex Method", Journal of the Korean Physical Society, Vol. 67 (9), p 1639-1645, 2015.
12. K. Hembram, T.N. Rao, R.S. Srinivasa and A.R. Kulkarni, "High Performance Varistors Prepared from Doped ZnO Nanopowders made by Pilot-Scale Flame Spray Pyrolyzer: Sintering, Microstructure and Properties", Journal of the European Ceramic Society, Vol. 35 (13), p 3535-3544, 2015.
13. T. Arunnellaiappan, N.K. Babu, L. Rama Krishna and N. Rameshbabu, "Influence of Frequency and Duty Cycle on Microstructure of Plasma Electrolytic Oxidized AA7075 and the Correlation to its Corrosion Behavior", Surface and Coatings Technology, Vol.280, p 136-147, 2015.
14. A. Gopalakrishnan, R. Krishnan, S. Thangavel, G. Venugopal and S.J. Kim, "Removal of Heavy Metal Ions from Pharma-Effluents using Graphene-Oxide Nanosorbents and Study of their Adsorption Kinetics", Journal of Industrial and Engineering Chemistry, Vol. 30, p 14-19, 2015.
15. S.V. Joshi and G. Sivakumar, "Hybrid Processing with Powders and Solutions: A Novel Approach to Deposit Composite Coatings", Journal of Thermal Spray Technology, Vol. 24 (7), p 1166-1186, 2015.
16. G. Sivakumar, M. Ramakrishna, R.O. Dusane and S.V. Joshi, "Effect of SPPS Process Parameters on In-Flight Particle Generation and Splat Formation to Achieve Pure Alpha-Al_2O_3 Coatings", Journal of Thermal Spray Technology, Vol. 24 (7), p 1221-1234, 2015.
17. A.Srinivas Rao and S. Sakthivel, "A Highly Thermally Stable Mn-Cu-Fe Composite Oxide based Solar Selective Absorber Layer with Low Thermal Loss at High Temperature", Journal of Alloys and Compounds, Vol. 644, p 906-915, 2015.
18. A.J. London, S. Santra, S. Amirthapandian, B.K. Panigrahi, R.M. Sarguna, S. Balaji, R. Vijay, C.S. Sundar, S. Lozano-Perez and C.R.M. Grovenor, "Effect of Ti and Cr on Dispersion, Structure and Composition of Oxide Nano-Particles in Model ODS Alloys", Acta Materialia, Vol. 97, p 223-233, 2015.
19. J.M. Choi, G. Veerappan, D.H. Wang and J.H. Park, "Self-Organized Formation of Embossed Nanopatterns on Various Metal Substrates: Application to Flexible Solar Cells", Electrochimica Acta, Vol. 176, p 636-641, 2015.
20. S. Nirmala, K. Bhargavi, M.B. Suresh, R. Johnson and A.S. Joshi, "Mixing Torque Measurement - An Effective Tool for Identifying Critical Binder Volume Concentrations for Ceramic Processing", Journal of Scientific and Industrial Research, Vol.74(9), p 504-507, 2015.
21. C.L.P. Pavithra, B.V. Sarada, K.V. Rajulapati, M. Ramakrishna, G. Ravi Chandra, T.N. Rao, and G. Sundararajan, "Controllable Crystallographic Texture in Copper Foils Exhibiting Enhanced Mechanical and Electrical Properties by Pulse Reverse Electrodeposition", Crystal Growth and Design, Vol. 15(9), p 4448-4458, 2015.
22. Y. Ikuma, S. Ogoe, M. Mitsugi, K. Niwa, S. Anandan, E. Yamauchi, H. Tajiri and O. Sakata, "Surface X-Ray Diffraction Study and Photocatalytic Activity of HF-

Treated Single Crystal Rutile $TiO_2(001)$ Surface", Ionics, Vol. 21(9), p 2495-2501, 2015.

23. K. Naga Mahesh, R. Balaji and K.S. Dhathathreyan, "Studies on Noble Metal-Free Carbon-Based Cathodes for Magnesium-Hydrogen Peroxide Fuel Cells", Ionics, Vol. 21(9), p 2603-2607, 2015.

24. A. Ajay, V.S. Raja, G. Sivakumar and S.V. Joshi, , "Hot Corrosion Behavior of Solution Precursor and Atmospheric Plasma Sprayed Thermal Barrier Coatings", Corrosion Science, Vol. 98, p 271-279, 2015.

25. D. Chakravarty, C.S. Tiwary, L.D. Machado, G. Brunetto, S. Vinod, R.M. Yadav, D.S. Galvao, S.V. Joshi, G. Sundararajan and P.M. Ajayan, "Zirconia-Nanoparticle-Reinforced Morphology-Engineered Graphene-Based Foams", Advanced Materials, Vol. 27 (31), p 4534-4543, 2015.

26. A.J. Sudagar and R. Subasri, "Fabrication and Characterization of Silver/Nickel Sulphide Solar Absorber Coatings on Stainless Steel by Chemical Bath Deposition", Materials Chemistry and Physics, Vol.163, p 478-484, 2015.

27. K. Suresh, V. Chandrasekaran and R. Gopalan, "52.7 kOe High Coercivity in $Sm(Co_{0.9}Cu_{0.1})_{4.8}$ Melt-Spun Ribbons", AIP Advances, Vol. 5(7), Article No. 077118, 2015.

28. T.Mamata Reddy, B. Padya, P.K. Jain and C. H. Shilpa, "Preparation and Characterization of Graphene Nano-Platelets Integrated Polyaniline based Conducting Nanocomposites", Superlattices and Microstructures, Vol. 82, p 287-292, 2015.

29. L. Veleva, R. Schaeublin, M. Battabyal, T. Plociski and N. Baluc, "Investigation of Microstructure and Mechanical Properties of W-Y and W-Y_2O_3 Materials Fabricated by Powder Metallurgy Method", International Journal of Refractory Metals and Hard Materials, Vol. 50, p 210-216, 2015.

30. D. Chakravarty and A.H. Chokshi, "Influence of Yttria and Zirconia Additions on Spark Plasma Sintering of Alumina Composites", Journal of Materials Research, Vol. 30(8), p 1148-1156, 2015.

31. I. Ganesh, "Solar Fuels vis-a-vis Electricity Generation from Sunlight: The Current State-of-the-Art (A Review)", Renewable and Sustainable Energy Reviews, Vol. 44, p 904-932, 2015.

32. S. Kavita, U.M.R. Seelam, D. Prabhu and R. Gopalan, "On the Temperature Dependent Magnetic Properties of As-Spun Mn-Bi Ribbons", Journal of Magnetism and Magnetic Materials, Vol. 377, p 485-489, 2015.

33. K. Rajeswari, S. Chaitanya, P. Biswas, M.B. Suresh, Y.S. Rao and R. Johnson, "Binder Burnout and Sintering Kinetic Study of Alumina Ceramics Shaped using Methylcellulose", Journal of Ceramic Processing Research, Vol. 16(1), 24-31, 2015.

34. A.K. Haridas, C.S. Sharma and T.N. Rao, "Donut-Shaped $Li_4Ti_5O_{12}$ Structures as a High Performance Anode Material for Lithium Ion Batteries", Small, Vol. 11(3), p 290-294, 2015.

35. N. Padmavathi, P. Ghosal and K.K. Ray, "Solution Based Processing and Properties of Carbon Fiber Reinforced SiC + ZrO_2 Composites", Composites Science and Technology, Vol.106, p 55-59, 2015.

36. M. Nagini, R. Vijay, M. Ramakrishna, A.V. Reddy and G. Sundararajan, "Influence of the Duration of High Energy Ball Milling on the Microstructure and Mechanical Properties of a 9Cr Oxide Dispersion Strengthened Ferritic-Martensitic Steel", Materials Science and Engineering A-Structural Materials Properties Microstructure And Processing, Vol. 620, p 490-499, 2015.

37. A. Karanja, M.B. Suresh, A.K. Khanra and R. Johnson, "Synthesis, Extrusion Processing and Ionic Conductivity Measurements of Sodium Beta-Alumina Tubes", Processing and Application of Ceramics, Vol. 9(3), p 131-138, 2015.

38. P. Kathirvel, J. Chandrasekaran, D. Manoharan and S.Kumar, "Deposition and Characterization of Alpha Alumina Thin Films Prepared by Chemical Bath Deposition", Optik, Vol. 126 (19), p 2177-2179, 2015.

39. P. Ramavath, P. Biswas, P.Suresh Babu, P. Laxminarayana and R. Johnson, "Compaction Curves: A Tool for Qualitative Evaluation of Quasi-static Compaction Behavior of Ceramic Powders", Journal of the Australian Ceramic Society, Vol. 51(2), p 130-136, 2015.

40. M.K. Patil, S. Shaikh and I.Ganesh, "Recent Advances on TiO_2 Thin Film Based Photocatalytic Applications (A Review)", Current Nanoscience, Vol. 11(3), p 271-285, 2015.

41. M.S. Archana, V.V.S. Srikanth, S.V. Joshi and J. Joardar, "Influence of Applied Pressure during Field Assisted Sintering of Ti (C,N)-WC-FeAl based Nanocomposite", Ceramics International, Vol. 41, p 1986-1993, 2015.

42. P.Sarvanan, V.T.P. Vinod, M. Cermik, A. Selvapriya, D. Chakravarty and S.V. Kamat, "Processing of Mn-Al Nanostructured Magnets by SPS and Subsequent Rapid Thermal Annealing", Journal of Magnetism and Magnetic Materials, Vol. 374, p 427-432, 2015.

43. R.Kumar, D. Navadeepthy, K. Hembram, T.N. Rao and S. Anandan, "Visible Light Induced Photocatalytic Disinfection of E-Coli Pathogens with Fe^{3+} Grafted ZnO Nanoparticles", Energy and Environment Focus, Vol. 4, p 232-238, 2015.

44. R. Shabadi, M. N. Avettand-Fenoel, A. Simar, R. Taillard, P.K.Jain and R. Johnson, "Thermal Conductivity in Yttria Dispersed Copper", Materials and Design, Vol.65, p 869-877, 2015.

45. R. Subasri and H. Hima, "Investigations on the Use of Nanoclay for Generation of Superhydrophobic Coatings", Surface and Coatings Technology", Vol. 264, p 121-126, 2015.

46. G.V. Ramana, P.S. Kumar, V.V.S. Srikanth, B. Padya, and P.K. Jain, "Electrochemically Active Plyaniline (PANI) Coated Nanopipes and PANI Nanofibres Coating Composite", Journal of Nanoscience and Nanotechnology, Vol. 15(2), p 1338-1343, 2015.

47. J. Millichamp , T. J. Mason , T. P. Neville , N. Rajalakshmi , R. Jervis , P. R. Shearing , D. J.L. Brett, "Mechanisms and Effects of Mechanical Compression and Dimensional Change in Polymer Electrolyte Fuel Cells - A Review", Journal of Power Source, Vol. 284, p 305 - 320,2015.

48. C. Sanju Rani, P. H. Borse, A. Pareek, N.Rajalakshmi and K. S. Dhathathreyan , "Photo-Current Enhancement in Carbon Quantum Dots Functionalised Titania Nanotube Arrays", Journal of Nanoscience and Nanotechnology, Vol. 15, 1–6, 2015.

49. R. Imran Jafri, N. Rajalakshmi, K.S. Dhathathreyan and S. Ramaprabhu, "Nitrogen Doped Graphene Prepared by Hydrothermal and Thermal Solid State Methods as Catalyst Supports for Fuel Cell", International Journal of Hydrogen Energy, Vol. 40, p 4337-4348, 2015.

50. C. Sanju Rani and N. Rajalakshmi, "Effect of Nanotube Diameter on Photo-Electro-Chemical Properties of Carbon Quantum Dot Functionalized TiO2Nanotubes", Journal of Clean Energy Technologies, Vol. 3 (5), 367-371, 2015.

51. S.Seetharaman, S.C. Raghu, M. Velan, K. Ramya and K. A. Mahabadi, "Comparison of the Performance of Reduced Graphene Oxide and Multiwalled Carbon Nanotubes based Sulfonated Polysulfone Membranes for Electrolysis Application", Polymer Composites, Vol. 36(3), p 475-481,2015.

52. M. Sreekanth, B.V. Sarada, S.R. Dey and S.V. Joshi, "Photoelectrochemistry of Sequential Pulse Electrodeposited Cu(In,Ga)Se2Thin-Films", Journal of Power Sources, Vol. 273, p 149-157,2015.

53. N. Islavath, E. Ramasamy, D. Das and S.V.Joshi, "Spray Coated Seed Layer for Scalable Synthesis of Aligned ZnO Nanowire Arrays on FTO Substrate and their Photovoltaic Properties", Ceramics International, Vol.41, p 4118 - 4122,2015.

54. V. Medha, K. Shravan, S. Das, N. Dahotre, R. Gopalan, D. Prabhu, A. Babu, H. Choi-Yim and S. Mukherjee, "Effect of Iron on the Enhancement of Magnetic Properties for Cobalt based Soft Magnetic Metallic Glasses", Metallurgical and Materials Transaction, Vol. 46A, p 1019-1023, 2015.

55. V. Dhand, J.S. Prasad, M.V. Rao. S. Kumar, P.K. Jain and B. Sreedhar, "Hydrogen Adsorption in Flame Synthesized and Lithium Intercalated Carbon Nanofibers – A Comparative Study", Journal of Nanoscience and Nanotechnology, Vol. 15, p 742-746, 2015.

56. K. Suresh, S.M. Shariff, A.K. Singh, M. Ramakrishna, G. Padmanabham and S V Joshi, "Evolution of Texture during Laser Surface Treatment of an Austenitic Manganese Steel", Materials Characterization, Vol.102, p 29-34, 2015.

57. G. Telasang, J. D. Majumdar, G. Padmanabham and I. Manna, "Wear and Corrosion Behavior of Laser Surface Engineered AISI H13 Hot Working Tool Steel", Surface and Coatings Technology, Vol. 261, p69-78 , 2015.

58. K.Bandhopadhyay, S. K. Panda, P. Saha and G. Padmanabham, "Limiting Drawing Ratio and Deep Drawing Behavior of Dual Phase Steel Tailor Welded Blanks: FE Simulation and Experimental Validation", Journal of Materials Processing Technology, Vol. 217, p48-64, 2015.

59. G. Telasang, J.D. Majumdar, N.P. Wasekar, G. Padmanabham and I. Manna, "Microstructure and Mechanical Properties of Laser Clad and Post-cladding Tempered AISI H13 Tool Steel", Metallurgical and Materials Transactions A, Vol. 46, p 2309-2321, 2015.

60. P. Barick, B.P. Saha, R. Mitra and S.V. Joshi, "Effect of Concentration and Molecular Weight of Polyethylenimine on Zeta Potential, Isoelectric Point of Nanocrystalline Silicon Carbide in Aqueoous and Ethanol Medium", Ceramic International, Vol. 41, p 4289-4293, 2015.

61. C. Sudipto, B. Shanmugarajan, S. Ghoshal and G. Padmanabham, "Application of Integrated Soft Computing Techniques for Optimization of Hybrid CO2 Laser – MIG Welding Process", Applied Soft Computing, Vol. 30, p 365-374, 2015.

62. M. Sreekanth, B.V. Sarada, S R. Dey and S.V. Joshi, "Enhanced Photoresponse of Cu(In,Ga)Se2/CdS Heterojunction Fabricated Using Economical Non-Vacuum Methods", Electronic Materials Letters, Vol. 11 (4), p 618 -624, 2015.

63. A.C. Badgujar, Sanjay R. Dhage and S.V. Joshi, "Process Parameter Impact on Properties of Sputtered Large-Area Mo Bilayers for CIGS Thin Film Solar Cell Applications" , Thin Solid Films, Vol. 589, p 79-84, 2015.

64. R.Dom, A.C. Chary, R. Subasri, N.Y. Hebalkar and P.H. Borse, "Solar Hydrogen Generation from Spinel ZnFe2O4 Photocatalyst: Effect of Synthesis Methods", International Journal of Energy Research, Vol.39 (10), p 1378-1390, 2015.

65. P. Nehe, G. Sivakumar and S. Kumar, "Solution Precursor Plasma Spray (SPPS) Technique of Catalyst Coating for Hydrogen Production in a Single Channel with Cavities Plate Type Methanol based Microreformer", Chemical Engineering Journal, Vol. 277, p 168–175, 2015.

66. N.P. Wasekar, A. Jyothirmayi, N.Y. Hebalkar and G. Sundararajan, "Influence of Pulsed Current on the Aqueous Corrosion Resistance of Electrodeposited Zinc", Surface and Coatings Technology, Vol. 272, p 373-379, 2015.

67. L. Rama Krishna, P.S.V.N.B. Gupta and G. Sundararajan, "The Influence of Phase Gradient within the Micro Arc Oxidation (MAO) Coatings on Mechanical

and Tribological Behaviors", Surface and Coatings Technology, Vol. 269, p 54-63, 2015.

68. L. Rama Krishna, G. Poshal, A. Jyothirmayi and G. Sundararajan, "Relative Hardness and Corrosion Behavior of Micro Arc Oxidation Coatings Deposited on Binary and Ternary Magnesium Alloys", Materials and Design, Vol. 77, p 06-14, 2015.

69. M. Kumar, H. Singh, N, Singh, S-M. Hong, I-S Choi, J-Y. Suh, N.M. Chavan, S. Kumar and S.V.Joshi , "Development of Nano-Crystalline Cold Sprayed Ni–20Cr Coatings For High Temperature Oxidation Resistance", Surface and Coating Technology, Vol. 266, p 122-133, 2015.

70. N. Kaur, M. Kumar, S. K. Sharma, D. Y. Kim, S. Kumar, N.M. Chavan, S.V. Joshi, N. Singh and Harpreet Singh, "Study of Mechanical Properties and High Temperature Oxidation Behavior of a Novel Cold Spray Ni-20Cr Coating on Boiler Steels", Applied Surface Science, Vol.328, p 13-25, 2015.

71. R. Subasri, K.R.C. Soma Raju, D.S. Reddy, Neha Y. Hebalkar and G. Padmanabham, "Sol-gel Derived Solar Selective Coatings on SS 321 Substrates for Solar Thermal Applications", Thin Solid Films, Vol. 598, p 46-53, 2015.

72. P. Biswas, Y.S. Rao and R. Johnson, "Processing of Aluminium Honeycomb Catalyst Substrates and Studies on Methyl Cellulose Binder Burnout Kinetics", Journal of Advanced Catalysis Science and Technology, Vol. 02, p 38-43, 2015.

73. P. Biswas, B.L. Sindhura, C.M. Nair, P. Ramavath, M.B. Suresh and R. Johnson, " Sonochemical Sunthesis of Nano-Structured Hydrooxyapatite with Unique Morphologies and Evaluation of Sintering Kinetics", Journal of Advanced Catalysis Science and Technology, Vol. 02, p 38-43, 2015.

74. N. Rajalakshmi, B. Yamini Sarada and K. S. Dhathathreyan, "Porous Carbon Nanomaterial from Corncob as Hydrogen Storage Material", Advanced Porous Materials, Vol. 2(3), p 165-173, 2015.

75. T. Ramesh, N. Rajalakshmi and K.S. Dhathathreyan, "Activated Carbons derived from Tamarind Seeds for Hydrogen Storage", Journal of Energy Storage, Vol.4, p 89–95, 2015.

76. S.M. Shariff, K.Suresh, T.K. Pal, G.Padmanabham and S.V. Joshi, "Continuous Wave Diode Laser Surface Texturing of Austenitic and Pearlitic Steels", Materials Sciences and Applications, Vol. 6(10), p 889-906, 2015.

77. K.B Jaimy, K.Vidya, H.U.N Saraswathy, N.Y.Hebalkar and K.G.K.Warrier, "Dopant-Free Anatase Titaniumdioxide as Visible-Light Catalyst: Facile Sol-Gel Microwave Approach", Journal of Environmental Chemical Engineering, Vol 3.(2), p 1277-1286, 2015.

78. S. Bhardwaj, G. Padmanabham, K. Jain and S.V. Joshi, "Innovation Paradigms: Contractual Models for Research and Technology Organisations (RTOs)", International Journal of Technology Transfer and Commercialisation, Vol.3(3-4), p 133-153, 2015.

79. S. Bhardwaj, G. Padmanabham, K. Jain, K.S. Momaya and S.V. Joshi, "Strategic Alliance for Advanced Materials Intellectual Property Value Chain: Research and Technology Organization's Perspective", International Journal of Intellectual Property Management, Vol.8 (3-4), p 207-226, 2015.

80. S. Nirmala, N. Aruna and A.S. Joshi "Computer Control of a Thermal Cycling System", Journal of the Instrument Society of India, Vol. 45(2), p 138-139, 2015.

81. S. Chaki, Ravi N. Bathe, S.Ghosal and G. Padmanabham, "Multi-Objective Optimisation of Pulsed Nd:YAG Laser Cutting Process using Integrated ANN–NSGAII Model", Journal of Intelligent Manufacturing, 2015, doi:10.1007/s10845-015-1100-2.

82. S. Pavithra, N. Rajender, M.V. Reddy, K.Murugan and K.I. Suresh "Effect of Graphene Oxide (GO) Size and Structure on Synthesis and Optoelectronic Properties of Hybrid GO-Poly (3-Hexylthiophene) Nanocomposites", Polymer Composites, 2015. DOI 10.1002/pc.23646.

83. G.Sundararajan, S.V.Joshi and L.Ramakrishna, "Engineered Surfaces for Automotive Engine and Power Train Components", Current Opinion in Chemical Engineering, Vol. 11, p 01-16, 2016.

84. S.Singh, M. Sribalaji, N. P. Wasekar, S.V. Joshi, G. Sundararajan, R. Singh and A.K. Keshri, "Microstructural, Phase Evolution and Corrosion Properties of Silicon Carbide Reinforced Pulse Electrodeposited Nickel–Tungsten Composite Coatings", Applied Surface Science, Vol. 364, p 264–272, 2016.

85. M. Masanta, S.M. Shariff and A. Roy Choudhury, "Microstructure and Properties of TiB2–TiC–Al2O3 Coating Prepared by Laser Assisted SHS and Subsequent Cladding with Micro-/Nano-TiO2 as Precursor Constituent", Materials and Design, Vol. 90, p 307-317, 2016.

86. A.K. Das, S.M. Shariff and A.Roy Choudhury, "Effect of Rare Earth Oxide (Y2O3) Addition on Alloyed Layer Synthesized on Ti-6Al-4V Substrate with Ti+SiC+h-BN Mixed Precursor by Laser Surface Engineering", Tribology International, Vol.95, p 35-43, 2016.

87. D. Narsimhachary, Ravi N. Bathe, J. Dutta Majumdar, G. Padmanabham and A. Basu, "Microstructure and Mechanical Properties of Double Pass Laser Welds on 6061-T6 Aluminium Alloy", Lasers in Engineering, Vol. 33(1-3), p 53-66, 2016.

88. P. Anish Mathews, S. Bhardwaj, G. Padmanabham and D. Srinivasa Rao, "Patent Trends of Detonation Spray Coating Technology", Recent Patents on Mechanical Engineering, Vol. 9(1), p 09-19, 2016.

89. M. Righeira Carnegie, A. Sherine, D. Sivagami and S. Sakthivel, "Anti-Reflection Coatings with Enhanced

Abrasion and Scratch Resistance Properties", Sol-Gel Science and Technology, Vol. 78 (1), p 176-186, 2016.

90. K. Zhang, L. Wang, J. K. Kim, M. Ma, Ganapathy. V, C. L. Lee, K. J. Kong, H. Lee and J. H. Park, "An Order/Disorder/Water Junction System for Highly Efficient Co-Catalyst-Free Photocatalytic Hydrogen Generation", Energy and Environmental Science, Vol. 09, p 499-503, 2016.

91. G.M. Joshi, K. Deshmukh and P.K. Jain, "Fabrication and Excellent Dielectric Performance of Exfoliated Graphite Sheets", Journal of Nano and Electronics Physics, Vol. 8 (1), 01022, 2016.

92. P. Biswas, A. Sharma, M. Krishnan, R. Johnson and M.K.Mohan, "Fabrication of MgAl2O4 Spinel Scaffolds and Sonochemical Sunthesis and Desposition of Hydrooxyapatite Nanorods", Journal of American Ceramic Society, Vol. 11(8), p 3789-3797, 2016.

93. H.Subrmaniyam, D.Sivaprahasam, M.Battabyal and R.Gopalan, "Phase Stability and Thermoelectric Properties of Cu10.5Zn1.5Sb4S13 Tetrahedrites", Journal of Alloys and Compound, Vol.667, p 323-328, 2016.

94. R.Gautam, D. Prabhu, V. Chandrasekaran, R. Gopalan and G. Sundararajan, "Effect of Si Addition on AC and DC Magnetic Properties of (Fe-P)-Si Alloy", AIP Advances, Vol. 06, Article No. 055921, 2016.

95. K.P. Remya, D. Prabhu , S. Amirthapandian, C. Viswanathan and N. Ponpandian, "Exchange Spring Magnetic Behavior in BaFe12O19/Fe3O4 Nanocomposites", Journal of Magnetism and Magnetic Materials, Vol. 406, p 233–238, 2016.

96. B. Kakati, A. Unnikrishnan, N. Rajalakshmi, R. Imran Jafri, K.S. Dhathathreyan and A. Kucernak, "Recovery of Polymer Electrolyte Fuel Cell Exposed to Sulfurdioxide", International Journal of Hydrogen Energy, Vol. 41, p 5598-5604, 2016.

97. K. Naga Mahesh, R. Balaji and K.S. Dhathathreyan, "Palladium Nanoparticles as Hydrogen Evolution Reaction (HER) Electrocatalyst in Electrochemical Methanol Reformer", International Journal of Hydrogen Energy, Vol.41, p 46-51, 2016.

98. M. Maidhily, R. Vedarajan, K. Rajesh, H. Abe, S. Ueda, A.Dakshnamoorthy, N.Rajalakshmi, K.S. Dhathathreyan and G.V. Ramesh, "Pt Decorated Free-Standing TiO2 Nanotube Arrays: Highly Active and Durable Electrocatalyst for Oxygen Reduction and Methanol Oxidation Reactions", Journal of Nanoscience and Nanotechnology, Vol.16, p 8269-8278, 2016.

99. B.R. Moharana, S.K. Sahu, S.K. Sahoo and R. Bathe, "Experimental Investigation on Mechanical and Microstructural Properties of AISI 304 to Cu Joints by CO2 Laser", Engineering Science and Technology, Vol. 19(2), p 684-690, 2016.

100. P.Suresh Babu, R. Jha, M.Guzman, G.Sundararajan and Arvind Agarwal, "Indentation Creep Behaviour of Cold Sprayed Alumina Amorphous/ Nanocrystalline Coatings" Materials Science and Engineering A, Vol.658, p 415-421, 2016.

101. I. Ganesh, "Al and Li Co-Doping Effects on Structural, Band-Gap, And Photocatalytic Properties of Pyro-Hydrolyzed ZnO Nano-Powder", Ceramics International, Vol.42, p 10410–10421, 2016.

102. I. Ganesh, "Electrochemical Conversion of Carbon Dioxide into Renewable Fuel Chemicals - the Role of Nanomaterials and the Commercialization", Renewable and Sustainable Energy Reviews, Vol.59, p1269–1297, 2016.

103. M. Nagini, R. Vijay, Koteswararao V. Rajulapati, K. Bhanu Sankara Rao, M. Ramakrishna, A.V. Reddy and G. Sundararajan, "Effect of Process Parameters on Microstructure and Hardness of Oxide Dispersion Strengthened 18Cr Ferritic Steel", Metallurgical and Materials Transaction A, Vol.47, p 4197-4209, 2016.

104. M. Nagini, A. Jyothirmayi, R. Vijay, Tata N. Rao, A.V. Reddy, Koteswararao V. Rajulapati, and G. Sundararajan, "Influence of Dispersoids on Corrosion Behavior of Oxide Dispersion Strengthened 18Cr Steels Made by High-Energy Milling", Journal of Materials Engineering Performance, Vol. 25, p 577-586, 2016.

105. A. Bhadauria, L. K. Singh, A.R. Ballal and R. Vijay, "Effect of Yttria Dispersion on Creep Properties of Pure Iron", Transactions of Indian Institute of Metal, Vol. 69, p 253-259, 2016.

106. M. Nuthalapati, S.K.Karak, D. Chakravarty and A. Basu, "Development of Nano-Y2O3 Dispersed Zr Alloys by Mechanical Alloying and Spark Plasma Sintering", Materials Science and Engineering A, Vol. 650, p 145-153, 2016.

107. P. Barick, Dibyendu Chakravarty, B.P. Saha, R. Mitra and S.V.Joshi, "Effect of Pressure and Temperature on Densification, Microstructure and Mechanical Properties of Spark Plasma Sintered Silicon Carbide Processed with β-Silicon Carbide Nanopowder and Sintering Additives", Ceramics International, Vol. 42(3), p 3836-48, 2016.

108. P.Sahani, S.K.Karak, B.Mishra, D. Chakravarty and D. Chaira, "Effect of Al Addition on SiC-B4C Cermet Prepared by Pressureless Sintering and Spark Plasma Sintering Methods", International Journal of Refractory Metals and Hard Materials, Vol. 57, p 31-41, 2016.

109. R.Kumar, K. Singh, D. Chakravarty and A. Chowdhury, "Attaining Neat-Theoretical Densification in Nanograined Pyrochlore La2Zr2O7 (LZ) Ceramic at 1150°C by Spark Plasma Sintering", Scripta Materialia, Vol. 117, p 37-40, 2016.

110. R. Kumar, J. Joardar, R.K.S. Raman, V.S. Raja, S.V. Joshi and S. Parida, "Effect of Alloying Addition on Anisotropic and Microstructural Characteristics of Ball Milled Iron",

Journal of Alloys and Compounds, Vol. 671, p 164-169, 2016.

111. R.Maharana, V.V. Bhanu Prasad, S.Roy, D. Prasad, K.Kumar, P.Paik, N.Y. Hebalkar, A. Shukla and R. Bal, "Synthesis of High Temperature Stable Carbon Coated Metal Nanoparticles in AlPO4 Based Matrix In-Situ in Oxidative Atmosphere", Journal of the American Ceramic Society Vol. 99, p 64-71, 2016.

112. S.B. Chandrasekhar, N.P. Wasekar, M. Ramakrishna, P. Suresh Babu, T.N. Rao and B.P. Kashyap, "Dynamic Strain Ageing in Fine Grained Cu–1 wt% Al_2O_3 Composite Processed by Two Step Ball Milling and Spark Plasma Sintering", Journal of Alloys and Compounds, Vol. 656, p 423-430, 2016.

113. K. Murugan, J. Joardar, A.S.Gandhi, B.S.Murty and P.H.Borse, "Photo-Induced Monomer/Dimer Kinetics in Methylene Blue Degradation over Doped and Phase Controlled Nano-TiO2 Films", RSC Advances, Vol. 6, p 43563-43573, 2016.

114. N. Sivanandham, R. Arunachalam, S.M. Shariff and A. Mahalingam, "High Power Diode Laser Surface Melting of SUS 420F Steel: Investigations on the Microstructure and Mechanical Properties", International Journal of Surface Science and Engineering, Vol. 10(1), p 11-26, 2016.

115. A. Venugopal, J. Srinath, L. Rama Krishna, P.R. Narayanan, S.C. Sharma and P.V. Venkitakrishnan, "Corrosion and Nanomechanical Behaviors of Plasma Electrolytic Oxidation Coated AA7020-T6 Aluminum Alloy", Materials Science & Engineering A, Vol. 660, p 39-46, 2016.

116. T. Arunnellaiappan, M. Ashfaq, L. Rama Krishna and N. Rameshbabu, "Fabrication of Corrosion-resistant Al2O3-CeO2 Composite Coatings on AA7075 via Plasma Electrolytic Oxidation Coupled with Electrophoretic Deposition", Ceramic International, Vol. 42, p 5897-5905, 2016.

117. N.P. Wasekar, P.Haridoss, S.K. Seshadri and G. Sundararajan, "Influence of Mode of Electrodeposition, Current Density and Saccharin on the Microstructure and Hardness of Electrodeposited Nanocrystalline Nickel Coatings", Surface and Coatings Technology, Vol. 291, p 130-140, 2016.

118. O.S. Rahman, N.P. Wasekar, G. Sundararajan and A. K. Keshri "Experimental Investigation of Grain Boundaries Misorientations and Nano Twinning Induced Strengthening on Addition of Silicon Carbide in Pulse Electrodeposited Nickel Tungsten Composite Coatings", Materials Characterization, Vol. 116 p 01-07, 2016.

119. S.Kumar, A.Jyothirmayi, N.P. Wasekar and S.V.Joshi, "Influence of Annealing on Mechanical and Electrochemical Properties of Cold Sprayed Niobium Coatings", Surface and Coatings Technology, Vol. 296, p 124-135, 2016.

120. S.Kumar, V.Vidhyasagar, A.Jyothirmayi and S.V.Joshi, "Effect of Heat Treatment on Mechanical Properties and Corrosion Performance of Cold Sprayed Tantalum Coatings", Journal of Thermal Spray Technology, Vol. 25(4), p 745-756, 2016.

121. N. Ravi, R. Markandeya and S. V. Joshi, "Effect of Substrate Roughness on Adhesion and Tribological Behaviour nc-TiAlN/a-Si3N4 Nano Composite Coatings Deposited by Cathodic Arc PVD Process", Surface Engineering, DOI:10.1179/1743294415Y.0000000005.

122. N.Manjula, R.Balaji, K.Ramya, K.S.Dhathathereyan and A. Ramachandraiah, "Studies on Development of Titanium Oxide Nano Tube (TNT) based ePTFE–Nafion–Composite Membrane for Electrochemical Methanol Reformation", International Journal of Hydrogen Energy, 2016. DOI:10.1016/j.ijhydene.2016.02.123.

123. B. V. Sasank, N. Rajalakshmi and K. S. Dhathathreyan, "Performance Analysis of Polymer Electrolyte Membrane (PEM) Fuel Cell Stack Operated under Marine Environmental Conditions", Journal of Marine Science and Technology, 2016. DOI 10.1007/s00773-016-0369

124. S. Manasa and R. Subasri, "Effect of Heat Treatment on the Optical Properties of Sol-Gel Derived, Fully Dielectric Solar Control Coatings on Glass", Journal of Coatings Technology and Research, doi 10.1007/s11998-015-9755-3. (In Press)

125. C.L.P. Pavithra, B.V. Sarada, K.V. Rajulapati, T.N. Rao, and G. Sundararajan, "Process Optimization for Pulse Reverse Electrodeposition of Graphene-Reinforced Copper Nanocomposites" Materials and Manufacturing Processes. (In Press)

126. S. Kavita, V. V. Ramakrishna, A. Srinivasan and R. Gopalan, "Structural and Magnetic Properties of the Low Temperature Phase MnBi with Ball Milling", Material Research Express. (In Press)

127. I.Ganesh, A. Gupta, P.Kumar, G.Padmanabham and G.Sundararajan, "Influence of Cobalt Doping on Solar Light Response of TiO_2", The Journal of Physical Chemistry. (In Press)

128. I.Ganesh and G.Sundararajan, "Preparation and Characterization of Cu Doped TiO_2 Materials for Electrochemical, Photoelectrochemical and Photocatalytic Applications", Applied Surface Science. (In Press)

129. I. Ganesh, "Co_3O_4-TiO_2-Li_2O-ZnO Composite Thin Film for Efficient Electrochemical Water Oxidation Reaction", Materials and Manufacturing Processes. (In Press)

130. I. Ganesh, "Emulsion based Sol-Gel Route for High Efficient Phosphorous Doped TiO_2 Nano-Powder for Photocatalytic Methylene Blue Degradation in Water", Materials and Manufacturing Processes. (In Press)

131. I. Ganesh, "Novel Composites of β-SiAlON and Radome Manufacturing Technology Developed at ARCI,

Hyderabad, for Hypervelocity Vehicles - A Critical Analysis", Bulletin of Materials Science. (In Press)

132. I. Ganesh, "Utilization of Waste-Stream Greenhouse Carbon Dioxide: Direct Uses and Feedstock for Energy Storage, Fine, Bulk and Renewable Fuel Chemicals Synthesis", Journal of CO2 Utilization. (In Press)

133. C. Sanju Rani, N. Rajalakhsmi, R.Vedarajan, N. Matsumi and K.S. Dhathatreyan "Effect of Binders on the Graphene Based Anode in Li-Ion Rechargeable Battery" Graphene. (In Press)

134. P.Sahani, S.K.Karak, B.Mishra, D.Chakravarty and D. Chaira, "A Comparative Study on SiC-B4C-Si Cermet Prepared by Pressureless Sintering and Spark Plasma Sintering Methods", Metallurgical and Materials Transactions A. (In Press)

135. S.Kumar, S.K. Reddy and S.V.Joshi, "Microstructure and Performance of Cold Sprayed Al-SiC Composite Coatings with High Fraction of Particulates", Surface and Coatings Technology-Sp. Issue. (In Press)

136. S. Kumar, V. Vidyasagar, A. Jyothirmayi and S.V. Joshi, "Effect of Heat Treatment on Mechanical Properties and Corrosion Behaviour of Cold sprayed Tantalum Coatings", Journal of Thermal Spray Technology. (In Press)

Conference Proceedings

1. P. Panda, B. Sravani, R. Ramaseshan, N. Ravi, F. Jose, S. Dash and A.K. Tyagi, "Growth and Characterization of Highly Oriented AlN Films by DC Reactive Sputtering" AIP Conference Proceedings, DAE-SSPS 2014, Vellore, Tamilnadu, Vol. 1665, Article. No. 80064, 2015.

2. Y. Markandeya, Y.S. Reddy, A.M. Devi, K. Suresh and G. Bhikshamaiah, "Effect of Ga Doping on Structural, Magnetic and Transport Properties of Ordered Ba_2FeMoO_6 Double Perovskite", IOP Conference Series-Materials Science and Engineering: International Conference on Materials Science and Technology (ICMST 2012), Kerala, Vol. 73, Article No. 12097, 2015.

3. A.C. Badgujar, K. Madhuri, S. Garner, S. R. Dhage and S.V. Joshi, "Non-Vacuum Route for CIGS Thin Film Absorber on Flexible Glass Substrates", Proceedings of the 42nd IEEE Photovoltaic Specialist (PVSC) Conference 2015, New Orleans, USA. DOI: http://dx.doi.org/10.1109/PVSC.2015.7356105.

4. V. A. Naidu, V. Rajashekar Reddy, R. Sudhakar Rao, M.B. Suresh, I.M. Chhabra and P. Kistaiah "Studies on Preparation and Characterization of NIR Antireflection Thin Films", Materials Today: Proceedings – 4th International Conference on Materials Processing and Characterization (ICMPC 2015), Hyderabad, Vol. 2 (4-5), p 1533–1540, 2015.

5. M.V.L. Ramesh, P. Srinivasa Rao, V. Venkateswara Rao and K. V. Phani Prabhakar, "Structure – Properties Evaluation in Laser Beam Welds of High Strength Low Alloy Steel", Materials Today: Proceedings – 4th International Conference on Materials Processing and Characterization (ICMPC 2015), Hyderabad, Vol. 2 (4-5), p 2532–2537, 2015.

6. V.V.N. S. Suresh, S.P Regalla, A.K. Gupta and G. Padmanabham "Weld Line Shift in the Case of Tailor Welded Blanks Subjected to Differential Strengths with Respect to TIG and Laser Welding", Materials Today: Proceedings - 4th International Conference on Materials Processing and Characterization (ICMPC 2015), Hyderabad, Vol. 2 (4-5), p 3501-3510, 2015.

7. K.R.C. Soma Raju, A. Jyothirmayi, L. Rama Krishna and R. Subasri, "Corrosion Behaviour of Anodized and Sol-Gel Duplex Coatings on Aluminum", Proceedings of International Conference and Exhibition on Corrosion (CORCON 2015), Chennai, Paper No CL-09, 2015.

8. L.Subashini, K.V. Phani Prabhakar, S. Ghosh and G. Padmanabham, "Laser Arc Hybrid Welding of 10mm Thick Maraging Steel Plate – A Comparison with Multi-Pass MIG Welding", Proceedings of the 2nd International Conference on Advances in Cutting, Welding and Surfacing, p 77-87, 2015.

9. K.R.C.Soma Raju, D. Rama Supriya, D.Sreenivas Reddy, A. Jyothirmayi and R. Subasri, "Investigations on Corrosion Resistance of Sol-Gel Derived Nanocomposite Coatings on Stainless Steel", Proceedings of 18th National Congress on Corrosion Control 2016, Chennai, 2016.

Books Chapters

1. A chapter on "Sol-Gel Nanocomposite Hard Coatings" authored by K.R.C. Soma Raju and R. Subasri in the 'Handbook on Anti-Abrasive Nanocoatings: Current and Future Applications', (ed.) M . Aliofkhazraei, Woodhead Publishers, UK., p 105-136, 2015.

2. A chapter on "Improving Corrosion Resistance of Metals/Alloys using Hybrid Nanocomposite Coatings Synthesized through Sol-Gel Processing" authored R. Subasri in the book on 'Comprehensive Guide for Nanocoatings Technology: Properties and Development', (ed.) M. Aliofkhazraei, Nova Science Publishers Inc., New York, USA. Vol. 3, p 123-142, 2015.

3. A chapter on "Nano Manufacturing for Aerospace Applications" authored by S. Anandan, Neha Hebalkar, B. V. Sarada and Tata N. Rao in the 'Source Books from the Book Series of Indian Institute of Metals (IIM) on Aerospace Materials and Technologies', (ed.) N. Eswara Prasad and RJH Wanhill Springer, Vol.2, Chapter 5, 2016.

4. A chapter on, "Nanomaterials for the Conversion of Carbon Dioxide into Renewable Fuels and Value Added Products" authored by I. Ganesh in the book on 'Nanotechnology for Energy Sustainability' (ed.)

Marcel Van De Voorde, Baldev Raj, and Yashwant Mahajan, Wiley-VCH Verlag GmbH, Germany. (In Press)

5. A chapter on "Techno-Commercial Opportunities of Nanotechnology in Wind Energy" authored by V. Patel and Y.R. Mahajan in the book on 'Nanotechnology for Energy Sustainability' (ed.), Marcel Van De Voorde, Baldev Raj, and Yashwant Mahajan, Wiley-VCH Verlag GmbH, Germany. (In Press)

6. A chapter on "Nanomaterials for Li-Ion Batteries: Patents Landscape and Product Scenario" authored by Md. Shakeel Iqbal, C.K.Nisha, Vivek Patel and Ratnesh K. Gaur in the book on 'Nanotechnology for Energy Sustainability', (ed.) Marcel Van De Voorde, Baldev Raj, and Yashwant Mahajan, Wiley-VCH Verlag GmbH, Germany. (In Press)

7. A chapter on "Nanotechnology in Fuel Cells: A Bibliometric Analysis" authored by M. Sinha, Ratnesh .K. Gaur and H. Karmarkar in the book on 'Nanotechnology for Energy Sustainability', (ed.) Marcel Van De Voorde, Baldev Raj, and Yashwant Mahajan, Wiley-VCH Verlag GmbH, Germany. (In Press)

8. A chapter on "Detonation Sprayed Coatings for Aerospace Applications" authored by D. Srinivasa Rao, L. Rama Krishna and G. Sundararajan in the book on 'Aerospace Materials and Technologies', (ed.) Baldev Raj, Eeswar Prasad, Pubs: Indian Institute of Metals, 2016. (In Press)

9. A chapter on "Wear and Corrosion Protection of Aluminum and its Alloys through Micro Arc Oxidation Coatings" authored by L. Rama Krishna and G. Sundararajan in the book on 'Encyclopedia of Aluminum and its Alloys', (eds.): George E. Totten, Olaf Kessler, Murat Tiryakioglu, Taylor & Francis Publishers, 2016. (In Press)

Articles

1. Ratnesh K. Gaur, "Ultrafast Rechargeable Lithium Ion Batteries (LIBS): The Need of the Day", Nanotech Insights, Vol. 6 (4), p 11-19, 2015.

2. B. Padma Bhavani, "Implications of Nanotechnology to Address Major Sanitation Challenges in India", Nanotech Insights, Vol. 6 (4), p 20-25, 2015.

3. K. Sambasivudu, "Nanotechnology-based Salt Water Desalination: A Worldwide Patent Scenario", Nanotech Insights, Vol. 6 (4), p 36-42, 2015.

4. Vivek Patel, "Patenting Trends in Nanotechnology by Indian Organizations", Nanotech Insights, Vol. 6 (4), p 32-35, 2015.

5. C.K. Nisha and Ratnesh K. Gaur, "Quantum Dot Enabled Backlighting for Liquid Crystal Displays: Emerging Technologies and Products", Nanotech Insights, Vol. 6 (3), p 02-08, 2015.

6. Vivek Patel, "The Impact of Nanotechnology on Wind Energy: A Long Term Emerging Market", Nanotech Insights, Vol. 6 (3), p 09-12, 2015.

7. K. Sambasivudu, "Nanotechnology-based Waterproof Coatings for Effective Protection of Electronic Gadgets", Nanotech Insights, Vol. 6 (3), p 13-18, 2015.

8. B. Padma Bhavani, "Medical 3D printing - A Paradigm for Personalized Healthcare", Nanotech Insights, Vol. 6 (3), p 19-27, 2015.

9. Vivek Patel, "A Patent Portfolio Report of Indigenous Indian Assignees on Graphene", Nanotech Insights, Vol. 6 (3), p 33-35, 2015.

10. K. Sambasivudu, "Worldwide Patent Scenario on Applications of Sol-Gel Nanocoatings for Automotive Industry", Nanotech Insights, Vol. 6 (3), p 36-41, 2015.

11. Vivek Patel, "Global Status of Commercially Available Graphene-Enabled End-Use Products", Nanotech Insights, Vol. 6 (2), p 18-21, 2015.

12. B. Padma Bhavani, "Biosensors Incorporating Nanotechnology in the Diagnosis of Viral Diseases", Nanotech Insights, Vol. 6 (2), p 22-26, 2015.

13. I. Ganesh, "Cobalt Oxide based Nano-Structured Thin Film Electrocatalyst for Efficient and Stable Water Oxidation Catalysis", Nanotech Insights, Vol. 7 (2), p 02-10, 2016.

14. A. Harish Kumar, T. Puneeth and J. Joardar, "Nanostructured 2D-Transition Metal Sulfides: Synthesis and Applications", Nanotech Insights, Vol.7, p 02-08, 2016.

15. C.K. Nisha and Y.R. Mahajan, "Nanocrystalline Structure – The Secret Behind Unique Properties of Aranmula Metal Mirror", Nanotech Insights, Vol. 7 (2), p 37-41, 2016.

16. C.K. Nisha and Y.R. Mahajan, "Birth and Early History of Carbon Nanotubes", Nanotech Insights, Vol. 7 (1), p 16-21, 2016.

17. V.D. Udayasri, "Nanocellulose – A Vital Boon for Advanced Biomedicine", Nanotech Insights, Vol. 7 (1), p 22-27, 2016.

18. Vivek Patel, "Nano S&T Publications 2015: Global Overview Including Comparisons with India", Nanotech Insights, Vol. 7 (1), p 37-40, 2016.

19. Ratnesh K. Gaur, "Bottom-Up Approaches for Nanoelectronics Fabrication", Nanotech Insights, Vol. 7 (2), p 19-24, 2016.

20. B. Padma Bhavani and V.D.Udayasri, "Nanotechnology based Novel Drug Delivery Systems", Nanotech Insights, Vol. 7 (2), p 25-32, 2016.

21. D. Ajay and Md. Shakeel Iqbal, "Global Nanotechnology Trends in Vaccine Development: A Comprehensive Patent Landscape Analysis", Nanotech Insights, Vol. 7 (2), p 42-48, 2016.

Awards and Honours

1. Dr. G. Sundararajan received the 'MRSI Distinguished Materials Scientist Award-2016'.

2. Dr. G. Padmanabham was awarded the 'Fellow of the Institution of Engineers (India)-2015'.

3. Dr. Sanjay Bhardwaj's doctoral research work on "Developing a Commercialization Model for the Advanced Materials Technology Sector in the Indian Context" has been chosen as 'Highly Commended Award Winner' by International Journal of Operations and Production Management (IJOPM) under the category of Operations and Production Management in the 2015 Emerald/EFMD Outstanding Doctoral Research Awards. IJOPM is one of the leading journals in the world in the field of Operations Management. Ph.D. degree for the above work was awarded by IIT-Bombay in the year 2014.

4. Dr. Malobika Karanjai has been selected as the 'Editorial Board Member of the Journal- Transactions of Powder Metallurgy Association of India' in 2015.

5. Dr. P. K. Jain was elected the 'Joint Secretary of Indian Carbon Society' for the period 2016-18 on January 08, 2016 at New Delhi.

6. Dr. Malobika Karanjai has been elected as the 'Governing Council Member' by Powder Metallurgy Association of India (PMAI) for the year 2016-17.

7. Mr. Sreekanth Mandati (Dr. B. V. Sarada) received the 'Dr. K. V. Rao Scientific Society's Young Scientist Award' for outstanding achievement in Chemistry (Allied Sciences) for the year 2014-15 on May 23, 2015.

8. Ms. L. Subashini (Dr. G. Padmanabham) received 'First Prize' for the 'Best Poster Presentation' on "Laser-MIG Hybrid Welding of 12 mm Thick Reduced Activation Ferritic Martensitic Steel [RAFMS]" at the 'Workshop on Advances in Materials Joining Technologies (AMJT 2015) on May 29, 2015.

9. Dr. Tata Narasinga Rao was elected as 'APAM Academician 2015' at the General Assembly of Asia-Pacific Academy of Materials (APAM), according to Article 3 of APAM constitution, held in Singapore on July 02, 2015.

10. Ms. L. Subashini (Dr. G. Padmanabham) received the 'Best Oral Presentation Award' for the paper on "Laser Arc Hybrid Welding of 10 mm Thick Maraging Steel Plate – A Comparison with Multi-Pass MIG Welding" at the '2nd International Conference on Advances in Cutting, Welding and Surfacing' held at Coimbatore during August 05-07, 2015.

11. Mr. Sreekanth Mandati (Dr. B. V. Sarada) received the 'INAE Innovation Project Award' under Doctoral Category for the year 2015 at New Delhi during September 2015.

Dr. Tata Narasinga Rao receiving the 'APAM Academician 2015' Award

12. Mr. D. Nazeer Basha (Dr. Ravi Bathe) received the 'Second Prize for the Best Poster Presentation' on "Laser Surface Micro Texturing of Cast Iron" at the 'International Conference on Application of Lasers in Manufacturing (CALM2015)' held at New Delhi during September 09-11, 2015.

13. Dr. R. Easwaramoorthi was awarded the 'Dr. APJ Abdul Kalam Gold Medal' by GEPRA, New Delhi on October 15, 2015.

14. Dr. Sathiya Mariappan was nominated as one of the six finalists for 'Science Award Electrochemistry' organised by BASF-Volkswagen at Tokyo, Japan during October 28-29, 2016.

15. Dr. S. Sakthivel was awarded the 'Bharat Jyoti Award' by the India International Friendship Society, New Delhi on October 26, 2015.

16. Dr. S. Sakthivel was awarded the 'Glory of India Gold Medal' by the International Success Awareness Society, New Delhi on October 26, 2015.

17. Mr. K. Nanaji (Dr. Srinivasan Anandan) received the 'Best Oral Presentation Award' for the paper on "Ordered Mesoporous Carbon as an Efficient Anode Material for Lithium Ion Battery Application" at the 'National

Dr. S Sakthivel receiving the Award

Conference on Carbon Materials 2015 (NCCM 2015)' held at New Delhi during November 26-28, 2015.

18. Dr. Manjusha Battabyal received the 'Elsevier Reviewer Recognition Award' from Fusion Engineering and Design Journal (Elsevier, Amsterdam, The Netherlands) on November 30, 2015

19. Dr. S. Sakthivel received the 'Who's Who in Science and Engineering Award (2016)' – From Marquis Who's Who Publication Board on December 14, 2015.

20. Mr. V. V. N. Phanikumar (Dr. R. Prakash) received the 'Best Poster Award' for the poster on "Effect of Polyvinyl Alcohol and Sodium Alginate Binders on Lithium Titanium Oxide Anode for Lithium Ion Batteries" at the 'National Conference on Frontiers in Chemical Sciences and Technologies (FCST)' held at NIT-Warangal during January 28-29, 2016.

21. Dr. Sanjay R. Dhage received the 'Elsevier Reviewer Recognition Award' from Solar Energy Materials and Solar Cells - Journal (Elsevier, Amsterdam, The Netherlands) during March 2016.

Mr. VVN Phanikumar receiving the 'Best Poster Award'

22. Ms. A. Yamini (Dr. Neha Hebalkar) received the 'Best Poster Award' for the poster on "Titania Microspheres for Self Cleaning Textile Applications: One More Step towards Make-in-India" at the '8th Bangalore Nano Conference' held at Bengaluru during March 03-04, 2016.

Ms. A Yamini receiving award for 'Best Poster'

23. ARCI received 'Best Exhibitor Award' in the category of 'Creative Design' at the '8th Bangalore Nano Conference' held at Bengaluru during March 03-04, 2016.

Dr. Tata Narasinga Rao receiving the 'Best Exhibitor Award' for ARCI Stall

ARCI Exhibition Stall at the 8th Bangalore Nano Conference

PERSONNEL
(as on March 31, 2016)

DIRECTOR

Dr. G Sundararajan (upto 31/12/2015)

DIRECTOR-IN-CHARGE

Dr. G Padmanabham (from 01/01/2016)

ADDITIONAL DIRECTOR

Dr. Shrikant V Joshi (upto 31/07/2015)

ASSOCIATE DIRECTORS

Dr. G Padmanabham (upto 31/12/2015)
Dr. K S Dhathathreyan (upto 29/01/2016)
Dr. Raghavan Gopalan (from 03/08/2015)
Dr. Tata Narasinga Rao (from 03/08/2015)

SCIENTISTS

Dr. Roy Johnson, Scientist 'G'
Dr. G Ravi Chandra, Scientist 'F'
Dr. Pawan Kumar Jain, Scientist 'F'
D Srinivasa Rao, Scientist 'F'
Dr. N Rajalakshmi, Senior Scientist
Dr. R Vijay, Scientist 'F'
V Balaji Rao, Scientist 'F'
Dr. R Subasri, Scientist 'F'
Dr. Bhaskar Prasad Saha, Scientist 'F'
Dr. Pramod H Borse, Scientist 'F'
Dr. L Rama Krishna, Scientist 'F'
Dr. Y Srinivasa Rao, Scientist 'F'
N Ravi, Scientist 'E'
Dr. S Sakthivel, Scientist 'E'
Dr. Malobika Karanjai, Scientist 'E'
Dr. Sanjay Bhardwaj, Scientist 'E'
Dr. I Ganesh, Scientist 'E'
Dr. Joydip Joardar, Scientist 'E'
Dr. G Siva Kumar, Scientist 'E'
Shakti Prakash Mishra, Scientist 'E'
K V Phani Prabhakar, Scientist 'E'
Dr. B V Sarada, Scientist 'E'
Dr. D Siva Prahasam, Scientist 'E'
Dr. S M Shariff, Scientist 'E'
Dr. Ravi N Bathe, Scientist 'E'
Dr. R Prakash, Scientist 'E'
S B Chandrasekhar, Scientist 'E'
Dr. Neha Y Hebalkar, Scientist 'E'
Dr. K Suresh, Scientist 'E'
Dr. Sanjay R Dhage, Scientist 'D'
Dr. Nitin P Wasekar, Scientist 'D'
Dr. Dibyendu Chakravarty, Scientist 'D'
Kaliyan Hembram, Scientist 'D'
Dr. K Murugan, Scientist 'D'
Dr. Dulal Chandra Jana, Scientist 'D'
Dr. K. Ramya, Senior Scientist
Dr. Krishna Valleti, Scientist 'D'
Dr. M Buchi Suresh, Scientist 'D'
Ms. S Nirmala, Scientist 'D'
R Senthil Kumar, Scientist 'D'
Dr. P Suresh Babu, Scientist 'D'
Dr. Srinivasan Anandan, Scientist 'D'
S Sudhakara Sarma, Scientist 'D'
Dr. R Easwaramoorthi, Scientist 'D'
Dr. S Kumar, Scientist 'D'
Ms. Priya Anish Mathews, Scientist 'D'
Prasenjit Barick, Scientist 'D'
Manish Tak, Scientist 'D'
Naveen Manhar Chavan, Scientist 'D'
M Ramakrishna, Scientist 'D'
Balaji Padya, Scientist 'D'
Ms. Papiya Biswas, Scientist 'D'
Dr. Gururaj Telasang, Scientist 'D'
Ms. J Revathi, Scientist 'C'
Arun Seetharaman, Scientist 'C'
Pandu Ramavath, Scientist 'C'
R Vijaya Chandar, Scientist 'C'
Dr. M B Sahana, Scientist
Dr. D Prabhu, Scientist 'C'
Dr. R Balaji, Scientist
Dr. Sathiya Mariyappan, Scientist
L Venkatesh, Scientist 'B'
Ms. K Divya, Scientist 'B'

TECHNICAL OFFICERS

Debajyoti Sen, Technical Officer 'D'
K R C Somaraju, Technical Officer 'D'
Ms. A Jyothirmayi, Technical Officer 'D'
Ms. V Uma, Technical Officer 'D'
G Venkata Ramana Reddy, Technical Officer 'C'
V C Sajeev, Technical Officer 'C'
P Rama Krishna Reddy, Technical Officer 'C'
V Mahender, Technical Officer 'C'
K Srinivasa Rao, Technical Officer 'C'
Ch. Sambasiva Rao, Technical Officer 'C'
D Sreenivas Reddy, Technical Officer 'B'
C Karunakar, Technical Officer 'B'
M Srinivas, Technical Officer 'B'
Ms. B V Shalini, Technical Officer 'B'
N Venkata Rao, Technical Officer 'B'
M Srihari, Technical Officer 'B'
J Nagabhushana Chary, Technical Officer 'B'
A Raja Shekhar Reddy, Technical Officer 'B'
A R Srinivas, Technical Officer 'B'
E Anbu Rasu, Technical Officer 'A'
S Sankar Ganesh, Technical Officer 'A'
K Naresh Kumar, Technical Officer 'A'
M Ilaiyaraja, Technical Officer 'A'
P V V Srinivas, Technical Officer 'A'
K Ramesh Reddy, Technical Officer 'A'
Ms. N Aruna, Technical Officer 'A'

R Anbarasu, Technical Officer 'A'
M R Renju, Technical Officer 'A'

TECHNICAL ASSISTANTS

J Shyam Rao, Technical Assistant 'A'

TECHNICIANS

D Krishna Sagar, Technician 'D'
K V B Vasantha Rayudu, Technician 'D'
G Venkata Rao, Technician 'D'
E Konda, Technician 'D'
A Sathyanarayana, Technician 'D'
B Venkanna, Technician 'D'
P Anjaiah, Technician 'C'
K Subba Rao, Technician 'C'
D P Surya Prakash Rao, Technician 'C'
A JayaKumaran Thampi, Technician 'C'
D Kutumba Rao, Technician 'C'
B Subramanyeswara Rao, Technician 'C'
K Vigneswara Rao, Technician 'C'
G Venkat Reddy, Technician 'C'
K Satyanarayana Reddy, Technician 'C'
Kurra Venkata Ramana, Technician 'C'
A Praveen Kumar, Technician 'C'
J Venkateswara Rao, Technician 'C'
A Ramesh, Technician 'C'
A Janga Reddy, Technician 'C'
Ch Venkateswara Rao, Technician 'C'
B Hemanth Kumar, Technician 'C'
Govinda Kumar, Technician 'C'
M Satyanand, Technician 'C'
A Jagan, Technician 'C'
Sushanta Mukhopadhyay, Technician 'C'
P. Suri Babu, Technician 'B'
G Anjan Babu, Technician 'B'
Prabir Kumar Mukhopadhyay, Technician 'B'
Shaik Ahmed, Technician 'B'
K Ashok, Technician 'B'
E Yadagiri, Technician 'B'
I Prabhu, Technician 'B'
D Manikya Prabhu, Technician 'B'
S Narsing Rao, Technician 'B'
Ch Jangaiah, Technician 'B'
Mothe Lingaiah, Technician 'A'
Aan Singh, Technician 'A'

CHIEF FINANCE & ACCOUNTS OFFICER

R Vijay Kumar

CHIEF ADMIN. & PERSONNEL OFFICER

R Prabhakara Rao (up to 30/06/2015)

STORES & PURCHASE OFFICER

N Srinivas

STAFF OFFICER TO DIRECTOR

P Nagendra Rao

SECURITY, FIRE & SAFETY OFFICER

S Kalyanaraman (on deputation)

OFFICER (ADMIN & PERSONNEL)

A Srinivas

OFFICERS

Anirban Bhattacharjee, Officer 'B'
G M Raj Kumar, Officer 'B'
Ms. N Aparna Rao, Officer 'B'
Y Krishna Sarma, Officer 'B'
G Ramesh Reddy, Officer 'B'
P Venugopal, Officer 'A'
B Uday Kumar, Officer 'A'
Venkata Ramana Pothuri, Officer 'A'
Ms. P Kamal Vaishali, Officer 'A'
P Dharma Rao, Officer 'A'
G Gopal Rao, Officer 'A'

ASSISTANTS

Ms. K Shakunthala, Assistant 'B' (MACP)
T Venu, Assistant 'B'
B Laxman, Assistant 'B'
Ms. Rajalakshmi Nair, Assistant 'B'
Ravi Singh, Assistant 'B'
Ms. K Madhura Vani, Assistant 'B'
Narendra Kumar Bhakta, Assistant 'B'
J Bansilal, Junior Assistant (MACP)
V Sreekanth, Assistant 'A'
B Venkatesham, Assistant 'A'
Ramavathu Ranga Naik, Assistant 'A'
P Sai Kishore, Assistant 'A'

DRIVERS

Md Sadiq, Driver 'C'
P Ashok, Driver 'B'
T Satyanarayana, Driver 'B' (MACP)
M A Fazal Hussain, Driver 'B'

LAB ASSISTANTS

Roop Singh, Lab Assistant 'C'
Gaje Singh, Lab Assistant 'C'
Hussain Ali Khan, Lab Assistant 'C'

HINDI TRANSLATOR (ON CONTRACT)

Ms. Rambha Singh

CONSULTANTS

Dr. Y R Mahajan
Arun Joshi
Dr. A Venugopal Reddy
A Sivakumar
Dr. T G K Murthy
Dr. Madhusudhan Sagar
Dr. V Chandrasekharan
Suresh Prasad Sarma
T Panduranga Rao
M V Bhargavan
Dr. S Venugopalan
Dr. K Satya Prasad
Prof. V V Kutumba Rao
Dr. D Yogeswara Rao
T Satyanarayana
K R A Nair

Financial Report

ANANT RAO & MALLIK
CHARTERED ACCOUNTANTS
B-310, Kushal Towers
Khairatabad
Hyderabad - 500 004

Date: 26.09.2016

INDEPENDENT AUDITORS' REPORT

The Governing Council, **INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY & NEW MATERIALS (ARCI),** Hyderabad

REPORT ON THE FINANCIAL STATEMENTS

We have audited the accompanying financial statements of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) ("the Society"), which comprise the statement of affairs as at March 31, 2016, the Income and Expenditure Account and Receipts and Payments Account for the year then ended and summary of the significant accounting policies and other explanatory notes.

Management's Responsibility for the financial Statements:

Governing Body of the society is responsible for preparation of these financial statements of the Society in accordance with the Generally Accepted Accounting Principles in India (GAAP) and the significant accounting policies stated in financial statements. This responsibility also includes maintenance of adequate accounting records for safeguarding the assets of the society and for preventing and detecting frauds and other irregularities; selection and application of appropriate accounting policies; making judgments estimates that are reasonable and prudent; and design, implementation and maintenance of adequate internal financial controls, that were operating effectively for ensuring the accuracy and completeness of the accounting records, relevant to the preparation and presentation of the financial statements, that are free from the material misstatement, whether due to fraud or error.

Auditor's Responsibility:

Our responsibility is to express an opinion on these financial statements based on our audit. We conducted our examination in accordance with the Standards on Auditing issued by the Institute of Chartered Accountants of India. Those Standards require that we comply with ethical requirements and plan and perform the examination to obtain reasonable assurance about whether financial statements are free from material misstatements.

Examination of financial statements involves performing procedures to obtain audit evidence about the amount of disclosures in the financial statements. The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal control relevant to the society's preparation and fair presentation of the financial statements in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on effectiveness of the entity's internal control. An audit also includes evaluating the appropriateness of the accounting policies used and the reasonableness of the accounting estimates made by the Management, as well as evaluating the overall presentation of the financial statements.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

Opinion:

In our opinion and to the best of our information and according to the explanations given to us, the aforesaid financial statements of the Society for the year ended March 31, 2016 are prepared in all material aspects, in accordance with Generally Accepted Accounting Principles in India (GAAP) and the significant accounting policies stated in Note 24 to the Financial Statements.

Other Matters:

a) In our opinion, proper books of accounts as required by the law have been kept by the Society so far as it appears from our examination of those books.

b) The Statement of Affairs, the Income and Expenditure Accounts, and Receipts and Payments accounts dealt with by this report are in agreement with the books of accounts.

For **ANANT RAO & MALLIK**
Chartered Accountants
Firm's Registration No. 006266S

Sd/-
V ANANT RAO
Partner
Membership No. 022644

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
ARC INTERNATIONAL FUND (OPERATIONAL) BALANCE SHEET AS AT 31.03.2016

(Amount in Rs.)

GRANTS-IN-AID: FUND AND LIABILITIES	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
GRANTS-IN-AID	1	1524931889	1541040467
RESERVES AND SURPLUS	2	0	0
EARMARKED/ENDOWMENT FUNDS	3	0	0
SECURED LOANS AND BORROWINGS	4	0	0
UNSECURED LOANS AND BORROWINGS	5	0	0
DEFERRED CREDIT LIABILITIES	6	0	0
CURRENT LIABILITIES AND PROVISIONS	7	173355512	144960910
TOTAL		**1698287401**	**1686001377**
ASSETS			
FIXED ASSETS	8	1277610988	1287440196
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUND	9	0	0
INVESTMENTS - OTHERS	10	0	0
CURRENT ASSETS, LOANS, ADVANCES ETC.	11	420676413	398561181
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)		0	0
TOTAL		**1698287401**	**1686001377**
SIGNIFICANT ACCOUNTING POLICIES	24		
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25		

AS PER OUR REPORT OF EVEN DATE
for **M/s. ANANT RAO & MALLIK**
Chartered Accountants
Firm Registration No. 006266S

Sd/-
V Anant Rao
Partner, Membership No. 022644

Sd/-
R. Vijay Kumar
Chief Finance & Accounts Officer

Sd/-
Dr. G Padmanabham
Director In-Charge

Date: 26/09/2016
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INCOME AND EXPENDITURE ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2016

(Amount in Rs.)

	SCHEDULE		CURRENT YEAR		PREVIOUS YEAR
INCOME					
Income from Sales/Services	12		0		0
Grants/Subsidies	13		0		0
Fees/Subscriptions	14		0		0
Income from Investments (Income on Investments from earmarked/endowment funds)	15		0		0
Income from Royalty, Publications etc.	16		0		0
Interest Earned	17		18597198		23868182
Other Income	18		26272201		5082450
Increase/(decrease) in stock of finished goods and work-in-progress	19		0		0
TOTAL (A)			**44869399**		**28950632**
EXPENDITURE					
Establishment Expenses	20		238492376		199227837
Other Expenses	21		153316236		129892418
Expenditure on Grants/Subsidies	22		650171		0
Interest	23		0		0
Depreciation (Net Total at the year-end: corresponding to Schedule 8) Less : Transferred to Grants-in-Aid		138519195 138519195	0	153702806 153702806	0
TOTAL (B)			**392458783**		**329120255**
Balance being excess of Income over Expenditure (A-B) Transfer to Special Reserve [specify each] Transfer to/from General Reserve			(347589384)		(300169623)
BALANCE being Excess of Expenditure over Income - Transfer to Grants-in-Aid			(347589384)		(300169623)
SIGNIFICANT ACCOUNTING POLICIES	24				
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25				

AS PER OUR REPORT OF EVEN DATE
for **M/s. ANANT RAO & MALLIK**
Chartered Accountants
Firm Registration No. 006266S
Sd/-
V Anant Rao
Partner, Membership No. 022644

Sd/-
R. Vijay Kumar
Chief Finance & Accounts Officer

Sd/-
Dr. G Padmanabham
Director In-Charge

Date: 26/09/2016
Place: Hyderabad

INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)

BALAPUR POST. HYDERABAD

ARCI (OPERATIONAL) FUND

SCHEDULE – 24 SIGNIFICANT ACCOUNTING POLICIES

1. **Basis of preparation of financial statements :**

   The financial statements of Operation Fund of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI/Society), Hyderabad, have been prepared on historical cost convention and on accrual basis unless otherwise stated.

2. **Grants:**

   Grants are recognized on receipt.
   Grants received from Department of Science & Technology (DST) are treated as Corpus of the Society.
   Expenditure incurred by the Society towards operations, maintenance and depreciation have been adjusted against these grants.
   Grants received from DST and earmarked for special projects by ARCI are grouped under Sponsored Project Fund.

3. **Fixed Assets:**

   Fixed assets are stated at cost. Cost includes duties, taxes, freight, insurance etc., attributable to acquisition and installation of asset.

4. **Depreciation and Amortization :**

   Depreciation on fixed assets (except Lease Hold building) is provided on written down value method as per rates stated in Income Tax Rules, 1962.
   Non-Refundable advance towards Lease Hold Building is amortized over lease period.

5. **Revenue Recognition:**

   Grants are recognized on cash basis. Interest income from bank balances/deposit is recognized on accrual basis.

6. **Research and Development (R&D) Expenditure:**

   R&D expenditure including cost of raw materials, consumables, other inputs etc., is charged off as revenue expenditure. Raw materials, consumables, stores spares and other inputs are procerred on need basis and issued to end users soon after they are received. Hence, values of closing stock of these materials is not recognized in the accounts.

7. **Foreign Exchange Transactions:**

   Foreign exchange transactions during the year are recorded at the exchange rate prevailing on the date of transaction.

8. **Retirement Benefits:**

   Contributions to Provident Fund and New Pension Scheme (Defined Contribution Plans) are charged to income and expenditure account as per applicable rules/statutes. Provision towards gratuity and leave encashment (Defined benefit Plan) is made on actuarial valuation carried out by Life Insurance Corporation of India as stated in AS–15 (Revised) – "Accounting for Retirement Benefits". The Society has covered its gratuity and leave encashment liability with Life Insurance Corporation of India (LIC) and contributions are made to LIC on yearly basis.

9. **Margin Money Deposits:**

   Margin Money Deposits placed with Banks towards Letters of Credit issued in favour of ARCI are grouped under Loans and Advances–Advances Recoverable in Cash/Kind.

AS PER OUR REPORT OF EVEN DATE
for **M/s. ANANT RAO & MALLIK**
Chartered Accountants
Firm Registration No. 006266S
Sd/-
V Anant Rao
Partner, Membership No. 022644

Sd/-
R. Vijay Kumar
Chief Finance & Accounts Officer

Sd/-
Dr. G Padmanabham
Director In-Charge

Date: 26/09/2016
Place: Hyderabad

INTERNATIONAL ADVANCED RESEARCH CENTRE
FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)

BALAPUR POST, HYDERABAD

ARCI (OPERATIONAL) FUND

SCHEDULE – 25 NOTES TO THE ACCOUNTS

1. Department of Science and Technology (DST) sanctioned and released during the year Rs. 38,83,64,000/- towards revenue and Rs. 8,16,36,000/- as capital grant-in-aid under Plan (Previous year Rs. 31,04,90,000/- and Rs. 12,59,17,000/- towards revenue and capital respectively under Plan grant-in-aid). Under Non-Plan, Grant-in-aid sanctioned was nil.

2. Contingent Liabilities: Letters of Credit outstanding with Bank Rs. 10,27,00,494/- (Previous year Rs. 11,87,83,150/-) fully funded through LC margin money in the form of fixed deposits.

3. Advances on capital accounts (Schedule 11) include advances to Hyderabad Metro Water Supply and Sewerage Board (HMWS&SB), Rs. 3, 97, 43,048/- paid during 2007-08 and 2008-09 for supply of Krishna water inter alia to the Society. This is an advance payment to Hyderabad Metro Water Supply and Sewerage Board (HMWS&SB) and work is executed and settlement is awaited.

4. During the year, the provision for Gratuity Liability was made based on the accrued liability furnished by LIC of India.

5. The figures of previous year have been regrouped/reclassified wherever necessary

Sd/-
R. Vijay Kumar
Chief Finance & Accounts Officer

Sd/-
Dr. G Padmanabham
Director In-Charge

AS PER OUR REPORT OF EVEN DATE

for **M/s. ANANT RAO & MALLIK**
Chartered Accountants
Firm Registration No. 006266S

Sd/-
V Anant Rao
Partner, Membership No. 022644

Date: 26/09/2016
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
RECEIPTS AND PAYMENT ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2016

(Amount in Rs.)

RECEIPTS	CURRENT YEAR	PREVIOUS YEAR	PAYMENTS	CURRENT YEAR	PREVIOUS YEAR
I. **Opening Balances**			I. **Expenses**		
a. Cash in hand	29419	58856	a. Establishment expenses	201032602	190291601
b. Bank Balances			b. Other expenses	154534823	136167321
i) In Current accounts	0	0	Total : Expenses	355567425	326458922
ii) In Deposit accounts	0	0			
iii) Savings accounts	228387	397073			
Total : Opening Balances	257806	455929			
II. **Grants Received**			II. **Payments made against various projects**	0	0
a. From Government of India	470000000	436407000			
b. From State Governments	0	0	Total : Payments made Against Projects	0	0
c. From other source [details]	0	0			
d. Fund received on closed Projects	0	5360670			
Total : Grants Received	470000000	441767670			
III. **Income on Investments From**	0	0	III. **Investments and deposits made**		
a. Earmarked/Endowment Funds	0	0	a. Out of Earmarked/Endowment funds	0	0
b. Own funds (other investments)			b. Out of own funds (investments-others)	0	0
Total Income on Investment	0	0	Total : Investments and Deposits	0	0
IV. **Interest Received**			IV. **Expenditure on Fixed Assets & Capital Work-in-Progress**		
a. On bank deposits	3939449	13507095	a. Purchase of fixed assets	123186491	112197020
b. Loans, Advances to staff etc.	820842	467423	b. Expenditure on capital work-in progress	175036	14704321
Total : Interest Received	4760291	13974518	Total : Expenditure on Fixed Assets & Capital WIP	123361527	126901341
V. **Other Income**	6326551	5111766	V. **Refund of surplus money/loans**		
			a. To Government of India	0	0
			b. To State Government	0	0
			c. To other providers of funds	0	0
VI. **Amount Borrowed**	0	500000	VI. **Finance charges (Interest)**	0	0

VII. **Any Other Receipts**			VII. **Other Payments**		
			a. Advance for Festival-Staff	154350	151500
a.Deposits from Suppliers	50000	0	b. Advance Others	1043433	0
b.Sales of Fixed Assets	3577840	0	c. Return of EMD & security deposits	50000	1180640
c.Deposit: Rent & Gases	207053	16000	d. Institutional grants	908700	510000
d.Repayment of HBA	9402	62940	e. Deposit: Gratuity to LIC	20039781	1902032
e.TDT Fund contribution for Manpower Usages	1816347	0	f. Deposit: EL Encashment to LIC	3799803	3715537
			g. Deposit-Others	0	13743
f.TDT Fund contribution for Equipment Usages	3776747	0	i. TDS receivables	392602	392023
			j. Advance to Staff-Vehicle	114686	97740
g.TDT Fund contribution for Utility Usages	39461	0	k.Advance to Staff-Computer	170090	307539
h. Reimbursement of previous years expenditure	15422343	0	l. Refund of Temporary Loan to TDT Fund	500000	0
Total : Any Other Receipts	24899193	78940	Total : Other Payments	27173445	8270754
			VIII. **Closing Balances**		
			a) Cash in hand	78831	29419
			b) Bank balances		
			i) In Current accounts	0	0
			ii) In Deposit accounts	0	0
			iii) In Savings accounts	62613	228387
			Total : Closing Balances	141444	257806
TOTAL	**506243841**	**461888823**	**TOTAL**	**506243841**	**461888823**

AS PER OUR REPORT OF EVEN DATE
for **M/s. ANANT RAO & MALLIK**
Chartered Accountants
Firm Registration No. 006266S

Sd/-
V Anant Rao
Partner, Membership No. 022644

Sd/-
R. Vijay Kumar
Chief Finance & Accounts Officer

Sd/-
Dr. G Padmanabham
Director In-Charge

Date: 26/09/2016
Place: Hyderabad

OUR COLLABORATORS

FOREIGN

Applied Materials, USA
Advanced Mechanical Optical System, Belgium
Corning Incorporated, USA
The Boeing Company, USA
Fraunhofer Institutions, Germany
Hoganas AB, Sweden
Industrial Materials Institute of National Research Council of Canada (NRC-IMI), Canada
Institute for Problems of Materials Science (IPMS), Ukraine
International Centre for Electron Beam Technologies, Ukraine
Li-ion Technologies Limited, Russia
Mc Gill University, Canada
MPA Industrie, France
REOSC, France
Toda Kogyo Corporation, Japan
Zoz GmbH, Germany

INDIAN

ABB India Limited
Advanced Surface Finishing Labs
Aerogel One and Shardul Amarchand
Andhra University
Astra Microwave Products Limited
Astun Technologies Private Limited
Bharat Electronics Limited
Bharat Heavy Electricals Limited
Bimetal Bearings Limited
Bhabha Atomic Research Centre
Bharat Forge Limited
Blue Fox Aerogel Development and Applications LLP
Central Scientific Instruments Organization
Central Institute of Plastics Engineering and Technology
Coat-X Hard Surface Makers
CSIR-Tech Private Limited
Cummins Technologies India Limited
Defence Research and Development Organization
Freyr Software Services Private Limited
Flash Forge Private Limited
Godrej and Boyce Manufacturing Company
Global Medical Education and Research Foundation
Hindustan Aeronautics Limited
Indian Institute of Chemical Technology
Indian Airforce
Indian Space Research Organization
Indira Gandhi Centre for Atomic Research
Indian Institute of Technology-Bombay
Indian Institute of Technology-Madras
Indian Institute of Technology-Kanpur
Indian Institute of Technology-Kharagpur
Indian Institute of Technology-Hyderabad
Indian Oil Corporation Limited
Infinity Microsystems
Larsen and Toubro
Metayage IP Strategy Consulting LLP
MMI India Private Limited
National Institute of Technology-Warangal
National Institute of Technology-Thiruchirapalli
National Institute of Technology-Nagpur
North East Institute of Science and Technology
National Engineering Industries Limited
Neyveli Lignite Corporation Limited
Oorja Energy Engineering Services Pvt. Ltd
Osmania University
Phasetron Engineers India Private Limited
Redson Engineers Private Limited
Resil Chemicals Private Limited
Renault Nissan Technology & Business Centre India Private Limited
Scitech Patent Art Services Private Limited
Sai Surface Coating Technologies
Tata Steel Limited
Tekzo Engineering
Titan Industries Limited
TVS Motor Company Limited
University of Hyderabad

एआरसीआई
ARCI

ADDRESS

International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI)
Balapur Post
Hyderabad - 500 005, Telangana, India
Phone: +91-40-24452200, 24452500
Fax: +91-40-24442699, 24443168
E-mail: info@arci.res.in
URL: http://www.arci.res.in

Delhi Cell
Plot No. 102, Institutional Area
Sector - 44
Gurgaon 122 003, Haryana, India
Phone: +91-124-2570215
Fax: +91-124-2570218

Chennai Cell
Centre for Automotive Energy Materials &
Centre for Fuel Cell Technology
IIT-M Research Park, Phase-1
2nd Floor, Section B1
TS No. 2D, F Block
6 Kanagam Road, Taramani
Chennai 600 113, Tamil Nadu, India
Phone: +91-44-66632700/723/803
Fax: +91-44-66632702

ए आर सी आई
ARCI

INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)

Balapur P.O., Hyderabad - 500005, INDIA

Tel: 0091-40-24443167, 24452200, 24452500; Fax: 0091-40-24442699, 24443168

Email: info@arci.res.in; URL: http://www.arci.res.in