2013-14

इंटरनेशनल एडवांस्ड रिसर्च सेंटर फॉर पाउडर मेटलर्जी एंड न्यू मटीरियल्स
INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY AND NEW MATERIALS

ए आर सी आई
ARCI

ARCI
PERFORMANCE REPORT

इंटरनेशनल एडवांस्ड रिसर्च सेंटर फॉर पाउडर मैटलर्जी एंड न्यू मैटेरियल्स
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ARCI is an autonomous R&D institute 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 Energy Materials

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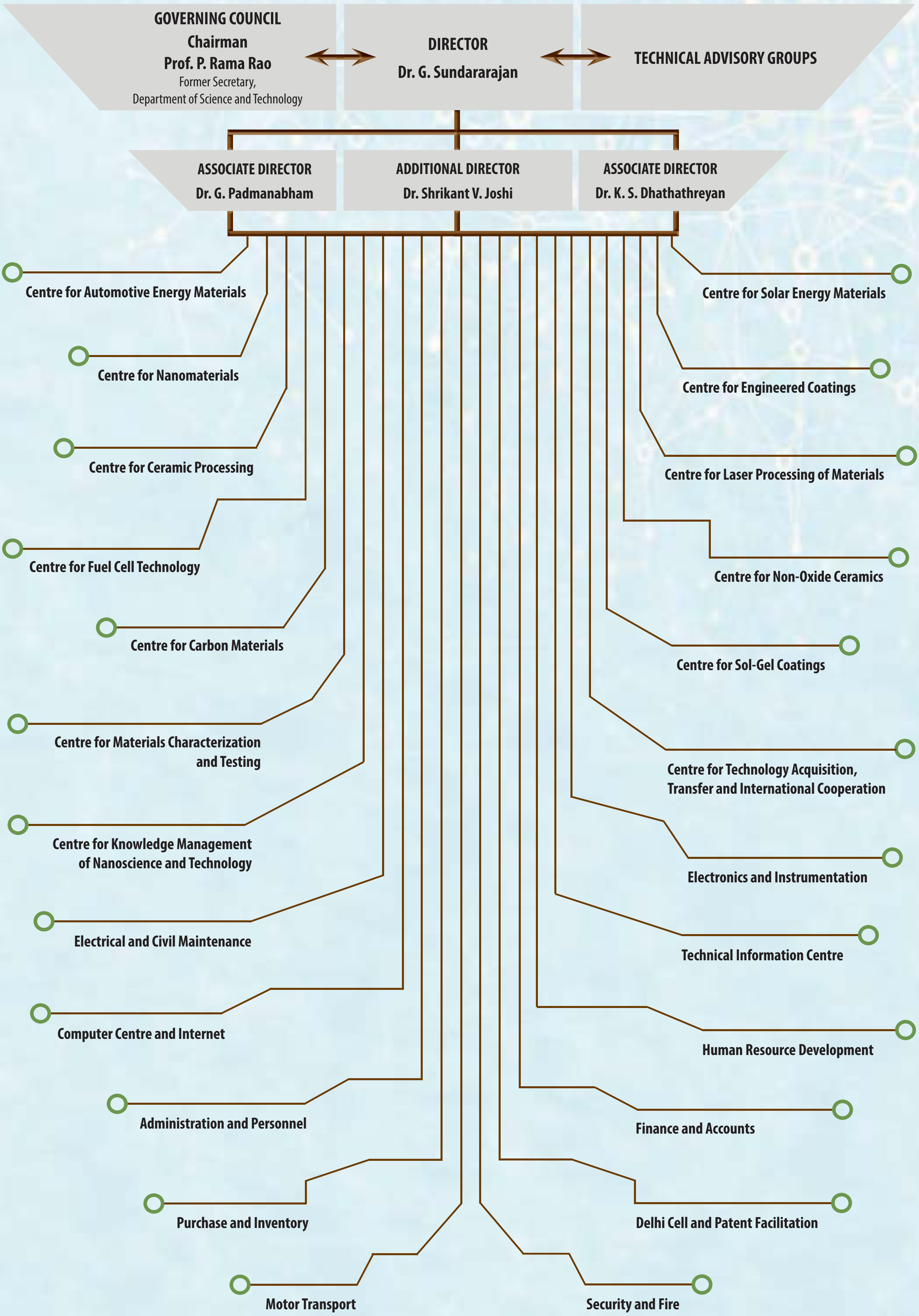
ORGANIZATIONAL STRUCTURE



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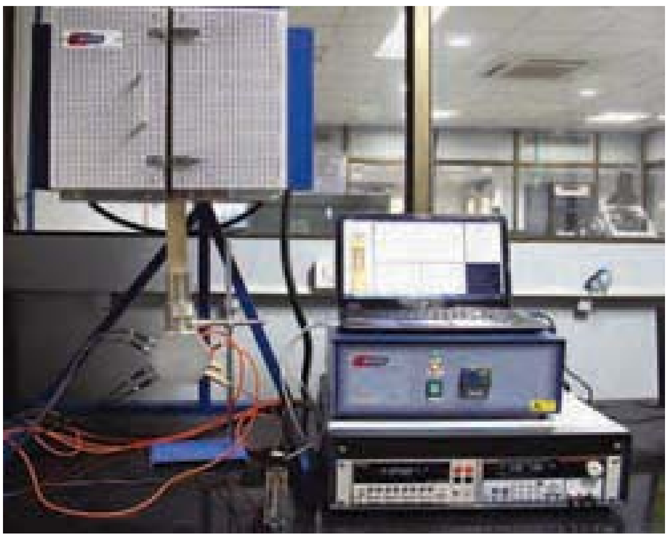
Director's Report

I am delighted to place before you the Annual Report of the International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI) for the year 2013-2014. As in the past, this report details the ongoing activities and accomplishments of the various Centres of Excellence (COEs) operating in ARCI. Following the same format that we adopted for last year's report, each Scientist/Technical Officer has been provided the opportunity to contribute an article highlighting a major activity taken up by him/her during the year.

At present, ARCI has in operation 12 COEs, of which 10 are located in Hyderabad on its main campus and 2 are located in space acquired by it in the IIT-Madras Research Park in Chennai. The internal assessment of the performance of each of these COEs is being carried out at regular intervals by the Associate Director concerned. However, to have a broader and unbiased assessment of the quality of performance of the COEs, a separate Technical Advisory Group (TAG) has been constituted for each of the COEs. Each TAG comprises recognised experts with substantial domain knowledge in the field of relevance to the concerned COE as evident from the list of TAG members provided elsewhere in this report. I am happy to inform you that the concept of COE-centric TAGs has already begun to yield the desired results, with the experts also providing considerable inputs in terms of identifying programmes to be pursued by each COE apart from evaluating the ongoing activities.

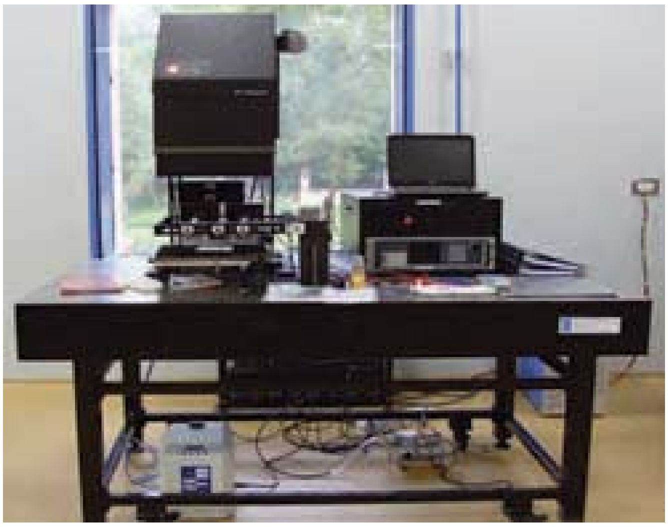
As you are aware, with the completion of 2013-14, two years of the 12^{th} five year plan period have been completed. Therefore, it is worthwhile to examine the actual progress made till date in respect of the major activities that were targeted in the 12^{th} Plan document against the time line proposed by ARCI. The establishment of pilot plant facilities for fabrication of Li-ion batteries as well as CIGS thin film solar cell panels has made significant progress and both the pilot plants will become fully operational in the year 2014-15. Setting up of facilities for producing magnetic materials for electric vehicle motors has also progressed satisfactorily. The above efforts have been simultaneously accompanied by establishment of sophisticated facilities for characterisation & testing of Li-ion batteries, PEM fuel cell, hard & soft magnetic materials for automotive applications, solar cells & materials and thermoelectric materials to position ARCI ideally to make meaningful contributions in the above areas.



Seebeck coefficient and resistivity measurement system

Battery power simulation testing system

Quantum efficiency measurement system



Solar light simulator for cell performance testing

The Laser Micromachining Centre being jointly developed by ARCI and National Research Council (NRC) Canada has now been fully integrated and has undergone comprehensive testing at NRC prior to being despatched to ARCI. This facility will become operational during the coming year and considerably augment the laser processing capabilities at ARCI. The mobile version of the cold spray coating technology, an improved version of the detonation spray coating technology and smaller units pertaining to the Micro Arc Oxidation (MAO) technology for usage in research environment will all be unveiled during the coming year.

Synthesis of nanomaterials for use as anode & cathode materials in Li-ion battery, in supercapacitors, as anti-bacterial & easy-to-clean additives to textiles and in ZnO varistors continues to be an area of focus and has opened up new avenues for development. Sol-gel coatings for a variety of applications have been demonstrated in an effort to spur commercialization. Activities related to hydrogen generation, demonstration of field applications of PEM fuel cell as a grid-independent UPS, and as a power source for fork-lift applications have been initiated at Centre for Fuel Cell Technology (CFCT). Other activities which are progressing well include laser material processing of a variety of materials of interest to the industry, use of pulsed electrodeposition for generating thick nanocrystalline coatings & relatively thin CIGS/CZTS coatings for photovoltaic applications, aerogels for insulation applications, nanoink route for CIGS photovoltaics, development of perovskite based photovoltaics, development of alternative materials to Nd-Fe-B for hard magnet applications and of thermoelectric materials with high figure of merit at elevated temperatures.

Table Comparing Performance Indicators

Parameters		**2012-13**	**2013-14**
Number of Employees		173	169
Number of Scientists		71	69
Number of Publications*		131	150
Indian Patents**	Granted	23	23
	Filed	46	55
International Patents**	Granted	5#	8#
	Filed	4	4
Scientists with Ph.D.		43	45
Scientists Registered for Ph.D.		15	14
No. of Deputations Abroad		47	37
No. of ARCI Personnel who attended Conferences/ Seminars/Training Courses (in India)		217	285
ARCI Fellows***		42	54@
ARCI Trainees		21	48@
M.Tech./B.Tech. Project Students****		50	50@

**Includes journal publications, conference proceedings and chapter in books*
***Cumulative figures up to the end of financial year*
****ARCI Fellows also include 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

As in the previous years, I would like to acknowledge the constant support that ARCI has been receiving from DST and the Governing Council. I also take this opportunity to thank the entire ARCI family for unstinted cooperation and dedication to work. Without such support it would not have been possible for ARCI to gradually evolve into an institute of considerable global repute.

G. Sundararajan

(G. Sundararajan)

Centre for Automotive Energy Materials

Globally, there is an urgent need for the development of alternative energy sources, especially for the automotive sector, due to the alarming depletion of fossil energy reserves. Lithium-ion battery has emerged as a promising candidate to alleviate this problem due to its attractive features. viz., high energy density (both volumetric and gravimetric), high current drain, high cycle life, low self-discharge, absence of memory effect and good low temperature performance. In case of, Lithium-ion batteries, India's market share is significant in the area of consumer electronics. It is expected to increase in the electric vehicle sector also. Keeping in view the rapid growth of the automotive sector and the need for development of material technologies for sustainable transportation, a Centre for Automotive Energy Materials (CAEM) has recently been established at Indian Institute of Technology (Madras) Research Park, Chennai.

The CAEM is developing Li-ion battery for electric vehicles, hybrid electric vehicles (EVs/HEVs) by setting up Research facility for Lithium-ion cells and battery packs at pilot plant scale. Lithium-ion battery technology is projected to be the leapfrog technology for automotive sectors to provide stationary storage solutions to enable effective use of renewable energy sources. In India, giant automobile manufacturers like M/s.Ashok Leyland, M/s.Tata Motors, M/s.Mahindra Reva are engaged in the EV manufacture based on Lithium-ion batteries (LIB's). The CAEM has initiated interactions to work closely with the above companies to demonstrate the ARCI's in-house Li-battery technology for EVs. The Centre adopts two modes in developing the Li-battery Technology: the first one is by setting up the state-of-the-art pilot scale facility and establishing the manufacturing technology with internationally known commercial electrode materials for the fabrication of Li-ion battery and the other mode of operation is by indigenously developing the technology for producing the standard electrode materials/new materials, and test them for the charge/discharge characteristics. The optimized process or the material technology will be scaled up and tested in the Lithium-ion battery pilot plant facility. The Centre has now successfully installed and commissioned all fabrication equipments, dry room for battery assembly and characterization facilities.

CAEM has also launched research programmes on developing high saturation soft magnets (Fe-P) and high coercivity rare earth permanent magnets (Nd-Fe-B, Sm-Fe-N) for EV motor applications The scientific and technological issues in developing the above magnets for high performance applications are addressed through close technical interaction with automotive companies. This interaction has led to development of a motor with ARCI in-house processed soft magnet rotors and the test results are encouraging.

Thermoelectric generator (TEG) for power generation has been in use for the past several decades in niche applications such as space exploration vehicles. The benefit of using this for common engineering applications such as waste heat recovery in automotives and diesel generator has gained great deal of interest in the recent years. However, unlike space application the TEGs for waste heat applications require high efficiency with lower cost, which is a major technological challenge. In recent years, several new abundantly available materials, have showed good figure of merit (ZT), which is an indicator for efficiency. Further improvement in ZT of these materials by innovative materials engineering can open up the possibilities for fabricating TEG with efficiency close to 8-10%. Keeping in view of the technological significance of TE materials, CAEM has initiated an R&D programme on development of materials with high TE efficiency for auto exhaust heat conversion applications.

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Large Scale Lithium-Ion Battery Fabrication Facility for HEV/EV Applications

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Electrification of transportation facilities is one of the prospective methods to significantly reduce the green house gas emission significantly, which is a primary cause for global warming. Lithium-ion battery (LIB) has emerged as a leading power source for hybrid electric vehicles (HEV) and electric vehicles (EV) since the leading car manufactures have demonstrated their HEVs/EVs using LIB technology. Consequently, many LIB manufacturing facilities have been established throughout the world. However, no such facility exists in India. Recently, ARCI has setup the pilot scale facility to develop LIB technology as well as to fabricate lithium-ion cells and batteries for EV.

LIB fabrication process requires humidity controlled environment. Two dehumidified rooms (electrode and cell assembly) were constructed using pre-fabricated Cam-Lock panel over the reinforced platforms containing electrostatic discharge mats. The recommended relative humidity (RH) values for electrode fabrication room is <30% and for the cell assembly room is <1%. The specifications of the dehumidified rooms were designed accordingly to meet the RH level. Commissioning of the rooms has been completed and the recommended RH values in both rooms are achieved (Fig. 1).

The LIB fabrication equipment (mixer, coater/drier, calender, slitter, winder, filler and welding units) was positioned inside dehumidified rooms and their installations have been carried out successfully. Anode and cathode slurries were prepared by mixing active materials with conductive carbon, binder and solvent. The mixer has both planetary and high shear blades, which are capable of mixing very high viscous fluid. The viscosity and viscoelestic behaviour of the slurries was investigated. The viscosity of the slurries were found to be ~70000 cp at normal shear rate and displayed shear-thinning behaviour as shear rate increases (Fig. 2b). Elastic or storage modulus (G') is a measure of slurry's cohesion characteristics and viscous or loss modulus (G") is a measure of slurry flow ability which aids in coating process. At low deformation G' and G" are constant, this region is called linear viscoelastic (LVE). If G' > G", the slurry behaves as gel; when G" > G' it behaves as fluid, which is not ideal for coating.

Two-side coated electrodes have been prepared by coating the slurries on current-collectors using comma coater, and dried by passing through hot air ovens. Both continuous and pattern coated electrodes (~200 m) were fabricated (Fig. 2c, 2d). The slurry-viscosity, line-speed, and temperature are the main parameters that affect the quality of electrodes. The electrodes were calendered by varying the line-speed, hydraulic-pressure, nip-gap and temperature to optimize the density and porosity, which in-turn enhances the conductivity. They were slit according to the required dimensions, the positive and the negative electrodes were wound together with the interposed separator either cylindrical or prismatic form (Fig. 2e, 2f). The electrode/separator tension and winding speed must be adjusted to get optimum wound cell (resistance > 4 GΩ). Tabs were welded on the uncoated areas of the electrode using the ultrasonic welder. Al-tab was used for the cathode and Ni/Cu for the anode. The tabs and the terminals, as well as the lid and the container were sealed hermetically by laser welding. Electrolyte (<10 ppm H_2O) was filled under vacuum through the fill-port. After welding the fill-port, the cell (Fig. 2g) will be subjected to electrochemical performance evaluation under various conditions. Depending on the performance, cells further undergo battery assembly and life cycle tests.

Fig.1 Frontal view of the dehumidified rooms showing the RH value

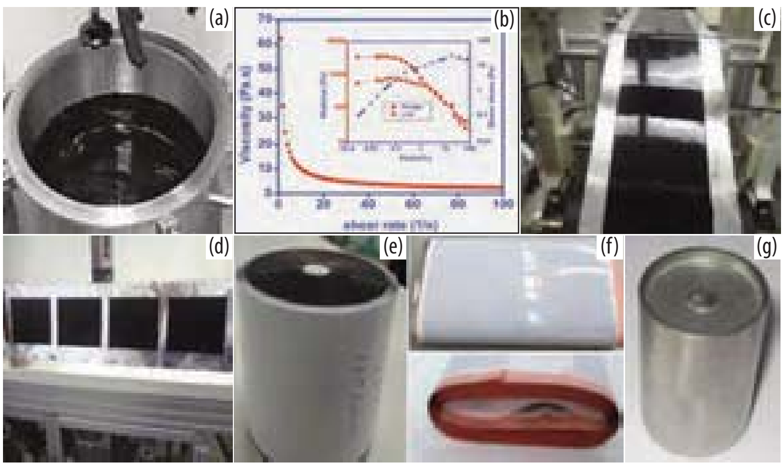

Fig. 2 LIB cell fabrication. (a) Cathode slurry (b) Rheological characteristics (c) Continuous coated & (d) Pattern coated cathode (e) Cylindrical (f) Prismatic wound jelly rolls & (g) Cylindrical cell

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Zinc Doped Tetrahedrite ($Cu_{10.5}Zn_{1.5}Sb_4S_{13}$) for Automotive Thermoelectric Application

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Thermoelectric (TE) materials required for automotive waste heat to power application needs to possess high figure of merit (ZT > 2), should be readily available in large scale, and stable at the operating temperature between 200-500ºC. Most of the currently investigated TE materials showing ZT>2 uses expensive rare earth elements whose availability is limited. Tetrahedrites, one of the most abundantly available sulfosalt, shows good thermoelectric behavior. The chemical formula of this compound is $Cu_{12}Sb_4S_{13}$. Currently reported ZT of this material is close to 1 at 700 K, which can be improved further by proper doping with elements such as Zn or Fe. Synthesizing this compound from the constituent element by melting and sulphurization is a difficult process. The sulphurization of the melted alloy require several days of solid state reaction between alloy powders and sulphur.

Zn substituted Tetrahedrite of the nominal composition $Cu_{10.5}Zn_{1.5}Sb_4S_{13}$ is synthesized and consolidated in to bulk solid for the purpose of thermoelectric module fabrication. The compounds Copper (I) sulphide (Cu_2S), Zinc Sulphide (ZnS) and Antimony (III) Sulphide (Sb_2S_3) were mixed in a required stoichiometric ratio, ball milled, annealed and sintered into a 10 mm diameter disc. The ball milling was carried out in high pressure vial using stainless steel balls with ball to powder ratio of 20:1 for 30 hours. High pressure ball milling ensures very low oxygen partial pressure during milling. Annealing of the milled powder was carried out for 6 h at 300ºC after compacting the powder, evacuating and sealing in a quartz tube. Fig. 1 shows the XRD pattern of the powder showing pure tetrahedrite phase obtained by the above processing route and its thermal stability up to 500ºC. The compound showed excellent thermal stability up to 500ºC, which is the typical operation temperature of the thermoelectric generators in automobile exhaust. Fig. 2 shows the SEM and TEM image of the powder. The elemental mapping of the powder shows uniform distribution of the constituent elements and the grain size of the compound is also very fine close to nanocrstalline range. The annealed pellets were crushed into powder and spark plasma sintered at 400ºC, under 400 MPa pressure for 10 minutes in a WC-Co die cavity under 10^{-5} mbar vacuum. The density of the sintered compacts are 4.73 g/cm^3 which more than 98.0 % of therotical density. The thermal conductivity measured by Hot Disk plane source technique is 1.15±0.04 w/m.K. Further decrease in the thermal conductviy by multiple doping is under progress.

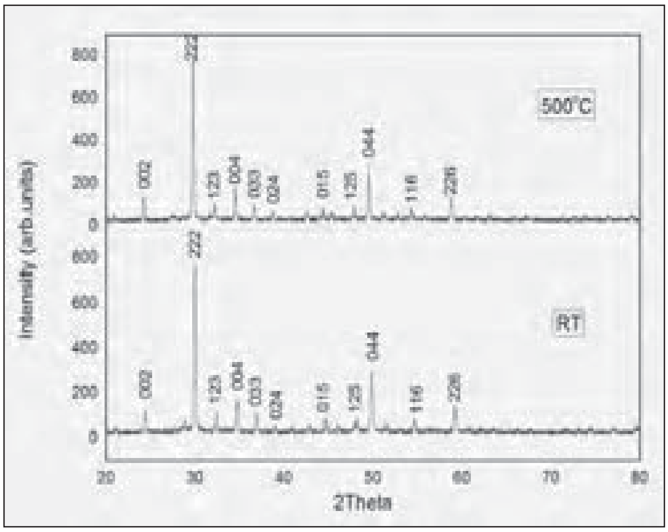

Fig. 1 XRD of the $Cu_{10.5}Zn_{1.5}Sb_4S_{13}$ tetrahedrite compound as synthesized and after heating to 500ºC

Fig. 2(a) SEM image of ($Cu_{10.5}Zn_{1.5}Sb_4S_{13}$) powder

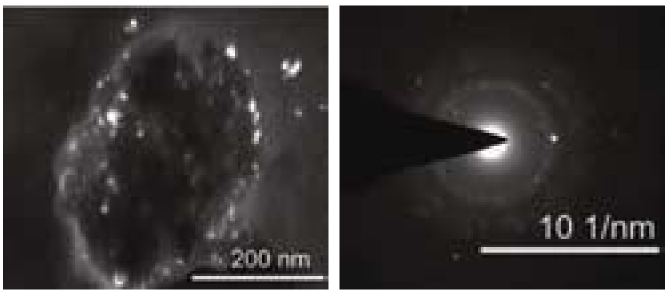

Fig. 2(b) TEM image of ($Cu_{10.5}Zn_{1.5}Sb_4S_{13}$) powder along with the SAED pattern showing the diffused ring corresponding to d_{hkl} – 222

Contributors: S. Harish, Manjuoha Bhattabyal and R. Gopalan

Fe-P : a Potential Alternate to Si Steel in Automotive Industry

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Automotive industry in India is growing in terms of the number of manufacturing and assembling plants being established. This in turn has put an increasing demand on local industries supplying automotive components. The need for increasing the fuel efficiency and the potential market of hybrid and electric vehicles demands for materials with better properties. Soft magnetic materials in particular have a huge demand as they form an important component as stators and rotors of motors, indispensable machines in automotive applications. Si steel is one of the best soft magnetic material used widely in industries. Mild steel is also another preferred soft magnetic material in industries owing to its cost effectiveness but with a compromise on magnetic properties. Hence there is a growing need in automotive industry of an alternate soft magnetic material with lower cost and better performance. At CAEM, we have identified Fe-P as a potential material to be developed into a soft magnetic material with competitive cost and attractive magnetic properties.

Fe-0.4 wt.% P with good DC magnetic properties like saturation induction (Bs) of 1.95 T, Coercivity (Hc) of 1 Oe and initial permeability (μi) 4300 was developed through the wrought alloy process of induction melting, forging, rolling followed by a two-step heat treatment. Though the DC magnetic properties were better than the Si-steel the AC magnetic properties in particular total core loss were found to deteriorate rapidly above 100 Hz compared to Si-steel. The total core loss is combination of the hysteresis loss and eddy current loss. The hysteresis loss is largely determined by DC magnetic properties while the eddy loss is determined by the resistivity of the material. Higher resistivity of the materials impedes the formation of eddy currents, when subjected to varying magnetic fields associated with alternating currents. The high core loss observed in Fe-0.4 wt.% P is mainly due to the relatively low resistivity of the alloy (22 μΩ cm) as compared to Si steel (~50 μΩ).

In order to enhance the performance of the Fe-P alloy, we tried minor addition of Si (< 1 wt.%) compared to standard Si-steel which has typical Si content of 4-6 wt.%. Large Si addition is not favored as it introduces brittleness making machining of these materials difficult. The new alloy Fe-P-(Si) was developed using very similar process employed for the Fe-P alloy. The saturation induction was found slightly to reduce to 1.8 T but coercivity (0.8 Oe) and intial permeability (4800) was found to be better than Fe-P. More importantly, the resistivity was found to increase to 38 μΩ cm. This was clearly reflected in the AC magnetic performance of the Fe-P-(Si) alloy. Fig. 1 compares the hysteresis loop of the different materials DC and AC magnetic field of 1 kHz. At DC field the hysteresis loss was relatively low for all alloys except for mild steel when subjected to AC magnetic field of 1 kHz only Fe-P-(Si) exhibited a performance matching Si-steel. Fig. 2 is a plot of the total loss measured at different frequencies. The plot clearly shows the rapid increase in total core loss of Fe-P above 100 Hz while the total loss of Fe-P-(Si) is very much comparable to that of Si-steel up to 1 kHz. This better performance is mainly attributed to the good DC magnetic properties and increase in resistivity achieved by the minor addition of Si.

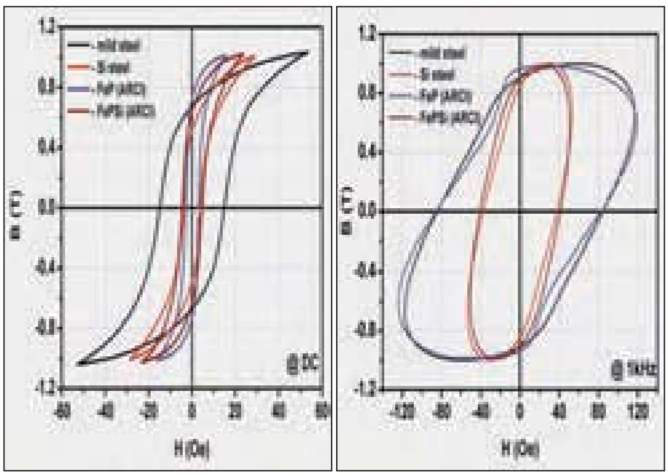

Fig. 1 Hysteresis loops of the four materials measured for Bmax of 1T at DC and AC current of 1 kHz shows the comparable performance of Fe-P-(Si) to Si-steel even at high frequencies

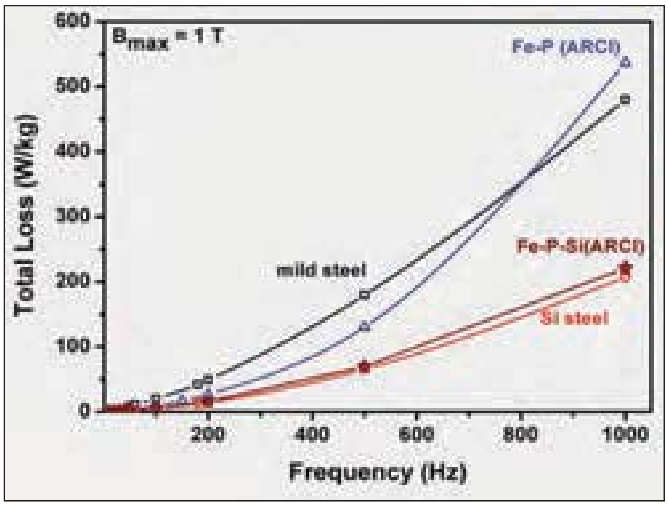

Fig. 2 Total loss measured as a function of frequency clearly shows the comparable performance of the Fe-P-(Si) alloy to Si-steel even at frequencies of 1 kHz

Contributors: Ravi Gautam, D. Sivaprahasam, V. V. Ramakrishna, S. B. Chandrasekhar, V. Chandrasekaran and R. Gopalan

Microstructure Investigation of $LiNi_{1-x-y}Co_xAl_yO_2$ Cathode Material Synthesized by Solid State Assisted Co-precipitation for Lithium Ion Batteries

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$LiNiO_2$ has been proposed as promising alternative for $LiCoO_2$ cathode material in lithium ion batteries for high power applications such as electric vehicles, hybrid electric vehicles and plug-in hybrid vehicles due to its higher energy density, low toxicity and lower cost. However, $LiNiO_2$ suffers from drawbacks such as cation mixing, structural instability leading to poor cyclic performance and oxygen evolution during de-lithiation leading to thermal instability. It is reported that, while Co substitution increases the ordering of cations in the layered structure, Al doping improves the thermal stability. Therefore in recent years, $LiNi_{1-x-y}Co_xAl_yO_2$ (LNCA) is intensively investigated as a cathode material for high power lithium ion battery applications.

Currently, we are optimizing the solid state assisted co-precipitation synthesis parameters to obtain electrochemically active monophasic LNCA. We have observed that stringent parameters such as pH of the solution and annealing conditions are essential to obtain hexagonal LNCA, and very long duration of annealing is essential to reduce secondary phases. Fig. 1a and Fig. 1b show the XRD pattern of LNCA, annealed for 12 and 24 hr respectively. The intensity ratio of the XRD peaks (003) and (104), $I_{(003)}/I_{(104)}$ increases from 1.3 for 12 hr annealed sample to 1.5 for 24 hr annealed sample, suggesting the better layered ordering in 24 hr annealed samples . Very small intensity peaks from 2θ = 20 to 35 degree appear due to impurity phases such as Al_2O_3, Li_2NiO_2, and sulphates of Ni, Co and Al. As expected, the intensity of impurity phases reduces with increase in annealing time. SEM micrographs of samples annealed for 12 and 24 hr (Fig. 2) depict that with increase in annealing duration the distribution of particle size becomes narrower, probably due to the growth of LNCA, at the expense of secondary phases having smaller particle size. Bright field TEM image of LNCA annealed for 24 hours confirms the narrow distribution of particle size (Fig. 3). HRTEM and SAD patterns of one of the particles, given as the inset in Fig. 3, confirms the formation of LNCA. Further optimization of process parameters for obtaining monophasic LNCA and its structure - electrochemical property correlation studies are under progress.

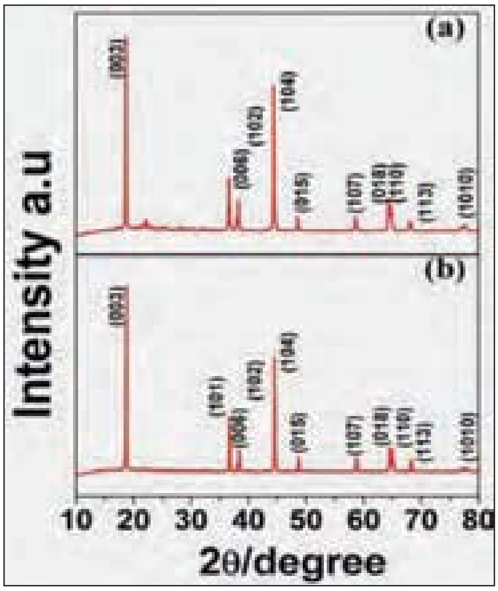

Fig. 1 XRD of $LiNi_{1-x-y}Co_xAl_yO_2$ synthesized by solid state assisted co-precipitation (a) annealed for 12 hr and (b) annealed for 24 hrs

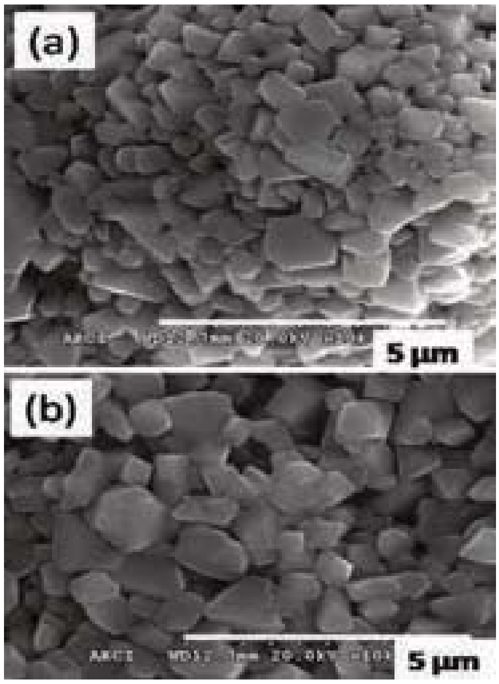

Fig. 2 SEM micrographs of $LiNi_{1-x-y}Co_xAl_yO_2$ synthesized by solid state assisted co-precipitation (a) annealed for 12 hr and (b) annealed for 24 hrs

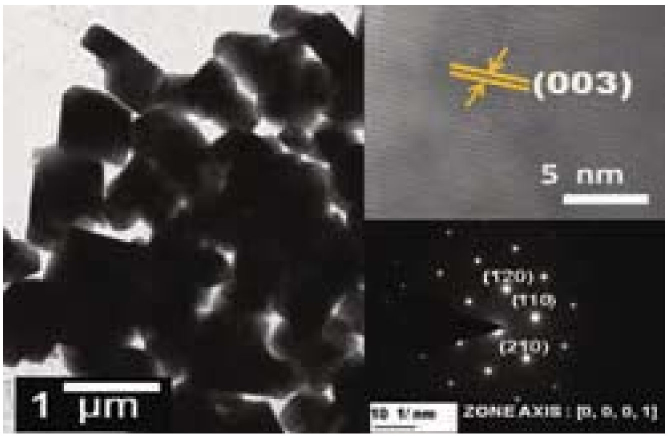

Fig. 3 TEM micrographs of $LiNi_{1-x-y}Co_xAl_yO_2$
Inset: HRTEM image and SAD of one of the particles

Contributors: N. Sasikala and R. Gopalan

Layered Oxide $LiMO_2$ (M=Co, Mn, Ni) Cathode Material Synthesized by Solid State Assisted Co-precipitation for Lithium Ion Batteries

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Lithium ion batteries (LIBs) are extensively used in portable electronic technology and recently their usage is extended to electric vehicles (EVs) and hybrid electric vehicles (HEVs). However, further improvement in energy and power density, cyclic stability, safety and reduction in the cost of the active materials are essential for LIBs to be used in high power applications. Layered oxide structures with the general formula $LiMO_2$ (M = Co, Mn, Ni) are one class of cathode materials that are used in LIBs applicable for EVs and HEVs applications. However, the electrochemical properties by the usage of monometallic oxides such as $LiCoO_2$, $LiNiO_2$ and $LiMnO_2$ are reduced because (i) only 0.5 Li can be extracted from $LiCoO_2$ and it possess high thermal instability along with toxicity, (ii) synthesizing $LiNiO_2$ is difficult (iii) stable $LiMnO_2$ is extremely challenging. Doping of Ni, Co, Mn in $LiMO_2$, i.e $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ (LNMCO) and (1-X)Li_2MnO_3: X $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$(LLO) is reported to give a better electrochemical performance compared to their individual counterparts. One of the research focuses in this field is to understand the nature of LLO, whether it is comprised of homogenous solid solution or Li_2MnO_3 domain in layered oxide matrix.

We have optimized the synthesis conditions to obtain phase pure, hexagonal LNMCO and LLO by solid state assisted co-precipitation method. Layered oxide phase formation was confirmed by powder XRD (shown in Fig. 1a and Fig. 1b), indexed with reference to ICDD pattern number 98-011-5146 and the calculated intensity ratio of the peaks (003) and (104) [$I_{(003)}/I_{(104)}$] is > 1.24. Stoichiometric ratios of Li, Ni, Co, Mn for LNMCO and LLO are calculated and synthesized under identical conditions. Presence of the monoclinic (1-X) Li_2MnO_3 peak at 2theta = 20.7 degree, along with all the peaks corresponding to hexagonal $Li(Ni_{1/3}Co_{1/3}Mn_{1/3}) O_2$, suggests the two phase nature of LLO, which is also corroborated by the TEM investigations. Fig. 2a depicts the TEM micrograph of LNMCO consisting of uniform microstructure and Fig. 2b shows HTREM image of one of the particles corresponding to (003) planes of LNMCO. In contrast to LNMCO, TEM bright field image of LLO (Fig. 2c) is comprised of two types of particles, one with an average particle size of 50 to 100 nm and another with average particle size of 400 to 500 nm. Fig. 2d shows the HRTEM image of the one of the large particles corresponding to LNMCO, and Fig. 2e is the HRTEM of the small particles, corresponding to monoclinic Li_2MnO_3. From XRD and TEM investigations, we surmise that LLO synthesized by solid state assisted co-precipitation comprised of composites of monoclinic Li_2MnO_3 and LNMCO. Further structural and electrochemical characterizations of LNCMO and LLO synthesized by solid state assisted co-precipitation are in progress and comprehensive structure property correlation of these cathode materials will be investigated.

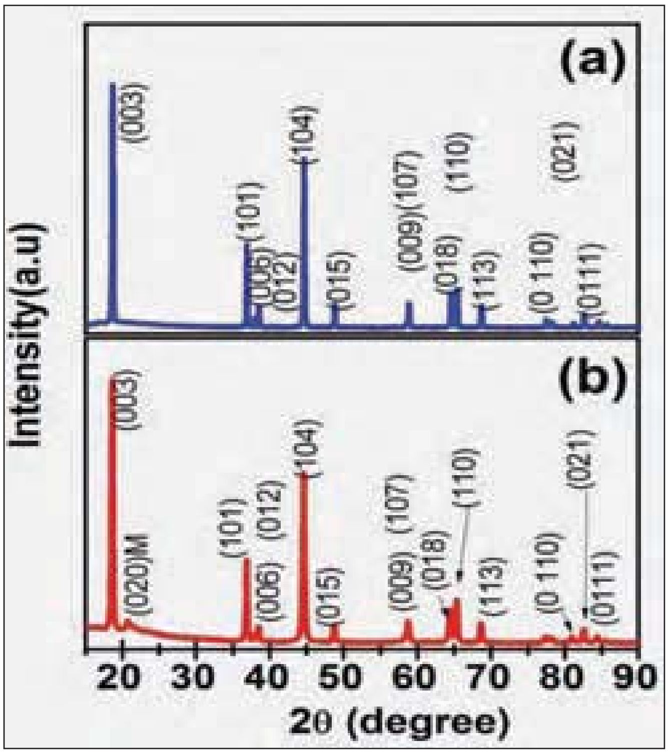

Fig.1 X-ray Diffraction of (a) $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ and (b) (1-X)Li_2MnO_3: X $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ synthesized by solid state assisted co-precipitation

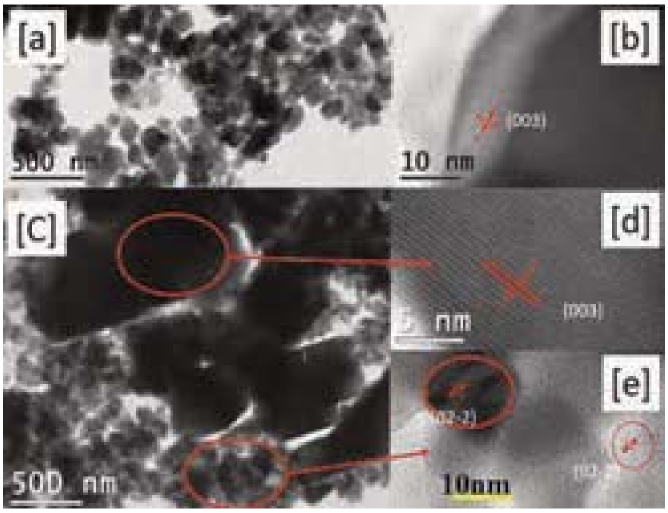

Fig.2 (a) Bright field TEM image and (b) HRTEM of Li $(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ (c) Bright field TEM, (d) HRTEM image of larger particle in LLO, interplanar distance corresponding to of $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ (e) HRTEM image of small particle in LLO, interplanar distance corresponding to Monoclinic Li_2MnO_3

Contributors: M. B. Sahana and R. Gopalan

Centre for Solar Energy Materials

The Centre for Solar Energy Materials (CSEM) was 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 setting up of a pilot line for fabrication of CIGS solar cell modules, development of ink-based and electro-deposition routes for CIGS and CZTS thin film solar cells and exploring solution processed perovskite solar cells based on earth abundant materials. Development of functional coatings like solar absorber, anti-reflection and self-cleaning coatings for photovoltaic and concentrated solar power (CSP) applications constitutes another major area of activity. State-of-the-art characterization facilities are also now available at CSEM to assist in accurate measurement of performance and durability of various photovoltaic and solar thermal devices.

The CIGS pilot line at ARCI is an especially unique facility in the country, capable of handling rigid and flexible substrates up to 300 mm x 300 mm in size. The special capabilities and tools available in this pilot line are (a) a sputter coater for the deposition of Mo, CuGa, In, i-ZnO and AZO (b) an evaporator-RTP for selenization, (c) a CBD tool for CdS deposition and (d) a laser-mechanical scriber for patterning the solar modules. The initial focus of the CIGS pilot line is on developing a comprehensive understanding and improving the two-stage process, sputtering of precursor layers followed by selenization and to deposit CIGS layers that will serve as a bench-mark for the ongoing R&D on non-vacuum processed CIGS and CZTS solar cells. It is also aimed to subsequently produce CIGS mini-modules for in-house demonstration of a utility-scale, thin film solar cell power plant.

Replacing the conventional dye with a high molar extinction coefficient, direct band gap semiconductor light absorber is a key strategy for capturing more sun light and improving the efficiency of next-generation nanostructured dye solar cells. In this context, methylammonium lead iodide ($CH_3NH_3PbI_3$) perovskite has been synthesized and successfully assembled in a planar hetrojunction device structure by spin coating technique. The optimum band gap (EG: 1.4eV) and larger grain size of $CH_3NH_3PbI_3$ film notably increased the solar light harvesting and charge carrier transport, respectively. Our current efforts are focused on the improvement of energy conversion efficiency from 1% to >8% in hole transporting material free perovskite solar cells and exploring their possible scale-up subsequently by screen printing method.

The major challenge in CSP technology is reducing the cost of parabolic trough 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 resistant properties. Considering their vast commercial potential, CSEM has also been focusing efforts on developing solar absorber, anti-reflection and self-cleaning coatings using cost effective processes (i.e., chemical/thermal oxidation, sol-gel, nanoparticle-incorporated precursor solutions) with demonstration of manufacturing feasibility on a commercially relevant scale. These anti-reflection and self-cleaning coatings are also imperative for realizing maximum cumulative power output from photovoltaic panels.

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Solar Energy Materials Bay

Ink-jet Printer

Quantum efficiency measurement system

Super Hydrophobic Coating with High Optical Property having Easy to Clean, UV and Corrosion Resistance

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There are numerous instances where optically clear articles are damaged on long exposure to moisture, sun-light and different weather conditions or are obscured by deposition of dust or dirt. Face shields, goggles, ophthalmic lenses, solar reflective mirrors, PV panels and automobile windows are just a few examples of articles that belong to the above category. Particularly in case of solar PV panels, the front surface of a PV module (glass window) must have a high transmission in the wavelength range (300 nm to 1200 nm) which can be harnessed by solar cells in the PV module. Similarly, in case of concentrated solar power (CSP) installations, the Al reflectors used in the form of parabolic (bent) or Fresnel (flat) structures must exhibit high reflection in the wavelength range (300 to 2500 nm) of interest.

In general, solar PV panels and solar receiver tubes convert sunlight into electricity. These devices are traditionally mounted outdoors on rooftops or in wide open spaces to maximize their exposure to sunlight. Unfortunately, this type of outdoor placement of the solar panels and reflectors subjects them to constant weather and moisture exposure. The devices need to be necessarily designed for many years of stable and reliable operation without failure due to moisture damage or degradation because of prolonged exposure to the ambient (e.g. by virtue of corrosion and UV). Even small solar cells used in consumer electronic devices demand rugged environmental protection as these devices are, by their very nature, also generally used outdoors or in areas of sun exposure.

A major challenge in finding a suitable protecting material for devices like solar panels, solar receiver tubes and reflector plates, arises from the need to impart a protecting surface that can provide best-in-class multifunctional properties desired to withstand all sorts of environments (dust/dirt, weather, corrosion, UV etc) without compromising optical properties. There may be some coating formulations that can provide good moisture barrier qualities but are not sufficiently transparent to pass light down to the solar panel or not sufficiently reflective to be of utility for CSP applications. Yet other coatings may be good at combating moisture and possess the requisite transparency / reflectance, but not be adequate to withstand UV and not have the desired dust / dirt repulsion capability which can otherwise significantly reduce the optical property (transparency / reflectance) on continuous use.

Due to the aforementioned problems, coatings having an improved environmental protection configuration with enhanced optical properties are desired for the top surface of PV panels, reflectors and receiver tubes utilized in the solar field. In response to the above need, a super-hydrophobic coating having easy-to-clean, UV and corrosion resistance properties as well as the optical characteristics desired for solar PV and CSP applications has been developed at ARCI.

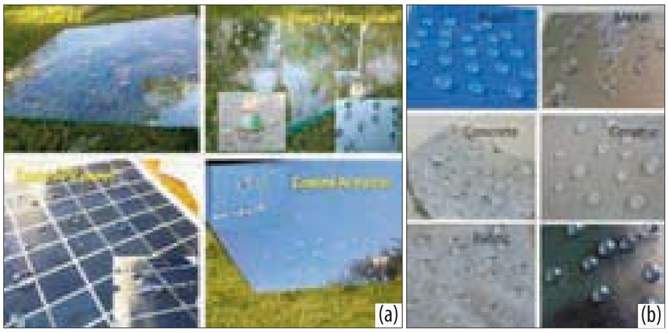

Fig. 1 Image demonstrating the super hydrophobic property of coating on (a) glass plate, Al reflector, PV panel and (b) other applications

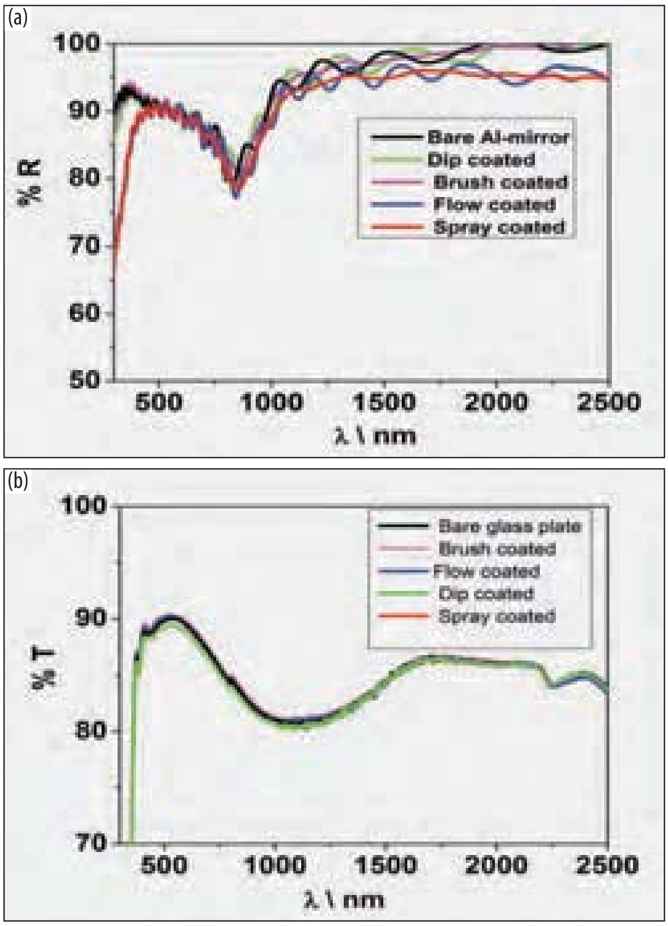

Fig. 2 (a) Reflectance and (b) transmittance spectra of the easy to clean coatings on Al reflector and glass plates, respectively, revealing no optical loss after coating

Contributors: S. Viswanathan, Dhavalkumar N Joshi and S. Sakthivel

CIGS Absorber Thin Film by Single-Step Non-Vacuum Intense Pulsed Light Treatment of Inkjet-Printed Film

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A $CuIn_{1-x}Ga_xSe_2$ (CIGS) thin film absorber layer is one of the most promising candidates for solar cell applications. CIGS-based solar cells based on sputtering and other vacuum processes have yielded power conversion efficiencies exceeding 20%. However, photovoltaic manufacturing technology today demands low-cost processing techniques because of the competitiveness of the solar cell market. Thus, to increase the commercial viability of CIGS solar cells, several solution-based approaches have been reported for CIGS deposition. However, a post-treatment in vacuum and/or a separate selenization step are essential in all the above mentioned processes to achieve device quality CIGS absorber thin films.

At ARCI, we have successfully demonstrated ink jet printing of a home-made CIGS ink (constituted of CIGS nanoparticles) on Mo coated glass which, following subsequent single-step Intense Pulsed Light (IPL) post-treatment without any vacuum and/or selenization treatment, yields device quality CIGS thin film absorber layers for solar cell applications. An ink jet printer with two embedded print heads (Model: L-Series, Make: Ceradrop, France) established at ARCI was utilized for ink jet printing of CIGS ink. Commerically available CIGS power was mixed with an appropriate organic binder and a solvent in a specific proportion to formulate an 'ink' with tailored rheology, such that it was suitable for ink jet printing. A print head plate containing 256 nozzles was used for testing the jetting behavior. Fig. 1 shows an image indicating large number of active nozzles in the print head with the formulated CIGS ink.

The inkjet-printed CIGS film was exposed to IPL treatment for densification. The XRD patterns of the Mo coated glass substrate and the $Cu(In_{0.7}Ga_{0.3})Se_2$ thin film obtained after IPL treatment are shown in Fig. 2. Recrystallization of CIGS was confirmed by powder x-ray diffraction studies, revealing that the annealed films of quaternary CIGS alloys were monophasic with no evidence of secondary phase generation. All the peaks in Fig. 2(b) correspond to the chalcopyrite tetragonal polycrystalline structure of $Cu(In_{0.7}Ga_{0.3})Se_2$.

As seen in Fig. 3, a crystalline, dense film with no voids is formed after IPL treatment. This indicates that melting and recrystallization of CIGS particles are realized during IPL treatment. The constitution of the obtained $CuIn_{0.7}Ga_{0.3}Se_2$ thin film is consistent with the constitution of the CIGS precursor material used, with the selected Ga/(Ga+In) ratio being retained. The CIGS film thickness, as determined by XRF, was 2.2 microns.

The present novel treatment process, demonstrated utilizing ink jet printed precursor layers using a home-made ink to make high quality CIGS films without vacuum and selenization, can have important implications in fabricating cost-effective CIGS solar cells. Further scale-up of the process and a detailed assessment of cell performance are now being simultaneously pursued.

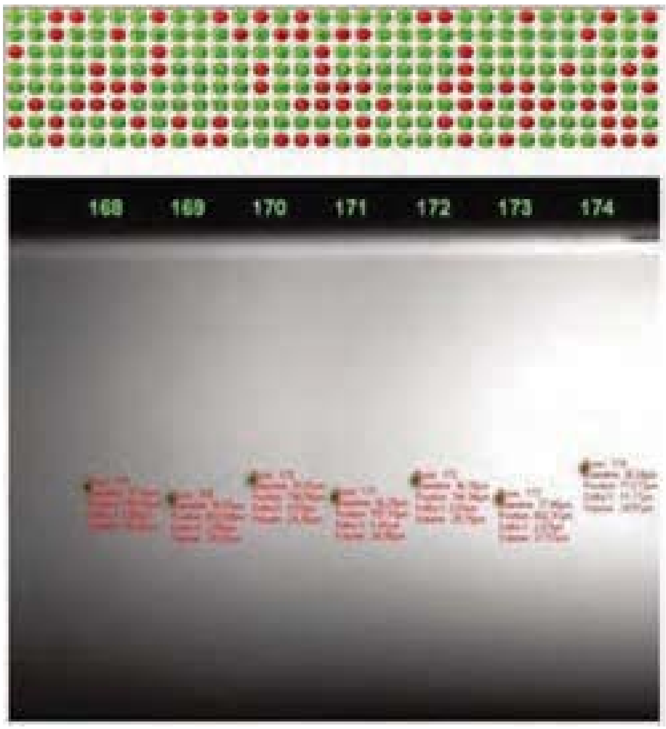

Fig. 1 Image indicating activity of nozzles (green-active nozzles) in the print head using the formulated CIGS ink. A representative image indicating drop analysis is also provided below that

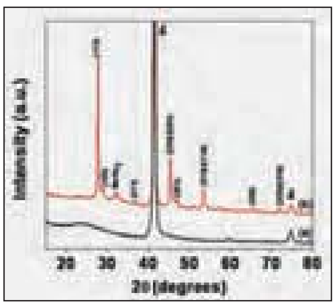

Fig. 2 XRD pattern of (a) Mo-coated glass substrate and (b) obtained $Cu(In_{0.7}Ga_{0.3})Se_2$ thin film after IPL treatment

Fig. 3 Surface morphology of CIGS films after IPL treatment

Contributors: L. Hatti Naik and S. S. Pal

Fabrication and Characterization of CIGS/CdS Heterojunction

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Cu(In,Ga)Se_2 (CIGS) based solar cells have yielded highest conversion efficiencies (≈ 20.8%) among thin-film technologies due to their suitable direct bandgap and large optical absorption coefficient. However, a pre-requisite to realize commercialization of these devices is to explore scalable methods for fabrication of CIGS films. In pursuit of this, electrodeposition has proved to be one of the simplest and economical methods and has yielded CIGS cells with promising efficiencies. A modified electrodeposition technique involving pulsed current and an additive-free electrolyte using a two electrode system has already been used at ARCI to fabricate stoichiometric CIGS thin-films.

For achieving high efficiency thin-film solar cells, a key requirement is also a suitable buffer layer which can form a heterojunction. This layer should have minimal absorption losses, be capable of driving out the photo-generated carriers with minimum recombination losses and transport them to the outer circuit with minimal electrical resistance. In addition, it should possess least lattice mismatch with the absorber layer. CdS, an n-type semiconductor and a direct bandgap material with a bandgap of 2.4 eV, satisfies all the above criteria and has been reported to yield the best efficiencies for CIGS-based devices. Chemical bath deposition is often used for CdS deposition over CIGS, as it provides better conformal coverage of CdS as desirable for a heterojunction.

In the present study, the CIGS/CdS heterojunction has been fabricated by conventional chemical bath deposition of CdS over a pulse electrodeposited CIGS layer. Mo sputtered glass was used as the substrate for electrodeposition of CIGS. Fig. 1a shows the morphology of the CIGS/ CdS heterojunction revealing conformal coverage of CdS over CIGS, which is desirable for high efficiency CIGS devices. The compact morphology of the pulse electrodeposited CIGS films aided the formation of high-quality heterojunction. Fig. 1b shows a typical XRD pattern of the heterojunction, which reveals peaks corresponding to (100) and (002) of CdS in addition to Mo and CIGS peaks, confirming the presence of hexagonal CdS and chalcopyrite CIGS. A rapid assessment of photoactivity is often desired for screening semiconductor absorber layers for PV applications. This can be achieved without fabricating an entire device by using an electrolyte contact and carrying out photoelectrochemical (PEC) characterization involving a linear/cyclic potential sweep while illuminating the electrode with chopped light. Amperometric I-t curves of CIGS and CIGS/CdS in 0.5M Na_2SO_4 are shown in Fig. 1c under dark and illumination with solar simulated light. CIGS films are noted to exhibit a photocurrent density of ≈ 0.5 mA/cm^2 whereas the CIGS/CdS heterojunction shows a significantly higher photocurrent density of ≈ 8.5 mA/cm^2. The improved photocurrent is due to the increased space charge layer and reduced recombination losses in a CIGS/CdS heterojunction.

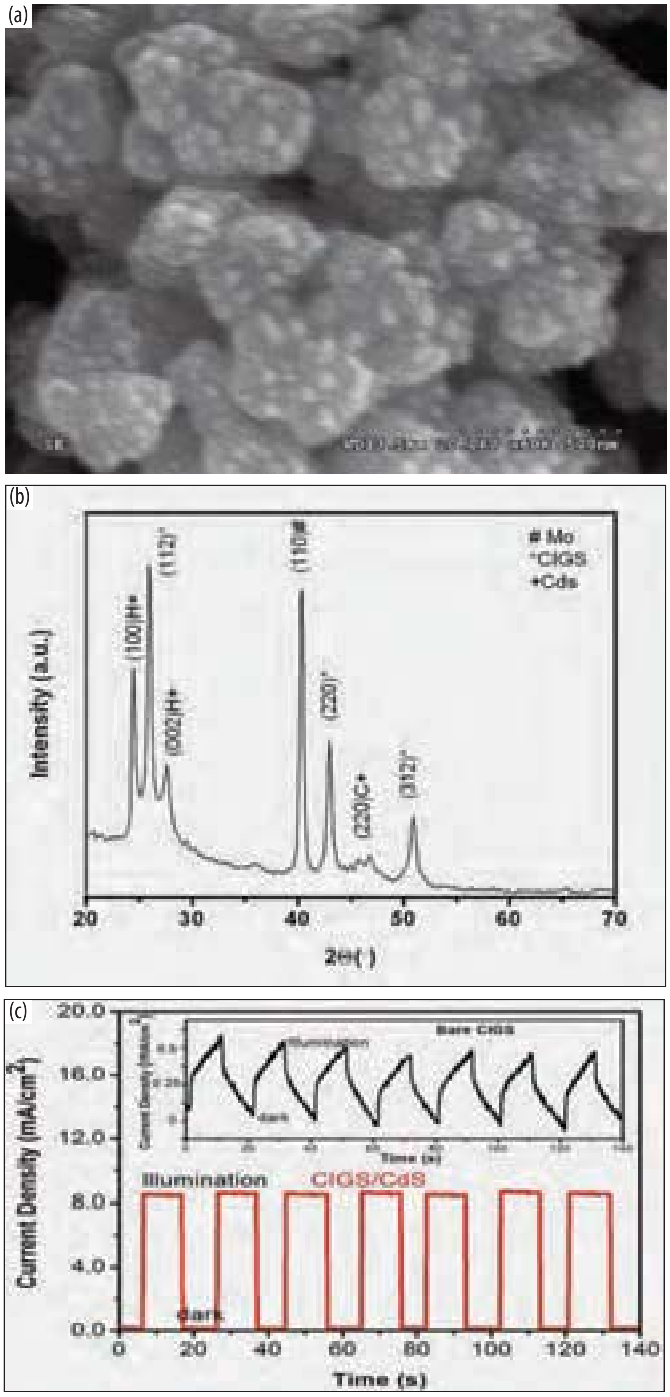

Fig. 1 a) Morphology, b) XRD pattern and c) Amperometric I-t curve of CIGS/CdS heterojunction

Contributor: M. Sreekanth

Organometal Halide Perovskite Solar Cells

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Solar cells based on dye-sensitized mesoporous metal oxide photoanode and solid-state hole transporting material (HTM) are emerging as a cost-efficient way for solar energy to electrical energy conversion. Champion devices based on ruthenium dye-sensitized TiO_2 as a photoanode and spiro-OMeTAD as a HTM have been reported to exhibit around 8% power conversion efficiency and moderate stability under standard test conditions (Air Mass 1.5G, 100 $mW.cm^{-2}$). Nevertheless, further improvements are required for commercialization of low-cost sensitized solar cell technology.

Optical response of the sensitizer molecule and the molar extinction coefficient are known to play a significant role in achieving high photocurrent and, thus, high power conversion efficiency. Replacing the conventional ruthenium dye with a suitable high molar extinction coefficient, direct band gap semiconductor material is a key strategy for capturing more sunlight and improving the efficiency of sensitized solar cells. Organometal halide perovskites (ABX3, A= CH_3NH_3, Cs; B= Pb, Sn; X= I, Cl, Br) have recently emerged as promising light harvesting material for high efficiency solar cells. This report focuses on synthesis of methylammonium lead iodide ($CH_3NH_3PbI_3$) perovskite crystals by a solution approach and assessment of their potential application in solar cells.

X-ray diffraction pattern (Fig. 1) of the bulk $CH_3NH_3PbI_3$ powder shows well defined peaks, and confirms the formation of a tetragonal perovskite structure with lattice parameters of a = b = 8.88 A^o and c = 12.68 A^o. The optical band gap (Eg) of the $CH_3NH_3PbI_3$ crystal is estimated to be 1.52 eV from the extrapolation of the linear part of Tauc plot.

Uncontrolled precipitation and fast reaction kinetics between inorganic (PbI_2) and organic (CH_3NH_3I) precursor invariably lead to a perovskite film with an uneven morphology, which hampers the photovoltaic performance of the final device. Hence, a sequential deposition method was adopted to prepare a uniform and smooth $CH_3NH_3PbI_3$ film on an electron selective contact. A schematic illustration of perovskite solar cell architecture, with a suitable electron and hole selective contact layer, is shown in Fig. 2. The compact and mesoporous TiO_2 layer shown was deposited on patterned FTO glass substrate by screen printing. For perovskite film preparation by the two step process, PbI_2 was first dissolved in dimethylformamide and spin coated on the mesoporous TiO_2 film. The PbI_2 coated TiO_2 film was then dipped in the solution of freshly synthesized CH_3NH_3I in 2-propanol, followed by drying at 70°C. The colour of the electrode was noted to swiftly change from yellow to dark brown, indicating the formation of $CH_3NH_3PbI_3$ perovskite film. The mesoporous TiO_2 acts as a scaffold and confines the PbI_2 crystals down to the electrode pore size (< 20 nm). Such small size PbI_2 crystals are completely converted into methylammonium lead iodide within few seconds of their exposure to CH_3NH_3I solution. Cross-sectional scanning electron microscopy confirms the formation of a uniform perovskite layer with intimate contact with the TiO_2 scaffold, which can facilitate the electron transfer process. Preliminary devices fabricated in a HTM-free planar hetrojunction configuration exhibit broad IPCE spectrum over the entire visible region and about 1 % solar to electric energy conversion efficiency. Our results show that the perovskite can be employed for efficient solar light harvesting up to 800 nm.

Efforts are now underway to fabricate a complete device by deposition of an HTM layer and a metal (Au/Ag) cathode on the $CH_3NH_3PbI_3/TiO_2$/FTO photoanode.

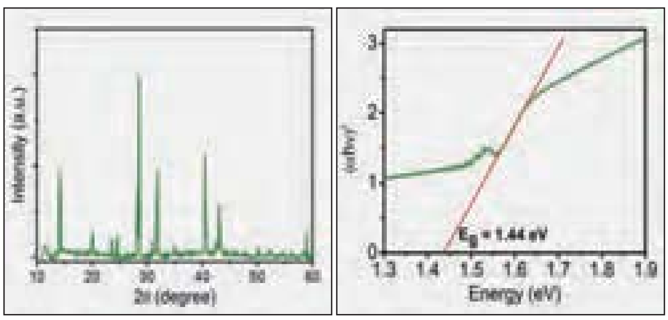

Fig.1 X-ray diffraction pattern (left) and Tauc plot (right) of $CH_3NH_3PbI_3$ perovskite crystal

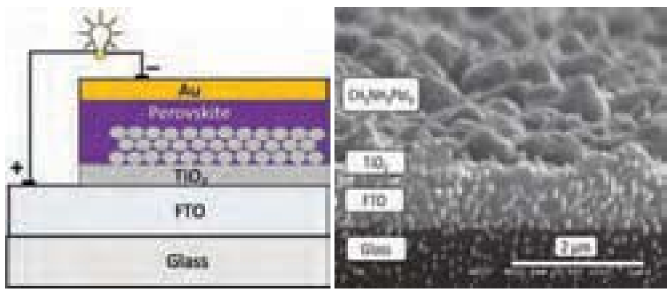

Fig. 2 Schematic diagram of a complete perovskite solar cell (left) and SEM cross-sectional view of a solution processed perovskite photoanode (right)

Contributors: K. Srinivas Reddy, S. Saroja and Nanaji Islavath

Chemical Bath Deposited CdS Buffer Layer for CIGS Thin Film Solar Cell Application

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Cadmium sulphide (CdS) thin films are widely used as a buffer layer in thin film solar cells owing to their wide-band gap (2.42 eV), ability to serve as an excellent heterojunction partner for p-type absorber materials, photo conducting nature and formation of a buried heterojunction through Cd-doping of CIGS. CIGS thin film solar cells with CdS as a buffer layer have been reported to exhibit efficiencies greater than 20%. Among the various deposition techniques reported for deposition of CdS, Chemical Bath Deposition (CBD) is simple and inexpensive, and can be employed to obtain a homogenous film with controlled stoichiometery over large areas. Apart from the above advantages, CBD provides good surface cleaning of the absorber layer and possible intermixing at the absorber interface, leading to improved lattice matching with the absorber layer. Film characteristics like thickness (which needs to be in the range of 50-80 nm), uniformity, transparency and crystallinity are important for using CdS as a buffer layer in CIGS thin film solar cells. As a part of the CIGS thin film pilot line at ARCI, a semi automated CBD facility has been established for CdS thin film deposition on substrates of size 300 mm x 300 mm.

As the quality of a CIGS thin film solar cell device is largely dependent on the quality of CdS films, a series of experiments were conducted to prepare high quality CdS films on glass substrates. Structural and optical properties of CdS films prepared using the CBD facility have been extensively studied employing varied processing conditions to make high quality films for CIGS thin film solar cell applications. In the CBD system, Cd-Salt, thiourea, Ammonia and DI water in appropriate concentration were used as precursors. The bath temperature, pH of mixture and deposition temperature was fixed and maintained throughout the process. The prepared CdS samples were characterized using X-ray Fluorescence spectrometer (XRF), Zygo Optical Profilometer, X-ray Diffractometer, FESEM and UV-Vis-NIR spectrometer.

CdS thin films prepared using the CBD system were found to be uniformly yellow in colour and adherent to the glass substrate. X-ray fluorescence measurement results revealed the average film thickness to be in the range 50-55 nm over the 300 mm x 300 mm area. The thickness of the representative sample was also determined using a Zygo optical profilometer and found to be 59 nm, with the line profile being as shown in Fig. 1. Fig. 2 shows the glancing-angle X-ray diffraction pattern of the CdS film on a soda-lime glass substrate and reveals only one peak at 26.70 corresponding to the Hexagonal (002) [ICDD data No: 00-001-0783] / Cubic (111) [ICDD data No: 01-074-5617] phase. The distinction between the two phases is difficult, as very often mixed phases of cubic and hexagonal phases are present.

The FESEM image of the surface of the CdS film deposited on a glass substrate shows a uniform coverage of fine grains all over the substrate, as shown in Fig. 3. The grain size distribution was in the range of 20 to 45 nm. Fig. 4 shows the optical transmittance and reflectance of the CdS film deposited on glass substrate. The inset in the figure corresponds to the optical band gap of the film, which was determined by extrapolating the linear portion of the (αhν)2 Vs. hν plot. The band gap of CdS was found to be 2.54 eV, which is slightly higher than the bulk value, with the difference being attributable to the smaller grain size. The CBD process conditions have now been optimized for CdS thin film deposition for use as buffer layer in CIGS thin film solar cell devices.

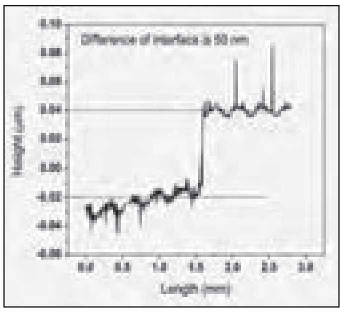

Fig. 1 Line profile used to determine CdS film thickness

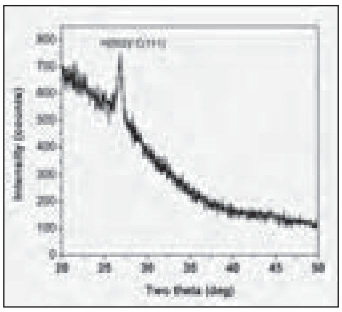

Fig. 2 XRD pattern of CdS films deposited on glass (G.I angle of 0.5 deg)

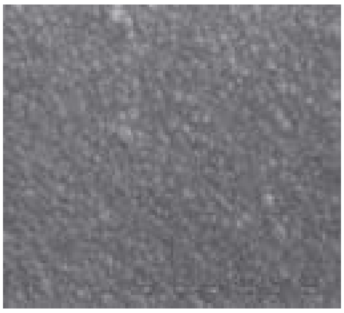

Fig. 3 FESEM Image of CdS film deposited on glass substrate

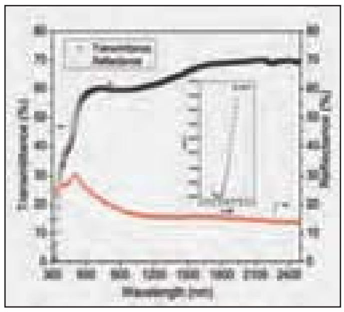

Fig. 4 Transmittance & reflectance spectra of CdS film deposited on glass substrate

Contributor: Sanjay R. Dhage

Patterning of Sputtered Mo Thin-Film using Laser Scriber for CIGS Thin Film Solar Cell Application

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Scribing is an essential step in manufacturing of CIGS thin-film based solar cell modules, which involves deposition and patterning of various layers in a specific sequence to form strips of series interconnected solar cells forming monolithic integration as shown in Fig. 1. Typical patterning steps for CIGS thin-film solar cells are P1, which consists of electrical isolation of Molybdenum back contact, followed by P2, which involves isolation of CIGS-CdS thin-film to achieve series interconnection between front and back contact. P3 involves electrical isolation of a bilayer thin film of i-ZnO and Al doped ZnO (AZO). The area from P1 to P3 becomes dead for photo-activity, thereby directly impacting the performance of a module, and should be restricted to the minimum. Perfect electrical isolation, with narrow scribe width and without a heat affected zone is highly desirable for obtaining a high quality device. Absence of cracks, debris, and melted scribe edges are characteristic of good scribing. Fig. 2 illustrates some different types of poor quality scribe lines, exhibiting non-uniform scribing, melting of edges and even delamination of the film, all of which need to be avoided while scribing thin films deposited on a substrate.

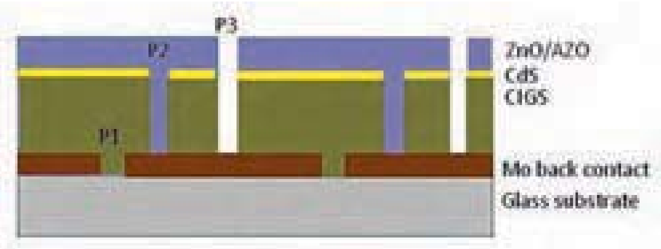

Fig. 1 Schematic representing scribing for monolithically integrated CIGS thin film solar cells

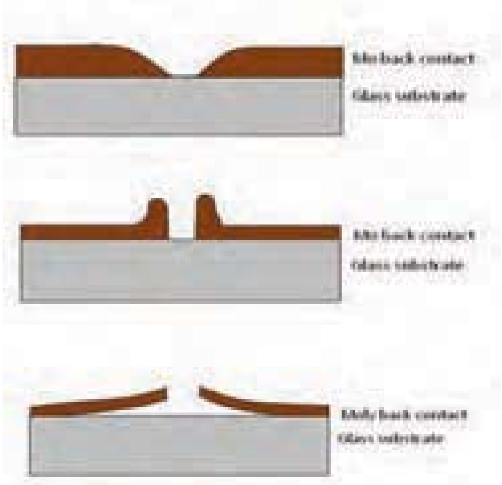

Fig. 2 Illustrations of different types of poor quality scribing

The Centre for Solar Energy Materials (CSEM) at ARCI has established a laser and mechanical scribing facility (Model: Presto, Make: LPKF SolarQuipment, Germany) equipped with a pulsed nanosecond 1064 nm laser source, with the capability to deliver a maximum power of 20 W. Substrates of size 300 mm x 300 mm with thickness up to 6 mm can be processed, with maximum axis speeds up to 2 m/sec. The scribing system is also equipped with a mechanical scribing tool with a 70 µm tip.

The laser scribing process depends upon various parameters like the spot size of laser beam, repetition rate, laser power, pulse duration, table speed and frequency attenuation. Various scribing experiments were carried out on Mo-coated glass substrates to optimize the scribing parameters. In order to get high quality scribe lines, the spot size of the laser beam needs to be approximately half of the desired scribe width. Tuning of spot size, frequency and table speed decides the optimum pulse overlap, which typically should not be more than 50% to avoid a broad heat affected zone. Scribing of sputtered Mo coating on glass substrate, using variable pulse duration at different laser powers at fixed frequency has been done. The results reveals that a shorter pulse duration facilitates removal of the Mo film effectively without forming cracks, burrs or ridges as less energy is used. Longer pulses, on the other hand, yield uneven scribing and significant debris.

Through an exhaustive study, involving detailed experimentation by varying all the significant process parameters, discussed previously, clean scribing of sputtred Mo thin films deposited on glass substrates has been successfully achieved. A similar exercise is presently ongoing to optimize conditions for other scribing steps essential to fabricate monolithically integrated CIGS thin film solar cells. Fig. 3 shows a microscopic image of a good quality Mo film scribe with the line width of 30 µm and ablation depth of 430 nm using selective parameters.

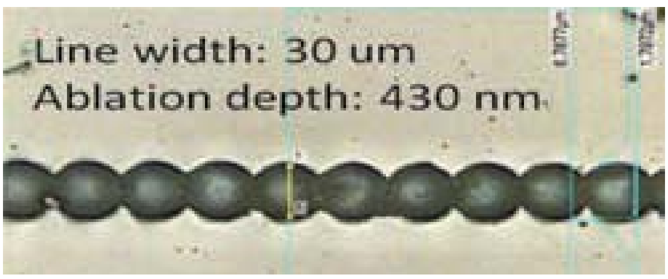

Fig. 3 Microscopic image of a good quality scribing of Mo film with selective parameters

Contributor: Sanjay R. Dhage

Centre for Nanomaterials

The Centre for Nanomaterials at ARCI was established a decade ago with an aim to conduct application oriented research in the emerging field of nanomaterials as relevant to Indian needs and conditions. As the scope for nanotechnology is huge, covering almost all industry segments. ARCI has opted to address only such technologies for which Indian demand and market are large, while cautiously dealing concurrently with the safety and toxicology aspects of the technology. Translation of laboratory research into technology is very challenging, and ARCI is striving to meet it head on using the available expertise and by establishing suitable pilot scale and testing facilities. Sponsored application oriented projects as well as carefully conceived in-house programs are efficiently handled, and few technologies have already been transferred to industries, while others are under development. The Centre for Nanomaterials is manned by a team of scientists from various science and engineering backgrounds, which is crucial for technology development.

As shown in the chart below, areas of research in nanomaterials at ARCI address water purification, alternative energy materials, nanocomposites, textiles and materials for automotive applications. In each case, specific applications are targeted, based on basic research carried out at laboratory level. Subsequent scaling-up is done at pilot level in case of material synthesis or prototypes are developed where proof of concept is a requirement. The cost of production, scalability, worker and user friendliness, as well as environmental impact are the key factors taken into consideration during technology development. ARCI closely works with public and private sector companies, as well as academic and research institutes. The following pages present selected highlights of ongoing activities at the Centre for Nanomaterials.

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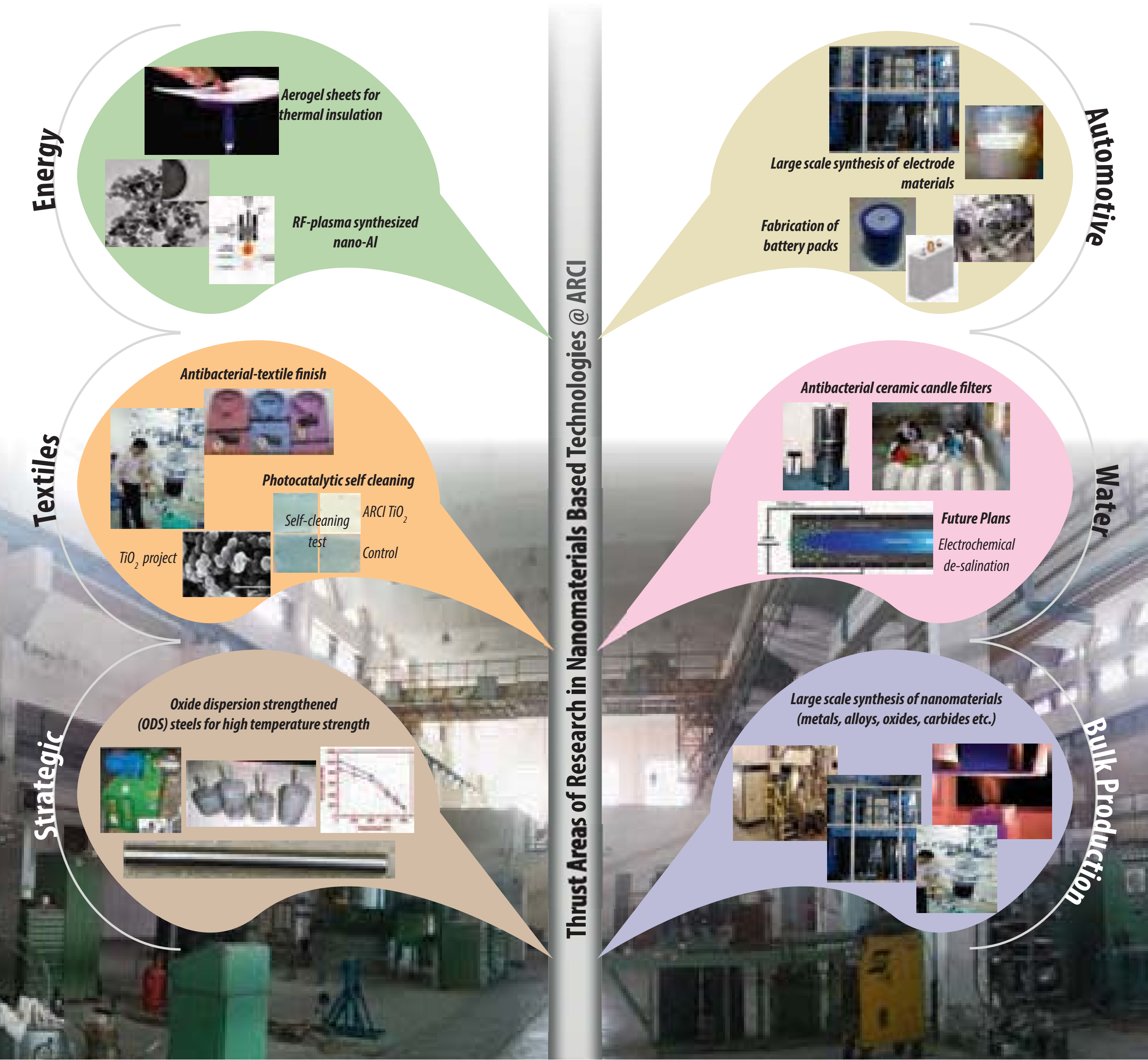

Sintering Temperature Dependent Grain Boundary Resistivity in ZnO Varistor

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Doped ZnO nanopowders with an average particle size of 20 nm were synthesized by flame spray pyrolysis and sintered at different temperatures. The sample code for sintering cycle 900°C for 0.5h and 825°C for 4h is given as S-1, 1000°C for 0.5h and 925°C for 4h is given as S-2, 1100°C for 0.5h and 1025°C for 4h is given as S-3 and 1050°C for 2h is given as S-4, respectively. Impedance measurements on the sintered varistor pellets were made with silver electrodes in air at temperatures ranging from 100 to 500°C on heating cycle in the frequency range from 1Hz to 1MHz. The normalized complex impedance and modulus plots at a temperature of 200°C for S-1, S-2, S-3 and S-4 samples are shown in Fig. 1(a) and (b), respectively. The inset of Fig. 1(a) shows the complex impedance plot at high frequency regions, which does not pass through the origin and RC model. The complex impedance plots show one semi-circle; however, complex modulus plots show two semicircles, which suggest that there are two parallel RC circuits. The inset of Fig. 1(b) shows the frequency dependence M" and Z" plot, a single peak was observed for the impedance plot at ~ 630 Hz, however, in modulus plot there were two peaks at 1900 and $2.5x10^5$ Hz.

The data were subsequently fitted to a resistance and two parallel RC circuits analogy. The solid line of figure Fig 1(a) is fitted to experiment data. The real part of impedance Z' can be expressed as

$$Z'(\omega) = R_3 + \left[\frac{R_2}{1+(\omega R_2 C_2)^2}\right] + \left[\frac{R_1}{1+(\omega R_1 C_1)^2}\right]$$

when ω=0, $Z(0)= R_1+ R_2+R_3$

The electric modulus M* is expressed as $M^*=j\omega C_o Z^*$.

where ω is the angular frequency, R_1, R_2 and R_3 are the resistance of grain boundary type I, type II and core grain resistance, respectively while C_1 and C_2 are the capacitance of the grain boundary type I and type II, respectively. C_o is the vacuum capacitance of the cell and is equal to $e_o.A.l^{-1}$, where e_o is the permittivity of free space, *A* is the area and *l* is the thickness of the space occupied by the sample.

The impedance is mainly composed of resistance and capacitance but dominated by resistance; however, modulus is mainly dominated by capacitance and, therefore, resolve weak peaks. From the above evidence, it was confirmed that the varistor pellet has two time constants, which represent a resistance and two parallel RC circuits analogy.

The high frequency intercept values are 192.5, 78.52, 74.16 and 78 Ω cm and total resistivity are $1.13x10^7$, $6.49x10^6$, $2.45x10^6$, $3.16x10^6$ Ω cm for S-1, S-2, S-3 and S-4 samples, respectively. The impedance values differences were attributed to amount and microstructure of grain boundary materials.

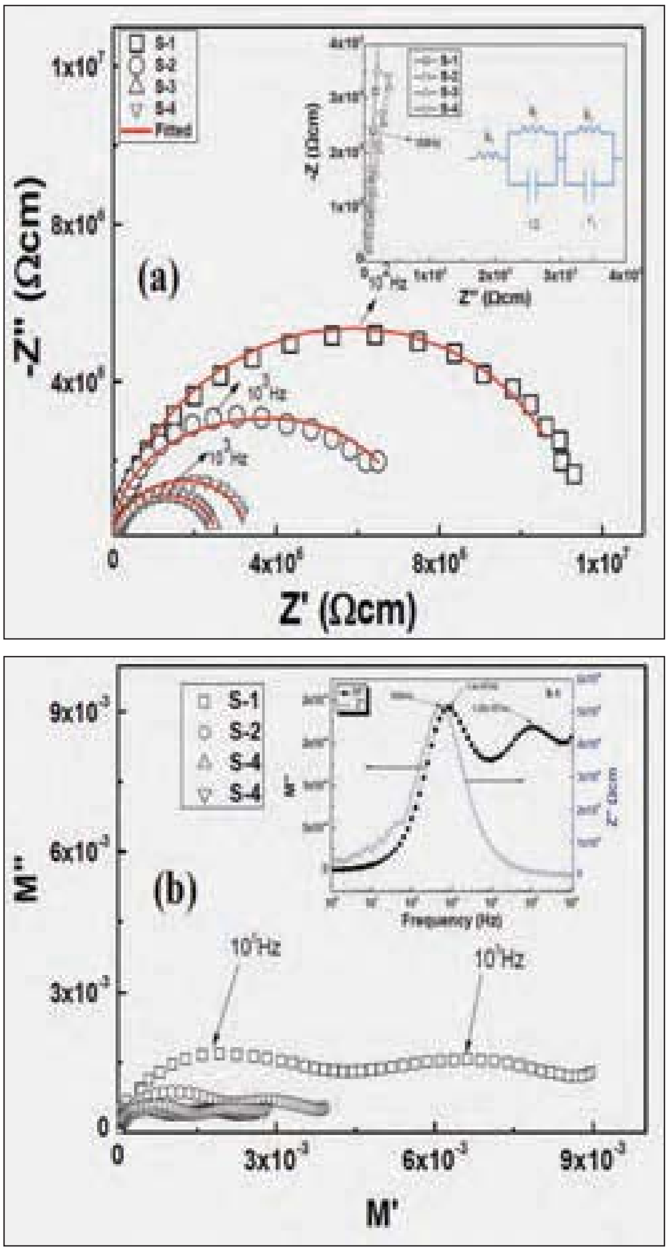

Fig. 1 (a) Normalized impedance plots for the ZnO varistor pellets made from different sintering conditions at 200°C temperature, the data are fitted into equivalent RC circuits, inset is the impedance plot of same data at higher frequency region showing none intersection of origin of the plot, (b) complex modulus plots at 200°C temperature, showing two semicircle dominated by capacitance, inset is frequency dependence modulus and impedance plot of sample S-1; thereby justifying choice of the two parallel RC circuits for data interpretation.

Contributors: Tata Narasinga Rao and Buchi Suresh

Reduced Graphene Oxide Grafted Porous Fe_3O_4 Composite as a High Performance Anode Material for Li-ion Batteries

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Rechargeable lithium ion batteries (LIBs) are one of the most attractive power sources for portable electronic devices and are also being intensively pursued for electric vehicles (EV) and hybrid electric vehicles (HEV). Though graphite has been extensively used as anode material in LIBs, the relatively low reversible capacity and poor stability at a higher rate restricts its use in EV applications. Thus, various alternatives such as transition metal oxides e.g., NiO, Fe_3O_4, Fe_2O_3, SnO_2, Co_3O_4, and CuO have been investigated. Among these, Fe_3O_4 has been considered as a promising material owing to its natural abundance, high electronic conductivity, low cost, and environmental benignity. However, its application has been hindered by poor cycling performance and volume expansion. In order to address this challenge, a well-designed porous nanostructured iron oxide is a prerequisite. Although various methods have been reported for the synthesis of porous nano-structured Fe_3O_4, these methods suffer from several disadvantages like slow reaction kinetics, non-uniform reaction conditions, and scale-up issues. Hence, a facile, quick and eco-friendly method to prepare porous nano-structured materials is of significant importance. In this regard, microwave-chemistry offers an efficient process for the synthesis of porous nano-structured materials. Rapid volumetric heating, high reaction rate, fast reaction time, less amount of external energy, and large scale production of nanoparticles are the advantages of this process.

As part of Nano mission project, ARCI is currently working on the development of efficient electrode materials, which can be used for EV applications. In the present study, we focused on the facile fabrication of Fe_3O_4/reduced graphene oxide (Fe_3O_4/RGO) composite by novel approach, i.e., microwave assisted combustion synthesis of porous Fe_3O_4 particles followed by the decoration of Fe_3O_4 by RGO. Studies on these Fe_3O_4/RGO composites demonstrate the formation of crystalline face centered cubic and hexagonal Fe_3O_4. The nitrogen adsorption-desorption isotherm shows the presence of porous structure with high surface area (81.67 m^2g^{-1}). The uniform coverage of RGO layer on Fe_3O_4 particles is clearly seen in TEM image (Fig. 1), in which RGO acts as a linker to bind the Fe_3O_4 particles together. The interlayer spacing of RGO layer in Fe_3O_4/RGO composite is 4.5Å (inset of Fig. 1), which would lead to a high Li-storage capacity. The electro-chemical studies (Fig. 2) reveal that Fe_3O_4/RGO composite exhibits a high reversible Li-ion storage capacity in comparison with Fe_3O_4 and RGO alone. It showed a reversible capacity of ~ 612, 543, and ~ 446 mAh g-1 at the current rates of 1, 3 and 5C (inset of Fig. 2), respectively with 98% of columbic efficiency after 50 cycles. Improved ionic diffusion by porous Fe_3O_4 particles, and increased electronic conductivity by RGO grafting are attributed to the excellent electro-chemical performance of Fe_3O_4, which make this an attractive anode material for Li-ion storage.

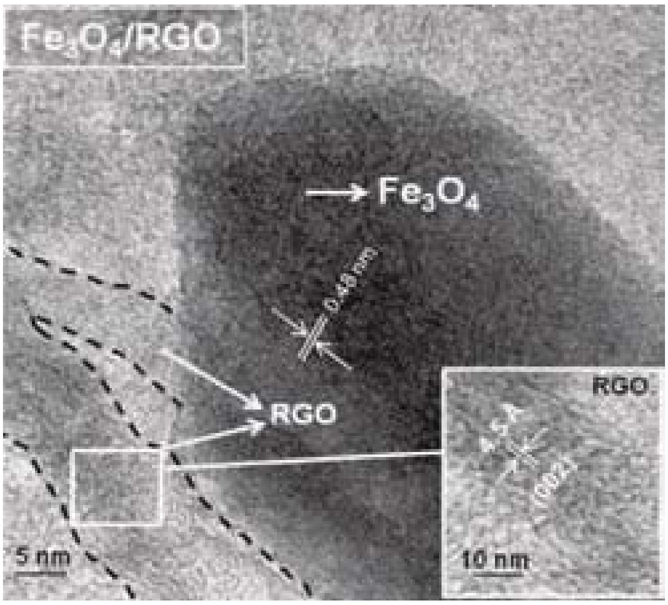

Fig. 1 HR-TEM images of Fe_3O_4/RGO. Inset: Interface between Fe_3O_4 and RGO can be seen in Fig. 1

Apart from the development of efficient carbon coated electrode material in lab-scale, ARCI is also working on up-scaling of the production capability for these materials.

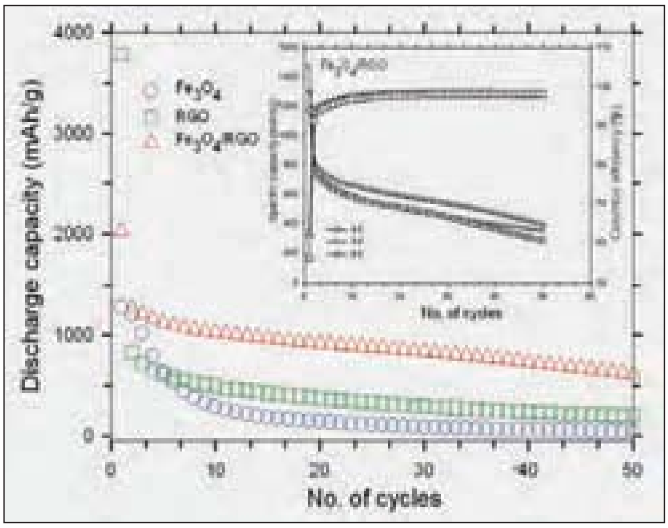

Fig. 2 Galvanostatic charge-discharge profiles of Fe_3O_4, RGO, and Fe_3O_4/RGO. Inset shows cycling performance and columbic efficiency of Fe_3O_4/RGO composite at 1, 3 and 5ºC current rate

Contributors: S. Bhuvaneswari, P. M. Pratheeksha and Tata Narasinga Rao

Influence of Yttria and Zirconia Additions on Spark Plasma Sintering of Alumina Composites

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The effect of yttria and zirconia concentration on the densification kinetics during spark plasma sintering (SPS) of alumina was investigated over a temperature range 1173 to 1573 K and applied stresses ranging from 25 to 100 MPa. Large additions of yttria led clearly to in-situ reactions during SPS and the formation of a YAG phase. Dopants generally lead to a reduction in the densification rate, with substantial reductions noted in samples with ~5.5 vol% second phase.

The experimental data suggests that a master curve approach may not be reasonable for the present experimental conditions. At low solute content coarse alumina grains were observed with a few isolated pores at the grain boundaries whereas at high solute content distinct second phase particles were observed at the alumina grain boundaries. The grains were equiaxed with an aspect ratio ~1, and there was no evidence of abnormal grain growth. The finer grain size at higher solute content is consistent with the Zener drag mechanism. Diffraction patterns from discrete nano particles at alumina grain boundaries in low solute compositions correspond to t-ZrO_2. Continuous EDS line scans across grain boundaries at regions devoid of these particles do not show evidence of segregation indicating the discrete particles are present only sporadically at grain boundaries without being completely dissolved and uniformly segregated throughout the compacted disk.

The slower densification rates and higher activation energies in AZ9 and AY2 are due to the presence of second phase particles, with the higher activation energies being consistent with measured changes in the interfacial energies. The experimental data reveal stress and inverse grain size exponents ~2 for the intermediate and final sintering stages for both AZ and AY, consistent with an interface controlled diffusion process. The influence of low solute content on the densification rates is less than that observed in creep due to differences in stress exponents for pure alumina (n~1) and doped alumina (n~2) during SPS, compared to n~2 for both during creep.

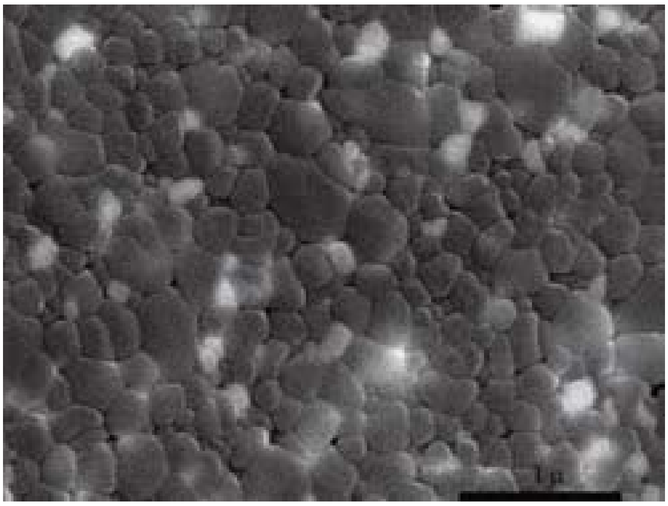

Fig.1 Microstructures of SPS AZ9 sample T = 1573 K, ρ = 99%, d = 190 ± 10 nm

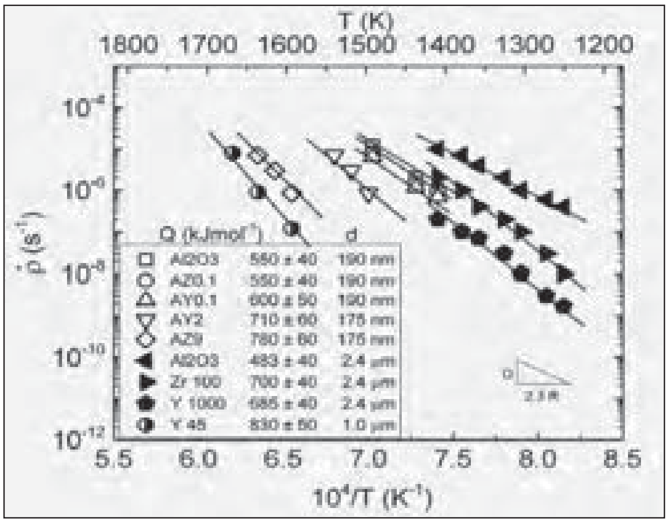

Fig. 2 Comparison of activation energies for alumina, AZ, AY composites from the present study and previous creep results of Yoshida et al. and Cho et al. The open, half open and solid symbols correspond to data from the present study and those of Yoshida and Cho, respectively

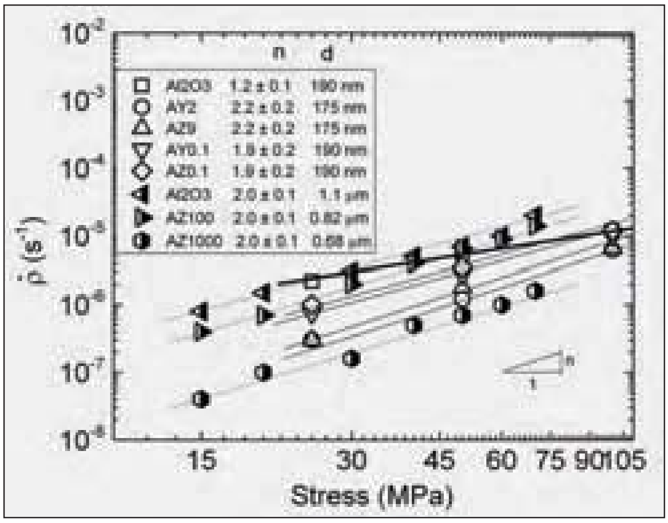

Fig.3 Comparison of stress exponents for alumina, AZ, AY composites from the present study and previous creep results of Wakai et al. The half open legends represent data from Wakai and the open legends the present data. The bold line corresponds to alumina from the present study. AZ 100 indicates 100 ppm Zr dopant in alumina

TiCN-WC-Metal/Intermetallic Nanocomposites for Oxidation Resistant Machining Inserts

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Commercial grade coarse and ultrafine TiCN cermets, used in high speed machining inserts, contain metal binders like nickel or cobalt. Binders play a critical role in the overall performance of these inserts as they bind together the hard phase particles in the insert and thereby preventing them from pull-out and premature failure during machining. Machining operations, which are usually carried out under ambient condition, lead to significant rise in temperature at the tool tip to the extent of ~800-1000°C or even more depending on the material properties and machining parameters like feed rate or cutting speed. Under these conditions, the metal binders are prone to oxidation. Consequently the machining inserts have a reduced tool life. It is envisaged that intermetallics like aluminides can perform better as an oxidation resistant binder in these grade of cermets.

Nanocrystalline iron aluminides Fe-40Al-xNi (0≤ x ≤50) as well as nanocrystalline nickel, as synthesized by mechanical alloying/milling, were used as binder for nanostructured Ti(CN)-WC powder blend. The powder composites were subjected to rapid consolidation by spark plasma sintering (SPS), carried out under a pressure of 30-100MPa (Fig. 1). Hardness and indentation fracture toughness of the ultrafine/nano-composites were found to be at par or superior to the commercially available ultrafine grade TiCN cermet based inserts (Fig. 2a). Studies on oxidation resistance revealed lowest weight gain in cermets with FeAl binder (Fig. 2b). The tribo-mechanical properties of the cermets could be correlated to the cermet microstructure as shown in Fig. 3(a-c).

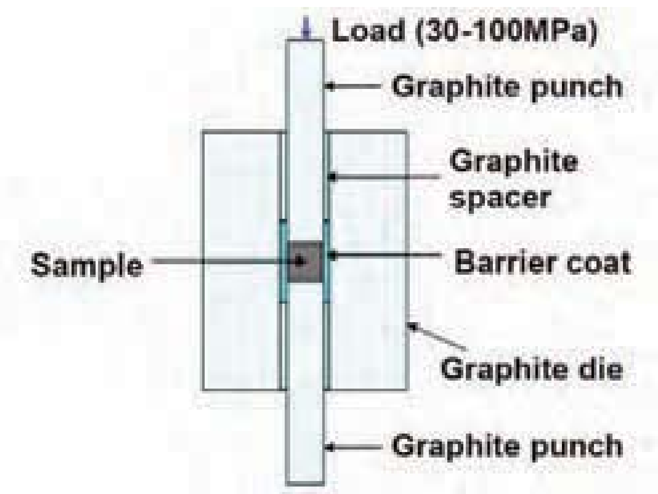


Fig. 1 Schematic of the SPS setup used in this study

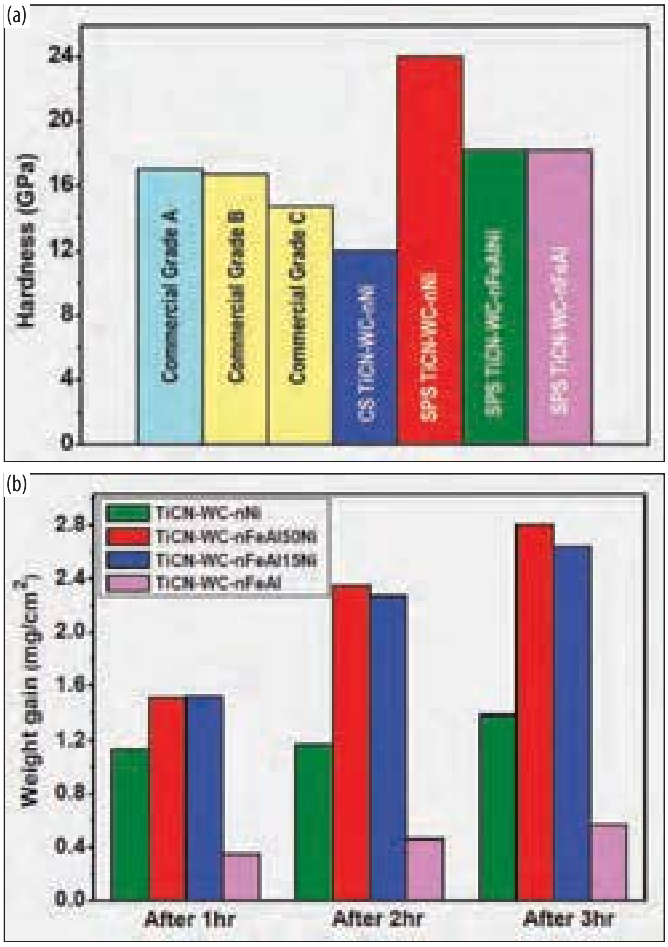
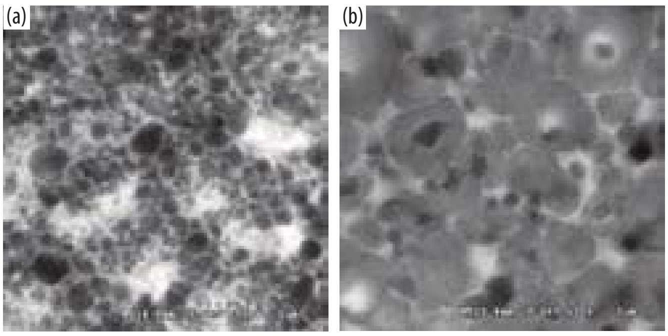


Fig. 2 (a) Vickers hardness of the TiCN-cermets developed at ARCI containing nano-Ni, and FeAl/FeAlNi binders compared to commercial grade cermets with Ni/Co binder (b) Relative oxidation resistance of the TiCN cermets with different binders



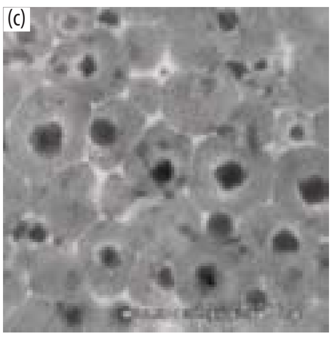


Fig. 3 Typical microstructure of the TiCN-WC based cermets developed at ARCI with (a) Ni (b) FeAlNi (c) FeAl binders Dark phase is the undissolved or partially dissolved TiCN (core), dark gray regions are the solid solution shell phase, bright thin layer around the dark core is W-enriched inner shell while light gray matrix is primarily the binder phase

Contributor: M. S. Archana

Thermal Stability of Silica Aerogels

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High performance silica aerogel based thermal insulation materials are being developed at ARCI for various applications in the field of aerospace, defense, architecture, paint, textiles etc. The thermal insulation performance of silica aerogel at higher temperatures depends upon the extent of the porosity retained after exposure to the heat, as heating of aerogel may lead to collapse of the nano pore walls in it. Hence, the study was performed to see the effect of temperature on the porosity in silica aerogel so as to find its maximum usage temperature as thermal insulator.

Silica aerogel, in powder form, was heated in air for one hour from 100°C to 1200°C and was subsequently characterized for any change in the packing density, thermal conductivity and porosity.

The nitrogen adsorption technique was used to characterize the effect of temperature on the porosity in silica aerogel. Fig. 1 shows the isotherm for as prepared and heated samples. It shows type IV isotherm, which is typical for mesoporous materials. After heating upto 600°C, the total quantity of N_2 adsorbed and hence the specific surface area increased, which is due to the removal of organic functional groups from the surface of aerogel. Heating above 600°C upto 1200°C shows the nature of isotherm and nitrogen adsorption quantity similar to that of the as prepared sample with some change in the hysteresis loop. The existence of such hysteresis loop is typical for the 3-D interconnected porosity in aerogels, and the torturous path in it for the nitrogen molecules during adsorption and desorption. The change in the hysteresis is due to the change in the pore size and pore volume distribution.

It can be seen from Table 1 that the surface area and the pore volume increased for aerogel heated upto 600°C and then decreasing trend observed for higher heating temperatures. The aerogels heated above 1000°C show shrinkage in the aerogel porosity to a large extent. Table 1 also lists the thermal conductivity values measured by transient plane method at ambient temperature. The conductivity is stable upto 1000°C and increases for sample heated at 1200°C. The packing density increases gradually after heating. From all these observations, it can be concluded that the silica aerogels prepared at ARCI can be used as a high temperature insulator upto 1000°C where the porosity and thermal conductivity are retained to a large extent.

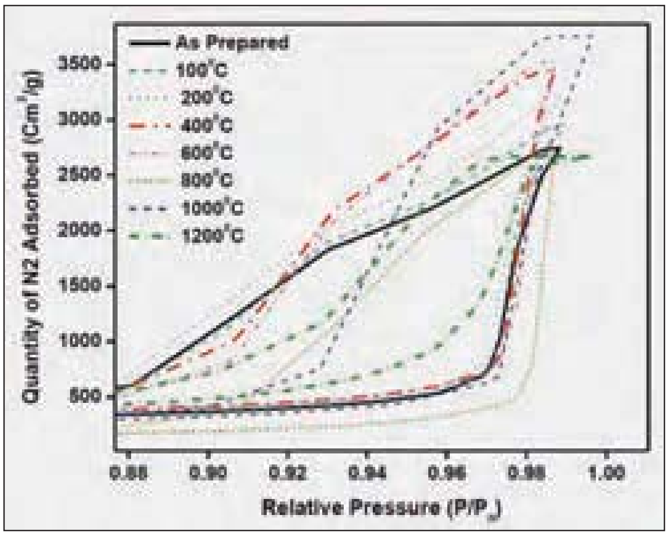

Fig. 1 BET isotherm for as prepared and heated silica aerogel at various temperatures
This is an expanded graph showing only the hysteresis loop

Table 1 Thermal conductivity, packing density and porosity of silica aerogel heated at various temperatures

Silica Aerogel Heated at	Thermal Conductivity (W/mK)	Packing Density g/cc	BET Surface Area m^2/g	Pore Volume cm^3/g
Ambient	0.027	0.052	468	4.26
100°C	0.027	0.059	483	4.59
200°C	0.028	0.066	510	5.00
400°C	0.028	0.070	605	5.32
600°C	0.028	0.074	582	5.47
800°C	0.028	0.078	521	5.15
1000°C	0.028	0.088	411	4.18
1200°C	0.034	0.138	329	4.02

Contributors: Ch. Swapna and K. Radha

Fabrication of Compound Nanofibers for Antibacterial Applications in Filtration

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Nanofibers with large surface area, small fiber diameters, high porosity and small pores, are being used in several application viz. coating on automotive air filter medium as well as other filter medium. Nano fiber coating on standard filtration medium improves the performance characteristics like filtration efficiency and dust holding capacity of the filtration medium. In air filtration, in addition to any improvement in the filtration performance of the media with nanofibers, it is also important to provide acceptable quality air through the air filtration medium. Generally, resistant bacteria exist in the filtration medium while using the air filters. Bacteria, which exist during usage of filters, will also grow and reproduce with the help of collected dust. In order to prevent bacterial contamination in the filtered air, anti-microbial mechanism needs to be provided on the filtration media.

Electrospun PA6 (Polyamide-6) nanofibers are used as coating on filtration medium for increasing the filter efficiency due to their good properties such as fatigue resistance, toughness, resilience and easy processability at room temperature. If these PA6 nano fibers coating can provide bacteria free air, it is expected to have techno-commercial implications in the field of air-filters. In recent years, use of nano silver has been one of the familiar techniques for the removal of bacteria. The presence of nanosilver on the surface of the filtration medium is expected to help in reducing/removing the bacteria while filtering the air. If nanosilver is incorporated in PA6 nano fibers, it is expected to provide a viable solution for removing the bacteria during filtration. However, nanosilver can not be directly incorporated in PA6. Though PVA (Polyvinyle alcohol) used in air filtration, PA6 is preferably used in filtration due to its good properties as discussed above. The present article demonstrates that the fabrication of compound composite nanofiber coatings (PVA/Silver Nitrate($AgNO_3$)/PA6 core-shell fibers) by co-axial electrospinning is a way out for incorporating nano silver in the PA6 based nanofibers coatings, which may find application in air filters. In these compound composite nanofibers, PVA is the shell fiber and PA6 is core fiber. PA6 nano fibers act as a structural material for coatings and nano silver on PVA provides the anti bacterial activity.

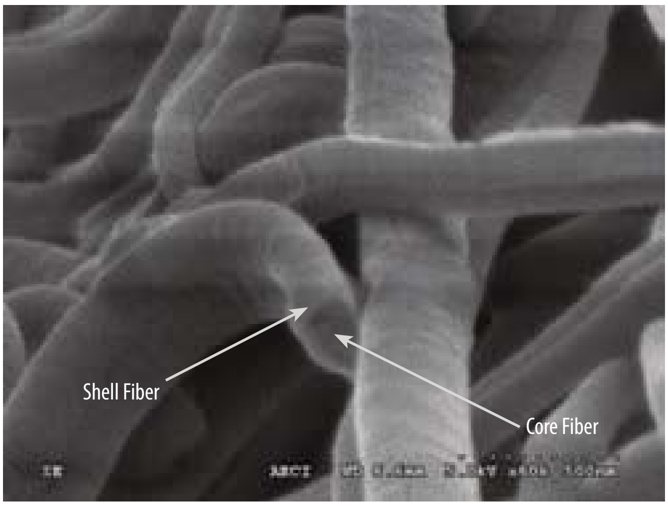

Fig. 1 Microstructure of compound nanofibers with it's cross section

The microstructure of the compound nanofibers, which were synthesized by coaxial electrospinning, is shown in Fig. 1. It is evident from the micrograph that the inside fiber is shielded by thin outer fiber. This clearly establishes coaxial electrospinning with two polymers. The outer surface was examined with energy dispersive x-ray spectroscopy (EDS) to detect presence of silver in the shell fiber. Fig. 2 shows the microstructure and EDS analysis of the compound composite fiber, which confirms the presence of nano silver.

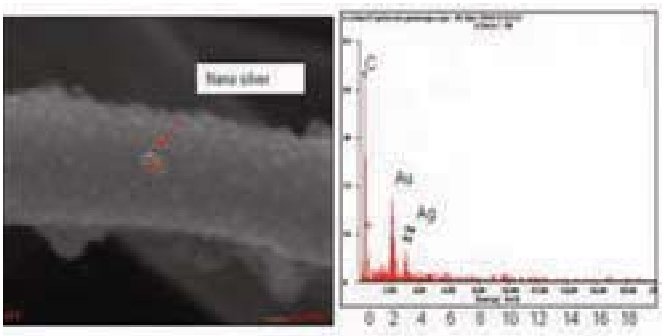

Fig.2 Microstructure and EDS profile

Thus compound nanofibers with nano silver can be fabricated through coaxial electrospinning and can be used as coatings on air filtration medium to get bacteria free or bacteria reduced air.

Contributor: Tata Narasinga Rao

Fabrication of Oriented Nano-Layered ZnO for Photoelectrochemical H_2 and Power Production

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Ongoing developments for utilization of hydrogen (H_2) energy generated from the renewable sources have spurred tremendous R&D efforts worldwide. Depleting non-renewable oil, and environmental-demand to reduce carbon emissions, are driving the efforts to facilitate a clean and reliable power-generation. In spite of its infancy status, H_2-technology foresees its potential applicability in energy and automotive sector. Solar assisted photoelectrochemical (PEC) H_2 generation via., water-splitting/natural oil oxidation is thus important. The technological out-reach of H_2 energy to society is limited by its high-cost, which is directly related to identification of efficient and stable material. TiO_2 and ZnO are similar and highly competitive constituent materials for photoanode of PEC cell. TiO_2 has been first material discovered for PEC application, but ZnO exhibits a superior electron-mobility ($10^2 cm^2 V^{-1}s^{-1}$ over $10^{-5} cm^2 V^{-1}s^{-1}$ of TiO_2) and hence ZnO remains important PEC candidate. In addition, its crystal structure favors nano-structuring desirable for improved transport properties. Further, development of an economic film deposition technique capable of yielding large film area ranging from 5 x 5 cm^2 to 30 x 30 cm^2 should be helpful. Thus, such efforts are of utmost importance to realize a commercially viable solar H_2-energy technology.

ARCI is developing low-cost, large-area nanostructured film by various hybrid fabrication techniques for its direct utilization in a large PEC H_2-generator. Such hybrid techniques involve a bottom-up nano-structuring approach e.g., chemical bath deposition, spray-pyrolysis, dip-coating, electro-deposition. We have achieved an oriented nano-layered ZnO film by simple precursor-spray over heated substrate.

In Fig. 1, right half displays schematic for fabrication of nanostructured film oriented along (100) direction while left half displays the SEM images of film at various film deposition parameters. Optimized parameters led to favorable features like optical-absorption and reduced band-gap, thus yielding an improved PEC performance. The film exhibits an increase in texture coefficient (TC) for (100) plane from 2.0 to 2.4. The microscopic and nanoscopic studies indicate a typical nano-fabric like morphology. The PEC-cell fabricated using the nano-layered ZnO film generates H_2 as well as electric power. Fig. 2 shows variation of TC(100), and enhanced PEC performance even under SS 1.5AM. Interestingly, ZnO-photoanode is found to work under sunlight. We deposited large area (>10-30 cm length) films and successfully demonstrated H_2 generation using the oriented films. These large area films are being modified to develop bigger PEC-cell with enhanced Solar–to-Hydrogen (STH) efficiency. This presents an eco-friendly, and economic methodology usable in energy applications.

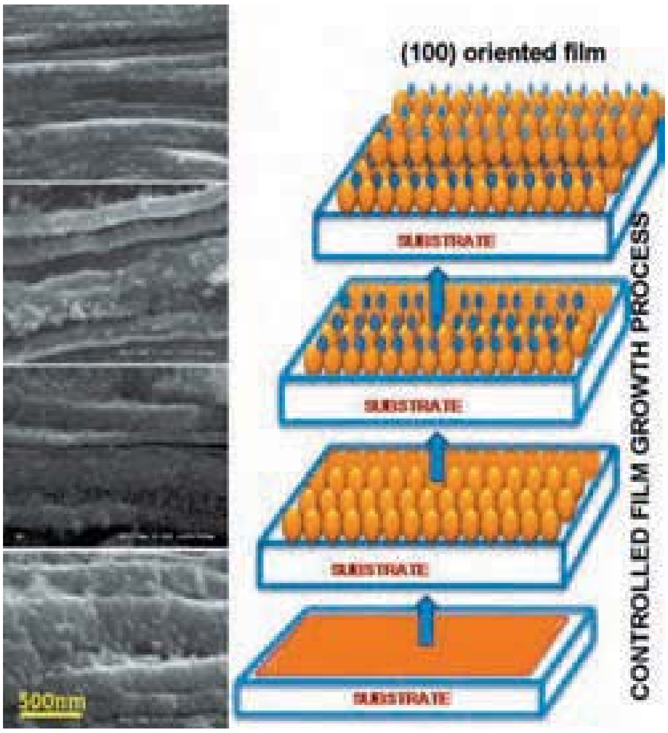

Fig. 1 Left side shows the changes in the film morphology with film deposition Right side shows schematic of the film-growth

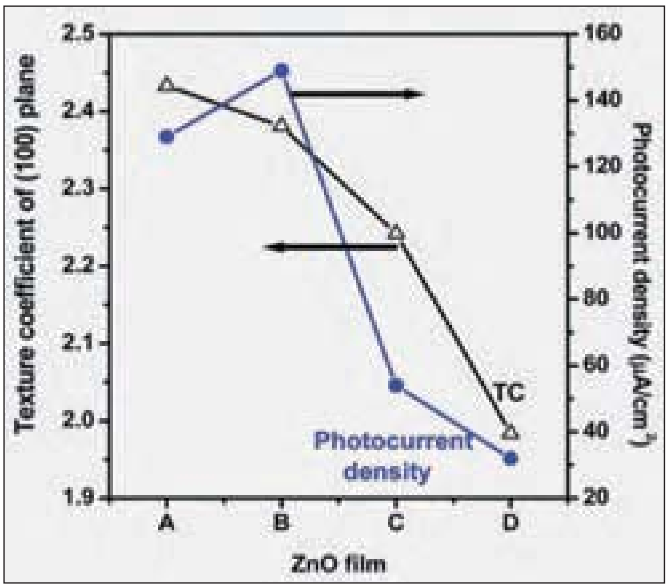

Fig. 2 The variation of the texture coefficient TC(100), and photocurrent density under solar simulator for different film thickness

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Nano Aluminium Powder Synthesis using RF Induction Plasma

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Aluminum particles are common ingredients in energy materials. These particles are used to increase the energy, flame temperature and burning rate in rocket propellants. An increase in burn rate between 2-10x is observed in nano Al powder fuel versus the standard 20 μm Al powder. Other potential applications for these powders are high power metallurgical reductants/sintering aids and catalyst carriers. However, the production processes for these powders have limitations: most of them have low throughput and result in high oxide and impurity levels. The increasing demand for aluminium nanopowders (particles size <100 nm) calls for the development of new technologies that could bring nanopowders synthesis at the industrial scale. Inductively-coupled plasma (ICP) is one of the most promising approaches in the production of a wide range of nanopowders with tailored properties, either at laboratory or industrial scales.

Here, 60 kW RF induction plasma system was selected to synthesize the nano Al powder on large scale basis for propellant applications. Nano Al powder of size ranging from 50 to 200nm was produced at a rate of 1 kg/hr. The as-synthesized powders were passivated by suitably flowing the oxygen gas. Fig. 1 shows the operation principle of the induction plasma torch, in which plasma is generated through the electromagnetic coupling of the input electrical energy into the discharge medium.

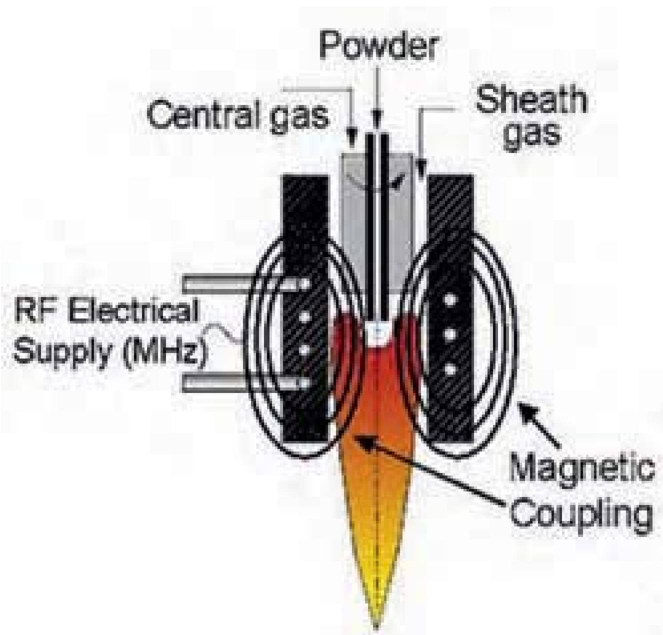

Fig. 1 Operation principle of the induction plasma torch

Fig. 2 shows the typical SEM micrograph of the nano aluminium powders synthesized by using RF induction plasma.

The powders are found to be highly dispersed with respect to the particle size varying from 50 nm to 200 nm. The inset in Fig. 2 shows uniform aluminium oxide layer of thickness 2-3 nm on nano aluminium powder after oxygen passivation. Fig. 3 shows the histogram of the particle size distribution of the powders thus produced following a log-normal distribution. An active Al concentration of 89% has been achieved in these Nano Al powders.

Fig. 2 SEM micrograph of nano aluminium powder produced using RF induction plasma. The inset shows uniform aluminium oxide layer of thickness 2-3 nm on aluminium powder after oxygen passivation

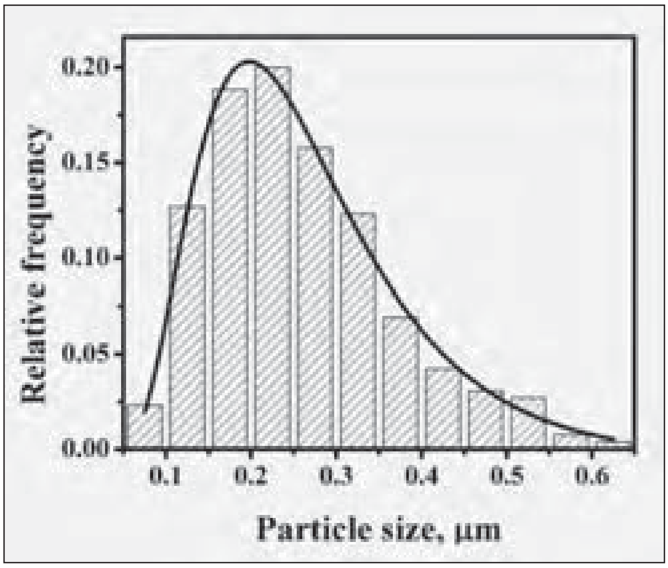

Fig. 3 Histogram of the SEM micrograph of nano aluminium powder produced using RF induction plasma

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Room Temperature Mechanical Behaviour of Oxide Dispersion Strengthened Iron

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Dispersion of fine oxide particles in a metal matrix is a well known strengthening mechanism that has led to the development of alloys with outstanding strength and creep resistance. The thermal stability of the complex oxides coupled with the oxide induced microstructural stability makes the oxide dispersion strengthened (ODS) steels ideal candidate materials for applications involving prolonged exposure to high temperatures. The ODS steels exhibit excellent resistance to irradiation damage and swelling, and hence hold promise for use as clad and structural materials in nuclear reactors. The studies so far conducted on ODS ferrous materials are focussed on Cr containing steels with Y_2O_3 or Y-Ti-O as the dispersoids. The present study has been undertaken to examine the influence of fine Y_2O_3 and Y-Ti-O dispersoids on the mechanical behaviour of hot extruded bulk iron samples without the influence of alloying elements like C and Cr.

Large batches of Fe, Fe-0.35Y_2O_3 and Fe-0.35Y_2O_3-0.2Ti compositions were prepared by milling elemental powders in an attritor at 300 rpm for 40 h with a ball-to-powder weight ratio of 15:1. The milled powder was filled in mild steel cans, degassed at 450°C and sealed. The sealed cans were upset at 1050°C under a pressure of 125 MPa and extruded at 1050°C under 160 MPa to 16 mm ϕ rods with an extrusion ratio of 9. The extruded rods were annealed at 950°C for 0.5 h.

Transmission electron microscopic examination was carried out on ODS iron rods to examine the size and volume fraction of dispersoids. The data on average size, number density and volume fraction of dispersoids of Fe-Y_2O_3 and Fe-Y_2O_3-Ti along with grain size, yield strength are presented in Table 1. The grain size decreases and yield strength (YS) increases in the order Fe, Fe-Y_2O_3 and Fe-Y_2O_3-Ti. While addition of Y_2O_3 to iron increases the strength parameters only marginally, addition of Ti increases the strength parameters dramatically.

The yield strength of ODS iron (σ_y) can be determined by linear summation of matrix strength (σ_m), grain boundary strengthening due to Hall-Petch relationship

$$(\Delta\sigma_{H-P} = K_{H-P} d_g^{-1/2})$$

and Orowan strengthening due to bowing of dislocation around dispersoids

$$(\Delta\sigma_{Or} = A\left(\frac{Gb}{S}\right)\ln\left(\frac{d_p}{2b}\right))$$

where S is estimated from:

$$S = \frac{d_p}{2}\left\{(2\pi/3f)^{1/2} - 2(2/3)^{1/2}\right\}$$

In the above equations, K_{H-P} is the Hall-Petch constant, d_g is the average grain size, A is a numerical constant, G and b are the matrix shear modulus and Burger's vector, respectively, d_p is the measured average dispersoid size, f is the volume fraction of dispersoids and S is the inter-dispersoid spacing. Assuming G = 82 GPa, b = 2.5 X 10^{-10} m (values for iron), A = 0.3, K_{H-P} = 7.8 GPa $nm^{1/2}$ and the values of other parameters as given in Table 1, the relative contributions of the various strengthening mechanism in the case of Fe, Fe-Y_2O_3 and Fe-Y_2O_3-Ti were calculated and presented in Fig. 1 along with the experimentally obtained σ_y values. It is clear that the yield strength of Fe-Y_2O_3-Ti is predicted well by the model while the yield strength of Fe-Y_2O_3 predicted by the model is lower than the experimental value.

Table 1 Experimental values of d_g, d_p, ND and σ_y

S.No.	Property	Fe	Fe-Y_2O_3	Fe-Y_2O_3-Ti
1.	Average dispersoid size (d_p), nm	-	20.5	12.0
2.	Number density of dispersoids (ND), no/m^3	-	7 X 10^{21}	3.9 x 10^{22}
3.	Volume fraction of dispersoids (f)	-	0.00327	0.0104
4.	Average grain size (d_g), m	14.0	11.0	8.0
5.	Room temperature yield strength (σ_y), MPa	252	290	534

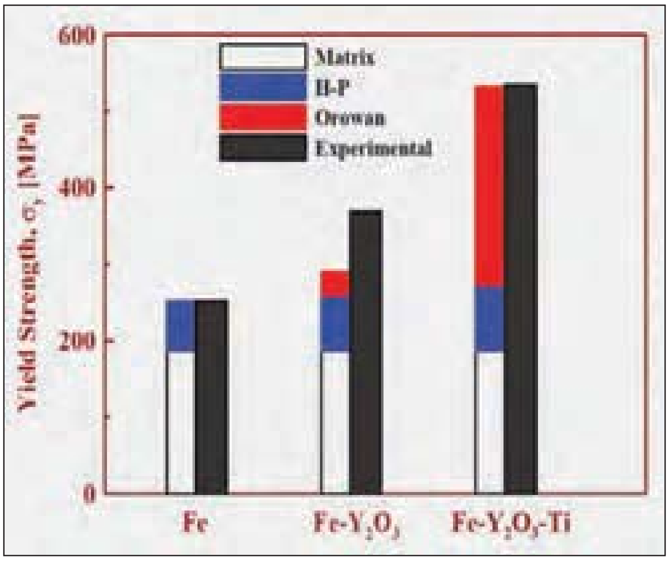

Fig.1 Calculated strengthening values along with experimental values

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Centre for Engineered Coatings

The Centre for Engineered Coatings (CEC) has been playing a lead role in development of state-of-the-art surface engineering technologies needed for the growth of Indian industries. The wide ranging coatings-related technological achievements at the Centre have gradually shaped ARCI into a globally prominent player in the area of surface engineering. The prominent past accomplishments have included the successful transfer and implementation of Detonation Spray Coating (DSC), Micro Arc Oxidation (MAO) and Electro Spark Coating (ESC) technologies, which were unique in the national context.

To further build upon the foundation laid by the above successes, numerous application and technology development programs were initiated by the Centre and are in different stages of maturity. A noteworthy step has been the design and development of an advanced DSC system to avoid/minimize mechanically moving parts, such that the in-service wear can be controlled and the overall productivity significantly increased. To explore applications for the Electron Beam Physical Vapor Deposition (EBPVD) technology, thermal barrier coatings have been demonstrated on aero-engine blades and vanes as part of a collaborative effort. The latest entrant in the family of thermal spray, the Cold Spray Coating (CSC) technology, has also been an area of particular interest, and the Centre has made significant progress towards the launch of a portable CSC system for commercial exploitation.

With a view that academic institutions in the country should also be benefited by the technologies that are developed at ARCI, the Micro Arc Oxidation (MAO) technology is being suitably tailored to enable cost-effective units to be built for sale to interested academic institutions. Concurrently, the MAO technology is also being utilized to develop niche applications relevant to the aerospace industry. Another recent progress at CEC is the development of layers of nickel-tungsten (Ni-W) alloys and Ni-W composite with SiC coatings by Pulsed Electrodeposition (PED) which are potential candiate coatings for replacing carcinogenic hexavalant chrome containing hardchrome plating. The centre is also actively engaged in development of various nanocomposite based wear resistant coatings using a Cathodic Arc Physical Vapour Deposition (CAPVD) for tools for high speed dry machining applications. Further, the Solution Precursor Plasma Spray (SPPS) technique has been successfully demonstrated for deposition of a wide array of coatings for thermal barrier and other applications. A brief report on some of the important activities undertaken at the centre during the past year is provided herein.

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Physical Vapour Depositon Bay

Nitride-based Novel Coating on SS for Effective Energy Management in High Temperature Solar Thermal Applications

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In recent years, with the development of concentrator and heat collecting technologies, the solar thermal power generation has been playing a pivotal role as alternate energy source. The advanced concentrators induce very high temperature (> 550˚ C) on the surface of heat collecting materials (kept at focal point of concentrator) such as stainless steel (SS) tube carrying molten salts (typically nitrates of K, Ca, Na and Li). In general, increased operational temperature increases the emissivity (ε) resulting in poor thermal efficiency. Therefore, to tailor the optical properties suitable for achieving high solar energy conversion efficiency, the heat collecting elements (SS tubes) are to be surfaced with selective coatings. The present work details the summary of concerted efforts placed at ARCI to develop high efficiency solar selective coating on stainless steel substrates suitable for high temperature operation using cathodic arc physical vapor deposition (CAPVD) technique with cylindrical cathodes.

Towards the above objective, Cr/TiCrAlN-G/TiAlN/AlSiN/AlSiO functional multi-layer coating has been developed on stainless steel substrates as shown in Fig. 1. The coating is studied thoroughly for its physical and optical properties. Such a complex multi-layer geometry has been formulated based on numerous fundamental aspects. The first Cr layer on the SS substrate acts as an IR reflector for minimizing the emission. The gradient second layer and third layer have been designed to enhance the absorption while the fourth and fifth layers together act as anti-reflective stack. Individual layer thicknesses were optimized to achieve maximum absorptivity (α). The order of layering was determined based on the refractive index of individual layer. The specific gradient structure in TiCrAlN is chosen to have a gradual transition from pure metallic Cr to the composite TiAlN so as to match the relative refractory index of layer beneath and the one on top. The best reflectance spectra obtained for optimized multilayer structure as shown in Fig. 2 exhibit an absorptivity value of 0.958 (ε – 0.09) at room temperature. The coating has been further examined for its emissivity at different temperatures, corresponding emissivity spectra's were shown in Fig. 3. The results clearly illustrate significant improvement in thermal stability even at 600˚C while keeping the emissivity values of ≤ 0.14 level.

The coating developed with α – 0.958 and ε – 0.09 (up to 600˚C) clearly highlights the great promise for its application in the field of solar thermal sector using CAPVD technique, therefore demonstrates ARCI's relentless efforts for developing high end materials development capability.

Fig.1 The schematic of Cr/G-CrTiAlN/TiAlN/AlSiN/AlSiO selective coating developed on SS-316 substrate (the background colour depicts the actual colour of the coating)

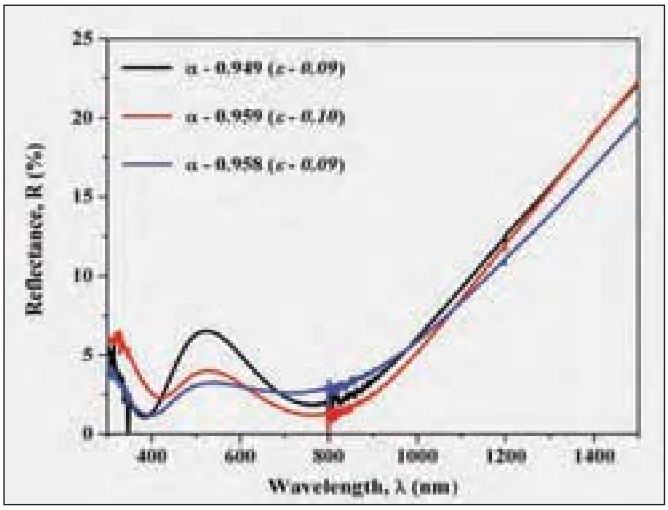

Fig. 2 Reflectance spectra of best Cr/TiCrAlN-G/TiAlN/AlSiN/AlSiO coating (three samples grown at similar deposition parameters to see reproducibility)

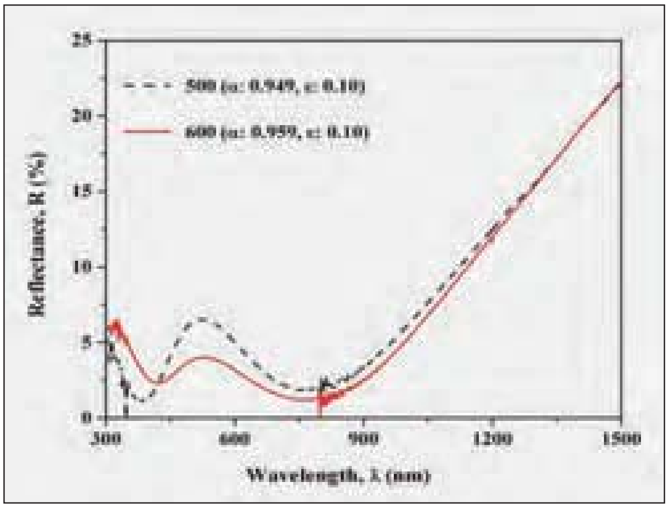

Fig. 3 The absorptivity spectra of Cr/TiCrAlN-G/TiAlN/AlSiN/AlSiO coating after heat treatment for 10 h at 500 & 600°C

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Deposition of Nickel by Thermal Softening using Modified Nozzle Geometry in Cold Spray

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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. Many conventional metals such as Cu, Al, Zn, SS, Ti, Ta etc. have been successfully deposited using air as the process gas. A very few of the recently reported studies demonstrate that dense nickel coating could be formed with either helium / nitrogen combined with an external powder pre-heater. However, it is still difficult to form dense nickel coating using air as process gas with conventional nozzle geometry. Nickel and its alloys show high degree of thermal softening sensitivity (plastic flow at high strain rates is strongly temperature dependant) which leads to better bonding and higher deposition efficiency when deposited at higher process temperature without changing the particle velocity. Dense coatings could be successfully formed at specific impact temperature even below the critical velocity of nickel. It is already a proven fact that the critical velocity of a metal decreases significantly with increasing particle impact temperature. To increase the heat input to the feedstock powder particle, certain key segments of the nozzle were redesigned and fabricated. Coating trials were carried out using different set of nozzle geometries at different process temperatures. Quality of the coatings was characterized by microstructure analysis, hardness measurement and porosity estimation. The increase in powder particle temperature is directly proportional to the plastic deformation of the impacting particle. It is evident from the scanning electron microscope images that the porosity and inter-splat bonding features of the coatings deposited using modified convergence nozzle have been significantly improved than that of conventional nozzle as shown in Fig.1. Splats in the coatings were thermally softened, well deformed and highly flattened which is consistence and evident from the cross sectional images. Micro hardness of the coatings is an indication of the degree of plastic deformation. The hardness values of the coatings deposited using conventional and modified nozzles are 152 HV0.2 and 231 HV0.2 respectively. The result indicated the fact that increasing plastic deformation at high strain rates enhances the micro hardness due to strain hardening and densification of the splats. The impact velocity alone is not sufficient to make intimate bonding in the case of nickel and its alloys. Thermally accelerated enhanced plastic deformation and resultant interface interactions at elevated temperatures are crucial for achieving successful bonding. The above fact could be mainly because of a decrease in the critical shear strain for shear instability (which is the key for bonding in cold spray) and increasing the rate of thermal softening. Also, it is believed that the flow stress generated, upon impact of nickel powder onto substrate/already impacted nickel splat, is a crucial factor which decides the state of cohesive bonding among the deformed splats. Enhanced process/particle temperature not only decreases the amplitude of the flow stress of the colliding bodies/splats but also narrows the stress propagation into the material due to thermal softening.

Though the activation energy of the bonding is much higher (Nickel has higher critical velocity among the conventional metals) than other metals, modifying the thermal history of the feedstock can enhance the adhesion factors which is clearly evident from the current results presented.

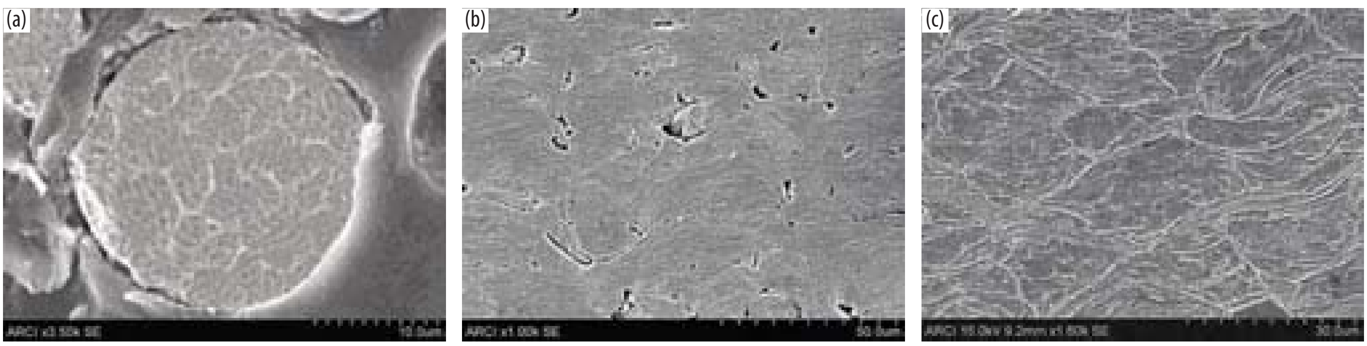

Fig. 1 SEM images of (a) etched Nickel powder, Nickel coatings deposited using (b) conventional nozzle and (c) extended nozzle at 15 bar, 600°C process condition

Contributor: Naveen Manhar Chavan

Influence of Magnesium Alloy Composition on the Properties and Performance of Micro Arc Oxidation Coatings

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Magnesium alloys characterized by high specific strength, resistance to high energetic particle penetration, notably better dimensional stability and electromagnetic shielding characteristics coupled with promising recycling potential, have been considered to be the most prospective candidate material for automotive, electronic, structural, biomedical and aerospace industry. Unfortunately, Mg and its alloys exhibit poor corrosion and tribological properties. Although it is reasonably well known that the alloying elements present in the substrate alloy actively take part in the oxidation reactions in the MAO process, the exact role of various alloying elements added to the Mg substrate in influencing the coating formation kinetics and coating properties is not yet clear. Such information is vital in alloy design to enable maximizing the overall functional performance of MAO coatings.

In the above context, the present study is aimed at understanding the influence of Al and Zn added to AZ series of Mg alloys by way of choosing 7-different substrate compositions namely 3-different commercially used Mg-Al-Zn ternary alloys (AZ31, AZ63 and AZ91) and 3-different specially fabricated binary Mg-Al alloys (Mg-3%Al, Mg-6%Al and Mg-9%Al) along with pure magnesium substrate and subjected them to MAO treatment under identical experimental conditions. The linear variation of coating thickness with time allows the coating formation rate to be defined as the slope of the linear best-fit curve, and the coating formation rate thereby calculated is presented in Fig. 1 as a function of Al content of the substrate Mg alloy. As indicative from "Ternary" AZ-series alloys in Fig. 1, addition of Zn electrochemically activates the Al and Mg to undergo rapid oxidation therefore promotes enhanced coating formation rates.

Phase composition as examined through the XRD analysis for Mg, Mg-9%Al and AZ91 Mg alloys clearly indicates that the coating formed on pure Mg substrate mainly comprises of MgO (Periclase) phase. However, in the case of coatings formed on high Al containing Mg alloys such as Mg-9%Al and AZ91, $MgAl_2O_4$ (spinnel) phase is present along with the MgO phase. Further, The MAO coatings formed on Mg and Mg-3%Al alloys exhibit a hardness values in the range of HV 320 to HV 380. In contrast, the MAO coatings formed on Mg-9%Al and AZ91 alloy substrates exhibit high hardness values in the range of HV 750 to HV 775. Analysis in terms of relative hardness indicates that the hardness of MAO coating is primarily determined by the Al content in the substrate. Zn in the substrate alloy does not have any influence on hardness of the MAO coating formed as Zn do not form any separate phase such as harder spinel phase as promoted by Al content of the substrate.

The MAO coatings formed on both binary and ternary alloys including the coating formed on pure Mg offers significantly lower corrosion rate than that on the bare substrate materials of all the compositions investigated in the present study. Further, the noticeably distinct gap between the filled points corresponding to bare binary and ternary alloys marked as "Region A" and the region between the open points corresponding to the MAO coatings formed on binary and ternary alloys marked as "Region B" as depicted in Fig. 2 highlights the dramatic role of Zn in significantly decreasing the corrosion rate. The Relative Corrosion Resistance (RCR) as defined by the ratio between the difference in corrosion rate of bare substrate and corresponding corrosion rate of coating with the corrosion rate of coating as a function of wt.% Al added to Mg alloys calculated to be in the range 10-40 indicating that the general corrosion protection offered by the MAO coatings is significantly promising.

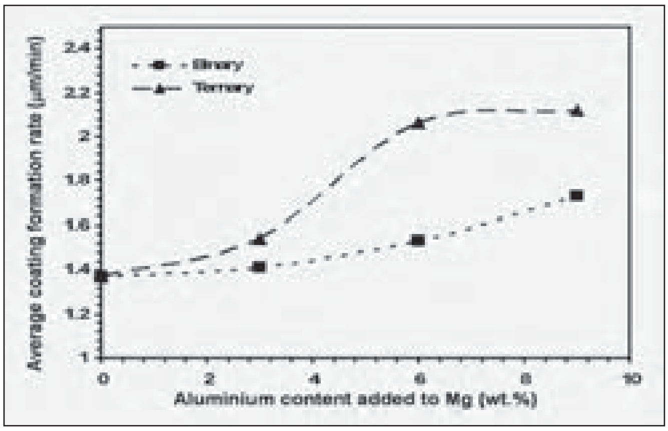

Fig. 1 Influence of Al content (wt.%) added to Mg alloys on the average coating growth rate for binary and ternary Mg alloys

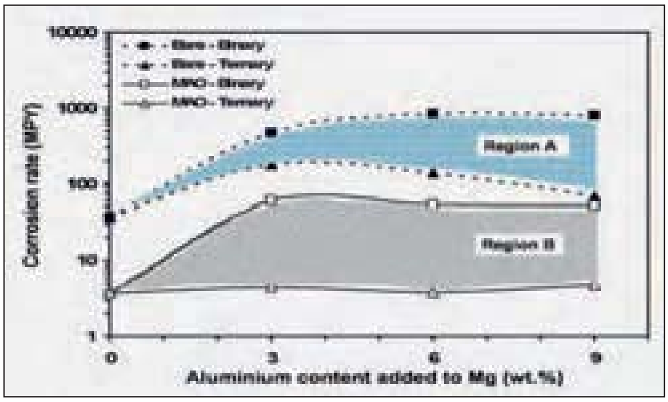

Fig.2 Influence of Al content added to Mg substrate on the corrosion rate of bare (■▲) and coated (□△) magnesium alloys of Mg-Al binary (□) and Mg-Al-Zn ternary (△) compositions

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Deposition of Nanocomposite Coatings Employing a Hybrid APS + SPPS Technique

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A novel approach hybridizing the conventional atmospheric plasma spraying (APS) and the solution precursor plasma spraying (SPPS) techniques has been explored to develop nanocomposite coatings. The above hybrid processing route involves simultaneous feeding of an appropriate solution precursor and commercially available spray-grade powder feedstock (50% Mo, 37.5% Ni-Al-Mo and 12.5% NiCrBSiFe) to realize unique microstructures comprising nanostructured and micron-sized features together. Plasma sprayed Mo-alloy coatings are known for their good tribological characteristics and therefore, used in numerous wear resistant applications. Further augmentation in performance of these coatings is expected through incorporation of distributed nanostructured oxide phases in the microstructure. An understanding of the coating deposition was carried out through splat formation studies as illustrated in Fig. 1. At lower plasma power or longer spray distance conditions, the splats exhibited inadequate flattening due to lack of precursor pyrolysis as well as re-solidification of in-situ formed particles. In contrast, at short spray distance and high plasma power, significantly smaller sized YSZ splats formed on the top of fully molten NiCrBSiFe splats and also on the top of partially molten NiAlMo and/or molybdenum splats as illustrated in Fig. 1. The large difference between the size of YSZ based splats and powder based splats can be observed in Fig. 1, such a typical microstructural distribution is primarily responsible for the formation of nanocomposite microstructure in the hybrid APS-SPPS coatings.

Hybrid composite coatings were deposited using the above conditions over stainless steel substrates and were compared with the normal powder based coating. Both coatings exhibit nearly identical cross-sectional features, although marginally higher porosity was evident in case of hybrid coatings as shown in Fig. 2. Such a marginal increase in porosity can be attributed to (a) lesser degree of melting at shorter distance and, (b) the YSZ particles distributed across the microstructure. TEM analysis revealed that YSZ was invariably found to be comprised of aggregates of numerous polycrystalline grains, and few unmelted spherical particles embedded within the solidified metallic matrix. In addition, the incorporation of YSZ was clearly evident from the additional set of tetragonal t`-ZrO_2 peaks in the XRD spectra of hybrid APS-SPPS coatings. Therefore, this study demonstrates that the desired hybrid nanocomposite microstructure can be realized through the proposed novel APS-SPPS hybrid processing route, under proper choice of processing conditions.

The sliding wear test results for the molybdenum alloy based APS coatings and the hybrid APS-SPPS nanocomposite coatings under various test conditions are summarized in Fig. 3. The wear rate of hybrid coatings was significantly low under dry as well as lubricated sliding conditions. Though the friction coefficient values were similar, an improvement in wear rate to the extent of about 40% under lubricated conditions and about 20% under dry test conditions was noted for the hybrid nanocomposite coatings. The improvements in the wear performance can be attributed to the role of fine-sized, hard and tough t`-ZrO2 splats within the metallic matrix.

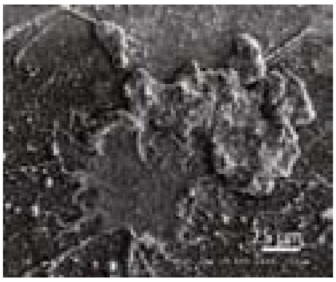

Fig. 1. Splat morphology of hybrid Mo-alloy + YSZ particles

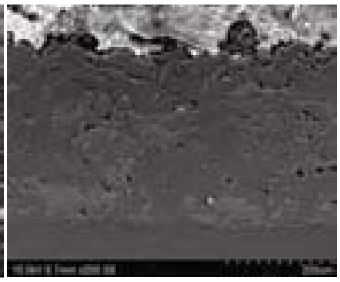

Fig. 2. Cross-sectional microstructure of hybrid Mo-alloy blend + YSZ coatings

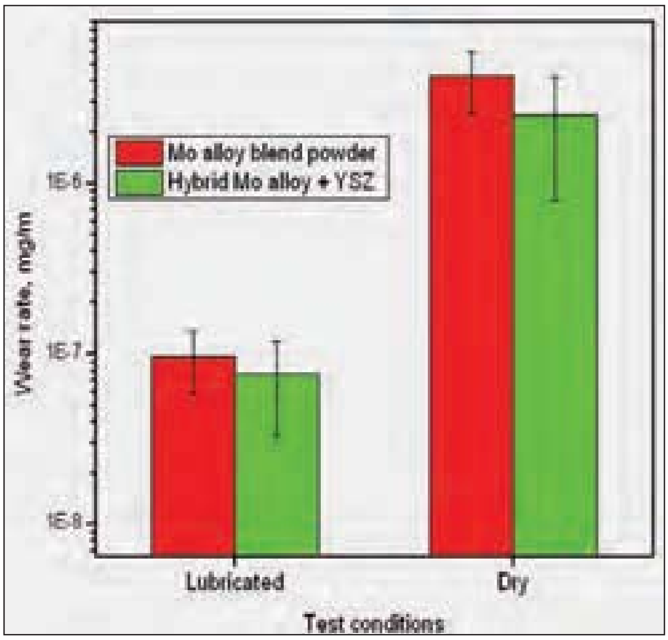

Fig. 3. Wear performance of hybrid Mo alloy blend + YSZ coatings in comparison with Mo alloy blend coatings

Contributor: A. Lohia and S. V. Joshi

Comparative Corrosion Performance of Electrodeposited Ni-W Alloy and Hard Chrome Coatings

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Electrodeposition has, over recent decades, evolved from an exact science to an economically viable technology for development of variety of coatings. Electrodeposition is economically important because of its low cost and technical flexibility. The ability to deposit a wide array of metals, alloy and composite materials by electrodeposition has graduated from a laboratory scale phenomenon to a practical industrial materials technology.

One of the most widely accepted applications of electrodeposition is (direct current) deposition of hard chrome coatings. The electrodeposited chrome is a hard (600-1200 HV) and wear resistant coating. The deposition process is extremely simple and easy to adopt. Therefore, during last 6 decades, hard chrome layers have gained wide acceptance as durable and high performance coatings on structural as well as engineering parts offering enhanced wear and corrosion resistance. However, the hard chrome process utilizes chromium in hexavalent state (Cr^{6+}), in the plating bath. Cr^{6+} is a known carcinogen that evolves in the form of fumes during the process. Any methodology aimed at reducing emission level in turn increases the effective coating cost. Several countries especially in Europe have imposed a ban on use of Cr^{6+} in the bath. This led to interest in finding suitable replacement globally using either thermal spray or electrodeposition.

Pulsed electrodeposition (PED), in which the current is imposed in a periodic manner with a rectangular waveform, is a powerful means of controlling the electrocrystallization process to produce nanocrystalline deposits with unique structure-property combination. In recent years, many nanocrystalline metals, alloys and composites have been produced by PED successfully. The present investigation deals with the feasibility studies on pulsed electrodeposited nanocrystalline Ni-W alloy coatings for hard chrome replacement in terms of corrosion resistance. Nanocrystalline Ni-W alloy coatings were pulsed electrodeposited using citrate bath on mild steel substrate. While, the hard chrome coatings were obtained from a commercial source and used for relative comparision. As illustrated in Fig. 1, Ni-W alloy coatings are found to be dense and devoid of micro cracks in contrast to hard chrome. The tungsten content of Ni-W alloy coatings was 25 (at) % with the hardness of 800 HV while the hardness of HCR is about 850 HV. The corrosion behavior was analyzed in $2NH_2SO_4$ using potentiodynamic polarization at a scan rate of 1mV/sec at room temperature.

The potentiodynamic polarization curves depicting corrosion potential and current are presented in Fig. 2. Ni-W alloy coating is found to have more noble corrosion potential and low corrosion current compared to hard chrome coatings. Upon calculation of corrosion rate, it was found that, Ni-W coatings are 85 times more corrosion resistant than hard chrome coatings in H_2SO_4 medium. The improved corrosion resistance of Ni-W was attributed to the dense structure and the formation of tungsten rich nickel oxide film that passivates the underlying Ni-W and substrate.

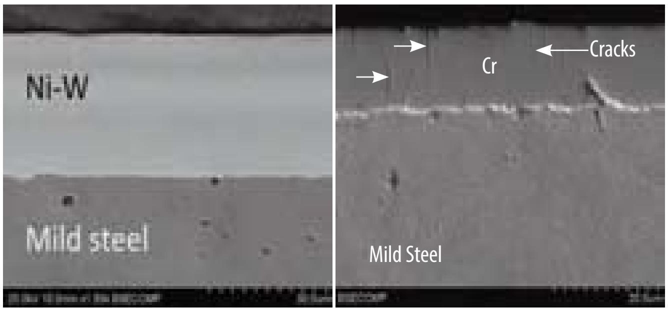

Fig. 1. SEM micrographs depicting Ni-W alloy and hard chrome coating cross section

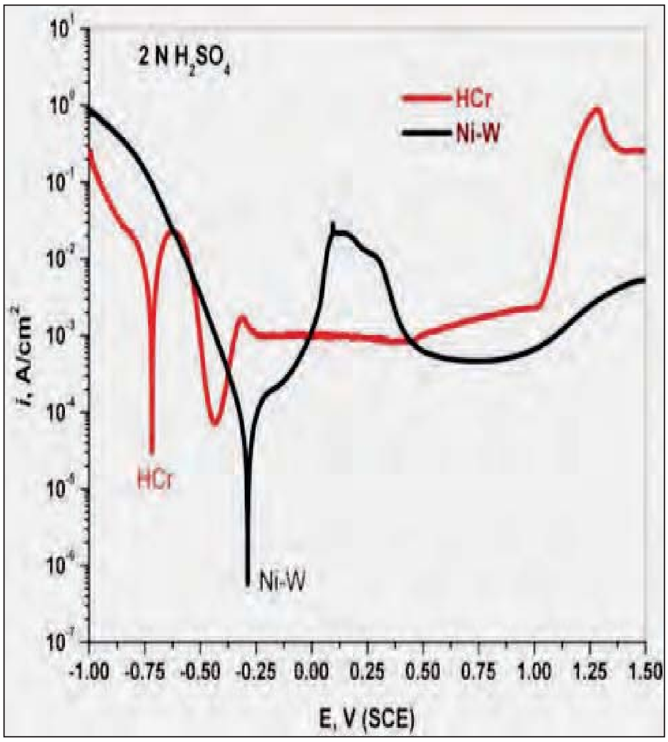

Fig. 2. Potentiodynamic polarization curves for Ni-W alloy and hard chrome coatings in $2NH_2SO_4$

Contributors: Pushpalatha, D. Srinivasa Rao and G. Sundararajan

Deformation Behavior of Copper Splats by Cold Spray

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Cold gas dynamic spray is a coating technique that involves high velocity impacts of micron sized metallic/alloy/composite powder particles (10-45 μm) in the solid state on the substrate. The coating formation is majorly accepted to be based on successful bonding between particle/substrate and particle/particle confined to localized areas at the respective interfaces undergoing adiabatic shear instability. In the present study, the influence of particle velocity on impact of individual copper particles (termed "splats" post impact) on SS 301 is studied. The microstrucutural evolution within the splat after such a high velocity impact along with some preliminary hardness mapping has also been attempted. An attempt has also been made to correlate the calculated strain gradient from centre to edge (jetting region) of the splat to the observed macroscopic flattening and grain size and hardness gradients.

Powder feedstock was sieved to obtain a narrow size distribution (38-44 μm) in order to minimize a wide scatter in measured particle velocities. Fig. 1 shows the SEM micrograph of the splats obtained at the lowest and the highest calculated particle velocities. It can be seen clearly that the "degree of flattening" increases as the particle velocity increases and also the jetting is enhanced at higher particle velocities. Fig. 1c shows the measured degree of flattening (using SEM and image analysis) as a function of particle velocity. Degree of flattening shown in Fig. 1c was obtained by dividing the maximum splat diameter in top view by average particle size. Alternatively, this can be done more accurately by dividing the longest dimension of splat (dl) in cross section by the equivalent circle diameter (de) where the area of the circle is equal to peripheral area of flattened splat.

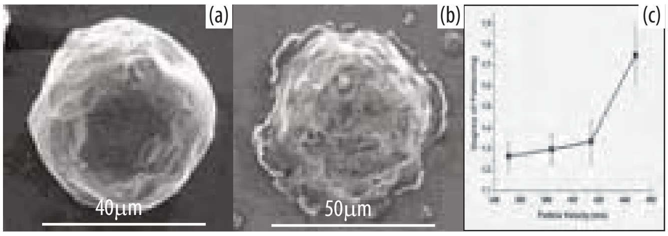

Fig 1. (a) Splat at 362.7 m/s and (b) 464 m/s and (c) Degree of flattening as function of particle velocity

Focussed ion beam milling of the splat was also performed in order to examine the grain size gradient induced by cold spraying. Fig. 2 shows the scheme of FIB operation carried out on the single powder [2a(inset) and 2b] particle before impact and another post impact [2c(inset) and 2d]. A closer look at the microstructure reveals that there is a great amount of inhomogenity in the degree of deformation as is evident from Fig. 2e. It should also be noticed that the strucutre shows a mixed population of dynamically recrystallised grains, highly elongated and deformed grains (and/or deformation twins) and plastic flow like features. All the above tend to fade gradually as we move from the interface to the top surface or even centre of splat in cross section view. The grain size tends to reach that of the original powder as we move up away from the interface.

An attempt was made to map local hardness using low load (2 mN) nano indentation studies. Hardness varying from about 1.5 to 3.2 GPa was recorded which is almost 4-5 times more than that of the hardness observed in completely annealed microscrystalline copper. This itself is a testimony to the amount of strain, strain rate gradient that cold spray induces as shown clearly in Fig. 2e.

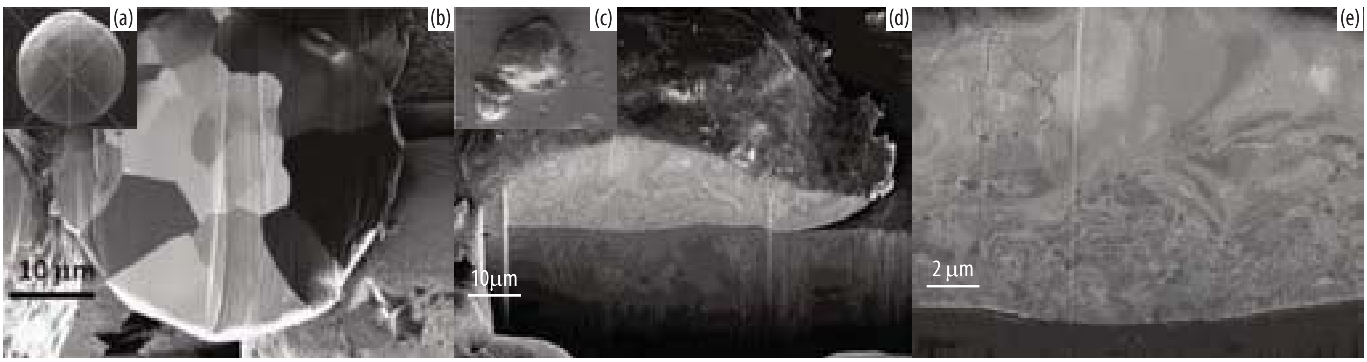

Fig .2. (a,b) Powder particle before and after dissection ; (c,d) Splat before and after dissection and (e) high magnification of splat in fig .2d

Contributors : S. Kumar, L. Venkatesh, Prita Pant and G. Sundararajan

Effect of Nitrogen Pressure on Properties of TiAlSiN Nanocomposite Coatings Deposited in Rotating Cathode CA-PVD

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Recently developed superhard nanocomposite coatings of the type nc-TiAlN/a-Si_3N_4 with hardness nearly 40 GPa are reported to be quite useful for dry machining applications. However, machining performance of the coated cutting tool depends up on numerous factors such as composition, adhesion, hardness and other mechanical properties of the coating material. Cathodic arc PVD is one of the best suited techniques for depositing nanocomposite coatings. The major process parameters in CAPVD are the nitrogen pressure, arc current, bias voltage and deposition temperature. Of these, nitrogen pressure is the key parameter that vitally influences the coating properties.

In view of the above, the present work is aimed to study the effect of nitrogen pressure on composition and mechanical properties of the nanocomposite coatings deposited on HSS substrates. The substrate material of M2 grade HSS and specimens of 12.5x12.5x5 mm size were used for deposition of nanocomposite coatings (nc-TiAlN/a-Si_3N_4) in a cathodic arc PVD, Pi 300, unit (Platit, Switzerland). Partial pressures of nitrogen were varied in steps of 0.005, 0.01, 0.02, and 0.03 mbar during the deposition process. Cylindrical cathodes of pure Ti and Al+Si were used to deposit these coatings. The thickness of the coatings, maintained around 2 µm, was evaluated using a calotester. The coatings were characterized by XPS, nanoindentation, scratch test.

Fig. 1 shows variations in coating hardness with nitrogen pressure, where the hardness decreases with the increase in nitrogen pressure. The hardness ranges from a minimum of 30 GPa to a maximum of 37 GPa. Hardness is also found to decrease with at% ratio of (Al+Si)/Ti. Addition of more than 50% Al in Ti (or at% ratio of Al/Ti>1) reduces the hardness of the coated films as shown in Fig. 2. Literature reports that the maximum hardness may be achieved once saturation ratio 1.0 of N/Ti is reached in TiN films. Based on this observation, the interrelationship between at% ratio of N/(Ti+Al+Si) and the hardness has been investigated and presented in Fig. 3.

It is clear that approximately at unit at % ratio of N/(Ti+Al+Si), the hardness reached a maximum value of 37 GPa indicating that a saturation ratio probably attained. In other films, where at% ratio is less than unity, the hardness decreases and the reason could be attributed to the deficiency in nitrogen atoms with unsaturated composition. This indicates that the TiAlSiN should have a proper at% ratios of (Al+Si)/Ti and also N/(Ti+Al+Si) to possess literature reported superhardness values of 40 GPa.

Fig. 4 shows the correlations between critical loads, Lc1 (where initial cluster of conformal cracks are formed) and Lc2 (where final delamination of the coating from the substrate takes place) with nitrogen pressure. It can be observed that the critical loads also depend on saturation ratio of at% N/(Ti+Al+Si) in similar lines of hardness.

The following conclusions can be made when nitrogen is varied in cathodic arc PVD process for deposition of nanocomposite coatings to study their resulting properties:

- Hardness is influenced by at% ratio of N/(Ti+Al+Si). Maximum hardness can be achieved when the ratio of N/(Ti+Al+Si) approaches 1.0
- Scratch adhesion strength follows the similar trend as that of the hardness

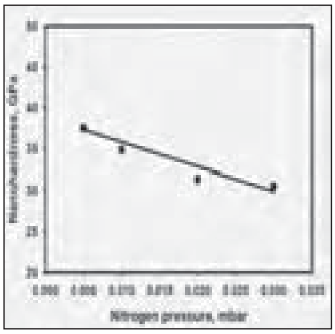

Fig. 1 Correlation between nitrogen pressure and coating hardness

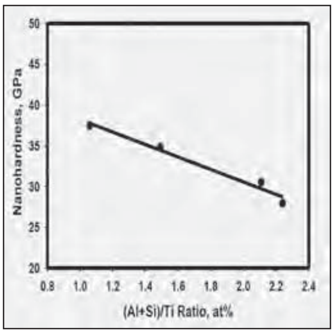

Fig. 2 Hardness variation with (Al+Si)/Ti

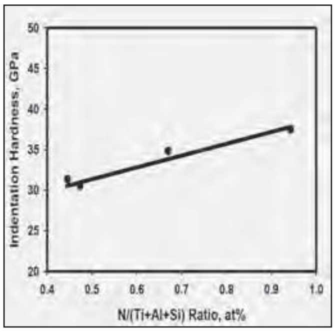

Fig. 3 Hardness against N/(Ti+Al+Si) at% ratio

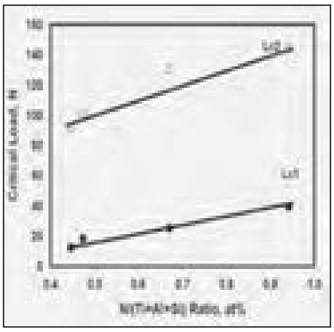

Fig. 4 Critical load against N/(Ti+Al+Si) at% ratio

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TBC Coatings on High Pressure Gas Turbine Blades and Vanes using Electron Beam Physical Vapour Deposition Technology

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The major objective in the design of advanced gas turbine engines; whether for industrial, marine or aero-engine application; is to achieve improvement in performance/ efficiency and reduction in overall cost. With the incessant demand for increasing engine thrust and efficiency, there has been a progressive increase in engine operating temperatures. Such an increase in operating temperatures has been accompanied by a constant demand for materials with improved high temperature capability and the above trend promises to continue in the years ahead. Currently, almost all the advanced gas turbine engines use nickel-base superalloys in the hot-sections of the engine. Notwithstanding the significant advances made in super alloy development over the years, the improvement in alloy properties achieved by modifying their composition has yielded diminishing returns in recent times. Therefore, a host of appropriate coatings are used on various components of an aero-engine gas turbine for providing protection and/or for performing certain specialized functions. Among these coatings, thermal barrier coatings (TBCs) have particular relevance in high temperature sections of the aero-engine. TBCs are multi-layer coatings consisting of an oxidation resistant metallic coating called bond coat. A zirconia-based ceramic coating is applied on the bond coat to provide thermal insulation to the component. Currently, a combination of Pt-modified aluminide bond coat and 7% yttria stabilized zirconia (7YSZ) ceramic coating (deposited by EBPVD method) has emerged as the best candidate for thermal barrier applications for aero-engine gas turbine components such as blades and vanes.

The most challenging task of design and development of job rotation manipulator has been successfully accomplished. The manipulator as shown in Fig. 1 has been fabricated and integrated with the EBPVD system. Subsequently, the development and optimization of TBC coatings have been carried out on Pt-Al bond coated test coupons. The coating thickness and surface roughness optimization was carried out on trial HPT blades and Vanes. Further, the most critical process parameters such as job rotation speed, substrate temperature were also optimized. In the as-deposited condition, the colour of the 7YSZ coating is dark grey due to oxygen deficiency in the EBPVD coating chamber. However, it became milky-white after exposing the same to 1000ºC for ½ hr in air in a box-furnace. Based on the optimized coating deposition conditions, numerous batches of HPT blades and vanes was TBC coated. Fig. 2 illustrates the cross-sectional morphology of the YSZ coating at various locations of blade. The coating was fairly uniform across various locations. The coating thickness varied in the range 140-150 μm at leading/ trailing edges whereas it was between 160-180 μm at other locations. Well-developed perpendicular columns were found in the YSZ coating deposited on the aerofoil independent of its geometrical location of blade surface.

The TBC coatings on several batches of microstructural test coupons, tensile and creep specimens have been carried out and subsequently analyzed. Detailed Oxidation performance tests were carried out on TBC coated AM1 alloy test specimens. It was found that the TBC without TGO resists spallation up to 700 cycles (cycle: 30 min. heating & 30 min. cooling) of oxidation at 1100°C in air, while the TGO generated Pt Al bond coated TBC resists spallation even beyond 1000 cycles (1100°C with 45 min soaking time) as illustrated in Fig. 3. This clearly demonstrates the unique capability of ARCI for developing EBPVD coatings usable in high temperature applications.

Fig.1 Manipulator used for TBC coating deposition on HPT Blade

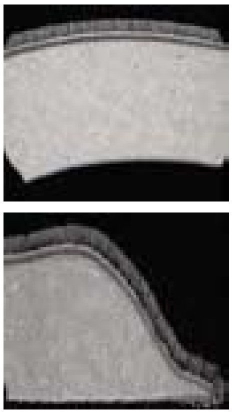

Fig.2 Cross sectional coating morphology indicating fairly uniform coating thickness

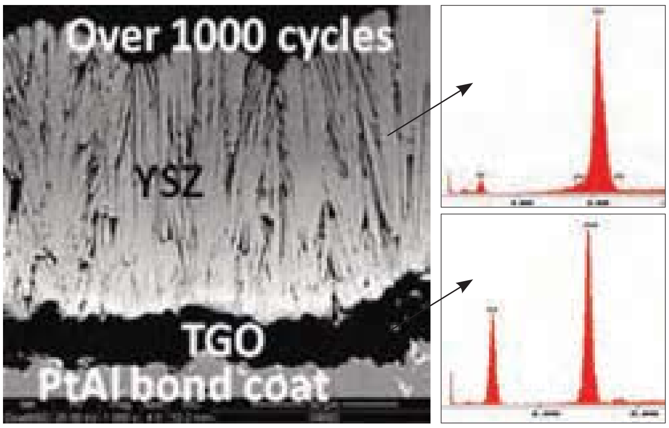

Fig.3. Oxidation performance of TBC coating on AM1 alloy

Contributor: D. Srinivasa Rao

Centre for Ceramic Processing

Centre for Ceramic Processing with its mission to develop innovative processing technologies and products went on realizing the products based on transparent and cellular ceramics as per commitments of the ongoing projects. Further, the centre has also explored the diverse applications and functionalities based on the relevance and potential in the area of transparent ceramics. Centre has also initiated activities on two new user driven sponsored programmes in the field of thermal management and solid electrolytes. Emphasis has also been given for fundamental studies in the area of defect free processing technologies namely, Chemical Vapour Deposition, Hot Isostatic Pressing and Pressure Slip Casting followed by the correlation of the observations to final product specifications.

Centre has successfully completed the process development of transparent spinel ceramics under a sponsored program achieving theoretical densities in combination with the close to theoretical transparency. Further a major project on complex shaping of transparent spinel ceramics has been granted due to the expertise gained by the team and significant progress has already been achieved. Centre is also exploring the application of transparent spinel for the fabrication of invisible orthodontic brackets, and as a first step excellent biocompatibility of this material is demonstrated through the cytotoxicity and genotoxicity assay studies conducted at INMAS, DRDO. Keeping in view the increasing importance of the transparent/translucent alumina ceramic envelops for the application in high intensity discharge lamps, the centre has also initiated activities in shaping envelops for energy efficient lighting.

As a part of the continuing in-house programs, attempts are also being made for improving the electrochemical performance of the honeycomb based solid oxide fuel cell (HCSOFC) modules. A second module was evaluated at ARCI's CFCT and further R & D efforts are in progress towards achieving the required current densities. In-house program on pressure slip casting of advanced ceramics has also demonstrated the feasibility for casting of > 99 % dense alumina parts using slurries with controlled rheology and optimum parameters.

Extrusion processing of porous zirconia based thermally insulating sleeves and pressure slip casting of sodium beta aluminate solid electrolyte tubes are two user driven sponsored activities initiated at centre during the period of this report.

The Centre has also undertaken several specialized job works in the area of its proven expertise and also prototypes have been supplied in multiple batches, as per supply order, based on already developed technologies. As a part of international collaboration under Indo-French Centre for the Promotion of Advanced Research Centre, the centre has also demonstrated a process for the fabrication of large volume crucibles for thermal shock resistant applications.

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Pressure Slip Casting Machine (SAMA GmbH) Model PCM-100-N-H 25

Investigation on the Effect of Micro-cracking on the Thermal Conductivity and Thermal Expansion of Tialite Ceramics

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Tialite (Al_2TiO_5) is explored as a candidate material for new generation diesel exhaust particulate filters because of its high thermal shock resistance resulting from inherent low thermal expansion, in combination with high refractoriness and low thermal conductivity. Tialite has a pseudo brookite structure with orthorhombic unit cell. Such a structure is responsible for the thermal expansion anisotropy and microcracking. This study attempts to correlate the effect of microcracks with thermal properties.

Two formulations pure Aluminum Titanate (AT) & Talc doped Aluminum Titanate (TAT), were prepared from commercially available precursor oxides. Phase composition of the samples was estimated by XRD, and fracture surfaces were examined under SEM. Thermal expansion behavior of the samples were studied using dilatometry using 25 mm length and 6 × 5 mm cross section. Samples were also subjected to thermal conductivity using the discs of 3 mm thickness for thermal conductivity determination using laser flash technique.

Variations of thermal expansion (dL/L0) and thermal conductivity with temperature of the AT and TAT samples are shown in Fig. 1 and Fig. 2, respectively.

It is evident that the thermal expansion and thermal conductivity of both the samples have shown a decreasing trend till the temperature reaches 350 to 400°C. Beyond 400°C, a prominent slope change is evident in thermal conductivity, whereas, the slope change is observed beyond 500°C in the case of thermal expansion behaviour. The observed decrease in thermal conductivity from room temperature to 400°C can be attributed to the low temperature phonon scattering. Relatively low thermal conductivity of the TAT sample in comparison to the AT sample can be attributed to the presence of substitutional Mg^{2+} and Si^{4+} at Al^{3+} site in Al_2TiO_5 generated during sintering, as a result of the high temperature decomposition of magnesium silicate. In addition, the observed inherent microcracks in the aluminum titanate ceramics are also expected to play important role in controlling the thermal behaviour. The low thermal expansion values observed for the TAT sample can be attributed to the increased crack density along with narrow crack opening width as marked in the micrographs shown in Fig. 3.

It can be summarized that, as the temperature increases, inter and intra-granular cracks get healed and provide paths for effective heat transfer through conduction.

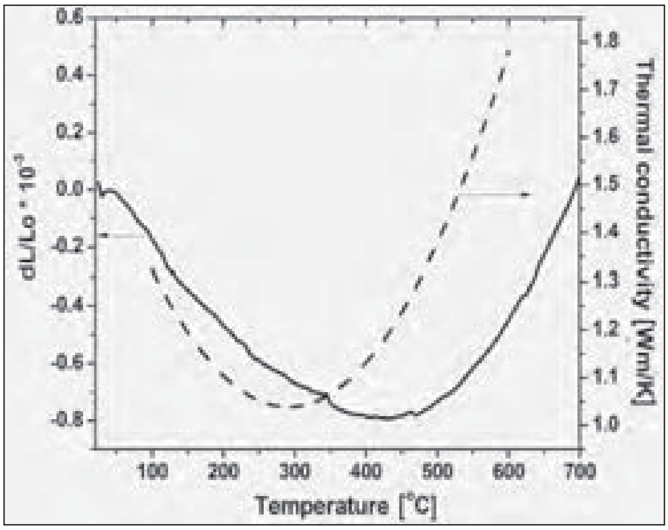

Fig. 1 Thermal conductivity variation with temperature of AT sample

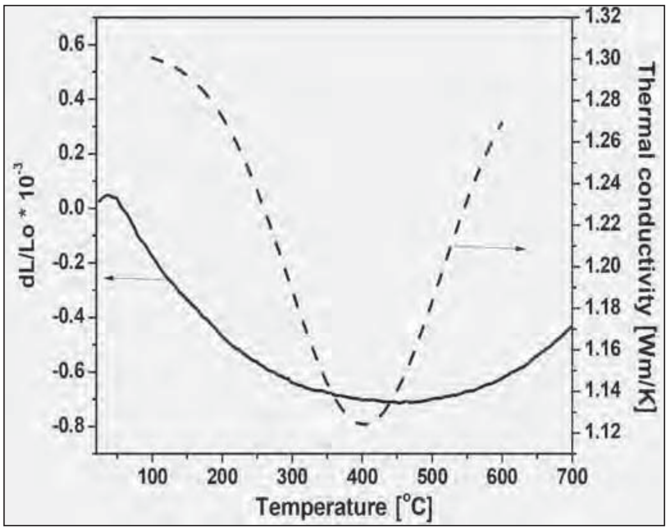

Fig. 2 Thermal conductivity variation with temperature of TAT sample

Fig. 3 Surface microstructure of sintered TAT sample

Contributors: R. Papitha, A. Rajashekar Reddy and Roy Johnson

Shaping of Advanced Ceramics through Cold Isostatic Pressing and Pressure Slip Casting: A Comparative Study

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Near net shaping of advanced ceramics with high green density and achieving close to theoretical density by sintering are challenges for the ceramic engineers. In the present study, attempt has been made to comparatively evaluate two near net shaping processes, Pressure Slip Casting (PSC) and Cold Isostatic Pressing (CIP), using stoichiometric mixture of alumina and titania as per Al_2TiO_5 stoichiometry. Aluminum titanate, due to its inherent low thermal expansion coefficient and high thermal shock resistance, has several potential applications.

Al_2TiO_5 stoichiometric mixture of alumina (Al_2O_3) and titania (TiO_2) formulations was made into aqueous slurries in distilled water using 1 wt.% Darvan 821A as dispersant. The suspensions were then milled for 2 hrs in a rubber lined ball mill using alumina balls at 1:1 charge to balls ratio to achieve optimum solid loading of precursor mix in the range of 65 wt.%. Rheological behavior of the slurries was studied at varying shear rates, and slurry is found to have a pseudoplastic behavior at lower shear rates adaptable for casting. Casting was carried out using a pressure casting machine model PCM-100 (SAMA) with a closing force of 1000 N and a maximum operating pressure up to 4MPa in polymer molds. Another batch of formulations made into dough with polyvinyl alcohol (PVA) as binder (2 wt. %). The powder was granulated, and granules with acceptable flow behavior were compacted by uniaxial pressing with a pressure of 55 MPa. Samples are vacuum sealed in plastic bags and isostatically pressed at 50, 100 and 140 MPa using a Cold Isostatic Press (Avure Technologies, USA).

Fig. 1 shows the (a) pressure cycles of PSC and (b) CIP cycles along with cast and compacted parts (Fig. 2). Processing techniques, consolidation pressure and the green densities are shown in Table 1. PSC resulted in a green density up to 60% of TD on application of pressures of 2 to 3 MPa. PSC involves the slip pressurization which in turn facilitates the rearrangement of particles through rolling, twisting and interlocking leading to the cast bodies at substantially low pressures in comparison to CIPing. Under CIPing conditions, high applied pressure of 100 MPa is essential in order to achieve similar densities. Requirement of high pressure, while CIPing, can be attributed to the necessity of overcoming the inter-particle friction within the dry precursor mixes. Present study reveals that the pressure slip casting can be considered as one of the most promising, near net and defect free processing technique due to its isostatic colloidal forming nature in combination with high productivity.

Table 1 Processing technique, consolidation pressure and green density of the sample

Sr. No.	Processing technique	Consolidation pressure (MPa)	*Green density (% TD)
1	PSC	2.0	60 ± 2
2	CIP	100	60 ± 3
(* Green densities are average of 3 samples)			

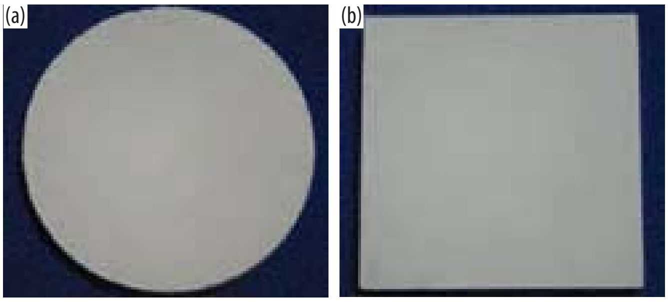
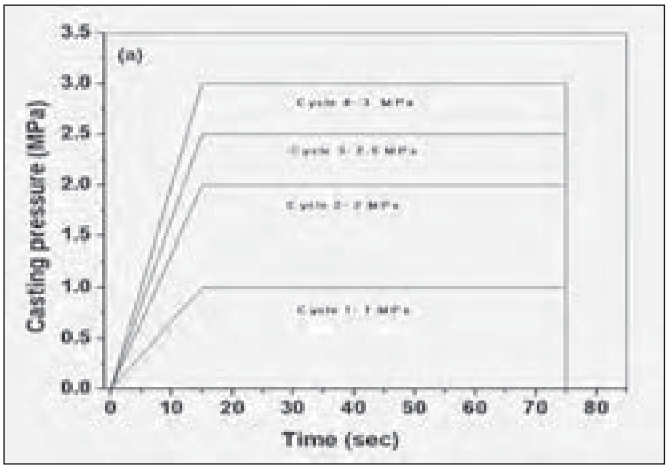


Fig. 1(a) Pressure cycle of PSC and (b) CIP cycle



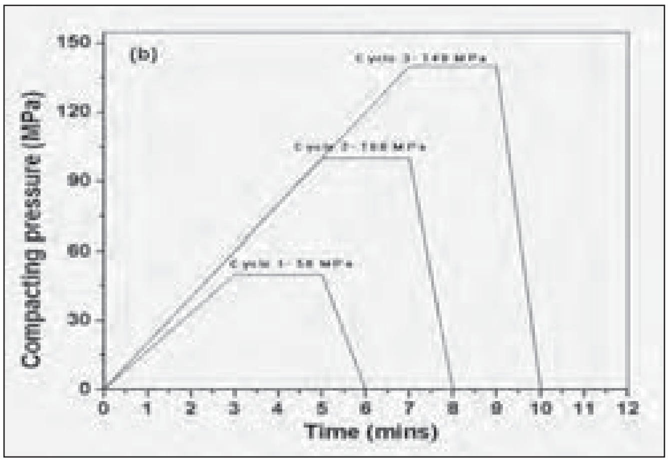


Fig. 2 Defect free green compacts (a) PSC (100 mm diameter and 10 mm thick) and (b) CIP (100 mm x100 mm x10 mm)

Contributors: R. Papitha and Roy Johnson

Translucent Polycrystalline Alumina for Energy Efficient Lighting

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High Intensity Discharge (HID) lamps are gaining interest due to the high intensity of light in combination with low power consumption. Lamp envelops are used generally in the form of tubes termed as arc tube to carry the plasma discharge of various metal halide salts containing mercury vapors acting as buffer gas. These arc tubes, while in operation typically experience temperatures between 1300°C and 1400°C and pressures up to 60 bars. High purity sintered poly crystalline alumina (PCA) is intrinsically translucent due to the hexagonal crystal structure and is suitable for high intensity discharge lamp envelop applications.

In the present study, monolith PCA tubes were fabricated using high purity alumina powder through aqueous slip casting method. Alumina suspension with solid loading above 75 weight % was prepared using Darvan 821A as a dispersant. Uniform flowing slurry with stable viscosity during the casting period is a key factor to control the casting rate and to achieve uniform thickness. Fig. 1 shows the viscosity studies conducted for the alumina slurry used for the present experimentation. It can be observed that the viscosity remained constant even over a period of 300 minutes which shows the stabilization of alumina suspension.

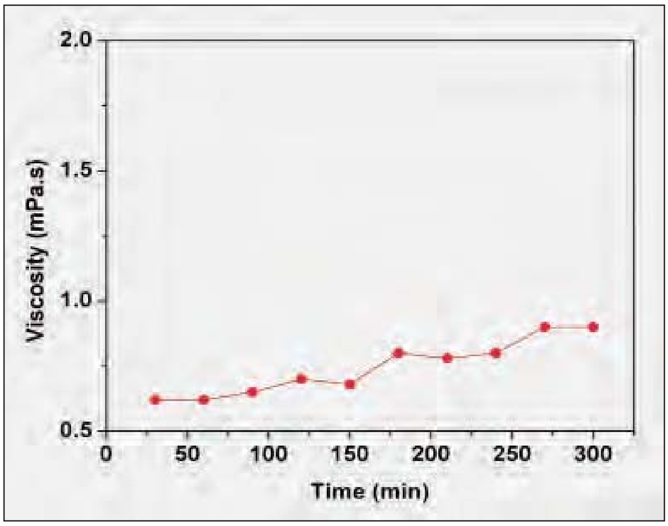

Fig. 1 Viscosity measurements of alumina suspension used for casting alumina lamp envelop

The cast samples were dried in ambient conditions for 24 hours and were further dried at 45°C – 60°C for 12 hours in a hot air oven. Dried samples were further sintered in air at 1500°C for 2 hours and were further pressed hot isostatically at 1800°C for 5 hours for achieving translucency. The hot isostatic pressed lamp envelops were further subjected to de-carbonization treatment by re heating the samples to 1000°C for 2 hours to achieve translucent alumina lamp envelops. Fig. 2 shows the alumina lamp envelops after densification (a) and HIPing and de-carbonization operation (b).

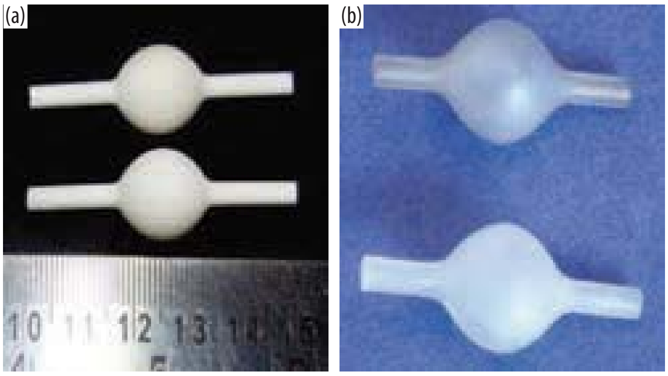

Fig. 2 (a) Sintered PCA tube (b) hot isostatically pressed PCA tube

Fig. 3 shows the SEM picture of the microstructure of alumina lamp envelops. It can be observed that the structure is free from natural pores and other inclusions. The density was measured as 3.98 g/cc which shows 100% densification, and Vickers hardness for these samples was found to be 1600 kg/mm^2.

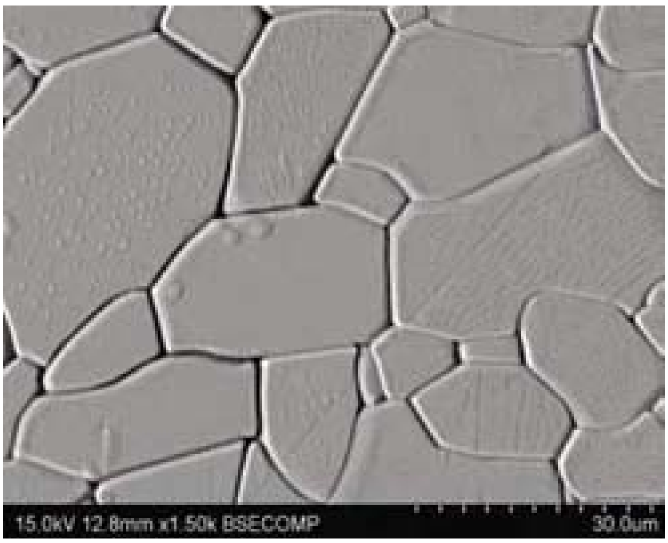

Fig. 3 Microstructure of PCA tube

Contributor: Roy Johnson

Biocompatibility Studies on Transparent Spinel Ceramics

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Orthodontic therapy is gaining popularity due to the increased concerns about facial aesthetics. Use of aesthetic brackets based on polycarbonates started in early 1970s. However, their low strength and consequent deformation and discoloration are major disadvantages. This paved the way for ceramic brackets especially polycrystalline opaque tooth coloured alumina or zirconia with inherent higher strength, wear resistance, colour stability and biocompatibility. Opaque alumina ceramic brackets exhibit reasonable mechanical properties. But aesthetic requirements for adult patients preferably call for invisible brackets. Hence, the use of single crystal transparent alumina with good optical properties fabricated through crystal growth technique followed by machining was gaining prominence. However, their use is often offset by the exorbitant cost and time involved in machining. In view of the above and recent advances in the development of polycrystalline transparent ceramics, transparent alumina polycrystal is identified as a cost effective alternative for the single crystal brackets. However, high hardness value of > 20 GPa compared to enamel (3-3.5 GPa) is a major reason for the attrition of opposing teeth. Therefore, it is appropriate to develop an enamel friendly material like spinel based invisible orthodontic bracket which has good transparency and adequate mechanical properties as an alternative to the existing alumina and zirconia types. Though physical and optical properties of spinel are well known, they are not so far correlated to the requisite features of orthodontic brackets and data on biocompatibility features of spinel is also limited.

Fig.1 Transparent spinel sample

In the present investigation, commercially available 99.96% pure spinel ($MgAl_2O_4$) powder was subjected to casting and pressure-less sintering followed by hot isostatic pressing. Typical sample is shown in Fig. 1 and the properties are depicted in Table 1. Cytotoxicity and genotoxicity assay were carried out at INMAS, DRDO. Human embryonic kidney 293 (HEK 293) cell lines were used for the in vitro toxicity assays. The cells were cultured in Dulbecco's modified eagle's medium containing antibiotics at 37°C in humid atmosphere with 5% CO_2. Cell growth was estimated by counting cells at different time intervals and was used for experiments after three passages in the media. No major difference was noticed between treated and untreated cells and in addition, they didn't show any growth inhibition even in high doses (1mg/cm^2). Material neither inhibited cell proliferation nor affected its morphology till 48 hrs of incubation (Fig. 2).

Table 1 Comparison of properties of Magnesium Aluminate Spinel and Enamel

Properties	Spinel	Enamel
XRD Phases	$MgAl_2O_4$	-
% Theoretical Density	~100	-
Hardness (GPa)	12	3-3.5
Fracture Toughness (MPa.m$^{1/2}$)	1.90 ± 0.1	0.7-1.5
Average Optical Transmission (0.4 – 0.7 µm)	80 %	Opaque

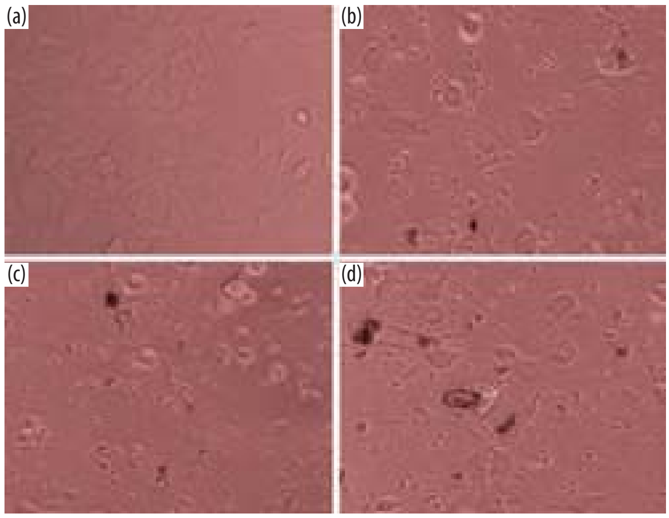

Fig.2 Morphology of HEK 293 cells with different concentrations of spinel (a) without treatment (b) 0.25 mg/cm^2 (c) 0.5 mg/cm^2 (d) 1 mg/cm^2

Toxicological studies of transparent spinel developed and evaluated in the present study on HEK cell lines exhibited excellent biocompatibility. Further, the studies also demonstrated spinel as a non-cytotoxic, not inducing apoptosis and non-genotoxic material. This unique combination of physical, mechanical, optical and biocompatible properties, suggests spinel as a prospective material for orthodontic bracket applications.

Contributors: K. Rajeswari, M. Buchi Suresh and Roy Johnson

Quasi-static Compaction Behaviour Analysis of Ceramic Powders using Compaction Curves

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Uniaxial die compaction is one of the widely used ceramic forming process and the quality of the compact is a strong function of the powder processing conditions. Under the compaction stresses, the granules undergo rearrangement followed by the deformation and form a compact. A typical compaction curve, in which sample density plotted as a function of compaction pressure shows regions representing these events. Hence, monitoring and analysis of the compaction curves can be used as an effective tool to monitor significance of compaction parameters while processing.

$MgAl_2O_4$ granules were compacted and the load – displacement curves were recorded. The sample was compacted to an initial pressure of 5 MPa, and the displacement values of the top punch were noted and the compaction pressure was further increased up to 260 MPa with definite increment of pressure. For every pre-set value of these pressures, the displacements of the top punch from the initial position are estimated. When the compaction cycle for each pressure is completed, the true compaction of the compact without contribution of the elastic interaction between the particles can be obtained from the plot of height (h) versus pressure. Further the segments were extrapolated to the axis of ordinates at the attained level of the initial pressure (5 MPa). Height of the compact (Hi) at different compaction pressures were calculated based on the value of the h_k from the equation (1)

$$H_i = H_k + (h_k - (h_{k-1})) \quad ... \quad (1)$$

where, H_k = pellet thickness at maximum pressure, h_k = displacement at k^{th} value, and h_{k-1} = displacement at $k-1^{th}$ value.

Variation of the thickness of the compact (h) vs pressure (P) demonstrating the elastic stresses on the compact is shown in Fig. 1.

It is possible to estimate the elastic contribution h_{el} (p_{ai}) to the compaction by subtracting the ordinates of the points that characterize the true compaction $h(p_{ai})$ and from the ordinates using equation (2).

$$h_{el}(p_{ai}) = h_{tot}(p_{ai}) - h(p_{ai}) \quad ... \quad (2)$$

When the sample is under compaction pressure, the strain energy is stored in the pellets and on release of compaction stresses, the pellet expands in axial direction while the pellet is still constrained within the die walls. From the mass (M) of the compact, the diameter (D) of the compact body and the thickness (H_i) of the compact, it is possible to estimate density $\rho_{ai\ tot}$ using equation (3). The true compaction curve can be described by equation (4)

$$\rho_{ai\ tot} = (4M)/(\pi D^2 H_i) \quad ... \quad (3)$$

$$\rho(p) = \rho_{tot} - \Delta\rho_e l \quad ... \quad (4)$$

Compaction curves obtained are depicted in Fig. 2. Curve of ρ_{tot} is regarded as the sum of compaction curve and incremental changes (from Fig.1). Curve $\Delta\rho_{el}$ is the variation of the density of the compact due to elastic interaction between powder particles in the compaction process and ρ(p) is the true compaction curve. It is observed that, the plot of relative density vs ln (compaction pressure) of the true compaction curve ρ (p) exhibit the acceptable fit with $R^2 = 1.0$. Compaction behavior can be described well by one parameter logarithmic equation $\rho = 4.72 \ln(p) + 30.63$.

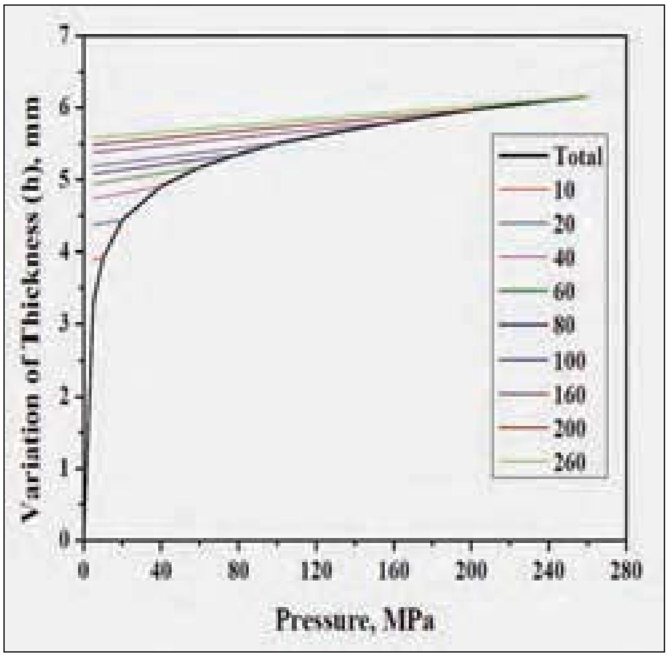

Fig. 1 Variation of thickness with pressure

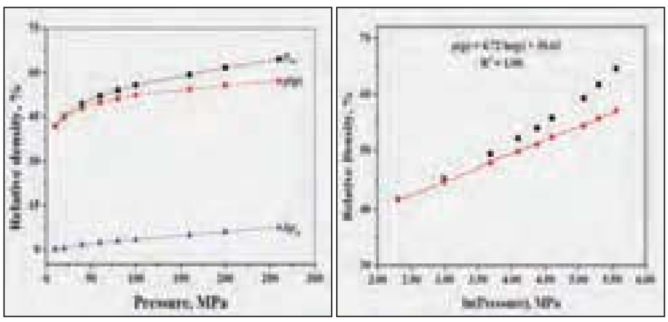

Fig. 2 Compaction curves

Contributors: V. Mahender, P. Suresh Babu and Roy Johnson

Centre for Laser Processing of Materials

The Centre for Laser Processing of Materials (CLPM) works towards development and promotion of laser-based manufacturing solutions for the Indian industry through:

- *Application oriented R&D towards demonstrating feasibility of laser processing route for specific industrial applications;*
- *Research towards better scientific understanding of various processes; and*
- *Job works of specialized nature*

in the areas of:

- *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*
- *Laser and laser assisted machining*

One of the important projects implemented during the year pertains to the establishment of an ultra fast laser processing system based on Ti sapphire, femto laser for micro surface engineering and micro machining. Work has been initiated on laser microtexturing of cast iron aimed at reducing friction losses in diesel engine. A considerable reduction in friction coefficient was observed on femto second laser textured surface. Laser scribing of P1, P2 and P3 layers of CIGS thin films for solar cells also has been attempted. Laser hardening for improved surface property and laser cladding for re building the damaged areas of dies made of hot work die steel H13 used in pressure die casting also shared promising results. Laser brazing of Aluminium alloys to steel for automotive light weighting applications has been investigated on a variety of Al-Steel combinations and filler materials, with and without flux. Usage of flux was found to be essential to form good brazed joints. Very high speed of joining are possible with laser brazing. Apart from this, many other R&D projects in welding, cladding and hardening have been pursued.

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Ultra Fast Laser Micromaching System

Laser Surface Micro Texturing of Gray Cast Iron

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Surface texturing has been proven to be an excellent method for reducing friction behavior of sliding surfaces by forming textures of micro dimples distributed in a certain pattern. Laser processing is most suited for this purpose as it is an extremely fast process with accurate control of shape, size, depth and area density of the dimples. The laser texturing process involves ablation, melting, and vaporization of the surface material resulting in micro-dimples. However, the laser textured surfaces are accompanied by heat affected zones and recast layer such as material pile-up around the dimples. However, by optimizing the laser parameters such as pulse duration, pulse energy and number of pulses, the collateral damage can be controlled. Recently, ultrafast/ femtosecond lasers with high pulse energy and repetition rates are available and ultrafast processing is expected to minimize the melt ejection and heat effects. Hence, it was felt that it could be useful for application in surface texturing. The work reported here is intended to be a step in the utilization of femtosecond lasers for surface texturing of auto-engine components. In the present study, the surface modification of grey cast iron, using millisecond (t_p = 0.5 ms), nanosecond (t_p = 40 ns) and femtosecond (t_p = 120 fs) pulse duration laser irradiation is attempted in order to establish a particular geometrical pattern with dimple features and dimensions, and investigate the effect on friction and wear.

Morphologies of the 40% textured surfaces produced on grey cast iron with millisecond, nanosecond and femtosecond laser sources are shown Fig. 1. In millisecond laser texturing, the dimples are ~ 200 µm in diameter and ~ 15 µm in depth. The texturing pattern was prepared using a single pass of the laser beam with a pitch (dimple to dimple distance) of 300 µm. In nanosecond and femtosecond laser texturing, the diameter of the dimples and the pitch are ~ 25 µm and ~ 40 µm respectively.

The friction and wear analysis was carried out by analyzing the ball-on-disk tribo testing for comparing the performance of textured and untextured surfaces under similar tribological conditions, repeating each individual test in order to verify the reproducibility of the results. Fig. 2(a) shows friction coefficient plotted as a function of sliding time (test duration) while the wear track profiles of untextured and laser textured surfaces are shown in Fig. 2(b). High instability of the friction coefficient curve and seizing on untextured and millisecond laser textured surface are related to the presence of debris at the contact sliding area. Nevertheless, femtosecond laser textured surface exhibits a considerably lower friction coefficient compared to the untextured, millisecond and nanosecond laser textured surface. The reason is ascribed to the absence or very minimal resolidification and spatter particles present on femtosecond laser textured surface. During sliding wear test, the spatter and re-deposited material in textured samples, collapse readily, which act as wear debris. Debris sticking to the wear surface also increases the friction response. The average friction coefficient observed was 0.55 for untextured sample, 0.31 for a millisecond laser textured sample, 0.02 for nanosecond laser textured sample and 0.01 for femtosecond laser textured sample, respectively, under normal force of 50 N and a sliding speed of 63 mm/s. The width of the wear track on the disk for the untextured, millisecond laser, nanosecond laser and femtosecond laser textured samples were 0.99 mm, 0.87 mm, 0.79 mm and 0.42 mm, respectively. A reduction of friction coefficient by a factor of 50 and wear by 65% was observed with femtosecond laser processing.

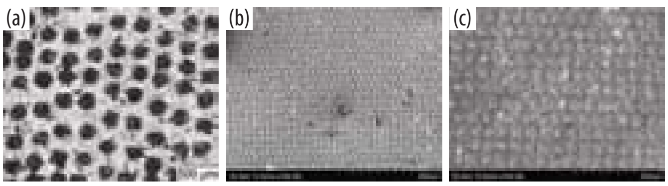

Fig. 1 Surface morphologies textured specimens of: (a) millisecond laser textured; (b) nanosecond laser textured; and (c) femtosecond laser

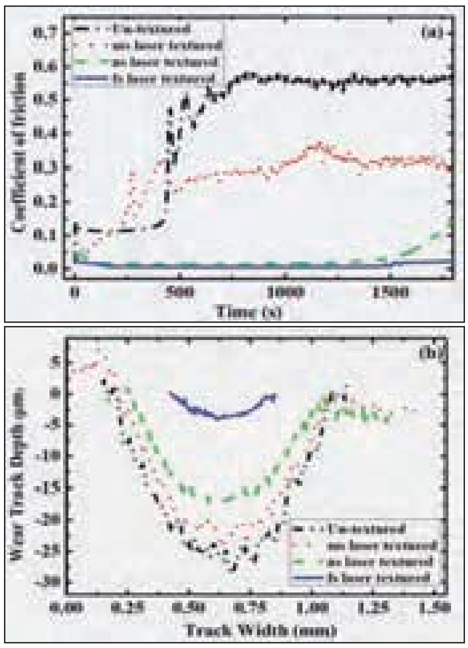

Fig. 2 Ball-on-disk test performed at room temperature: (a) Friction coefficient as a function of time (test duration) and (b) Wear track profile for untextured and textured specimens

Contributors: Sai Krishna and G. Padmanabham

A Novel Method of Texturing Steel with a Continuous Wave Diode Laser

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Surface morphology/topology is a significant factor influencing the optical, tribological, mechanical and many other functional properties of a material. In recent times, the ability to modify the above has been exploited to provide technological advantages in various fields like electronics, energy, tribology, biology, information technology etc. Due to the precise control of spatial and temporal parameters afforded by a laser, well-defined textured surfaces can be potentially realized depending on the material and the processing conditions involved. The extremely high cooling rates possible with laser processing induce some unusual exotic and non-equilibrium microstructures as well as surface textures that stimulate great research interest because of the potential to realize novel properties and functions. The high temperature gradients possible in rapid laser melting, with a wide range of G (temperature gradient)/R (solidification rate) ratios at the solid-liquid interface facilitate production of refined solidification structures with well-defined orientation relationships between the constituent phases. The present work illustrates the influence of diode laser processing interaction time on the evolving texturing effect on austenitic manganese steel.

In the present work, solution treated austenitic manganese steel with 1.3% C has been subjected to laser surface melting with a 17 mm wide diode laser beam under power density of 1.75 x 10^6 W/cm^2, varying interaction time (3.3 – 100 ms) and argon shielding atmosphere. Fig. 1 illustrates as-treated textured surfaces obtained with varying interaction time. It is clear that at specific threshold interaction duration (for example - 25 ms), the morphology of the surface is textured with self-aligned γ-Fe crystals in (200) crystallographic orientation, perpendicular to beam movement. XRD analysis shown in Fig. 2 corroborates this effect. The cross-sectional microstructure examination also showed growth of cellular-dendrites of austenite at interface with segregation of inter-dendritic network of carbides of Fe & Mn. It may be plausible that a steel such as this one with low thermal conductivity (as compared to carbon steel) and high thermal expansion co-efficient under diode laser irradiation at critical processing conditions can result in such self-aligned textured surface.

Although free-surface texturing disappeared in steels processed beyond 33.3 ms duration, crystallographic texturing of γ-Fe in (200) orientation increased further. SEM analysis of subsurface microstructure showed continuous increase in γ-Fe dendrite growth height in direction perpendicular to laser movement. This could be attributed to enhanced cooling rate coupled with highly localized solidification/evaporation effects.

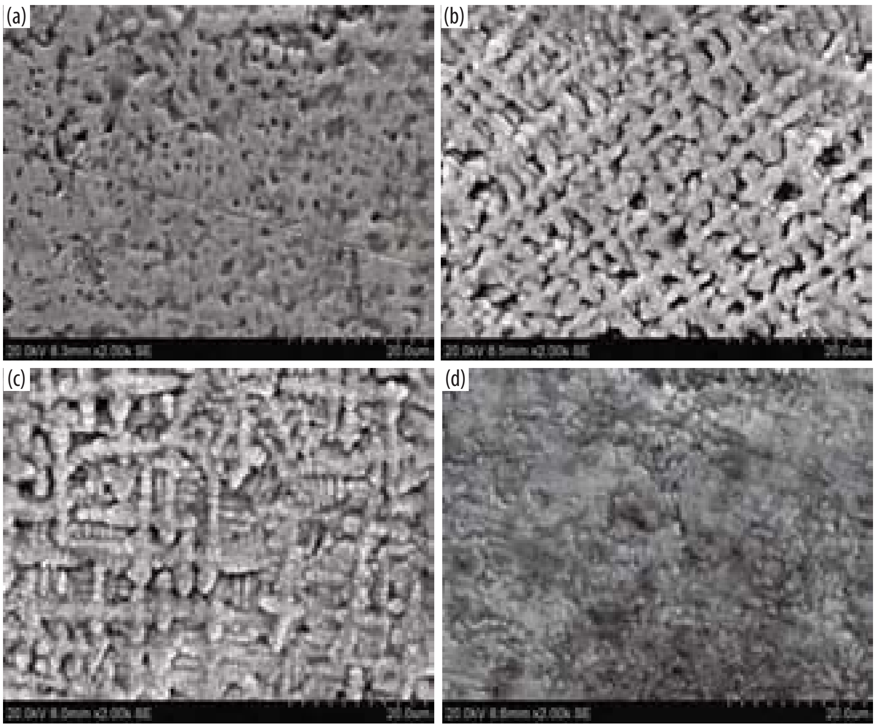

Fig. 1 As-treated surface morphologies processed with different interaction time: (a) 20 ms (b) 25 ms (c) 33.3 ms and (d) 50 ms

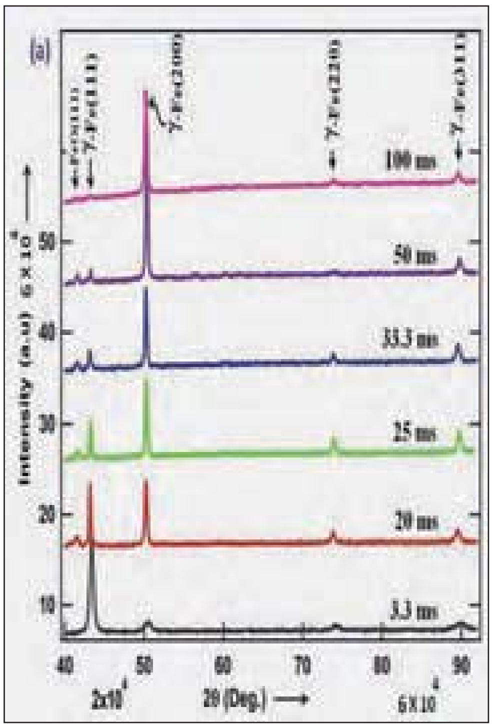

Fig. 2 X-Ray Diffraction patterns of as-treated surfaces processed with varying interaction times

Contributor: G. Padmanabham

Refurbishment of Pressure Die Casting Dies by Laser Cladding Process

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AISI H13 hot work tool steel (5% Cr) is the most common die material used in metal forming and casting industries. Dies are prone to damage prematurely due to severe hot-working process conditions like thermo-mechanical fatigue, molten metal erosion and high temperature wear. Laser cladding process is an emerging technique for precision repair and refurbishment of worn out or damaged parts by depositing a high-performance material or material same as the work piece.

In the present study, hot working AISI H13 tool steel (0.4 wt.% C, 1.0 wt.% Si, 0.4 wt.% Mn, 5.2 wt.% Cr, 1.5 wt.% Mo, 1.0 wt.% V, Fe balance) plates with dimensions of 100 mm × 100 mm × 12 mm in hardened and tempered conditions were used as substrates for laser cladding operation. Precursor powder (feeding material) used in laser cladding was AISI H13 tool steel viz., same as substrate. Particles were of spherical morphology and an average particle size of 100 µm. Cladding was carried out using a 6 kW continuous wave diode laser (wavelength 915-980 nm) coupled with fiber delivery and optical head mounted on 6-axis robot with a beam spot diameter of 3 mm. A co-axial powder feeding nozzle assembly was used to feed the powder co-axially with laser beam. Argon (Ar) was used as carrier gas (at 1.5 bar pressure) to feed the powder with a 4 bar pressure and 7.5 l/min flow rate. Powder density was varied from 10.6×10^{-3} to 16×10^{-3} g/mm^2 to form single layer multi-track overlap clads (Fig. 1 and Fig. 2). A 45% overlap was maintained to obtain 0.85 – 1.3 mm thick clad layer, covering 90 mm x 90 mm substrate area.

In this study, the effect of laser variables (applied energy density and pulsing) on the microstructures, phases, stress distribution and hardness distribution of single track laser clads was investigated. In addition, the effect of post-clad heat treatment operation on the microstructures and microhardness of the clad zone was also studied. It was observed that the microstructure of the single track clad zone consists of prior austenite dendrites along with the presence of martensite, retained austenite and carbides with an increased hardness (610 - 630 VHN) as compared to the base material (480 -500 VHN). Cladding with a pulsed laser showed an increased degree of microstructural refinement. Post-clad tempering led to reappearance of carbides from supersaturated martensite which formed during laser cladding. The hardness of both the clad and post-clad tempered steel was higher than hardened and tempered AISI H13 tool steel. Interestingly, laser cladding introduced residual compressive stress of 670±15 MPa, which reduces to 580±20 MPa following isothermal tempering. Micro-tensile testing of samples made from the clad zone prior to and post-cladding tempering, revealed (Fig. 3) ductile failure with 4.7 % and 8% elongation, respectively with yield strength and tensile strength comparable to conventionally hardened and tempered AISI H13 tool steel. Significant improvement in fretting wear behavior was observed in clad zone against WC surface as compared to hardened and tempered AISI H13 tool steel substrate. Laser surface engineering reduces the coefficient of friction under steady state (0.35) considerably as compared to substrate (0.60) under fretting wear testing at 20 N load. Other relevant performance tests are underway.

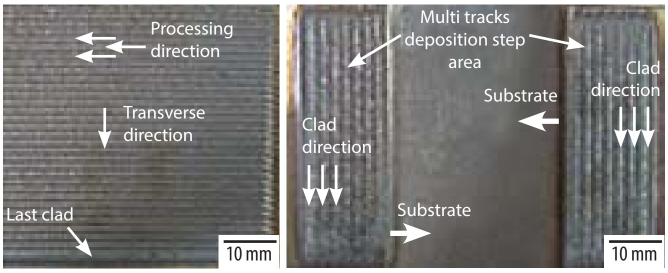

Fig. 1 Photograph of as-clad surface

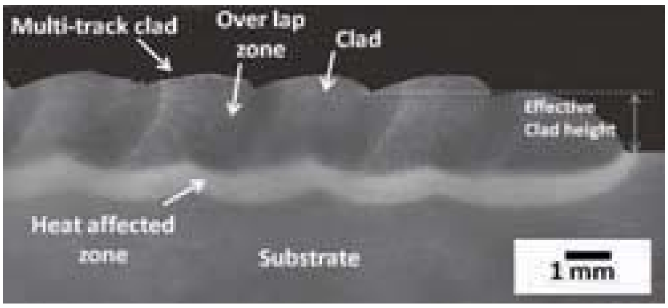

Fig. 2 Optical micrograph showing cross-section across process direction

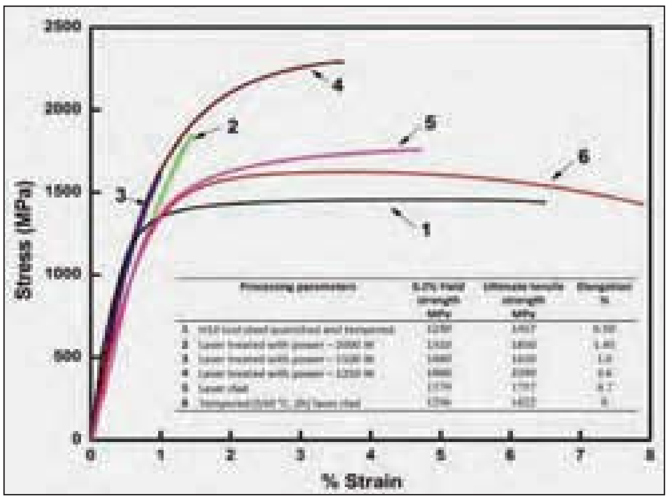

Fig. 3 Engineering stress-strain curve obtained from micro-tensile testing of laser clads

Contributor: G. Padmanabham

Repair of Cast Iron Components using Laser Clad-Deposition Process

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Grey cast iron provides excellent machinability and heat absorption properties coupled with excellent anti-galling and anti-damping properties. Components such as engine blocks, molding dies etc made of grey cast iron, if repaired, can be reused. However, presence of significant amount of graphite nodules was found to be a big deterrent in developing appropriate refurbishment techniques such as weld repair or other deposition/ coating methods. The presence of graphite flakes in cast iron makes the repair task difficult by virtue of its emission of COx during welding or cladding process. Additionally, formation of hard and brittle heat affected zone below the interface region further reduces its feasibility to produce an acceptable refurbished layer. With the advent of laser-coating based refurbishment technologies, development of suitable methodology has become feasible as it is a precise and low heat input process.

In view of the above factors, and the need to develop a suitable refurbishment methodology, the present work was taken up to systematically study laser cladding route using a 6kW diode laser. A Ni-based alloy powder was used as a coating material. Initial trials exhibited high porosity in the clads owing to entrapment of COx gas in the melt pool during cladding process. Additionally, cracking in clads was also observed due to formation of hard brittle interface below HAZ due to high cooling rates, leading to formation of hard martensite and carbides.

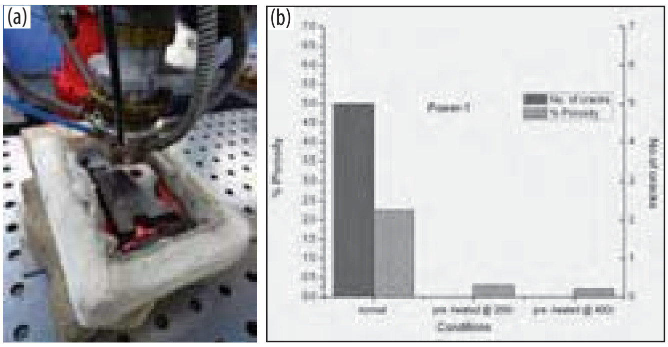

Fig. 1 (a) Laser cladding experiments using in-situ preheating (b) porosity and cracks for samples processed under different preheating conditions

Laser cladding trials were conducted with an *in-situ* flexible ceramic-pad arrangement to pre-heat the substrate at a pre-determined temperature and analyzed its effect on clad quality. Fig. 1(b) shows the effect of preheating temperature on reduction of porosity and cracking propensity. It can be observed that pre-heating of the substrate showed significant reduction in porosity and eliminated cracking. Reduction in cooling rate not only facilitated reduction in cracking propensity but also the porosity reduction as there was enough time for escape of gases/vapors.

Comparison of SEM micrographs (Fig. 2) with pre-heating showed coarsening of dendrites of γ-Fe (Ni) as compared to that without pre-heating. It is clear from the study that repair of cast iron components with a defect free clad deposition is feasible using a laser cladding process with in situ preheating. Relevant performance tests to prove the efficiency of the process are underway.

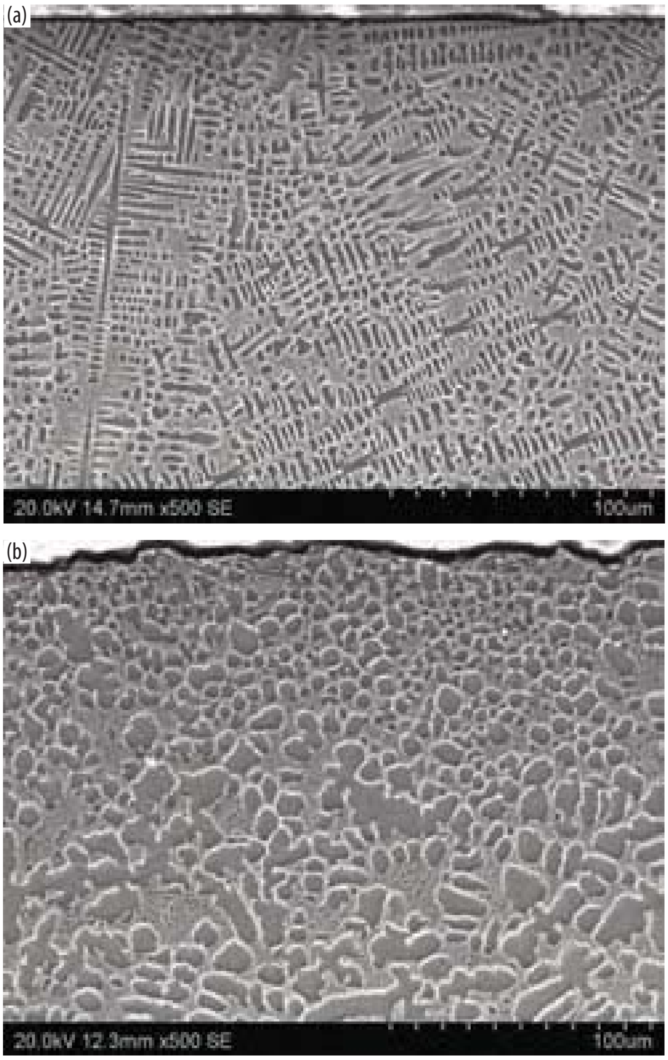

Fig. 2 SEM micrographs at cross-section of the clad processed at a) room temperature b) preheating temperature of 400°C

Contributors: S. M. Shariff and G. Padmanabham

Pre-reduced Cu-doped TiO_2 Thin Film Cathode to Reduce CO_2 into CO in Conjunction with BMIM-BF_4 Ionic Liquid

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Conversion of waste-stream greenhouse carbon dioxide (CO_2) gas into methanol, carbon monoxide (CO), etc., using solar energy or the electricity derived from sunlight is popularly known as artificial photosynthesis (AP). AP can address the problems associated with the CO_2 related global warming, energy storage, and energy crisis (i.e., depletion of fossil fuels). The large scale energy storage can be accomplished by AP in much better-way than any of the existing technologies as on today for all the high-energy intensive applications. Furthermore, as methanol formed in the AP can be directly employed to replace the fossil fuels presently being used in the existing energy distribution infra-structure; there may not be any severe economical consequences while transforming from fossil fuel energy to non-fossil fuel (solar renewable energy) operations. In view of this, a research program was initiated at ARCI to develop AP process. As a part of this program, a nano-size thin film electrocatalyst was successfully prepared by depositing 50 wt.% Cu-doped TiO_2 on the surface of an electrically conductive Flourine doped Tin Oxide (FTO) substrate (referred to as 50CDTT electrode) by conventional sol-gel dip-coating technique followed by calcination for 30 minutes at 550°C. The calcined electrode was then reduced at -2000 mV (*vs*. Ag/AgCl in 3M NaCl solution) for 20 min in 0.2M acetate buffer (pH = 5). This reduced electrode has been employed as a cathode in conjunction with 1-bytyl-3-methylimidazolium tetraflouroborate (BMIM-BF_4) ionic liquid dissolved in a non-aqueous electrolyte (acetonitrile containing 0.1M $TBAPF_6$) to reduce CO_2 to CO with a faradaic efficiency of >85% and a selectivity of >95% at -2500 mV (*vs*. Ag/Ag+) in a controlled potential electrolysis (CPE) experiment performed in a two-compartment electrochemical cell. Cell separation was achieved by using a commercial Nafion membrane (Fig. 1). A Pt rod (ϕ = 5 mm) was employed as an anode, and the anolyte was a 0.2 M sodium phosphate buffer (NaPi) (pH = 7.4) containing 0.5 mM Co^{2+} ions. The results obtained in this study are presented in Table 1. Fig. 2 (a & b) shows a typical gas chromatography (GC) profile recorded by injecting the headspace gases formed in the cathode compartment during CO_2 reduction over the pre-reduced 50CDTT electrode in reaction conditions as presented in 5th row of Table 1 during CPE performed in a two-compartment electrochemical cell, and the response factors of H_2 and CO gases in thermal conductivity detector (TCD) of GC.

Fig. 1 Electrochemical cell employed for reducing CO_2

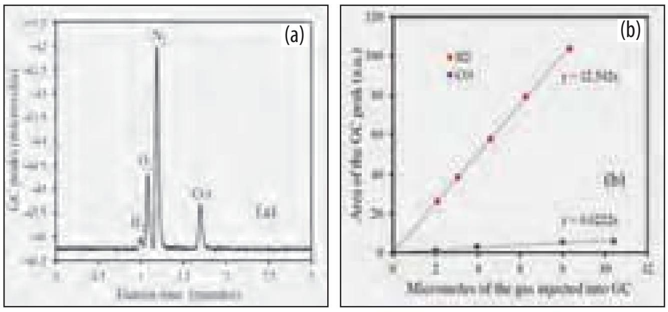

Fig. 2 (a) GC profile showing the product gases formed in the CO_2 reduction occurred in CPE experiment (5th row of Table 1 conditions); and (b) the response factors of H_2 and CO gases determined based on gas chromatography (GC) profiles generated by thermal conductivity detector (TCD)

Table 1 Reaction conditions employed for electrochemical reduction of CO_2 over the thin film cathode consisting 50 wt.% Cu-doped TiO_2 thin film deposited on FTO (referred to as 50CDTT electrode) in a two-compartment electrochemical cell separated by a Nafion membrane together with products selectivity and Faradaic efficiency

50CDTT cathode‡	Composition of catholyte	Composition of anolyte $	Applied voltage (mV)	Faradaic efficiency (%) (±0.2)	Selectivity (%) (±1)	
					H_2	CO
As-prepared	H_2O + 0.5M KCl + 0.5M $KHCO_3$ + 20 mM pyridine (pH = 5.4)!!	1 M NaPi + 0.1 M $Co(NO_3)_3$	-1500#	36	73	27
As-prepared	0.2M NaPi (pH=7.4) + 0.5M $KHCO_3$	1 M NaPi + 0.1 M $Co(NO_3)_3$	-1500#	28	88	12
Pre-reduced	MeCN + 0.1M $TBAPF_6$ + 20 mM BMIM-BF_4 (ionic liquid)	1 M NaPi + 0.1 M $Co(NO_3)_3$	-2500¥	83	19	81
Pre-reduced	MeCN + 0.1M $TBAPF_6$ + 50 mM BMIM-BF_4 (ionic liquid)	1 M NaPi + 0.1 M $Co(NO_3)_3$	-2500¥	85	6	94
Pre-reduced	MeCN + 0.1M $TBAPF_6$ + 50 mM BMIM-BF_4 (ionic liquid)	1 M NaPi + 0.1 M $NaClO_4$	-2500¥	82	4	96

Contributor: G. Padmanabham

Centre for Fuel Cell Technology

The R&D activities at the Centre for Fuel Cell Technology (CFCT) during the year encompass efforts to consolidate the leadership in Low Temperature PEM (LT-PEM) fuel cell technology development in the country, demonstrate high temperature PEM fuel cell stacks, development of alternative materials for use in PEM fuel cells, hydrogen generator and low cost electrochemical conversion devices. Materials have also been developed for use in hydrogen storage systems. For the first time in the Country, a DC Room wherein all the appliances which operate on DC power (fan, light, air conditioner, refrigerator, Hub motor) powered by LT-PEMFC has been established. The DC Room is powered by a 5 kW LT-PEM fuel cell stack built indigenously and the bus voltage is 48 V DC. To facilitate evaluation of fuel cell stacks under different atmospheric conditions such as temperature and humidity, an "Environmental fuel cell stack test facility" has been established . This facility, again, is the first of its kind in the Country. A 600 watts High temperature PEM fuel cell stacks built using indigenously developed bipolar plates made from exfoliated graphite has been demonstrated proving the efficacy of these bipolar plates in HT-PEMFC besides in LT-PEMFC and hydrogen generator. To improve performance of the fuel cells and reduce cost, several attempts are being made. Methods have been developed to make mesoporous catalysts (Pt, Pt-Ru, Pt-Ni, Pt-Co,Pd) and catalysts supported on different types of carbon. In one such study, Nitrogen doped graphene (different N contents) which can be used as catalyst support for Pt has been prepared. Modified Pt/Nitrogen doped graphene (NG) shows higher CO tolerance which is normally seen only with Pt-Ru catalyst. Some of these catalysts also show tolerance to impurities such as SO_2, H_2S in fuel cell operation. In order to prepare PEMFC for use in marine environment, studies have been carried out to find efficacy of fuel cells in such an environment.

Novel porous carbon materials have been prepared from agricultural wastes. These carbon samples besides having high surface area have both micro and meso pores. Besides their efficacy as a hydrogen storage media (a hydrogen storage capacity of ~ 4.3 wt % at 40 atm, $30^{o}C$ has been achieved), they also provide good support for electro catalysts for fuel cell reactions. Catalysts supported on these low cost carbon supports show improved performance compared to commercial Pt/C. Building on the development of 1000 litres/hour capacity hydrogen generator disclosed in the previous year, CFCT is now addressing cost reduction in these units. A mesoporous palladium catalyst, which shows performance similar to platinum based catalyst normally used on the cathode in this type of hydrogen generator with considerable cost reduction, has een prepared. Similarly, a composite membrane made from Nafion and Teflon template shows potential to reduce the cost of the electrolyte used in these cells. Alkaline electrolysers using anion exchange membrane are also being investigated. Some of these alternate membranes are also being investigated for use in supercapacitor development. A supercapacitor was fabricated with hydroxyl ion conducting alkaline anion exchange membrane and commercial Vulcan XC carbon based electrodes. The maximum specific capacitance, power density and energy density of the supercapacitor were 45 F/g, 23 kW/kg and 6.25 Wh/kg, respectively. Continuing on the work on rechargeable metal – air batteries demonstrated in the earlier year which were based on ionic liquid electrolyte, the Centre has initiated work on developing aqueous electrolyte based rechargeable Zinc-air secondary battery. Preliminary studies are promising. In the field of REDOX flow battery, studies are being carried out to increase the concentration of the vanadium species in the electrolyte which is critical for increasing the energy density. A novel method, which shows higher columbic and energy efficiency than conventional system, has been developed. Metal–Hydrogen Peroxide based electrochemical cell is another subject that is being investigated.

Several diagnostic studies (impedance, thermal imaging etc.), which can help in identifying malfunctioning cells in a stack and, which may occur due to flooding, fuel starvation etc., are being carried out. In addition to the above, modelling studies for both high and low temperature PEMFC are being carried out. Use of Phase Change Materials (PCM), materials for heat removal in the fuel cells, recovery of platinum from the used electrodes by electrochemical method are some of the ongoing investigations. A new study has been initiated to look at the thermoelectric properties of high temperature polymers, which are being investigated for use in HT-PEMFC.

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Establishment of a DC Room Powered by LT-PEM Fuel Cell System

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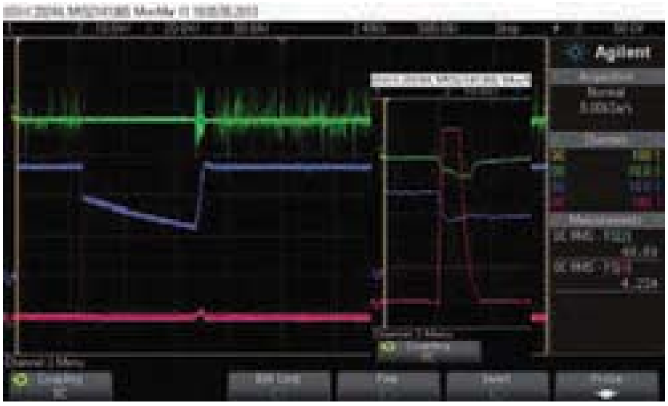
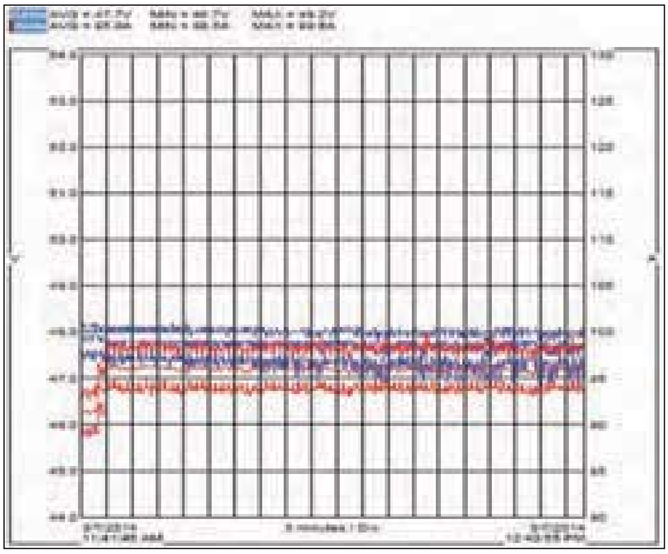
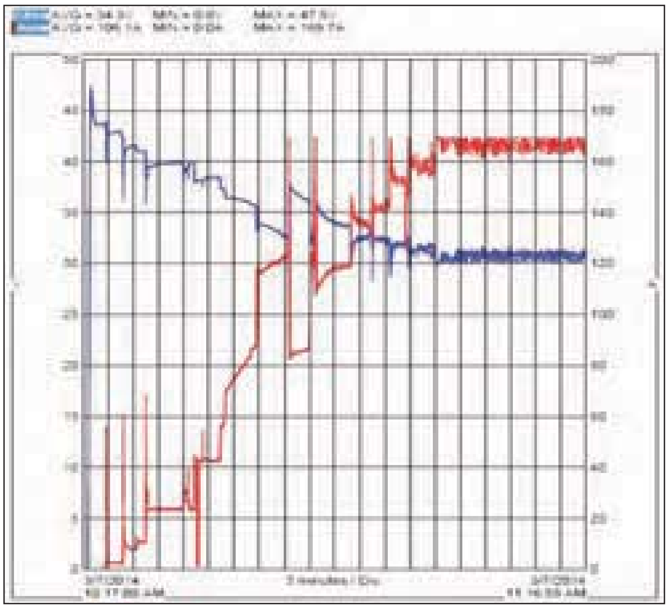
In the previous year, CFCT started exploring the idea of using DC power to run appliances so that several conversion losses normally encountered in the present energy supply chain can be minimised. As part of this development last year, CFCT announced the preliminary results and demonstrated the concept. During the current year, CFCT has established a "DC Room" where all the appliances are powered by 48 V DC. Normally, fuel cell systems in many stationary applications, use complicated power electronics to convert the variable DC power from the fuel cell stack to usable AC power supply (230V/415 V, 50-60 Hz), which is accompanied by severe efficiency losses. First the variable DC power is converted to create a constant DC voltage output. An inverter is then used to convert the direct current to an alternating current (AC) for usable power because most appliances run on AC. In applications such as computers/servers, the AC power is again rectified to provide DC power. Now, we have demonstrated a "DC Room" where different appliances varying from resistive load to inductive load are powered by a 5 kW LT-PEMFC developed indigenously. While use of these fuel cell stacks with DC–DC converters with lighting load is easily achieved, integration of these systems with appliances such as refrigerator and air-conditioners requires several studies. The responses of the system under various transient loads were studied.



Response of DC-DC converter under power surge

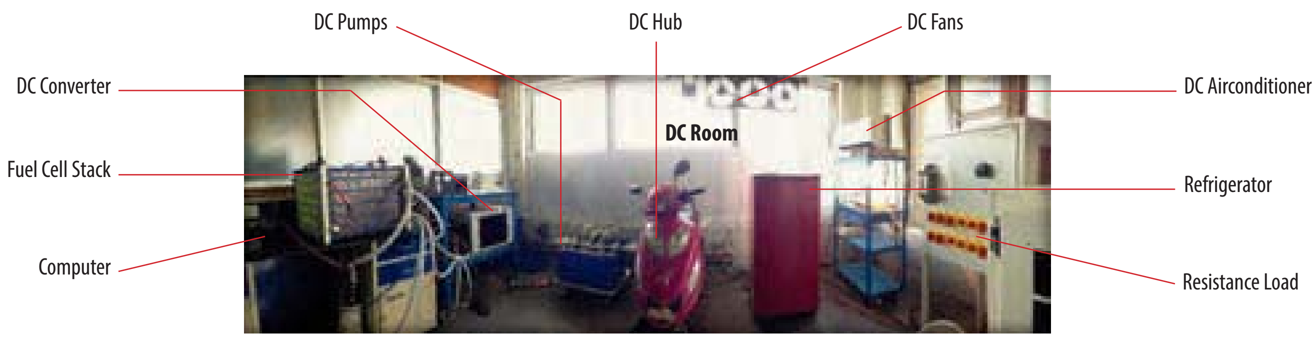


Voltage- Current characteristics of the DC-DC converter



Voltage- Current characteristics of the stack

This demonstration, we believe, would pave the way for eventual use in "Smart Grid" or " Micro Grid " applications.



Contributors: N. Rajalakshmi, M. Kannadasan, L. Babu, R. Vasudevan, T. P. Sarangan and R. Parthasarathi

Evaluation of PEMFC Stacks under Different Environmental Conditions

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PEM fuel cells have the potential to be deployed in a number of applications. Fuel cells are normally tested in standard laboratory conditions. In a country like India where the atmospheric conditions vary widely during different seasons it is important that the fuel cells are tested in different atmospheric conditions especially the temeprature and humidity. CFCT has established a test facility, a first of its kind in India, to evalute fuel cell stacks of upto 5 kW capacity under different atmospheric conditions, .

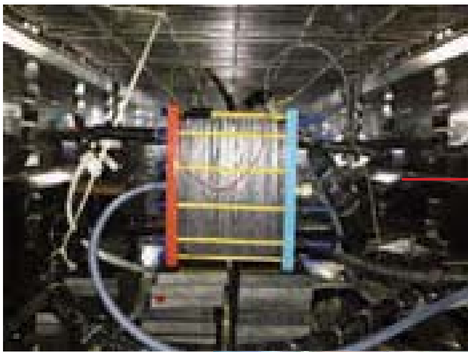
PEM fuel cell stacks of capacity 200 watts and 2 kW were tested under moderate to tough environmental conditions. The conditions primarily include relative humidity (RH) and temperature of the environment surrounding the fuel cell stack. Under such variable conditions, the performance output of the fuel cell stacks in terms of the total power delivered was studied. The base performance delivered by the stack under normal environmental conditions of Chennai city (India) was used for reference. The fuel cell stack was operated under each environmental condition, spanning over a total of 6 hrs. The stack and the air blower used to supply air to the fuel cell stack were installed inside the environmental chamber. The temperature and humidity of the air supply to the fuel cell stack were controlled. The air is supplied to the chamber from an air conditioning unit that can condition the air to the specified humidity and temperature conditions. Several extreme and normal environments were identified for the testing of PEM fuel cell stacks. These environments include several pairs of RH and Temperature conditions. The pairs of RH and temperature were mapped with pertinent geographical locations in the country.

The stacks have been tested at three different temperature ranges of 40°C, 50°C and 60°C respectively. The RH and environment temperature were paired up as RH/T-85/30, 20/30, 85/20, 50/20, 50/50. The identified RH/T pairs reflect the environmental conditions at places like Chennai, Hyderabad, Mumbai, Cherrapunji, Jaisalmer and Thiruvananthapuram.

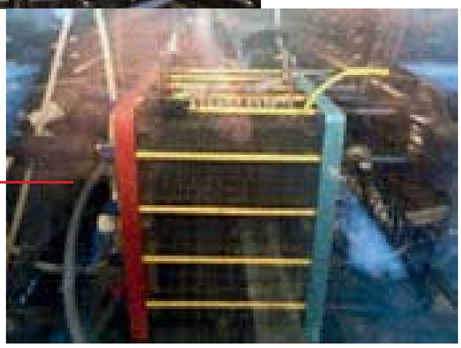
The 200 watts (nominal power at standard test conditions in the laboratory) PEM fuel cell stack, built with indigenously developed process know-how and which uses bipolar plates made form exfoliated graphite, delivered an average power varying from 190 to 210 watts under different environmental conditions. Hydrogen was supplied under dry conditions and the maximum stack temperature was kept below 60°C.

Similarly, an indigenously built 2 kW stack was tested. This stack delivered an average of 1.9 to 2.1 kW power under different environmental conditions. The maximum stack temperature was kept around 50°C.

These studies indicate that the process know how developed at CFCT for the electrodes and the stack assembly are suitable for operation in different atmospheric conditions. This we believe adds to considerable cost savings for the system providers.

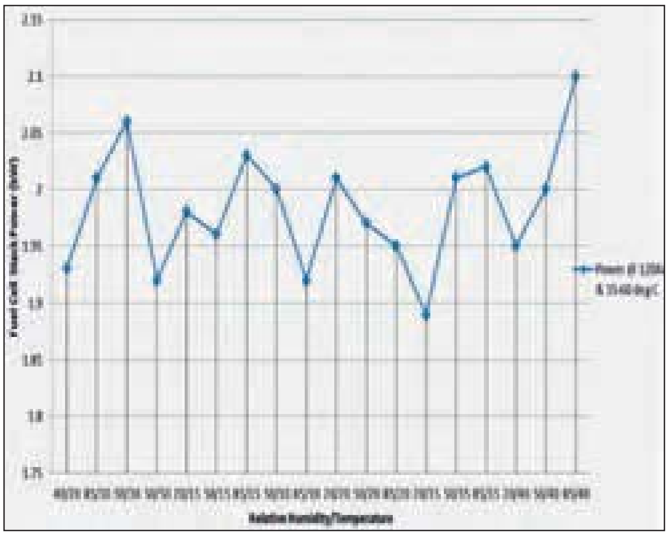


A vew from inside environmental chamber



A view from inside environmental chamber (during operation)

2kW PEM fuel cell stack



Fuel cell power distribution over RH/T ranges

Contributors: B.Sasank Viswanath and K. S. Dhathathreyan

Development of 600W High Temperature PEMFC Stack

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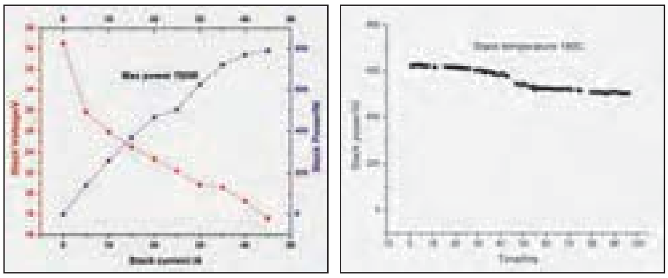
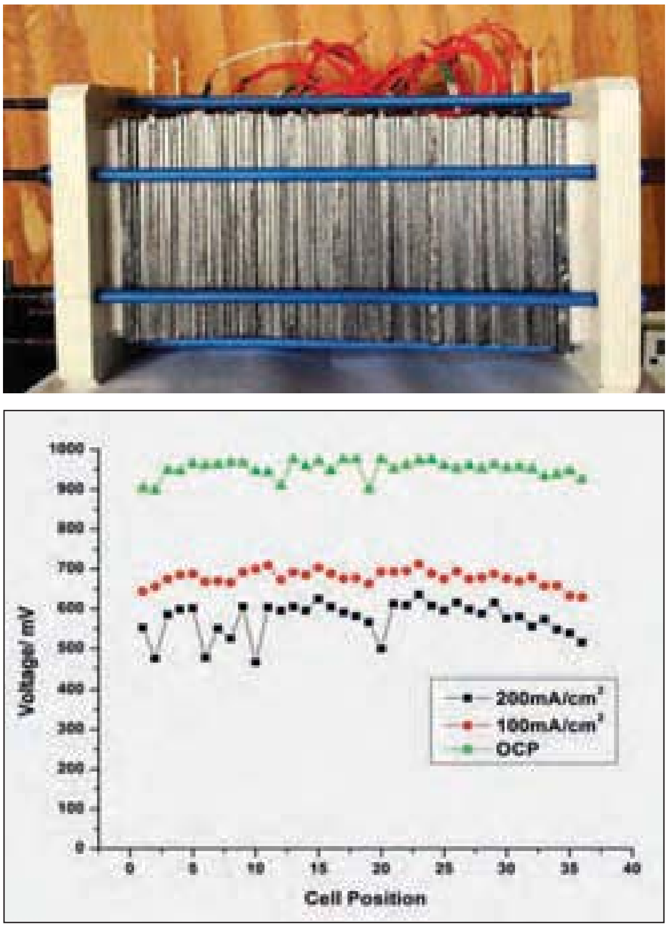
Fuel cells offer power at the site of consumption (distributed generation) thus shifting the power generation control to the consumer. The Centre has been involved in development of polymer electrolyte membrane fuel cell (PEMFC) technology for power generation. Recently, a program on high temperature (160 to 180° C) fuel cells was initiated as the high temperature PEM fuel cell (HT-PEMFC) does not require high pure hydrogen and has better water management characteristics. Like any other fuel cell, HT-PEMFCs are also modular, scalable and efficient. The exhaust gas streams have high temperatures, which can be exploited for combined heat and power (cogeneration) generation. HT-PEMFC when combined with a suitable cogeneration system can result in very high efficiency. HT-PEMFC stack developed at the centre is meant to provide clean electricity for commercial and industrial applications. Based on the preliminary results, which showed that the bipolar plates made from exfoliated graphite (indigenous process) can replace the conventionally used machined graphite plates, a stack which can deliver a nominal power of 600 watts has been developed. The stack delivers a peak power of 800 watts. Round the clock operation capability at high temperatures was demonstrated by testing the stack continuously at nominal power for ~100 hrs without stoppage. Further, the stack was operated with dry reactants and no external cooling was used. It was also found that stack heating was required only in the beginning to bring the cell to its operating temperature of 180°C.



Stack characteristics



600W HTPEMFC stack

One of the important issues in HTPEMFC stacks is the heat removal from the outlet gases, when the cell is operated 180°C, using water or other medium. A micro-CHP system (a combined heat and power system) providing electricity and heat (hot water) for a stationary power system was designed for a four cell, 70W stack developed earlier. Such a system converts the chemical energy of the fuel into both electrical power and useful heat. 26W of energy as heat was recovered from the stack and was used to obtain hot water. Heat recovery studies from 500W stack is currently being pursued.

Due to higher temperature of operation in HTPEMFCs, the waste heat is of high quality and thermoelectric generators may be introduced to recover the heat from these systems. Power generation and solid state heating/cooling are the potential applications of a thermoelectric material as direct conversion between thermal energy and electrical energy can be realized in these materials. Work on the development of composite conducting polymer based thermoelectric generators is also in progress with a view to improving heat to power conversion ratios.

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Studies on Development of Alternative Materials for PEM Based Electrochemical Methanol Reformer (ECMR)

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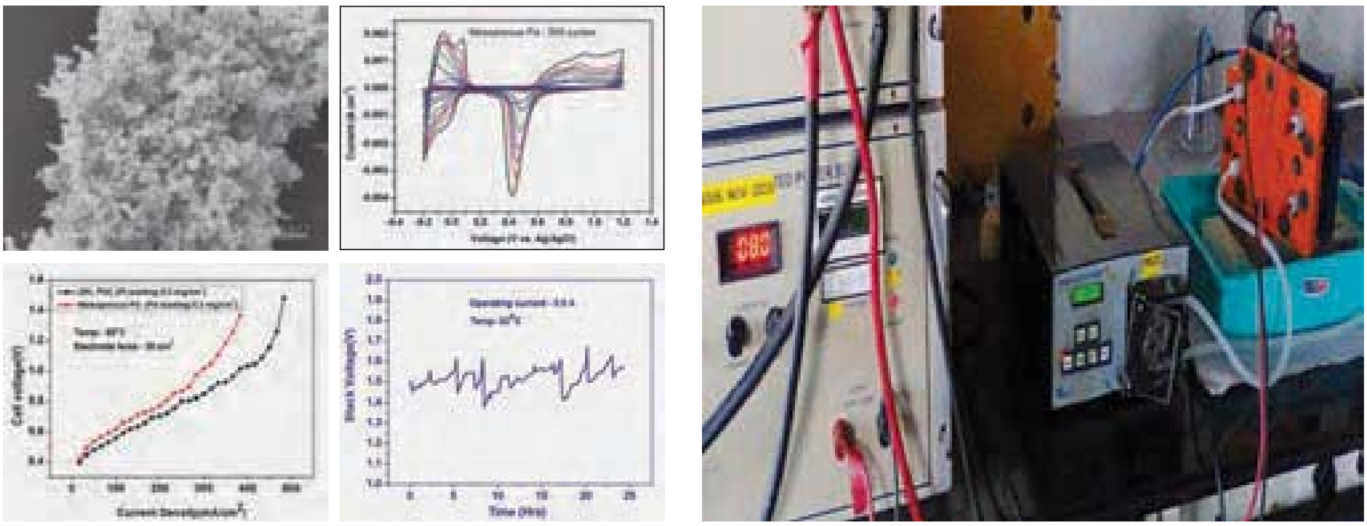
CFCT has successfully developed and demonstrated a PEM based electrochemical methanol reformer, which can deliver 1000 l/hr hydrogen. Presently, studies are being carried out to reduce the capital cost of the unit. One of the approaches is to replace the presently used Pt/C catalyst with other low cost catalyst. The second approach is to develop composite membrane for use as electrolyte in place of the currently used Nafion membrane.

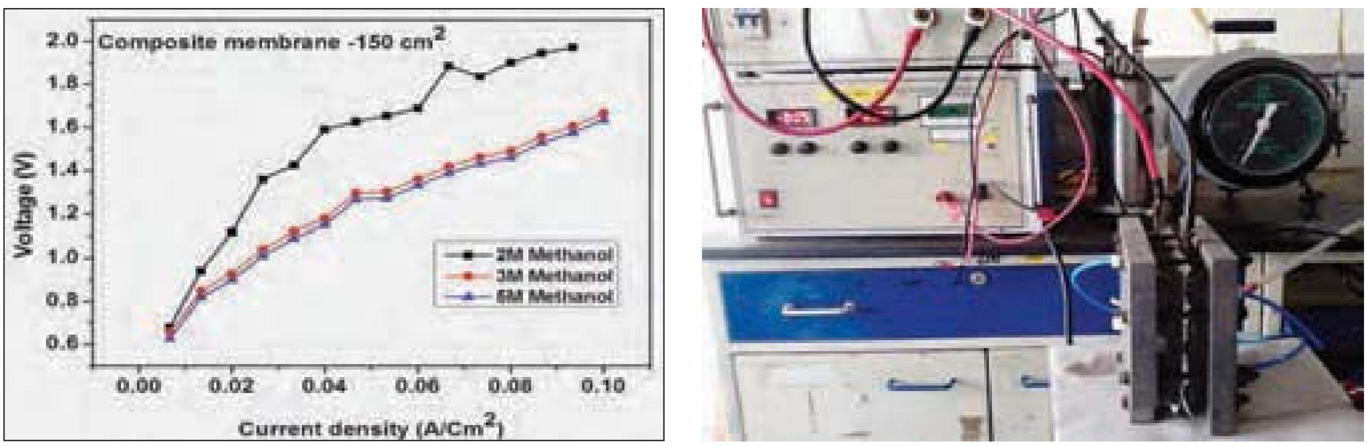
Preliminary studies indicated that Pd/C can replace Pt/C used as electro catalyst on the cathode in these cells and thus has the potential to reduce the capital cost. Based on the success of using porous or network structured metals (mesoporous electrolcatalyts) in LT-PEMFC; which showed superior physical and chemical performance due to their high surface area, low density and high gas permeability; a study was initiated to prepare mesoporous palladium for its use as cathode catalyst in the hydrogen generators.

The electrochemical stability and performance of synthesized Meso-Pd electrocatalyst for Hydrogen Evolution Reaction (HER) evaluated in short stack,comprising of two cells shows comparable performance with Pt/C.

In addition, attempt has also been made for the development of composite membrane using a PTFE matrix and Nafion ionomer. This composite membrane suggests a saving of nearly 50-60% of the electrolyte cost of the ECMR. Using this composite membrane short stack comprising of two cells of area 150cm^2 was developed and tested. The result has provided scope for further improvement in the performance of ECMR. In addition, attempts to modify the electrode structure (conductivity, porosity, thickness, hydrophobicity and hydrophilicity) are also under progress.



Performance test results of ECMR developed using mesoporous palladium as HER catalyst



Performance test results of ECMR developed using composite membrane

Contributors: K. Ramya, Nagamahesh, Manjula Reddy and K. S. Dhathathreyan

Centre for Non-Oxide Ceramics

Non-oxide ceramics, which include various carbides, nitrides, borides and silicides, have been the subject of immense interest because of their extraordinary material properties including low density, superior mechanical properties at ambient and elevated temperature, excellent thermal properties etc. The Centre for Non-Oxide Ceramics (CNOC) at ARCI has been actively pursuing R&D activities focusing on various non-oxide ceramics, their coatings and composites for a wide range of applications. This has led to successful development of technologies for a range of products such as reaction bonded, pressureless sintered and hot pressed silicon carbide for mechanical seals, wear and impact resistant parts, and critical components required for light-weight and high stiffness applications. The Centre has also developed theoretically dense and uniformly smooth chemical vapour deposited (CVD) SiC coatings on large area substrates (up to 1000 mm diameter). Polishing of this CVD SiC coating can result in an extremely smooth surface upon systematic grinding and polishing that can be used for high energy (ultraviolet-visible, X-ray, synchrotron radiations) reflectors and celestial environments.

Recently, the Centre has established a single-screw horizontal extrusion facility with a maximum pressure rate of 150 bar and capable of extruding tubes of up to 100 mm diameter. This facility can be used for processing 3-4 meter long SiC receiver tubes for concentrated solar power applications. For such requirements, the Centre has also developed in-house compositions for joining of SiC/SiC and SiC/stainless steel tubes. Development of hot pressed silicon carbide, boron carbide, titanium diboride and composite materials, as well as nitride based ceramics with low dielectric constant and excellent mechanical properties is also being addressed. Ongoing R&D activities of the Centre are also aimed at enhancing the basic understanding of densification kinetics of compacts and implement the same for the development of technologies like ready-to-press SiC powder through proper selection of additives and binders, nano composites either by using nano powder as primary phase or incorporating them in the matrix as a secondary phase, near-net shape ceramic parts through gel casting, reaction bonded boron carbide parts etc. Aqueous gelcasting for processing of green SiC, Si_3N_4 and SiAlON based complex shapes has also been established. The Centre is also equipped with 5-axis CNC and ultrasonic facilities for machining, including drilling of high hardness ceramics (SiC, B_4C and their composites) for high precision applications.

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Failure Origin In Solid-State Sintered Silicon Carbide Ceramics

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Silicon carbide (SiC) is a brittle ceramic with low fracture toughness and it fails due to the presence of pre-existing flaws including cracks, voids and microstructural defects. The occurrence of flaws and their population in brittle materials can arise from variety of origins. The cracks can be a result of processed microstructure due to the presence of impurities, hard agglomerates, weak interfaces, presence of pores, voids etc. Also the most severe flaws are the surface cracks, which are introduced through sectioning and surface grinding to achieve dimensional accuracy in the actual parts or even during handling. Careful investigation of the sizes of the critical flaws based on the flexural strength of the SiC specimens showed that the strength-limiting flaws are originated from machining operations rather than the flaws that are associated with the processed microstructure. The size of estimated surface flaws is also validated by microscopic examination of sintered SiC.

The presence of flaws in a body, when subjected to mechanical loading, results in stress concentration. Following is the relationship between stress intensity factor (K) and applied stress (σ):

$$K = \sigma Y \sqrt{c} \qquad \ldots \qquad (1)$$

where c is the crack length and Y is a dimensionless parameter that depends on the crack and loading geometries. The stress intensity factor increases with increase in applied stress as per the Eq. 1 and reaches a critical value at the point of failure. Considering opening mode of crack propagation (mode-I), the critical value of stress intensity factor is known as the fracture toughness (K_{IC}) and the applied stress at the point of failure is the fracture strength (σ_f). It is understood from Eq. 1 that the largest crack existing in the body results in maximum stress intensity factor and eventually limits the strength. The size of the critical flaws is determined from the measured fracture strength (σ_f) and fracture toughness (K_{IC}). Assuming a semi-elliptical surface crack in the specimen where Y is 1.12 time of $\sqrt{\pi}$, the critical flaw size (c) can be estimated according to the following equation:

$$c = \frac{1}{1.25\pi}\left(\frac{K_{IC}}{\sigma_f}\right)^2 \qquad \ldots \qquad (2)$$

The strength data as determined by four-point flexural experiments are considered as the fracture strength for estimation of the critical flaw size. The specimens for four-point flexural strength measurement (49 mm x 7.5 mm x 4 mm) are made through sectioning of sintered SiC tiles (50 mm x 50 mm x 8 mm) and then through surface grinding by diamond gritted wheel. The sharp edges are rounded off to avoid stress concentration and then tested for four-point bending strength in a universal testing machine over the outer/inner span length of 40/20 mm and crosshead speed of 0.5 mm/min.

It is observed in this study that, the estimates of critical flaw size ranges between 32 and 110 μm for a set of fifty specimens tested by four-point bending strength measurement. This indicates that, the sizes of critical flaw are much greater than any features relating the microstructural defects. Hence, it is argued that, the critical flaws causing the failure might have introduced in the specimen during sectioning and surface grinding. A relative comparison between scanning electron micrographs of polished and etched microstructure of sintered SiC as well as the surfaces of sintered SiC prepared by sectioning and surface grinding is shown in Fig. 1. As can be seen from the Fig. 1 (a), the defects associated with microstructure of SiC (e. g. intergranular pores, voids, agglomerates etc.) are within 10 μm. On the contrary, the representative crack length as revealed from the micrograph of SiC surfaces after sectioning and surface grinding [Fig. 1(b)] is observed to be 38 μm. This crack length is well comparable with the estimated critical flaw size based on the fracture strength and toughness of SiC. Hence, it can be concluded that, often the strength limiting flaws in sintered SiC are originated during machining processes adopted for specimen preparation.

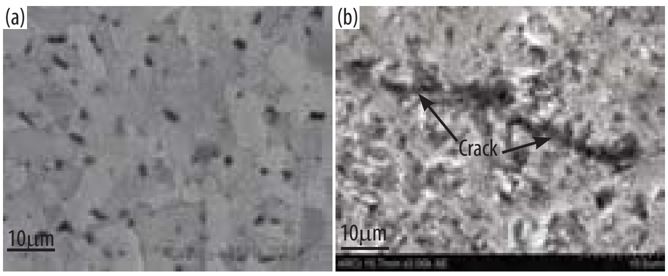

Fig. 1 SEM micrograph of (a) sintered SiC surface after polished and etching and (b) sintered SiC surface prepared by sectioning and surface grinding.

Contributors: Prasenjit Barick and Bhaskar Prasad Saha

Effect of the Concentration and Molecular Weight of Polyethylenimine on Zeta Potential of Nanocrystalline SiC

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The stability of powder slurry depends on the zeta potential (preferably higher value) and hence, it is of paramount importance to optimize the zeta potential through the selection of suitable dispersant and its concentration. Among several available dispersants, Polyethylenimine (PEI) plays an effective role in stabilization of nanometer sized silicon carbide (SiC) powder. In this study, an attempt has been made to investigate the role of PEI in terms of its concentration and molecular weight (MW) on the zeta potential of nano SiC powder in aqueous medium.

A 0.01 vol% nanosized SiC containing slurry was used for zeta potential measurement. Aqueous solutions of 0.05 M HCl and 0.1 M NaOH were used for titration of SiC slurries. Initially, PEI (MW 50000-100000) in different amount; such as 0, 0.08, 0.16, 0.40, 2 and 4 wt%; was added to each slurry specimen respectively. PEI with different MW, such as 2000 and 25000, were also used at two specific concentrations of 0.40 and 4 wt%. This has been done to assess the influence of MW on zeta potential, keeping the conditions of slurry preparation identical to those adopted in case of other SiC slurry specimens.

As depicted in Fig. 1, within the acidic pH range (3-6.5), the zeta potential is maximum due to the increase in ionization potential (αi) of PEI. This indicates that the PEI becomes more cationic in the said range of pH. The cationic PEI chains are more effective in dispersing the SiC particles through electrosteric stabilization mechanism, and therefore lead to maximization of zeta potential. Further, zeta potential was found to decrease progressively because of the decrease in αi of PEI as pH is shifted towards basic region. Near the isoelectric point, the PEI chains lose their charges as their positive charges are neutralized by OH- ions of the basic titrant. Hence, the zeta potential is almost zero at isoelectric point. At higher pH > 10, the polymer chains tend to coil tightly, and the interaction between molecules is enhanced leading to polymer bridging. Therefore, the SiC particles are mainly stabilized by steric hindrance, which in turn is responsible for the relatively lower zeta potential. However, the relationship between zeta potential and pH is noted to remain virtually unchanged with molecular weight of PEI as observed from Fig. 2(a&b).

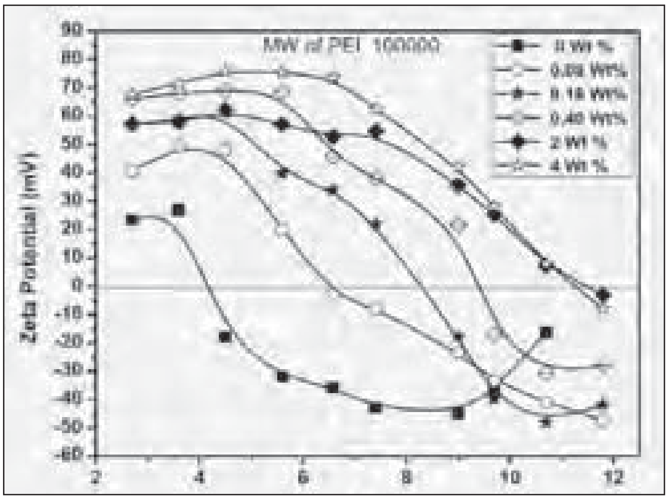

Fig.1. Zeta potential as a function of pH with different PEI concentration

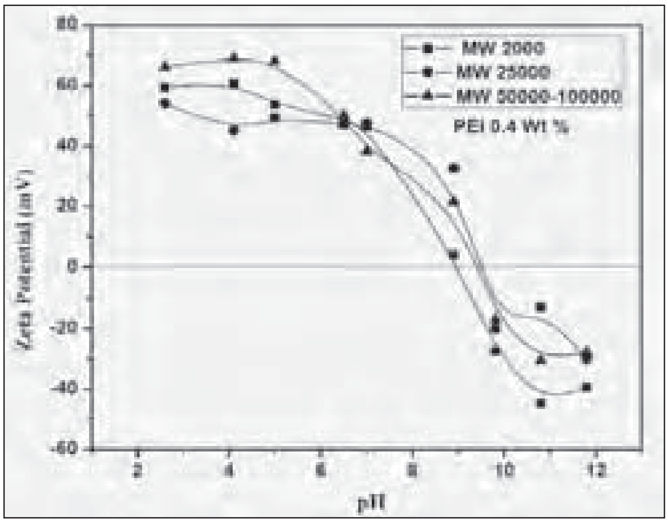

Fig.2a. Zeta potential as a function of pH with MW of 0.4 wt.% PEI

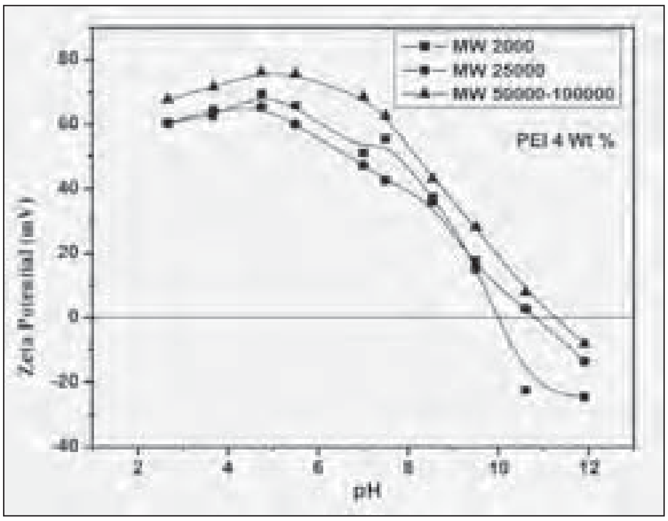

Fig.2b. Zeta potential as a function of pH with MW of 4 wt.% PEI

Contributors: Dulal Chandra Jana and Bhaskar Prasad Saha

Centre for Carbon Materials

In the recent past, nano-materials have emerged as important materials for the engineering applications due to its extraordinary properties. Among, nano-materials, nano carbons are key materials for wide range of applications. The uniqueness of carbon materials is well known due to its ability to bond in different ways and also its existence in mixed phase mode, thus leading to many interesting materials, such as fullerenes, nanotubes, graphene, and amorphous carbon graphite nanoplates. This has led researchers to explore new avenues in the design of advanced materials for high performance applications by taking advantage of multi-functionality in the structures. In other words, the properties of carbon nanostructures can produce the next generation of materials. However, there are certain challenges in their synthesis and processing with consistent properties. At Center for Carbon Materials, research is being carried out in the following areas:

- *Synthesis of vertically aligned carbon nanotubes (CNTs) via chemical vapor deposition technique (CVD). Subsequently, these CNTs were micro machined via ultra fast laser processing to get the patterning of CNTs for field emission application.*
- *Development of graphene oxide & reduced graphene oxide based free standing flexible paper for energy storage applications*
- *Development of graphite nanosheet/polyanilene based composites.*
- *Synthesis of carbon onions via arc discharge using Ni & Co catalysts.*
- *Exploratory studies of CNTs for various applications.*

Recently, a UV Visible Spectrometer has been added to the Centre.

Make : PERKIN ELMER Model: Lambda 35

Features:

Range	:	*190 nm – 1100 nm*
Bandwidth	:	*0.5 – 4 (Variable)*
Absorbance Range	:	*3.2 A*
Samples	:	*Liquid and Powder*

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Carbon Materials Bay

Few Layers Onion-Like Carbon Nano Particles by Arc Discharge

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The last few decades have witnessed an exponential growth in the field of carbon nanotubes studies worldwide and this has led to the synthesis of other carbon like materials including onion like carbon nano-particles (OCNs). The OCNs, which consist of concentric graphitic shells, represent another new allotropic nano-phase of carbon. OCNs are core shell structures with typical diameters between 3 and 50 nm. The cores in OCNs are hollow and their diameters are usually in the range 0.7-5 nm. OCNs are differentiated based on size, morphology and shape. OCNs have already been shown to offer new diverging applications such as solid lubrication, electromagnetic shielding, fuel cells, heterogeneous catalysis, and gas and energy storage owing to their incredible chemical and physical properties offered by their nano dimensions. According to a recent study, OCNs can also be used to produce ultrahigh power micrometer-sized supercapacitors due to their accessible external surface area for ion adsorption. OCNs were produced by DC arc discharge method using Ni and Co catalysts. The representative HR-TEM images for purified OCN at various magnifications and local areas are shown in Fig. 1. It can be clearly seen that onion like carbon nanostructures were formed. Noteworthy observations from Fig. 1(a) and 1(b), that both body soot and sheet soot onion like carbon nanostructures represented by concentric spherical graphitic shells which are represented as “G” and hollow represented with “H” in the Fig. 1c, can be clearly observed.

The outer diameter of the spherical graphitic shell structures is between 10-20 nm. The distance between the two graphitic planes in the onion like shells was determined to be 0.34nm (Fig. 1(c) inserted image), which is the inter-planar distance in pristine graphitic structure.

The BET result for sheet soot for showed an extremely large surface area of around 200 M^2/gm, significantly larger than that reported for carbon nanotubes and body soot as shown in Fig. 2.

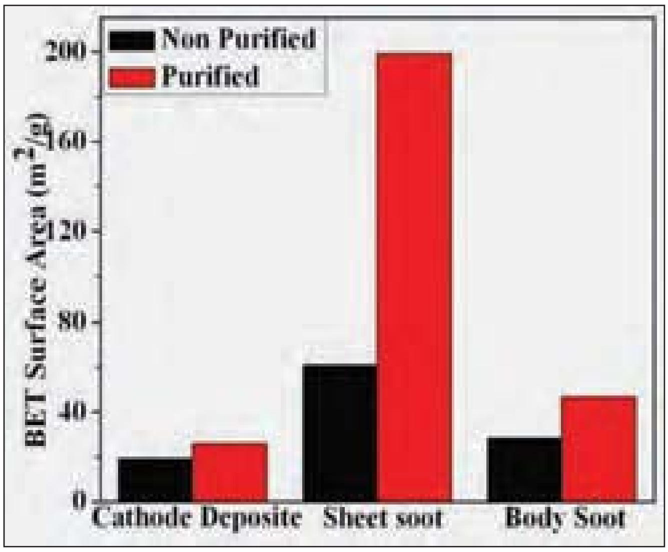

Fig 2 BET Surface area of non-purified and purified

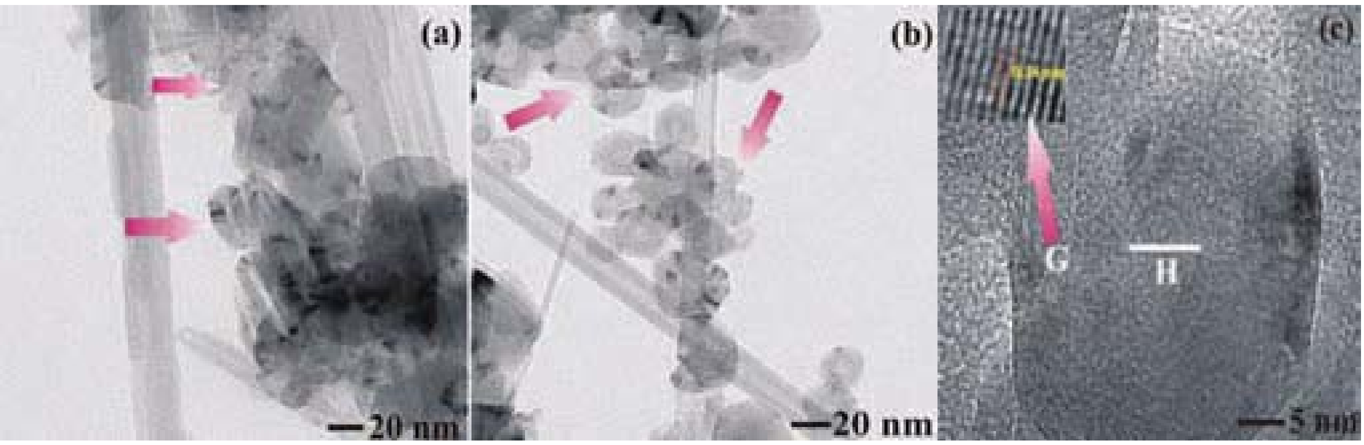

Fig. 1 TEM images of (a) Body Soot, (b) sheet soot, and (c) High resolution sheet soot

Contributors: Veldandi Ashok Kumar & Balaji Padya

Carbon Nanotube based Cold Cathode for Electron Gun Applications

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Carbon nanotubes (CNT) have been recognized as one of the most promising materials for cold cathode for field emitters as tubular carbon structure possesses remarkable thermal, electrical, electronic and mechanical properties. The high aspect ratio combined with sharp tips of CNT paves facile way and aids in emission of electrons to a large extent. Inclusion of heteroatom in a carbon network is one of the well known techniques to modify the electronic states, Fermi level and work function of the base material to improve FE.

Herein, we have grown self-organized nitrogen doped CNT arrays carpet (Fig. 1a) on silicon wafer by thermal chemical vapor deposition. The straight walled graphene layers in CNTs were transformed into compartmentalized bamboo-like structure due to substitutional nitrogen doping in CNTs as shown Fig. 1b. It resulted in open edges which improves the number of emission sites. The increase in nitrogen doping level in N-CNTs will lead to decrease in in-plane crystallite size and increase in defect density.

Field emission (FE) is the extraction of electron from a solid material by tunneling through surface potential barrier. Field emitters have several advantages over thermo-electronic emitters like it need not be heated for electron emission and the emitted current can be controlled with applied voltage.

CNT based cold cathode was integrated to multi-electrode electron gun, and FE behavior was studied. FE study of CNT arrays indicated that they are good emitters with very low turn-on and threshold field. The maximum current density was observed to be 139.20 mA/cm^2 at an electric field of 2.25 V/μm which is illustrated in Fig.1c. The maximum transmission of signal was observed to be ~57.10% at a current density of 78.02 mA/cm^2.

The alignment of CNTs and presence of lone pairs of electrons on nitrogen atom that supplies more numbers of electrons to the conduction band are responsible for the enhanced FE performance of doped CNT arrays.

Cold cathode material finds application in field emission display, travelling microwave tubes, X-ray tubes, electron gun in sputtering unit, and probes for scanning electron microscopy.

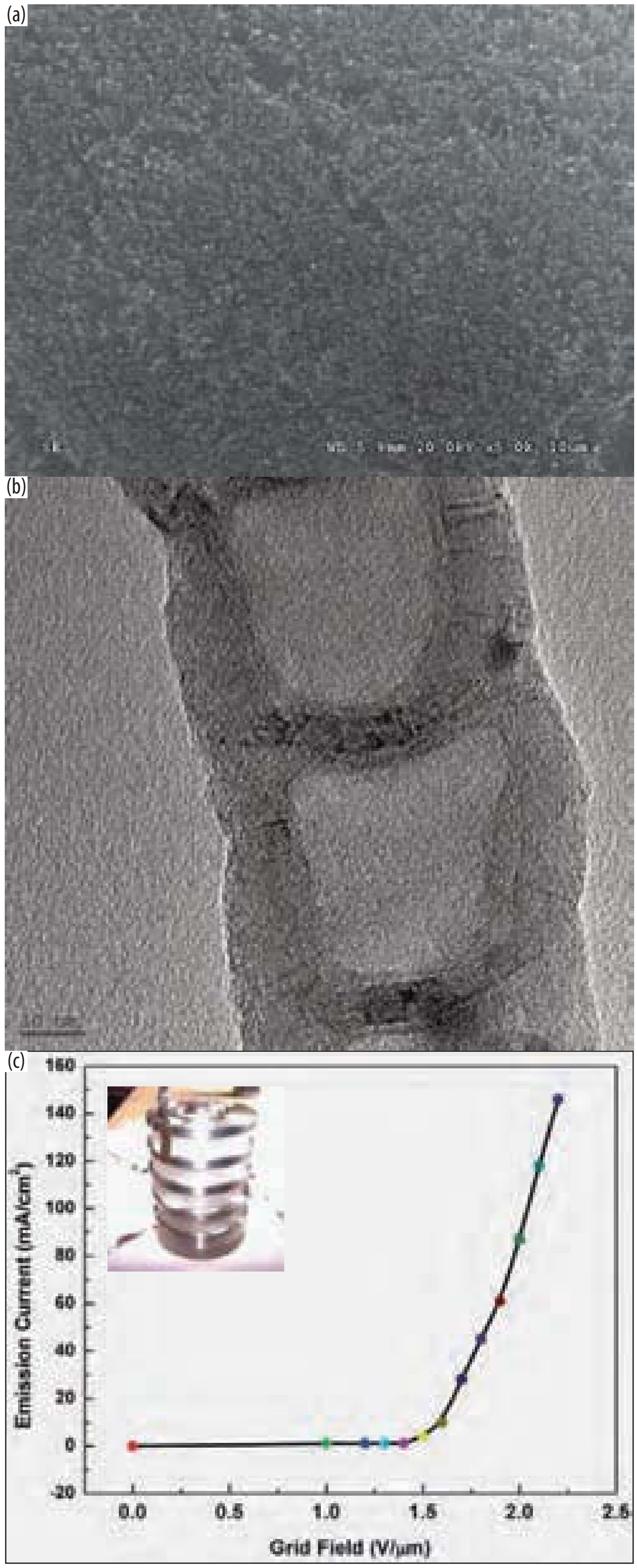

Fig. 1 NCNT arrays (a) SEM micrograph (b) TEM micrograph (c) FE properties and multi-electrode electron gun (as inset)

Contributors: A. V. B. Subrahmanyam and P. K. Jain

Centre for Sol-Gel Coatings

Sol-gel processing is one of the wet chemical methods that can create nanocrystalline or nanoscaled amorphous materials/coatings. Processing of organic-inorganic hybrid nanocomposite coatings using this technique is now an active field of research. The advantage of an organic-inorganic hybrid coating is that it can favorably bring synergy between the dissimilar properties of organic and inorganic components in a single layer with possibility of different functionalities such as corrosion resistance, solar selectivity, anti-reflection, scratch & abrasion resistance, anti-bacterial etc. Consequently, hybrid nanocomposite coatings generated by sol-gel process are promising for commercial exploitation. The Centre has been working with several industrial partners for development and demonstration of sol-based nanocomposite coatings for a wide variety of applicatons. Some of the recent focus areas are:

1. *Corrosion protection coatings on aluminum and its alloys*
2. *Anti-tarnish coatings on noble metals*
3. *Decorative coatings on glass for architectural applications*
4. *Flame retardant coatings on textiles*

There is an urgent need to replace toxic hexavalent chrome conversion coatings applied on aluminum and its alloys, for corrosion protection. There are concerted efforts all over the world to find replacements to hexavalent chrome coatings. A new dimension in this area is to make the coatings as self-healing so that a prolonged corrosion protection can be realized. Containing the corrosion inhibitors in smart nanoreservoirs, which can be released on demand, is a way to achieve self-healing effect. Different types of encapsulation materials (organic and inorganic) are being investigated at Centre for Sol-Gel Coatings for containing the corrosion inhibitors. An electrophoretic deposition technique is also being explored, due to the fact that dense, pore-free coatings are possible. Promising preliminary results have been obtained and further work is underway.

Anti-tarnish coatings on noble metals developed at the centre were found to offer very good resistance to H_2S (anti-tarnish property). However, coatings were found to fail when tested for perspiration resistance. Systematic analysis was conducted to find the reasons for failure and accordingly, the coating technology has been fine tuned. Efforts are ongoing to establish the consistency of the coating quality.

Pigmented, organic-inorganic hybrid nanocomposite coatings on glass for architectural applications were investigated in-depth from an application development point of view. Coatings were spray deposited on large glass sheets in order to verify the consistency of coating quality, when automated systems were employed to generate the coatings. As is common in any scale-up endeavor, few defects were noticed when coatings were generated on large work-pieces. Systematic investigations were carried out to probe into the reasons for defect generation, which resulted in promising findings.

In addition, research on eco-friendly, flame retardant coatings for textiles has recently been initiated in the backdrop of serious accidents occurring in trains and buses, where the curtains were the first to catch fire. Though there are solutions available commercially, they are halide-based and are not eco-friendly, which calls for new developments in coating formulation technology.

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Sol-Gel Coatings Bay

Weatherometer

Smart Nanoreservoirs for Self-Healing, Corrosion Protection Coatings on Aluminum

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Aluminum and its alloys are widely used as structural materials due to their high strength-to-weight ratio and low cost. During service, the metal/alloy surfaces are constantly exposed to extreme atmosphere conditions, due to which they may become highly susceptible to corrosion attack. Chromate conversion coatings have been the most widely used self-healing, anti-corrosion treatments for aluminum and its 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. Further, use of self-healing materials in the corrosion protection coating can increase materials' lifetime, reduce replacement costs, and improve product safety. Conceptually, self-healing materials have the built-in capability to substantially recover their mechanical properties after damage. Such recovery can occur autonomously and/or be activated after an application of a specific stimulus (e.g., heat, radiation, pressure, pH etc.). Self-healing coatings can be of different types, e.g. based on only polymeric materials, coatings containing micro- or nanocapsules, or by use of hybrid oxide coatings, where self-healing materials or corrosion inhibitors are encapsulated into containers and added to the coating formulation. These corrosion inhibitors are released only on demand, i.e. when there is a scratch in the coating leading to exposure of the metal substrate to the corrosive medium. Fig. 1 shows a schematic representation of working of the self-healing concept. Recent focus has been on using eco-friendly, inorganic systems as smart nanoreservoirs to encapsulate the corrosion inhibitors, since organic encapsulation of the corrosion inhibitor/self-healing material does not possess adequate mechanical properties.

Investigations were carried out on the feasibility of using aluminosilicate nanotubes (lumen diameter - ~ 15 nm and length ~ 800 nm) for encapsulation of Ce^{3+}, that was used as the corrosion inhibitor. Inhibitor loaded nanoreservoirs were loaded into a hybrid silica sol and dip coated onto aluminum substrates. After appropriate curing of the coating, an artificial scratch was made on the coated substrate by employing 8 N load and the scribed substrate exposed to 3.5% NaCl for 150 h to study the self-healing activity. Elemental mapping of the scratched, coated substrates before and after exposure to 3.5% NaCl solution showed that the concentration of Ce^{3+} had increased in the vicinity of scratched area, thereby confirming the release of corrosion inhibitor, once triggered due to increase of pH in and around the vicinity of the scratch. The present investigation indicates the promise of inorganic nanoreservoirs for use in self-healing coatings for prolonged corrosion protection of metals/alloys.

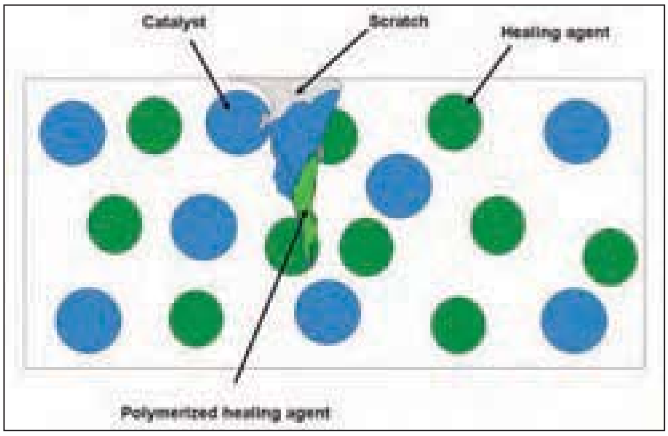

Fig 1. Schematic representation depicting self healing concept

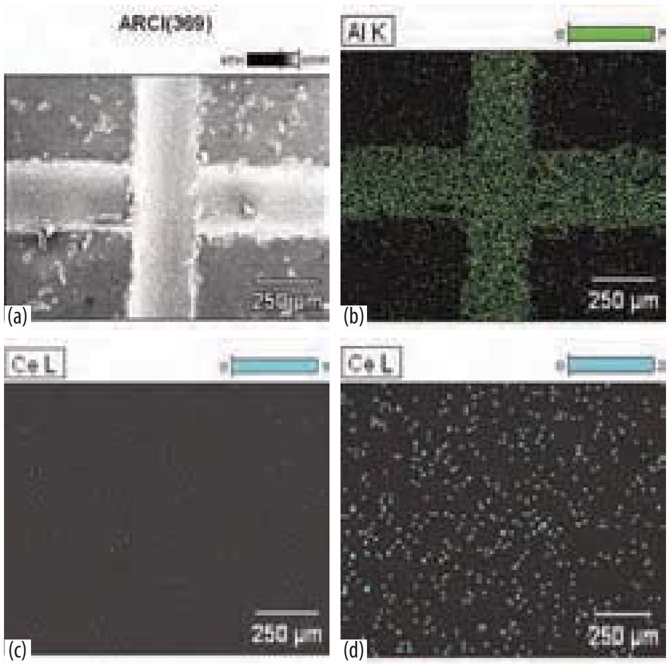

Fig 2. (a) SEM image of coated substrate with an artificial scratch and (b, c) elemental mapping before and (d) after exposure to 3.5 % NaCl solution for 150 h

Contributors: S. Pavithra and J. Noodhana

Ag-TiO_2 Plasmonic Nano-Composite Thin Films by Sol-Gel Method

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Plasmonics have been recognized as one of the emerging fields in the frontier areas of research. It is understood from the recent literature that the field of plasmonics may lead to an entirely new class of devices as well as improve the performance of the existing devices such as microscope, light - emitting diodes and sensitivity of chemical and biological sensors. It has been reported that in order to enhance the visible and near infrared (NIR) light absorption, one could use wavelength tuning of surface plasmon resonance (SPR) absorbance by designing on orderly dispersion of metal nano particles in a dielectric medium. The ability to tune SPR depends on the metallic particle size, shape, filling factor and the surrounding dielectric medium. In general, gold, silver, copper, cobalt and molybdenum nano particles embedded in titania (TiO_2), silica (SiO_2) and zirconia (ZrO_2) dielectric matrix have been effectively used for various applications. Such plasmonic thin films or particles are often produced by physical vapor deposition (PVD) techniques. In order to precisely control the geometry and spacing of metallic islands, advanced lithographic techniques are also used to obtain the plasmonics structure. However, these techniques are expensive and have a limitation of handling large substrates. Sol–gel technique has been accepted as an economical and promising technique for growing most of the transition metal oxide thin films including, TiO_2, SiO_2, ZrO_2 and Nb_2O_5 etc. On the other hand, the sol-gel thin film processing has its own limitation to generate metallic nano particles except gold, silver and platinum. In the present study, an attempt has been made in order to estimate the SPR for various Ag-TiO_2 composites using Mie scattering theory and validate the estimated SPR frequency for Ag-TiO_2 thin films fabricated by sol-gel dip coating method.

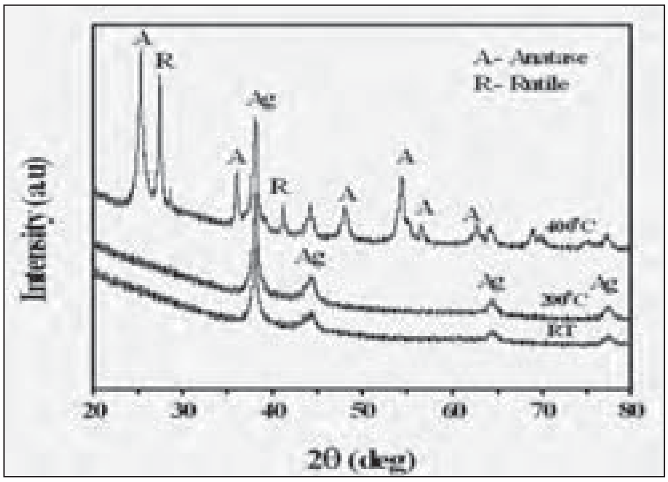

Fig. 1 XRD patterns of the Ag-TiO_2 powder synthesized by firing the precursor at 400°C

The structural characterization of the synthesized Ag-TiO_2 composite thin film was carried out using thermo-gravimetric and differential thermal analysis (TG-DTA), X-ray diffraction (XRD) techniques. The optical characterization was carried out by UV- visible absorbance spectroscopy and variable angle spectroscopic ellipsometer. The estimated resonance wavelength obtained from Mie scattering is reliable and trustworthy, which is seen to be in agreement with the UV visible absorbance spectrum. Fig. 1 shows the XRD pattern of the synthesized 10 wt.% Ag-TiO_2 dry gel powder at room temeperature and after firing at 200°C and 400°C. The XRD pattern for specimen fired at 400°C shows crystalline silver peak along with anatase and rutile phases of titania. Since the crystallization temperature of titania is above 300°C, the XRD patterns of dry gel powder at room temperature and 200°C show only the silver peaks. Fig. 2 shows the surface morphology and cross-section analysis of the 10 wt.% Ag-TiO_2 nano composite thin film having thickness ~ 60nm, confirming uniform distribution of 30-80 nm Ag particles. Fig. 3 compares the estimated and experimental surface plasmon resonance wavelength for 10 wt.% of Ag-TiO_2. The estimated SPR wavelength for the Ag-TiO_2 shows peak at 512 nm, where as the SPR for synthesized Ag-TiO_2 shows 580 nm. The difference may be due to the lower refractive index of TiO_2 when compared to the theoretical refractive index which may be difficult to achieve at the lower firing temperature of 400°C. Further investigations are underway to confirm the SPR characteristics of Ag-TiO_2 thin nano composite films that can yield better optical properties.

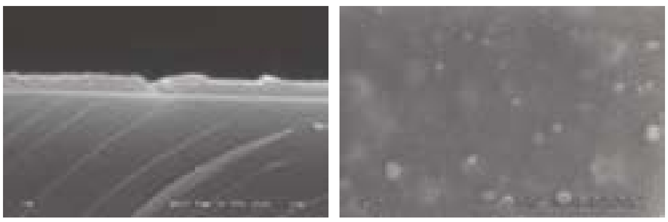

Fig. 2 Surface morphology and cross section of the 10 wt.% Ag-TiO_2 film prepared at 400°C.

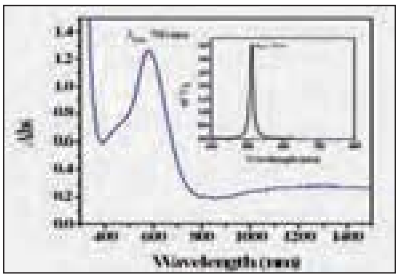

Fig. 3 SPR resonance wavelength for synthesized 10 wt.% Ag-TiO_2 film prepared at 400°C. Inset shows estimated SPR resonance wavelength

Contributors: G. Sowmya and Nabormi Mukhopadhyay

Solvent Vapour Effects on Crater Defect Formation in Spray Deposited Sol-gel Coatings

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Glass is one of the most modern building materials in contemporary architecture, and is being used extensively for interior decoration and building elevation purpose. However, featureless plain glass lacks the aesthetic appeal for many applications. Though coloured glass is available in few shades, its use is not wide spread due to limited mostly dark colours as well as difficulty in recycling. Hence, designers have opted to use colour lacquered glass. But such coloured coatings are organic which do not possess scratch and abrasion resistance and are prone to delamination in the presence of moisture, limiting the applications.

Pigmented organic-inorganic hybrid sol-gel coatings, on the other hand, offer scratch and abrasion resistance. Coatings can be transparent, translucent or opaque and can be applied by air spraying, either by manual process or by employing a manipulator, on large glass sheets. When pigmented silica-zirconia hybrid sol-gel coatings were spray coated on 1000 mm x 500 mm glass sheets using automated flat spray equipment with a High Volume Low Pressure (HVLP) gun having 0.8 mm orifice, few defects were noticed, as shown in Fig. 1. Thicknesses were of the order of 8-10 µm. Coatings were cured at 150^{o}C. Crater defects arise due to Marangoni forces that are established during air drying of the coating. Hence, effect of physical properties of solvent in coating on the formation of craters was investigated. Sol-gel synthesized nanocomposite coatings, diluted with different solvents at different ratios as presented in Table 1, were deposited on glass sheets as per optimized spray parameters. Defects were studied under microscope in an effort to assess the mechanism responsible for such defects.

Crater defect is evaporation driven instability. Based on the defect analysis by D. P. Birne III (`Rational solvent selection strategies to combat striation formation during spin coating of thin films', Journal of Materials Research, Vol 16 (4), Pg 1145-54, 2001) in spin coating, evaporation establishes a composition gradient at the surface as volatile species leave and less volatile components are left behind. Moreover, evaporation also causes evaporative cooling that is localized at the top surface where solution is in contact with the surrounding air. Both of these effects create a condition where top surface has higher surface tension than the solution at the bottom. Fig. 2 depicts a schematic representation of the liquid (solvent) movement due to differences in surface tension called Marangoni Effect. The regions that have higher surface tensions pulls out the material from the region where surface tension is lower causing a crater like defect. Experiments were conducted with solvents of different volatility in the coating material. Coatings prepared with solvent of lower volatility resulted in defect-free coatings. The defect density increased with increase in the volatility of solvent. Higher surface tension seems to amplify the effect. Optimised sol compositions with an appropriate solvent were found to result in defect free coatings with good consistency.

Fig.1 Optical micrograph of crater defects found in sol-gel coatings

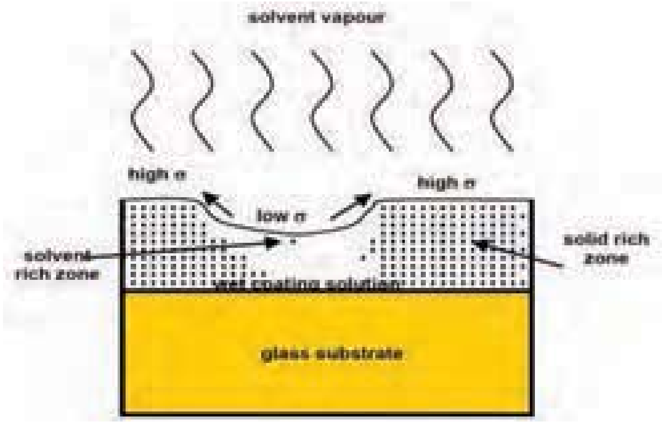

Fig. 2 Schematic representation of mechanism responsible for crater defect

Table 1. Comparison of physical properties of solvents utilized along with results obtained for the coatings

Solvent	Surface tension mN.m-1	Vapour pressure kPa	Viscosity mPaS	Boiling point, ^{o}C	Remarks
IPA, C_3H_8O	21.7	5.33	2.37	82.5	Good
Methanol, CH_3OH	22.5	13.33	0.593	64.7	Craters
Ethanol, C_2H_6O	22.7	5.95	1.2	78.3	Craters
2-butoxyethanol, $C_8H_{14}O_2$	26.6	0.079	2.9	171	Craters
IPA+ $C_8H_{14}O_2$	-	-	-	-	Craters
$C_8H_{14}O_2$+ $C_5H_{12}O_2$ +IPA	-	-	-	-	Craters

Contributor : R. Subasri

Control Circuit for Automated Rotation of Substrate During Electrophoretic Deposition of Sol-gel Coatings

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Sol-gel processing is a wet chemical synthesis route to obtain organic/inorganic hybrid materials in the form of powder, thick and thin films etc. There are many deposition techniques of sol-gel based coatings viz spray coating, flow coating, dip coating, spin coating, screen printing, pad printing and electrophoretic deposition.

Electrophoretic deposition (EPD) is a process in which colloidal particles suspended in a liquid medium migrate under the influence of an electric field (electrophoresis) and get deposited onto an electrode. All colloidal particles that can form stable suspensions and carry a charge can be used for electrophoretic deposition. This includes materials such as polymers, pigments, dyes, ceramics and metals. Increased critical thickness and dense coating can be obtained using such process when compared to simple dip coating of the sol. Fig. 1 shows the schematic of EPD.

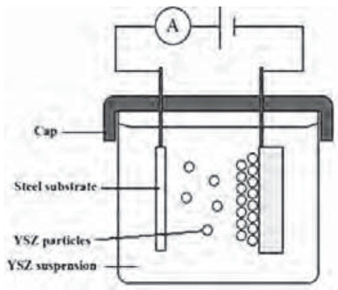

Fig 1. Schematic sketch of Electrophoretic deposition process

In the EPD process, if the work piece is axisymmetric, it is rotated in the solution to achieve uniform coating on its surface. An experimental set up with sample rotation facility has been indigenously developed to coat tubular sample using EPD technique. The design criteria for the circular motion in the bath are based on the torque characteristics of the motor, different control speeds for optimization of the coating time and size of the motor. A unit has been developed for the application using micro controller and H bridge control driver circuit as shown in Fig 2. to rotate the sample with stepper motor.

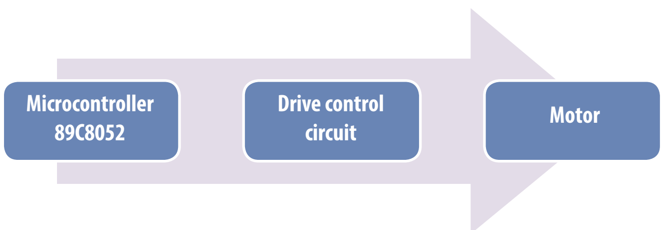

Fig 2. Block diagram of the process

Stepper motor is brushless synchronous electric motor that can divide a full rotation into large number of steps. It can be positioned without feedback mechanism unlike servo motors. Generally, stepper motors have high torque at low speeds. The motor was selected to rotate an SS tube of 40g weight rotating at low speeds. Three different speeds are programmed to suit the conditions as per the viscosity of the sols. Clock-wise and anti-clockwise directions can be selected as required.

Table 1 Specifications of the Motor

Type	Torque	Voltage	Current	Step angle	Stepping mode	Steps for revolution	No. of teeth
DC stepper motor	500g-cm	12	0.16 amp/ph	1.80	Bipolar	200	50

IC L298 is a dual full bridge driver that is used in the drive circuit control card. The IC has a high operating voltage range and can handle load currents up to 3A. The IC has a low saturation voltage and an over temperature protection to handle the torque required by the stepper motor.

Programming was written in C language and embedded in the microcontroller 89C8052. The speed selections are done by incorporating the delay sequence in the program. Program can be modified and re-written in the chip as per the EPD process requirement.

The unit that has been developed as shown in Fig. 3 is found to perform satisfactorily.

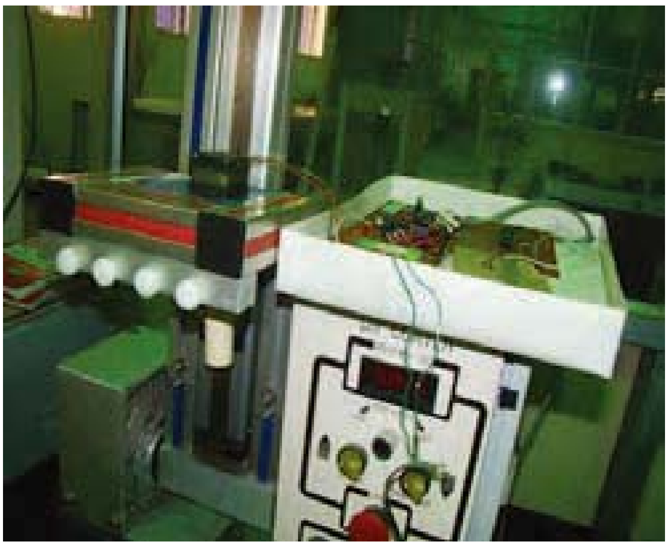

Fig.3 Experimental set up for rotating the sample during EPD.

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Multilayered Hybrid Sol-gel Coatings for Corrosion Protection of Aluminum Alloys used in Automotive Industry

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Aluminium and its alloys are rapidly replacing steels in automotive industry due to their high strength–to-weight ratio. But, they get scratched easily and have poor corrosion resistance. Chromate conversion coatings are applied to enhance corrosion resistance and to promote adhesion of organic paints that are applied as top coats. However, hexavalent chromium is carcinogenic and hence extensive efforts are on to replace the chromate conversion coatings on aluminium and its alloys. Of all the available coatings, sol-gel coatings are the most promising replacement for chromate conversion coatings. Inorganic sol-gel coatings are very hard and exhibit excellent scratch, abrasion and corrosion resistance. However, inorganic coatings are brittle, thin and need very high heat treatment temperature. Hybrid organic-inorganic sol-gel coatings provide excellent corrosion resistance as well as scratch and abrasion resistance. Unlike purely inorganic coatings, hybrid sol-gel coatings are thick, flexible and low temperature curable. Multilayered coatings on aluminium alloys that are used to make automobile wheels were attempted.

In the present investigation, multilayered sol-gel hybrid coatings were prepared using Poly Methyl Metha Acrylate (PMMA) as first layer and the top coat was made of a nanocomposite consisting silica-zirconia. Coatings, applied on polished aluminium coupons and cured at 80°C for 1 hr in an air circulating oven, were evaluated for thickness, pencil scratch hardness and gloss using appropriate characterisation techniques. Corrosion resistance of the sol-gel coatings was assessed using both 300 hrs of neutral sodium chloride salt spray (ASTM-117) as well as 1 hr potentiodynamic polarisation test using Cupric Acetate Salt Solution (CASS) as the corrosion media.

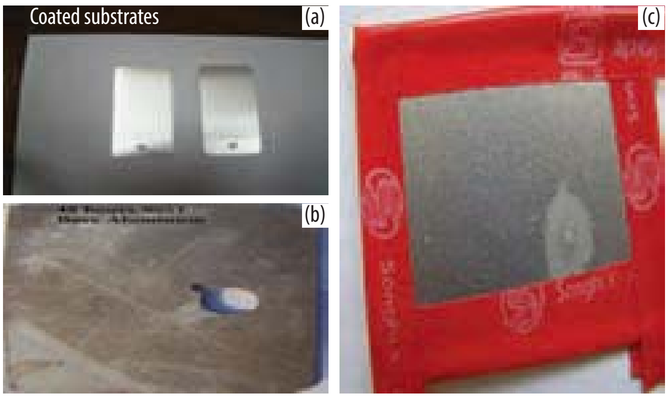

Fig. 1. Condition of the uncoated and coated test specimens after NaCl salt spray test (ASTM-117) a. Coated coupons, b. Uncoated & tested and c. Coated and tested.

The double layer coating thickness was found to be ~ 12 µm with a pencil scratch hardness of 4H each. Gloss of coatings was determined to be 850 units. Salt spray tests showed no signs of corrosion of coated substrates even after 300 hrs. Potentiodynamic polarization test results, as shown in Fig. 2, confirmed the excellent barrier effect of dual layer sol-gel coatings.

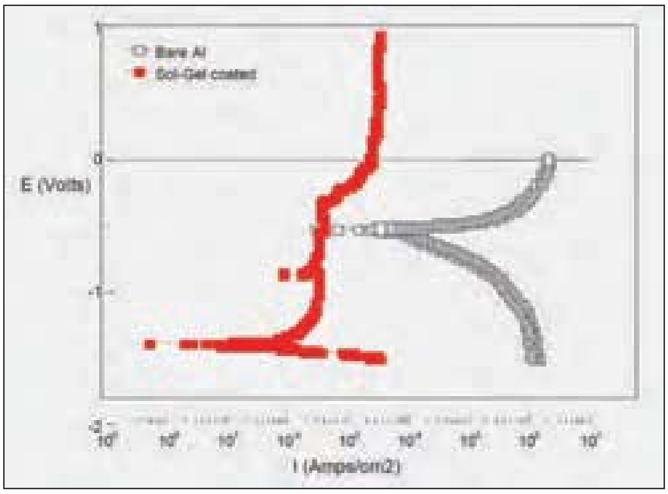

Fig. 2. Polarization curves in Cupric Acetate Salt Solution (CASS) for bare and sol-gel coated specimens. Red: Coated 0.17 mpy and Black: Uncoated 139 mpy.

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Centre for Materials Characterization and Testing

The Centre for Materials Characterization and Testing (CMCT) at ARCI was created by the amalgamation of the Centres for Mechanical and Microstructural Characterization and Chemical and Structural Characterization. The mandate of CMCT is threefold:

1. *To cater to characterization needs of ARCI's technology development and internal R&D activities*
2. *To undertake independent research projects in line with ARCI's interest*
3. *To extend consultancy and characterization support to users from other Institutions*

In order to fulfill its mandate and go beyond, the Centre has established state-of-the-art characterization facilities which can be divided broadly into five categories: Electron and optical microscopy, structural analysis, study of mechanical properties, corrosion studies and surface profiling. To keep pace with the increasingly diverse nature of ARCI's research portfolio and the growing load on the Centre, the following new facilities are to be soon established to further augment the vast array of facilities that already exist:

- *Nanoindenter with nano-impact facility*
- *Microfocus x-ray diffraction and*
- *Creep testing units*

Over the past year, the Centre has lent able support to several projects in the areas of oxide-dispersed strengthened steels, nanomaterials and nanostructural materials, coatings, sol-gel technology, laser cladding, fuel cells and ceramics etc. Team members are also involved in independent research projects utilizing transmission electron microscopy, small angle x-ray scattering and electron backscatter diffraction, and in the area of corrosion studies. A few select highlights of the work being carried out by the team are presented herein.

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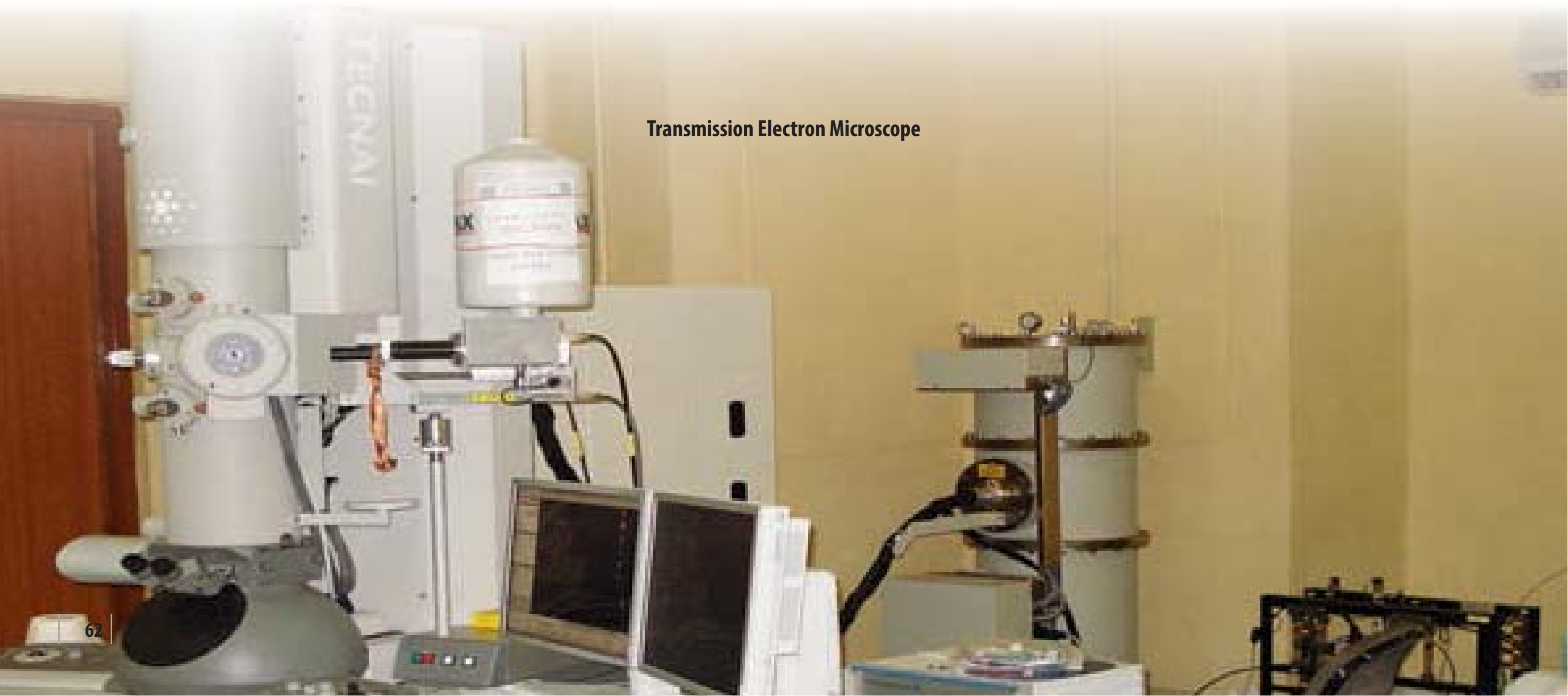

Transmission Electron Microscope

Columnar to Equiaxed Transition in Laser Clad Inconel-Chromium Carbide Layers

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Laser cladding is one of the popular methods for coating deposition. The finer microstructure and metallurgical bonding obtained in this process are presumed to be responsible for better tribological properties as compared to coatings deposited by other methods. In this typical rapid solidification process, the cooling rates involved are of the order of 106 K/s. The cooling rate determines the nature of the grain structure formed and depending on the process parameters, there is a variation in the cooling rate within the coating from the surface to the coating/substrate interface. In this study, the nature of solidification and the grain structure evolved in Inconel-chrome carbide has been evaluated using Electron Back Scattered Diffraction (EBSD).

Solidification processing leads to two types of grain morphologies namely equiaxed or columnar. Equiaxed grain growth occurs when the heat flows in all directions and the nucleated grains grow radially. Columnar grains on the other hand result when the heat flux flow is in one direction and the grain growth direction is opposite to the heat flow direction. Both equiaxed and columnar grains can be either eutectic or dendritic. In this study, Inconel-50Cr_xC_y was deposited on 0.27% C steel using a 6 kW diode laser.

The initial powder contained both Cr_7C_3 and Cr_7C_3 carbides but the final clad layers contained only Cr_7C_3 type of carbide as identified by EBSD. The Cr_7C_3 solidified dendritically as shown in Fig. 1. It is seen that all the clad layers processed at 1600W (Fig. 2) showed finer grains at the interface and coarser columnar grains away from the interface. Since the substrate acted as a heat sink in this case, the heat flow was unidirectional and the grains grew in a columnar fashion. On the other hand, the clad layer processed at 2400W and 24 mm/s showed finer carbide grains at the surface and coarser equiaxed grains away from the surface (Fig. 3). Since the heat flow was in all directions, the grains grew in an equiaxed fashion.

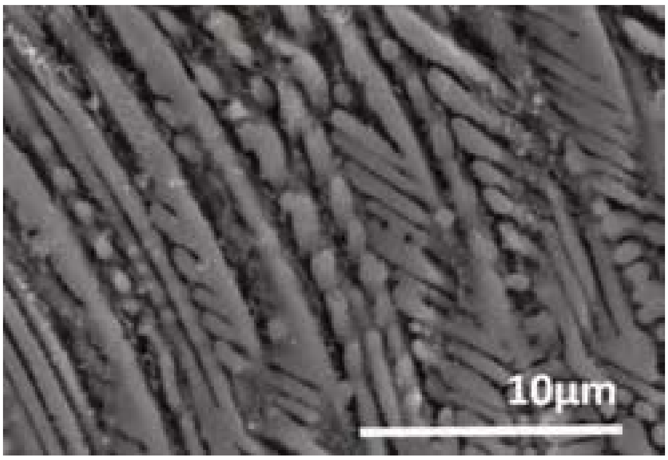

Fig.1 Dendritic Cr_7C_3 in laser clad processed at 2400W and 24 mm/s

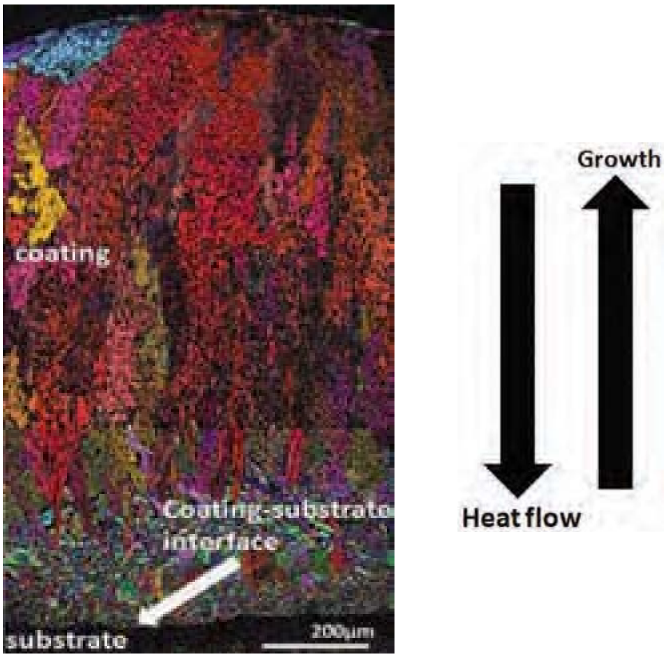

Fig.2 Crystal orientation map of laser clad layer processed at 1600W and 8 mm/s

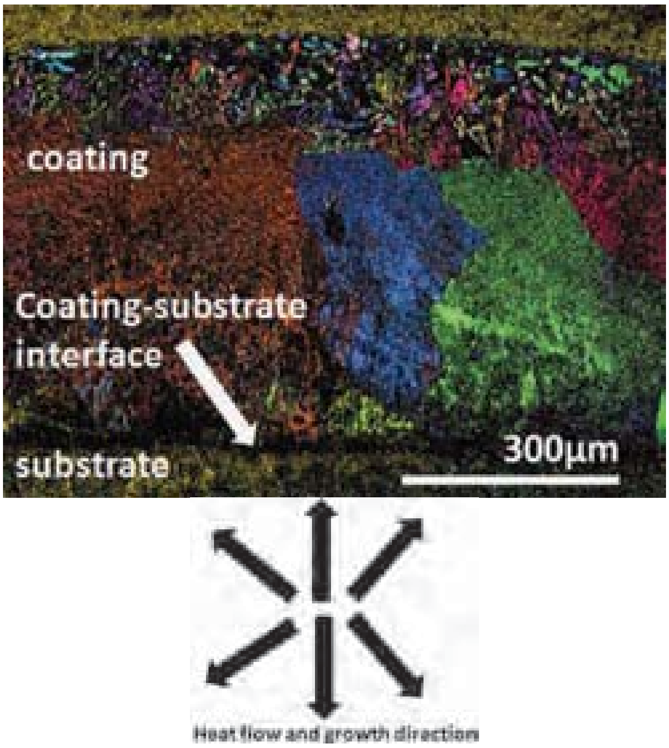

Fig.3 Crystal orientation map of laser clad layer processed at 2400W and 24 mm/s

Contributor: ***Manish Tak***

TEM Study on As-milled 18Cr-ODS Steel Powders

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Oxide Dispersion Strengthened (ODS) steels are candidate materials for fuel cladding in high temperature structural applications and are primarily processed via the powder metallurgy route. The processing of ODS steels involves milling of pre-alloyed Fe-Cr powder mixed with Yittria for a sufficient duration and then consolidating by hot extrusion. As part of ODS project at ARCI, 18Cr ODS steel alloy was processed using this process. Pre-alloyed powders of composition Fe-18Cr-2.33W-0.34Ti were mixed with Yittria powder and then milled for 1hr, 3hrs and 6hrs using Simoloyer mill. Transmission electron microscopy (TEM) studies were carried out on the as-milled powders to observe the effect of milling time on the Yittria particle size.

TEM of 1h milled sample showed the presence of a group of fragmented Y_2O_3 particles along the powder-powder interfaces of Fe powder particles, seen as bright regions in Fig. 1. The selected area electron diffraction (SAED) pattern obtained from the same area, shown in the inset of Fig. 1(a), contains extra spots whose d-spacing matches with the d400 of Y_2O_3. EDS from the same region confirms enrichment of Y in the particles. Fig. 1(b) shows the lattice resolution image from one of the Y_2O_3 particles. The inter-planar spacing measured from the lattice image is 0.27 nm, which corresponds to {400} of Y_2O_3.

Fig. 2 shows the Dark Field (DF) images from the 3h milled sample. The extra spots in the SAED pattern in addition to that of matrix bcc phase match with that of Y_2O_3 phase. The EDS spectra obtained from the bright region of Fig. 2 confirm the presence of Y. Therefore, it can be inferred that clusters of Y_2O_3 particles are still present in 3h milled sample.

Fig. 3 shows the Bright Field (BF) image and the corresponding SAED pattern of the 6h milled sample. It was observed that the extra spots mentioned above were not present in the diffraction pattern, which implies absence of Y_2O_3 particles. Similar diffraction patterns were obtained at several areas in the sample. However, in one instance the diffraction pattern showed extra spots. Though the d-spacing corresponding to extra spots does not match with any of that of Y_2O_3 phase, the EDX spectrum from the region shows presence of Y. Hence, the results suggest that Y_2O_3 particles got fragmented to large extent after 6h of milling leaving very fine particles dispersed sparsely in the 6h milled powder sample.

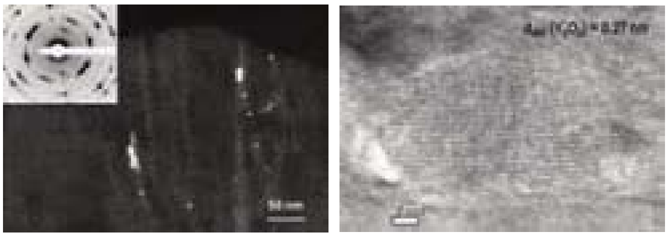

Fig. 1(a) DF image and SAED in inset. (b) HR image of a Y_2O_3 particle of 1hr milled sample

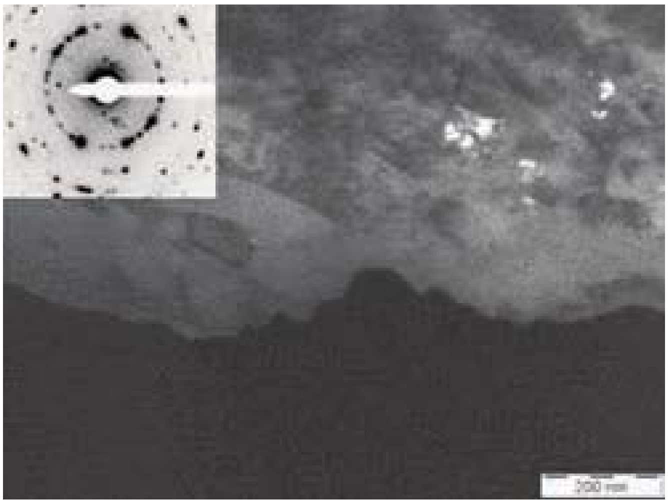

Fig. 2 DF image from the sample milled for 3 hrs, showing Y_2O_3 particles and SAED from the same region

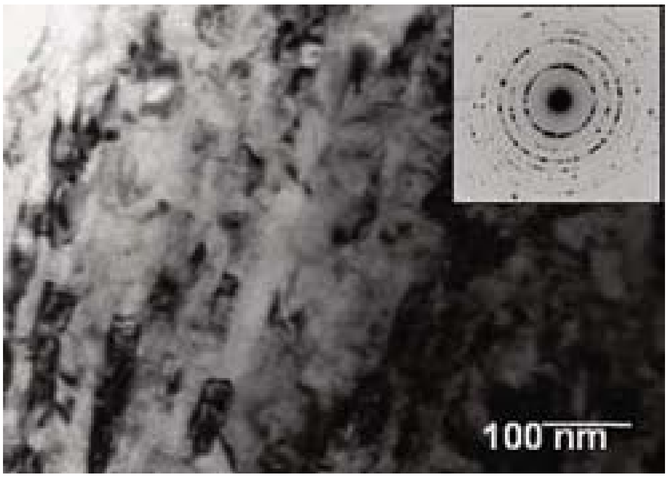

Fig. 3 BF image from powder milled for 6 hrs, with SAED from the region in inset

Contributors: R. Vijay and K. S. Prasad

Corrosion Performance of One Step Anodized/Sol-gel Deposited Ce^{3+}- doped Self-healing Coatings on Aluminium

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Aluminium due to its low cost, light weight coupled with high thermal and electrical conductivity is widely used in automotive and industrial applications. A thin passive layer artificially generated through an anodizing technique enhances its corrosion resistance. However, this passivated layer is porous and deteriorates in aggressive media e.g. chloride-containing environments. In second step, sol-gel coating is usually deposited over the porous anodised layer, in order to seal the pores thereby rendering good barrier properties. The present work involves a novel one-step anodization/sol-gel deposition from a Ce^{3+}-doped silica-zirconia sol to obtain self-healing coatings on aluminium and studying their corrosion properties. A ~ 20 μm thick crystalline aluminosilicate layer alongwith an amorphous sol-gel top layer was generated after optimizing the electrodeposition process parameters.

Potentiodynamic polarization and electrochemical impedance analyses were carried out for electrolytically coated and bare aluminium substrates after 1hr and 24 hr exposure to 3.5% NaCl solution at room temperature by using a Solartron electrochemical interface SI 1287 with Impedance/ Gain phase analyzer SI 1260. Fig. 1 shows the polarization and Nyquist plots for bare and coated samples exposed to 3.5% NaCl for 1hr and 24hr. Table1 shows the parameters obtained from R_p fitting of polarization plots and circuit fitting of Nyquist plots. It could be seen that the electrolytically coated Al provided a good barrier protection to the aluminum substrate, since the corrosion current density, i_{corr} was lower when compared to that for the bare aluminum substrate. It has been reported that the presence of Ce^{3+} in electrolyte solution reduces the rate of oxygen reduction reaction and E_{corr} shifted to more negative as compared to the electrolyte without Ce^{+3} ions. In the present case, the Ce^{3+} ions were present in coating itself. For the coated substrate (ED 1hr, ED 24 hr) cathodic arms were shifted to more negative potentials and also lower current densities when compared to those of bare aluminum substrate, indicating a reduction in the rate of oxygen reduction reaction as shown in Fig. 1(a). A well-established passive region can be observed for ED samples for 1hr itself and it is still improved for 24hr. This shows that the coatings are highly resistant to corrosion.

The charge transfer resistance (R_{ct}) values of the ED coated samples were higher by two orders of magnitude than those of bare samples after 1hr and 24 hr exposure which shows that the coating is impervious to the electrolyte. The R_{pore} (resistance to charge transfer through pores) values were also found to be higher (Table 1) for coated samples, which confirms that the electrodeposited coatings are highly dense with very less porosity. The higher R_{pore} value of ED sample exposed for 24 hrs is due to closing of the existing pores by Ce^{3+} ions which are converted into $Ce(OH)_3$ and $Ce(OH)_4$ precipitates that can provide self-healing property. This novel method of one step anodization cum sol-gel coating deposition is seen to be promising to generate dense, self-healing coatings on aluminum for prolonged corrosion protection.

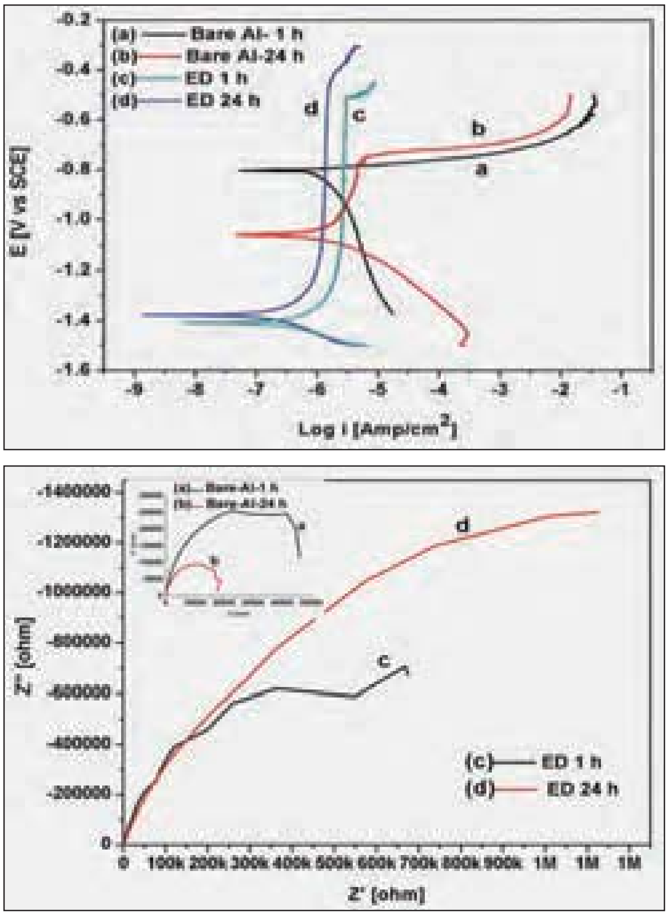

Fig.1 (a) Potentiodynamic polarization and (b) Nyquist plots of bare and coated Al (with ED) after 1 hr and 24 hr exposure to 3.5% NaCl solution

Table 1 E_{corr} and I_{corr} obtained from polarization results shown in Fig. 1(a); R_{pore} and R_p from Nyquist plots in Fig. 1(b)

Sample ID	E_{corr} (Volts)	I_{corr} [A/cm²] x 10^{-7}	R_{pore} [Ω/cm²]	R_p [Ω/cm²]
Bare Al-1 hr	-0.806	64.104	70.44	6.04E4
Bare Al-24 hrs	-1.059	15.849	124.7	2.11E4
ED-Al-1 hr	-1.409	5.247	163.5	2.02E6
ED-Al-24 hrs	-1.377	2.513	637.2	4.34E6

Contributors: N. Kumar and R. Subasri

Probing Cu Clusters on TiO_2 Nanoparticles Using Small Angle X-ray Scattering

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There has been an intense focus in recent years on the development of visible-light active photocatalysts for indoor applications. Very recently, co-catalyst (Cu^{2+} or Fe^{3+}) ion grafted semiconductors are being considered as efficient visible-light-sensitive photocatalysts since Cu^{2+} modification induces visible-light absorption (Fig. 1(a)) in semiconductors by interfacial charge transfer between the valence band of the semiconductors and surface Cu^{2+}-ions upon light excitation. Moreover, the holes generated in the valence band during the process have strong oxidation power, and the excited electrons in Cu^{2+}-ions cause efficient oxygen reduction and retard the electron-hole recombination. The resulting Cu^{2+}-modified semiconductor, TiO_2 in the present work, shows excellent photocatalytic activity for the degradation of hazardous pollutants and pathogens under visible-light illumination. However, the nature of Cu^{2+}-ions on the surface of the semiconductor is still not clear. Therefore, it is very important to observe the size and shape of the Cu-ions on the surface of TiO_2 particles to understand the relationship between microstructure and photocatalytic activity. Such a study will help understand the nature of Cu-ions on the surface of the TiO_2 nanoparticles as to whether the Cu-ions are coated to the thickness of a single layer or a few layers, or if the ions are present as clusters/particles and are attached to TiO_2 nanoparticles. Transmission electron microscopy studies were carried out to study the microstructure, using additional tools such as EDS and EELS but no significant conclusions could be drawn in both cases, with and without Cu-ion-containing TiO_2 nanoparticles, owing to the very low concentration of Cu-ions for mass contrast. Moreover, the Cu-ions may not be in a crystalline state to show diffraction contrast. Therefore, we have applied the small angle x-ray scattering (SAXS) technique to study the microstructure of the same.

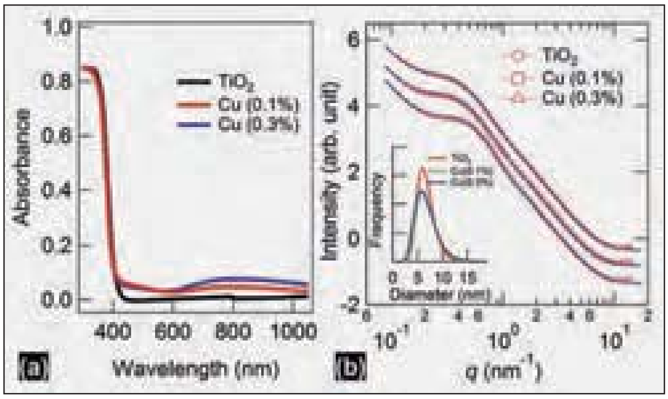


Fig. 1 (a) UV-visible spectrum, and (b) SAXS profiles of TiO_2, -Cu (0.1%) and -Cu (0.3%). Inset to (b) Size distribution of TiO_2 nanoparticles obtained by SAXS profile fitting analysis

SAXS is a very sensitive technique to probe heterogeneities in a material even if the heterogeneity volume fraction is less than 0.01%. SAXS intensity depends upon the incident x-ray flux and scattering contrast (electron density contrast between heterogeneity and matrix, $\nabla\rho^2=|\rho_h-\rho_m|^2$).

SAXS studies were carried out in transmission geometry using high flux/high transmission Mo laboratory source. The measured 2D-SAXS profiles were converted into 1D-profiles and the intensities of these profiles were calibrated to an absolute scale using standard glassy carbon. Fig. 1(b) shows the 1D-SAXS profiles of surface modified TiO_2 with 0.1 and 0.3% Cu-ions. In the low q-region (around 3 nm^{-1}), high scattering intensity is observed owing to TiO_2 nanoparticles. The size of the particles was estimated using profile fitting analysis and found to be 6±0.5 nm. While SAXS studies did not indicate whether the growth of the TiO_2 particles was with Cu-ion or a core-shell type structure, it can be assumed that these Cu-ions are clustered on the surface of the TiO_2 nanoparticles and the expected size of these clusters is a few nanometers. The corresponding scattering appears in the high q-region. The inset of Fig. 3 (top right) shows the differences in SAXS intensity. To obtain the scattering intensity only from the Cu clusters, the SAXS profile of bare TiO_2 was subtracted from the other two profiles as shown in Fig. 2 (circles). The subtracted SAXS profiles clearly exhibit evidence of scattering from the Cu clusters, and their size (radius of gyration, r_g) was estimated using Guinier analysis to be 0.46 and 0.85 nm for the 0.1 and 0.3% Cu samples, respectively.

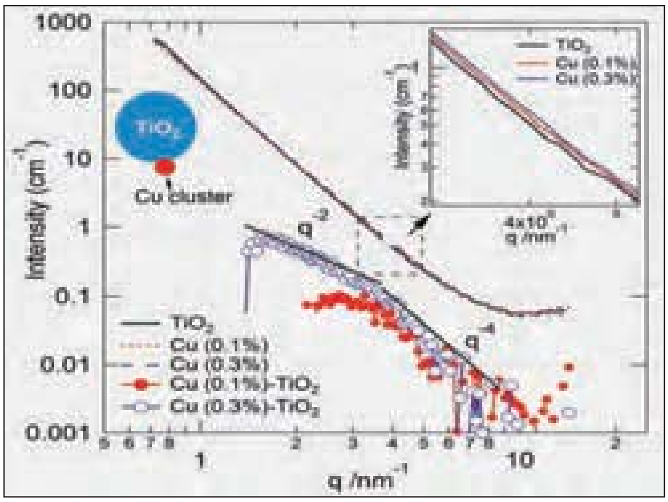


Fig. 2 SAXS profiles (continuous and broken lines) of TiO_2, -Cu (0.1%) and -Cu (0.3%) and inset Fig. 3 (top right) show higher SAXS intensity from Cu modified TiO_2 samples. Subtracted SAXS profiles (open and closed circles) show the scattering from the Cu clusters. Schematic of the Cu clusters on the TiO_2 nanoparticles shown in inset (top left)

Contributor: S. Anandan

Centre for Knowledge Management of Nanoscience and Technology

The Centre for Knowledge Management of Nanoscience and Technology (CKMNT) was set up by ARCI with partial financial support from the Nano Mission of the Department of Science and Technology, Government of India. Since its establishment, CKMNT has taken several initiatives with an objective to foster the exchange and dissemination of advanced technological knowledge in the rapidly expanding field of nanoscience and technology. A number of activities have also been undertaken from time to time as per the requirements of the Nano Mission. The Centre has evolved a broad framework for knowledge management of nanoscience and technology, whereby it continuously monitors and analyzes the developments taking place globally using state-of-the-art S&T/Company databases/resources available in-house and disseminates the information to different stakeholders through diverse platforms.

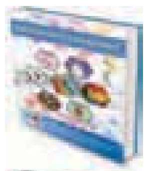
Products and Services Offered by CKMNT

Nanotech Insights – Quarterly publication	*Nanoscience & Technology Databases*	*Market Research Reports*
Techno Economic Feasibility Reports	*Techno-Commercial Reports*	*Identifying Potential Technology Collaborations*
Patents Search & Analysis	*Literature Search & Analysis*	*Technology Assessment Reports*
Strategic inputs to nano Mission		

CKMNT is becoming highly visible as a nano-knowledge management centre of excellence through its various products and services. Gradually, it has also begun to attract attention of various research organizations and companies, with specific requests to prepare on-demand documents/reports. The Centre has recently completed a company solicited Patent Novelty Search Report and brought out a Techno-Commercial Report on Nanofibers for Biomedical and Healthcare Applications as well as the Indian Nanotechnology Directory-2013. The salient features of these reports prepared by CKMNT are provided below.

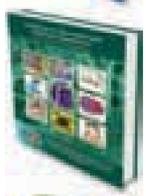
Patent Novelty Search and Analysis Report

A comprehensive novelty and prior art search report has been prepared for one of Asia's largest innovative silicone formulator for textiles finishing, pre-treatment and specialty processes. The report identifies relevant prior art (patent & non-patent literature) and claims and analyzed the possibility for product as well as process patent for the company's innovation.



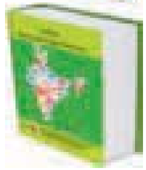
Techno-commercial Report - Nanofibers for Biomedical and Healthcare Applications

The techno-commercial report on "Nanofibers in Biomedical and Healthcare Applications" prepared by CKMNT provides a comprehensive overview of various technologies, potential applications, global markets, key market opportunities, trends and important players/suppliers/end users working in this field.



Indian Nanotechnology Directory - 2013

The first edition of the Indian Nanotechnology Directory containing 745 pages provides detailed profiles of 280 government institutions which include academic institutes of national importance such as IISc, IITs, IISERs, NITs, research institutions under DST, DBT, DAE, ICMR, ICAR, etc., CSIR Laboratories, Government funded central & state universities and also 300 companies active in the area of nanoscience and technology.



Other Ongoing Activities

Nanotech Insights *Eighteen issues of the newsletter have been published and about 2000 copies of each issue are being circulated annually among various nanotechnology stakeholders in the country*	
Industry Solicited Reports *Technology Foresight & Market Report on Nanotechnology Applications in Energy Sector*	***In-house Techno-commercial Reports*** • *Nanosensors for Automobiles* • *CNT-Metal Matrix Composites*
Patent Analysis • *CNT & Graphene based materials for armour applications* • *Sol-gel coatings for automotive applications* • *A process for carbon containing silica aerogels granules – Freedom to Operate (FTO) analysis in USA, Europe and Asia regions*	***Database Preparation*** • *Global Carbon Nanotubes and Graphene Industry Directory* • *Indian Nanotechnology Directory 2014 (Being updated)*

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Centre for Technology Acquisition, Transfer and International Cooperation

The Centre for Technology Acquisition Transfer and International Cooperation (CTATIC) plays important role in catalyzing ARCI's effort in adapting its technologies for transfer and commercialization. CTATIC works towards strengthening of ARCI technologies' value chain by contributing in the following aspects:

- ★ *Identifying possible collaborators for all activities ranging from co-development to technology transfer*
- ★ *Identification of start-ups/established companies to commercialize ARCI's technologies through various direct and indirect channels such as participation in industrial exhibitions, business opportunity workshops, and also through web and tele-marketing*
- ★ *Understanding competing technologies and preparing techno commercial feasibility analysis report for technologies being offered by ARCI for transfer*
- ★ *Formalizing Agreements/Contracts to effect alliances in science and technology value chain*
- ★ *Facilitating patent related services such as prior art searches for patent filing, research planning, market research etc and coordinating patent drafting and patent filing activities at ARCI*
- ★ *Costing for technologies and projects*
- ★ *Receivables management, monitoring of technology development programmes and performance reporting etc.*
- ★ *Coordinating visits of ARCI personnel deputed abroad for project related activities, equipment inspection and training, conferences, meetings etc.*

Out of several activities mentioned above, it will be pertinent to briefly discuss about different models being adopted by ARCI to engage with other organizations for technology development, demonstration and/or transfer. Following prominent Agreements are being signed by ARCI to implement such engagement models:

- ***Cooperative R & D Agreement***
  Through Cooperative R & D Agreements (CRADAs), ARCI associates with an industrial organization for the scientific and technical conduct of a project. Collaborative and intellectual contribution by RTO's partner organization is expected in this mode. Modus operandi for utilizing CRADA results is a crucial component of CRADA.
- ***R & D Consortium Agreement***
  ARCI collaborates with academic institutions and private industrial organization(s) either from a single nation or from different nations, to implement these Agreements. These projects, involving pre-competitive research, aim at finding innovative solution(s) that can potentially benefit an industry sector.
- ***Inter-Institutional Agreement***
  These Agreements are being used by ARCI to forge alliances with academic or R & D institutions to collaboratively develop and/or demonstrate a technology.
- ***Sponsorship Agreement***
  ARCI enters into such Agreements with private or government organizations, which are interested to leverage ARCI's knowledgebase, tangible and intangible assets.
- ***Joint Demonstration Centre Agreement***
  Such Agreements are being used to accelerate ARCI's international technology collaborations. Implementation involves establishment of a Joint Technology Demonstration Centre by ARCI and partner industrial organization generally from a foreign country. Partner industrial organization has already demonstrated the usefulness of a technology by proving applications in a country other than India. Joint work - utilizing technological understanding of a partner organization and ARCI's technology transfer/commercialization experience - is carried out to demonstrate newer applications in India.
- ***Technology Demonstration and Transfer Agreement***
  ARCI executes these Agreements with appropriately identified industrial partners for technologies, which need to be demonstrated for applications of interest to the associated industrial organizations.
- ***Option Agreement***
  These Agreements are being used by ARCI to provide an opportunity to possible technology seekers to assess the commercialization potential of a technology that is available for adaptation/transfer.
- ***Technology Transfer Agreement***
  These Agreements are being signed for to effect transfer of those technologies, which have already been developed and demonstrated.

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Intellectual Property Development Indices (IPDIs) and Contractual Agreements: RTO's Perspective

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Intellectual Property Development Indices (IPDIs) can be used to assess readiness of an R & D programme being undertaken by Research and Technology Organizations (RTOs). Generally, RTOs are responsible for ideation, development and demonstration of technologies so that transfer of demonstrated technologies can be planned effectively and efficiently. At the same time, entering into suitable Agreements at the right stage with collaborators (from industry, academia and/or R & D) to make ready a transferable technology, and with prospective technology receivers to effect technology transfer is crucial for giving the right impetus to the Technology Value Chain (TVC) comprising development, demonstration and transfer. It also helps in setting realistic goals. An attempt has been made to correlate crucial aspects of the IPDIs and contractual Agreements for the TVC. A schematic model has been proposed in Fig. 1 for the advanced materials TVC activities being pursued by RTOs like ARCI. The basis of such correlation is briefly described below.

Exploratory studies can be used to initiate a new technological programme. Idea can be screened keeping in view the possibility to address a problem. Collaborations can be initiated at this stage. Contractual Agreements that can be signed at this stage include Co-operative R & D Agreement, R & D Consortium Agreement, Inter-Institutional Agreement and Sponsored Research Agreement. Completion of scientific studies and shortlisting of target application(s) shall be titled as Intellectual Property Development Index 2 (IPDI 2). Activity may not go beyond IPDI 2, if initial studies do not indicate promising results. Coupon level testing is conducted using miniaturized version of real-life components and gets completed at IPDI 5. This should be followed by developing prototypes. Testing prototypes at identified end-users' sites shall be regarded as achieving IPDI 6. Pilot production to undertake limited field trials and to check consistency should initiate after completing IPDI 6. Repeated and expected performance of prototypes in real-life conditions shall be termed as achievement of IPDI 7. At this point, reassessment with regard to competing technologies and potential techno-commercial feasibility needs to be conducted (IPDI 8). While moving from IPDI 6 to IPDI 8, Joint Demonstration Centre (JDC) Agreement, or Technology Demonstration and Transfer (TDT) Agreement can be signed. The JDC Agreement is signed to leverage complementary capabilities of an RTO and an industrial partner (having commercialized the same technology usually in a foreign country) for technology demonstration initially at a facility established at the RTO's premises. In case of a TDT Agreement, an industry partner can seek a technology transfer on exclusive basis while committing to co-operate for field trials. However, an RTO should attempt to involve industry partners ready to accept nonexclusive technology transfer. In that scenario, a technology can be offered to multiple technology seekers for widespread dissemination of the technology. To enhance the chances of commercialization success, an RTO should initiate technology transfer after arriving at IPDI 8. At this stage, either a Technology Transfer Agreement or an Option Agreement can be used to interact with potential technology seekers. An Option Agreement, providing either an exclusive or non-exclusive option to the industry partner, minimizes risk in commercializing a new technology. However, if a technology seeker is convinced of potential market success of an RTO's technology, it would be appropriate to execute a Technology Transfer Agreement without going through the route of Option Agreement. An RTO should also perform consistent patentability assessments using techno-legal analyses from IPDI 3 onwards.

Fig. 1 Schematic showing IPDIs and applicable contractual agreements

IPDI	1	2	3	4	5	6	7	8	9	10
Activities	Basic concepts and understanding of underlying scientific principles involved	Shorlisting of target applications (analyzing patents & literature)	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	Re-assessing feasibility & conducting freedom to operate analysis	Initiate technology transfer	Support in stabilizing production
Technology chain milestone(s)	Exploratory studies		Laboratory demonstration			Field trials			Technology transfer	
Possible contractual agreement (s)	• Co-operative R & D • R&D Consortium • Inter-institutional • Sponsored research					• Joint demonstration • Technology demonstration and transfer			• Option • Technology transfer	

Contributor: G. Padmanabham

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 14 technologies to 26 receivers and few technologies are under transfer. The following table depicts the technologies transferred:

Sr. No	Technology	Technology Recipient	Status
1-8.	Electro Spark Coating (ESC) equipment	Hard, wear resistant coatings	Transferred to 8 companies on nonexclusive 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

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 Development: 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

S. No	Technology and Related Issues	Key Features and Applications	
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 Development: 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
3.	**Nanocrystalline Zinc Oxide (ZnO) based Varistors** (Indian Patent Application Number 1669/DEL/2006 dtd. 20/07/2006) Level of Development: In-house testing completed	***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	***Possible Applications:*** Surge voltage protection in electrical and electronics industry
4.	**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)	K***ey 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	***Application:*** Ceramic candles for drinking water purification
5.	**Silica Aerogels** (Indian Patent Application Number 2406/DEL/2010 dtd. 08/10/2010) Level of Development: In-house testing completed	***Key Features:*** - Stable from cryo (-50^{0} C) to 1000^{0} C - Thermal conductivity (0.03 W/mK) - Fire resistant - Chemically inert - Easily cut - Hydrophobic - Thickness range from 5-25 mm can be produced	***Possible Applications:*** - Thermal insulation in automotives - Heating/cold storage - Thermal clothing - Aerospace etc.
6.	**Laser Welding and Laser-MIG Hybrid Welding** Level of Development: Testing on some actual components as per users' requirements done successfully	***Key Features:*** - High power density - Single pass welding of thick sections - Controlled heat input welding with precision (even foils) - No vacuum requirement	***Possible Applications:*** - Can weld a wide variety of materials and thicknesses - Can weld magnetic materials unlike Electron Beam Welding - Tailor welded blanks for automotive applications etc. - Steel plates, thick section welds, ship building etc.
7.	**Laser Surface Hardening Treatment** Level of Development: Testing on some actual components as per users' requirements done successfully	***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 - Refined homogenous microstructures - Controlled case depth - Minimal distortion - Chemical cleanliness	***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.
8.	**Laser Surface Coating (Alloying and Cladding)** Level of Development: Testing on actual components done successfully	K***ey 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

<table>
<tr><th>S. No</th><th>Technology and Related Issues</th><th colspan="2">Key Features and Applications</th></tr>
<tr><td>9.</td><td>Laser Drilling

Level of Development: Testing on actual components done successfully</td><td>Key Features:
- Non-contact drilling method
- Holes of large aspect ratio and very small diameter (0.3 mm) can be drilled
- Holes can be drilled at shallow angles to the surface
- Precise control of heat input</td><td>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.</td></tr>
<tr><td>10.</td><td>Micro Arc Oxidation
(Indian Patent Number 209817 granted on 06/09/2007; US Patent Number 6893551 granted on: 17/05/2005)

Level of Development: 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)</td><td>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</td><td>Possible Applications:
- For a wide array of applications in industries such as textile, automobile etc.</td></tr>
<tr><td>11.</td><td>Detonation Spray Coating (DSC) Technology

Level of Development: Small scale production (Technology transferred to 4 entrepreneurs and is available for all Indian states except for Delhi, Haryana, Punjab, Uttar Pradesh, Uttaranchal, Bihar, Jammu & Kashmir, and Himachal Pradesh and for export)</td><td>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 properties</td><td>Possible Applications:
- Coatings for applications such as wear and corrosion resistance etc., for various industries</td></tr>
<tr><td>12.</td><td>Exfoliated Graphite and its Value Added Products
(Indian Patent Number 187654 granted on 07/06/1995)

Level of Development: Commercial Scale (Technology transferred to one company and is available for transfer to all Indian states on non-exclusive basis)</td><td>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</td><td>Possible Applications:
- Fuel Cells
- Automotive
- Oil refineries
- Petrochemical industries etc.</td></tr>
<tr><td>13.</td><td>Electro Spark Coating (ESC) Equipment Manufacturing Technology
(Indian Patent Application Number 1610/DEL/2005 dtd. 21/06/2005)

Level of Development: Small scale production (Technology transferred to one company and is available for transfer to all Indian states on non-exclusive basis)</td><td>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 to 130 μm</td><td>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</td></tr>
</table>

Support Groups

Performance Evaluation of Solar Panels in a Rural Environment

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It is well known that rural population constitutes a vast majority of India. This work is expressly aimed at reducing the energy poverty experienced by people of these regions. In the semi-urban and rural off-grid areas of the country, electricity is needed mainly to illuminate homes, offices & schools, charge mobile phones, power household appliances and run small businesses. To address problems associated with acute shortage of electrical energy prevalent in these areas, ARCI recently initiated an effort to examine development of off-grid renewable energy solutions in developing countries and emerging markets. As part of this work, we have installed a Solar Home System (Fig. 1) comprising of one photovoltaic (PV) panel (125Wp), one sealed lead-acid battery (150Ah), one charge controller (20A), six energy-efficient lamps (12V DC) and two table fans.

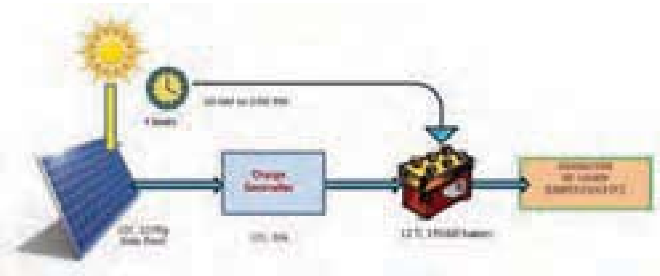

Fig. 1 Basic scheme illustrating utilization of solar energy for the study

The system is adequate to power low-consumption electrical appliances. The solar DC home demonstration setup at ARCI is presently being used for panel performance studies (on commercially available PV panels with and without ARCI developed Anti-Reflection coatings). The studies are being carried out with the help of a data logger system developed in-house. The ongoing work covers logging of solar panel parameters (voltage, current and temperature) for different panel orientations and different connected loads. We have verified that maximum power transfer takes place when the connected load impedance equals the solar panel impedance.

On the basis of theoretical considerations and practical tests conducted, a design scheme has been worked out for sizing solar panels and battery ratings for a given application. This is illustrated diagrammatically in the chart below (Fig. 2). Consider a load that requires 12 V DC and draws 4 amps for 4 hours. Such a power requirement can be provided by a solar panel of one square meter (12V,100Wp) that feeds a 12V, 16 AH storage battery. Assuming 50 % efficiency and 4 hours of assured sunlight, such a battery will deliver full power at full load [12 V @ 4 amperes] for 4 hours. The period of usage will increase correspondingly for lower loads.

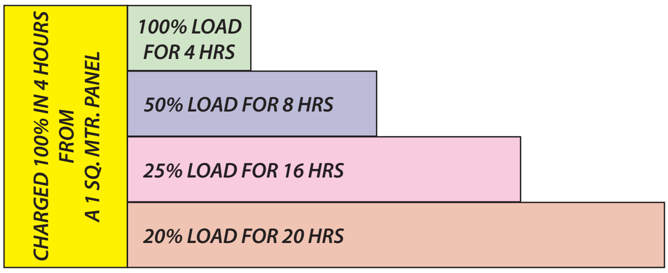

Fig. 2 Solar power available from a 1 sq m solar panel connected to a 16AH battery

In a practical real world environment, other factors are also brought into play. It is not possible to foresee the load requirement accurately, which in general will vary with time and/or period of usage. In order to circumvent this problem, we have designed a control circuit with both hardware and software using Arduino Microcontroller and drivers to automatically supervise the available battery power and switch the loads to permit optimum usage and prevent overloading (Fig. 3).

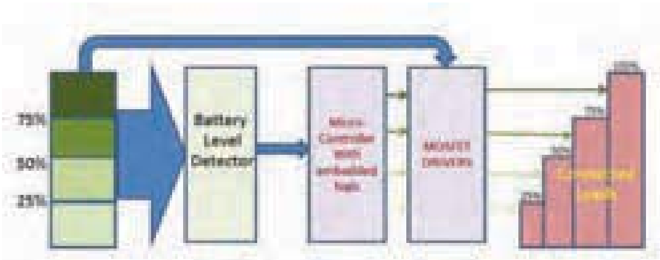

Fig. 3 Control circuit to automatically supervise the available battery power

It is an accepted global fact that less than a quarter of the incident solar radiation is actually utilised for generating electricity. Concerted efforts are being made to improve this factor by developing coatings on the panels to enhance the energy conversion ratio. We have developed a scheme with continuous data logging of parameters to compare two solar panels, out of which at least one has been subjected to a different surface coating treatment.

In the past, many cases have been reported where PV systems have been abandoned after malfunctioning because the owner cannot read the manual. Therefore, particular attention has been paid to ensure a very high degree of reliability as maintenance support is not readily available in rural areas.

Contributors: Ch. Rajesh, M. Aravind, N. Aruna and A. S. Joshi

Development of a PC Controlled Electro Spark Coating System

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The Electro-Spark Coating (ESC) process is a technique which permits application of metallurgically bonded coatings at ambient temperature. The ESC technique essentially utilizes short-duration, high-current electrical pulses to melt material from a consumable electrode and deposit it on the substrate. In principle, any electrically conductive material available in electrode form can be coated on any conducting substrate by the ESC process and this makes the ESC technology extremely versatile.

The ESC technique itself is very simple as well as financially attractive because of low capital equipment costs involved. The heart of the ESC unit is a generator containing a bank of capacitors, which releases stored energy in controllable bursts upon contact between the positive and negative poles of the generator. In practice, the consumable electrode, made of the material to be deposited, forms the positive pole (anode) while the work piece forms the negative pole (cathode). An ESC equipment ARCI-6M has already been developed by ARCI for generating a range of coating thicknesses from 10-130 nm, in 6 different selectable modes. This equipment and the technology for its fabrication have been transferred on an exclusive basis to M/s Bharadwaj-e Technologies, Hyderabad.

The ESC circuitry basically consists of a pulse generator. The pulse generator delivers a set of three pulses sequentially, which are used to switch a MOSFET into conduction. The MOSFET charges the voltage across a bank of capacitors [CB] through a choke, a vibrator anode and the work piece cathode. When the MOSFET is not in conduction, the charge stored in the choke discharges through the vibrator (anode) and the work piece (cathode). The amplitude, durations and intermediate pauses between the three pulses is defined by one of the six possible modes selected. This mode selection is done by a front panel membrane keypad.

The membrane switches were observed to fail occasionally in operation and it was not always easy to identify the cause of failure, which could be attributed to either the electronic circuitry itself, or the membrane switches or both. There was, therefore, a need to develop an alternate scheme to dispense with the membrane keypad and interface the rest of the circuit it. To address this requirement, we have now developed a computer-controlled program written in Lab VIEW to control the above sequence of operations. The software was interfaced with the hardware through driver circuits and a Data Acquisition (DAQ) module as shown in the schematic diagram (Fig. 1). The modified ESC version consists of a Graphical User Interface (Front Panel Fig. 2), where the operator can set parameters like mode selection, frequency and amplitude of vibration. A Block diagram (Fig. 3) of the program shows the graphical code designed for implementing the sequence of operation in an ESC unit. The developed program is very flexible and user friendly.

The computer controlled system now serves as an alternate means for operating the ESC equipment. As it can be interfaced with the control circuit easily, it also serves to trace any possible faults in the membrane keypad.

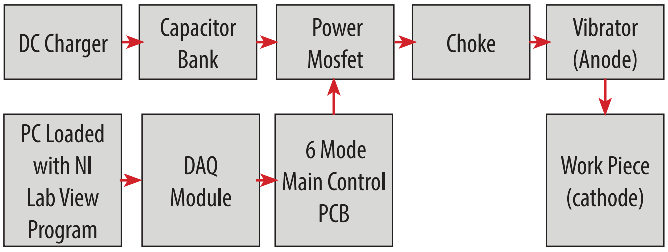

Fig.1 Schematic diagram of PC controlled ESC system

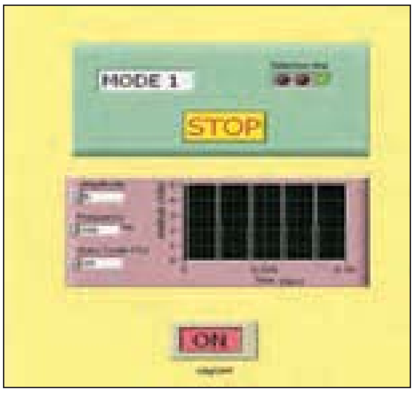

Fig.2 Screen shot of front panel

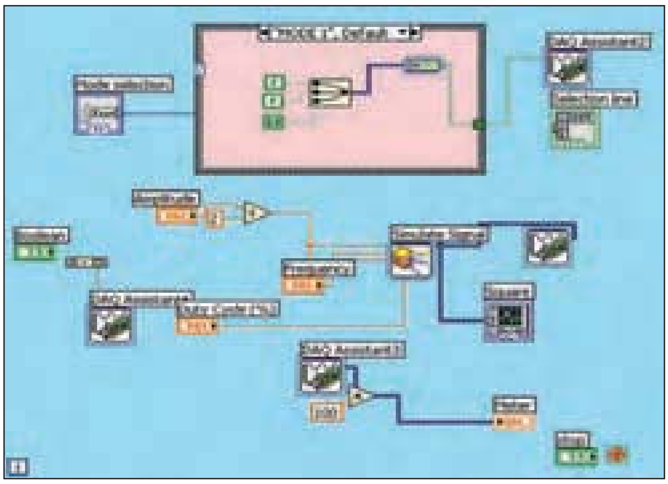

Fig.3 Graphical view of the block diagram

Contributors: S. Nirmala, N. Aruna and A. S. Joshi

Smart Grid – An Intelligent Electrical Infrastructure

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The electrical industry across the globe is striving to address challenges such as generation diversification, optimal establishment of expensive assets, demand response, energy conservation and low carbon foot print. These critical issues cannot be addressed with the existing electricity grid as it is an unidirectional system. Nearly 8% of its output is lost in transmission lines and about 20% of its generation capacity caters to meet the peak load demand. Further, electric utility performance indicators are eroding the economy, reliability, security, asset value, profitability, sustainability and service quality.

The next generation electricity grid known as the smart grid or intelligent grid is expected to overcome these major short falls of the existing grid. The smart grid deploys real-time monitoring and control of the existing infrastructure, and accommodates disturbances due to national and state grid interruptions, volatility in the availability and price of fuel; distributed generation and storage; increased consumer involvement through local automation; and 24 x 365 on-line service commerce and trade. In fact, new electronic telecommunications and information technologies with power system engineering will allow smart grid to achieve unprecedented efficiency, economy, quality of service, safety, security, sustainability and flexibility.

A smart grid is going to be necessary. It will yield great benefits and is possible with existing and emerging technologies. A smart grid will result from a continuous process of up gradation with adoption of latest technologies in every aspect of present grid parameters.

ARCI is pursuing automation program for its premises and also to add on solar PV generation that help realize distributed generation concept within its campus.

Table 1 Comparison with smart grid and existing grid

Existing Grid	**Intelligent Grid**
Electromechanical	Digital
One-Way Communication	Two-Way Communication
Centralized Generation	Distributed Generation
Hierarchical	Network
Few Sensors	Sensors Throughout
Blind	Self – Monitoring
Manual Restoration	Self - Healing
Failures and Blackouts	Adaptive and Islanding
Manual Check / Test	Remote Check / Test
Limited Control	Pervasive Control
Few Customer Choices	Many Customer Choices

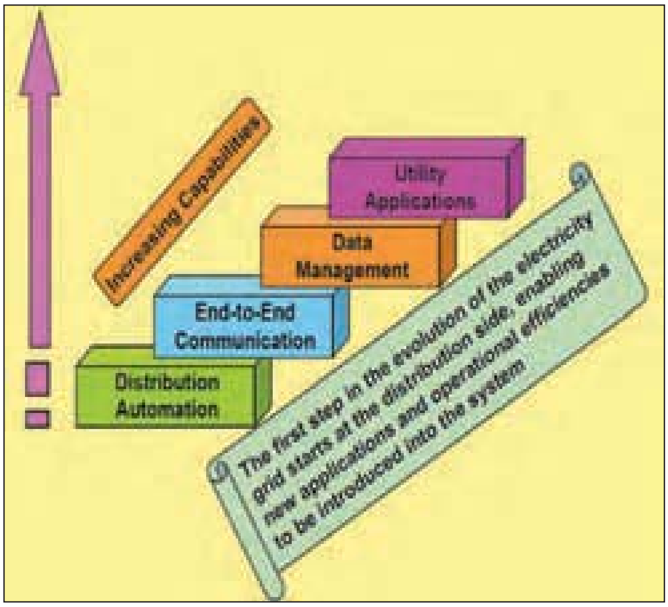

Fig. 1 Build-up pattern of a smart grid

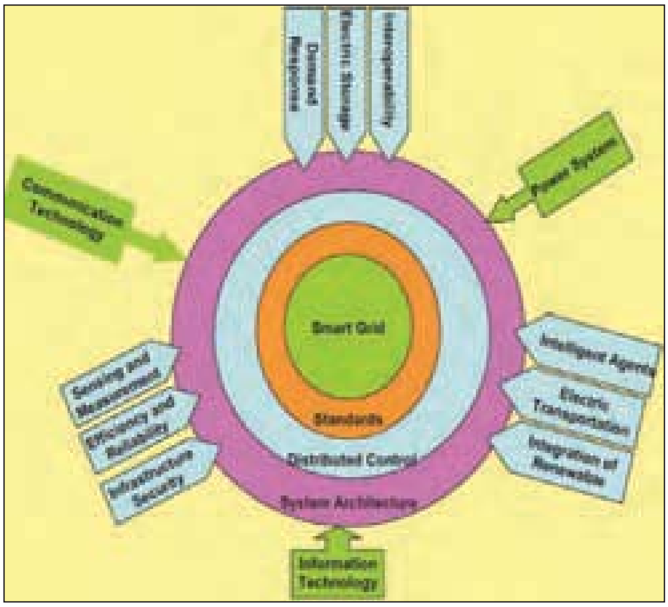

Fig. 2 The convergence of communication and information technologies

(Source : F. Hassan (2010), The Path of the Smart Grid, IEEE Power and Energy, 8(1), pp. 18-28)

Contributor: V. C. Sajeev

Proper Selection of New Electric Lamps Helps Reduce the Carbon Foot Print of Lighting Installations

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Since the introduction of incandescent lamps in 1879 there has been steady improvement of electric lamps. Today we have an array of electric lamps suitable for lighting applications under three major categories:

(a) Incandescent: General lighting service (GLS) lamps and Tungsten-Halogen lamps

(b) Discharge: High Pressure Mercury Vapor (HPMV), Low Pressure Sodium Vapor (LPSV), Linear Fluorescent, High Pressure Sodium Vapor (HPSV), Metal Halide, Ceramic Metal Halide (CMH), Compact Fluorescent (CFL) and the Induction and the Sulfur lamps which do not exactly fall under this group.

(c) Electroluminescent: Light Emitting Diode (LED), Organic Light Emitting Diode (OLED) and Electron Stimulated Luminescence (ESL) lamps.

Technological developments are predicted on electroluminescent light sources and the discharge lamps that improve luminous efficacy and cost resulting in their enhanced utilization in applications dominated until now by conventional lighting technologies.

World over an estimated 10 to 15% of the total electricity generated is used for lighting purposes. This apparently suggests that the lighting sector as a whole has immense potential to pursue energy efficiency options. Energy efficiency is also viewed as a 'resource option' apart from being pollution rate retardant. Energy efficiency is effectively achieved when energy usage in a specific product is reduced without affecting output or user comfort levels.

Though for optimal lighting solutions, the total system involving day-lighting, lamps, luminaire, lighting controls, configuration, interior materials and furnishing needs to be considered holistically, better luminous efficacy of the light source reduces input energy. For example, by replacing traditional light bulbs with compact fluorescent lamps, one uses only 25% of the energy originally needed. Fig 1 shows the development of luminous efficacies of electric lamps over time.

Another important factor that helps reduce green house gas emissions is to use electric lamps with better life expectancy thus reducing production inputs of the lamps and their end of life processing. Lumens maintenance charts of various lamps is given in Fig. 2. In conclusion, a lamp with better luminous efficacy and longer lumen maintenance property reduces the carbon foot print of a lighting installation.

ARCI is trying to shift to more efficient LED, induction lamp and T5 lamp fittings by using these when replacement of a light fitting or a lamp is needed in old installations. The new buildings exclusively are going to be illuminated with LED and induction lamp fittings which are currently the most energy efficient, long living and demanding less maintenance, thus placing ARCI amidst the race for energy efficiency.

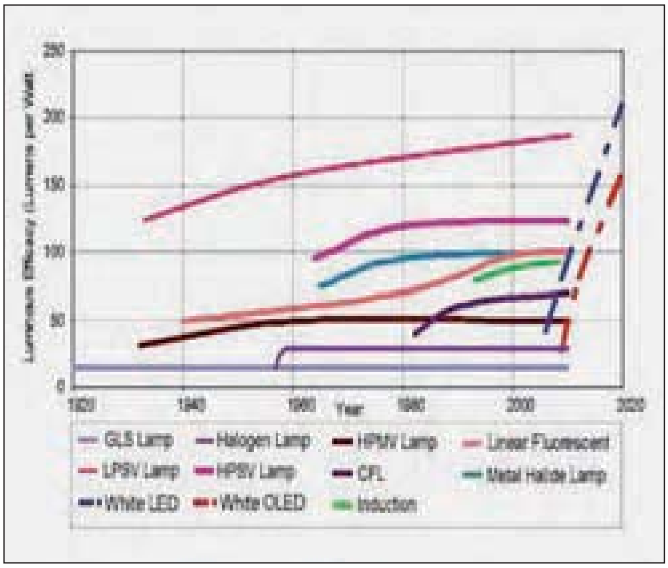

Fig. 1 Development of luminous efficacies of light sources

(Source : www.lightinglab.fi)

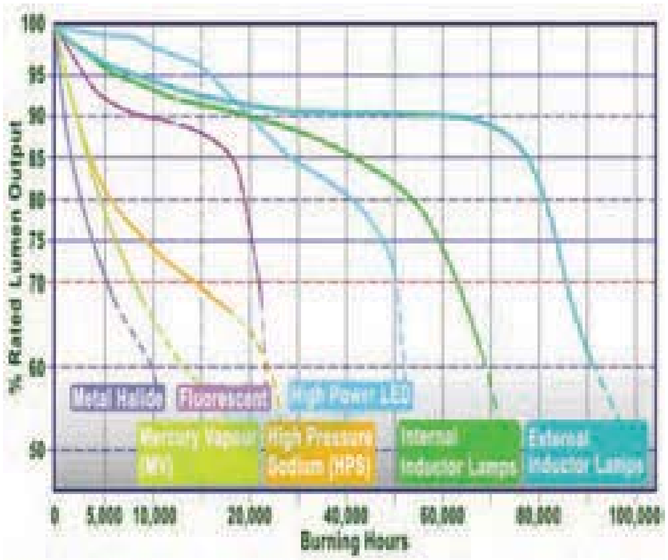

Fig. 2 Lumen maintenance curves for various commercial light types

(Source : www.EconoLuxIndustries.com)

Contributor: V. Balaji Rao

Pre-Engineered Building Vs Conventional Building

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Pre–engineered building system is, one of the fastest growing systems. Steel has become the material of choice in building, construction, compared to concrete and timber. Thus steel building designs have become more flexible, durable, applicable and adaptable. Industrial buildings having large span and use of steel structures are preferable compared to concrete structures. Pre-Engineered buildings (PEB) are being preferred over conventional steel building for industrial construction due to its fast construction. Following is the comparison between pre-engineered buildings and conventional steel buildings:

1. Structure Weight - Pre-engineered buildings are on an average 30% lighter because of the efficient use of steel. Primary framing members are with tapered section. With larger sections in areas of higher stress. Secondary members are light weight roll formed "Z"or "C" shaped members. For conventional building, primary steel members are hot rolled "T" sections, which are, in many segments of the members heavier than what is actually required by designs as they have constant cross section regardless of the varying magnitude of the local stresses along the member length. Secondary members are selected from standard hot rolled sections which are much heavier.

2. Design - Since PEBs are mainly formed by standard sections and connections design, time is significantly reduced. Basic design based on international design codes is used. Each conventional steel structure is designed from scratch with Fever design aids available to the engineer.

3. Completion period - On a average 6 to 8 weeks for PEBs and 20 to 26 weeks for Conventional Building

4. Foundations - Pre-engineered buildings have simple design are easy to construct and light weight. and conventional buildings are a bit complex and heavy foundation required.

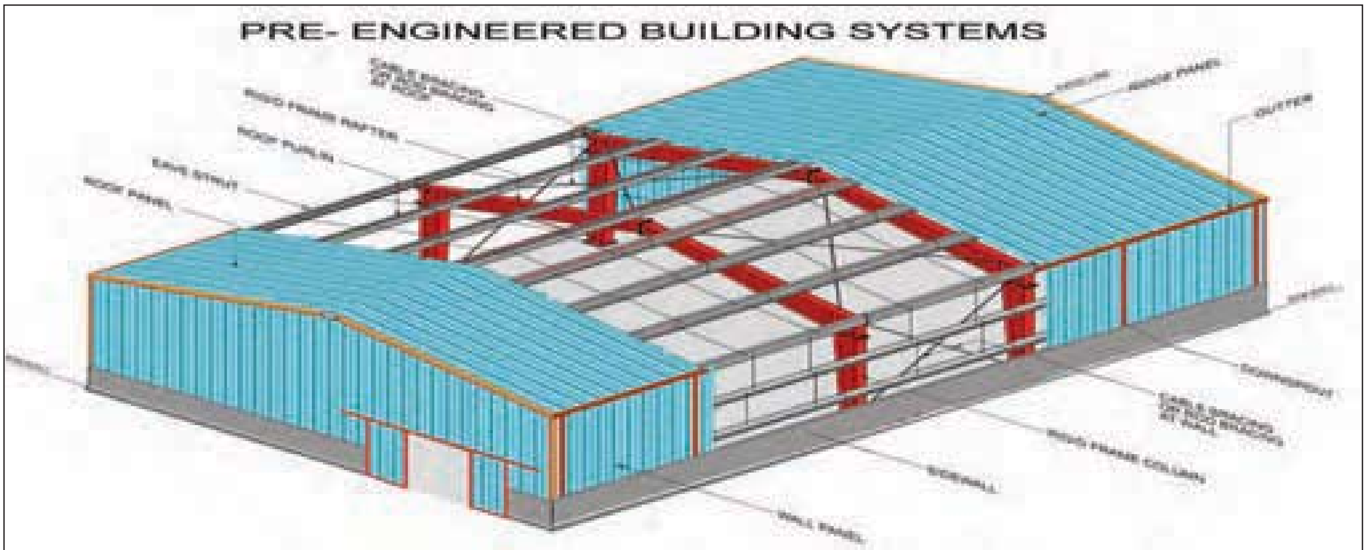
5. Erection Cost and Time for PEBs - both costs and time of erection are accurately known based on experience with similar buildings. The erection process is faster and much easier with very less requirement for equipment. Typically, conventional steel buildings are 20% more expensive than PEB in most of the cases, the erection costs and time are not estimated accurately. Erection process is slow and extensive field labour is required.

6. Cost of Construction - For PEBs, price per square meter may be as low as 30% of the conventional building.

7. Future Expansion - Future expansion is very easy and simple for PEBs where as it is most tedious and costlier for conventional buildings.

8. Responsibility - Single point responsibility for design, supply and erection of PEBs is important as multiple responsibilities can result in question of who is responsible when the components do not fit in properly.

9. Performance - PEB components are specified and designed specially to act together as a system for maximum efficiency, precise fit and peak performance in the field. Conventional building components are custom designed for a specific application on a specific job. Design and detailing errors are possible when assembling the diverse components into unique buildings.



(Source : www.bansalmetallics.com)

Contributor: V. Balaji Rao

Events, Data and Statistics

Major Events

Jayanthi Celebrations

ARCI celebrated Dr. B. R. Ambedkar Jayanthi and Dr. Babu Jagjivan Ram Jayanthi on April 14, 2013.

Sports

ARCI constituted a sports committee to conduct sports and games for the year 2013-14. Sports and Games were inaugurated on June 21, 2013 by Dr. G. Padmanabham, Associate Director.

Subsequently, more than 100 employees actively participated in 21 events such as Volleyball, Cricket, Tennicoit, Badminton, Football, Caroms, Chess, Running, Discus Throw, Shotput, Quiz competition etc. There was active participation from all Women employees. Prizes were distributed to the winners and runners-up for all events by Dr. S. V. Joshi, Additional Director, Dr. G. Padmanabham, Associate Director and Shri R. Prabhakara Rao, Admin and Personnel Officer. Shields were presented to House Captains of the winner and runner-up teams. Special Prizes were given to the Sports Women and Sports Man of ARCI for the year 2013-14.

Active participation of Women in Discus Throw

Rolling Shield being presented to the Winners Team for the year 2013-14 by Dr. S. V. Joshi and Dr. G. Padmanabham on the Sports Day celebration

Rolling Shield being presented to the Runners Team for the year 2013-14 by Dr. S. V. Joshi and Dr. G. Padmanabham on the Sports Day celebration

Independence Day

ARCI celebrated Independence Day on August 15, 2013. Dr. S. V. Joshi, Additional Director hoisted the National Flag and addressed the gathering on the occasion.

Annual Medical Check-up

The Annual Medical Check-up programme for ARCI employees was organized during August 22-23, 2013. Employees were categorized into two age groups i.e. below and above 45 years of age and special medical tests such as TMT, 2D ECHO etc., were undertaken for employees above 45 years of age. Special medical tests such as pap-smear and ultrasound scanning were carried out for all women employees as a part of Annual Medical check-up.

Annual Medical check-up in progress

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 the Official Language in ARCI. During the year 2013-14, ARCI issued more than 1800 letters

Participants during the Hindi week celebrations

etc., in bilingual form and surpassed the target set by the Department of Official Language (D.O.L), Ministry of Home Affairs, Government of India. To propagate the use of Hindi during work, ARCI not only conducted Hindi workshops on a quarterly basis for its employees but also imparted training on 'Typing in Hindi' to its employees. ARCI has also been imparting Training in Hindi to its Employees under the Hindi Teaching Scheme and has trained a number of employees in Prabodh, Praveen and Pragya levels.

ARCI celebrated Hindi Week during September 16 to 20, 2013. Various programmes and competitions like Quiz, Elocution, Noting and Drafting in Hindi, Essay Competition were conducted, and the winners were given prizes. On this occasion, ARCI organized a lecture on 'Derivation and Development of Hindi as an Official Language' delivered by Dr. M. Venkateshwar, (Retd.) Distinguished Professor, English and Foreign Language University, Hyderabad.

ARCI in collaboration with DRDO jointly organized the "9th Joint Scientific and Technical Rajbhasha Sammelan" held at DMRL, Hyderabad on February 13 and 14, 2014. Dr. P. K. Jain, delivered a technical lecture and Shri N.K. Bhakta, delivered a non-technical lecture in Hindi during the Sammelan.

Vigilance Awareness Week

ARCI observed Vigilance Awareness Week from October 28 to November 02, 2013. As a part of this occasion, Shri D. Srinivasa Rao, Vigilance Officer-ARCI administered the pledge in the presence of personnel from Administration, Stores, Finance & Accounts, Computer Centre, and Centre for Technology Acquisition, Transfer and International Coordination. The Team Leaders from other centres of excellence administered the pledge at their respective centres in presence of their team. During the week, ARCI also organized a lecture titled 'Promoting Good Governance-Positive Contribution of Vigilance', which was delivered by Shri T. V. Reddy, Chief Vigilance Officer, Mishra Dhathu Nigam Limited, Hyderabad. An exhibition displaying posters on different aspects of vigilance awareness was also organized.

Shri T. V. Reddy delivering the lecture on vigilance awareness

Annual Day

ARCI celebrated its 17th Annual Day on December 27, 2013. On this occasion, Dr. G. Sundararajan, Director delivered a speech detailing various achievements during the year. Dr. S. V. Joshi, Additional Director, Dr. G. Padmanabham, Associate Director and Mr. K. V. Phani Prabhakar, Convener-Annual Day Committee also addressed the gathering. As a part of these celebrations, a special musical programme by Divine Charitable Trust, where the complete musical troupe, including singers and musicians are blind, was organized. The troupe gave an amazing performance and enthralled the audience. Various other cultural events with participations from employees and their family were also organized, and prizes were distributed to the participants.

Dr. G. Sundararajan addressing the gathering during the 17th Annual Day celebrations

Musical troupe from Divine Charitable Trust entertaining the audience

Republic Day

ARCI celebrated Republic Day on January 26, 2014. Dr. G. Sundararajan, Director hoisted the National Flag and addressed the gathering on the occasion.

Dr. G. Sundararajan, Director hoisting the National Flag

Women Welfare

ARCI celebrated International Women's Day on March 12, 2014. As a part of this occasion, ARCI arranged two lectures. Dr. Tessy Thomas, Project Director, AGNI Missile Development Programme, DRDO, Hyderabad was invited as Chief Guest and she delivered a lecture on 'My Experiences in the Technology Growth of AGNI System'. The second lecture was delivered by Dr. Radhika Acharya, Consultant Psychologist-The Deccan Hospitals, Hyderabad on 'Stress Management for Working Women'.

Dr. Tessy Thomas delivering a lecture as a part of Women's Day celebrations

Conference/Workshops Organized by ARCI

Powder Metallurgy Short Course (PMSC-13)

- The Powder Metallurgy Short Term Course 'PMSC-13' was held at ARCI, in association with Powder Metallurgy Association of India (PMAI) during November 18-21, 2013. The course was inaugurated by Dr. S. V. Joshi, Additional Director, ARCI in conjunction with Mr. N. Gopinath, President, PMAI and attended by about 61 students from leading academic and research institutes, faculty and industry personnel from both government and private sectors. 28 lectures on different topics were delivered by eminent speakers from faculty, scientists and industry, each having wide experience in the field of PM technology.

Workshop on Development of Automated System for Design and Testing Radio-Electronic Devices

- A workshop on 'Development of Automated System for Design and Testing Radio-Electronic Devices' was held at ARCI on November 22, 2013.

Participants during the International Women's day celebrations

Participants of Powder Metallurgy Short Course (PMSC-2013)

In-House Training Programme on Industrial Safety

- A two-day in-house training programme on industrial safety was conducted for all the members of safety committee as well as for safety coordinators of ARCI during December 05-06, 2013 and March 06-07. 2014. The training was facilitated by two faculty trainers, Shri P.M. Rao and Shri T. Nityananda, arranged by National Safety Council, Mumbai. Participation certificates were distributed to all the participants.

Participants of the in-house tranining programme on industrial safety

Discussion Meet on Advanced Thermal Spray Processing and Reclamation Technologies

- A one day discussion meeting on Advanced Thermal Spray Processing and Reclamation Technologies was held at ARCI on January 20, 2014. The meet was jointly organized by ARCI and General Electric. A total of 45 participants from industry, research labs and thermal spray service providers attended the meeting and seven speakers delivered talks on various aspects of thermal spray technologies.

Discussion Meet on Additive Manufacturing

- A one-day meet of experts in the field of laser additive manufacturing and engineers from various industries in the manufacturing sector was held at ARCI on February 21, 2014. Expert lecture by Dr. U. Chandrasekhar, Director, Engineering Staff College of India, Hyderabad on 'Additive Manufacturing Technology' and a technical lecture by Mr. Udo Behrendt, Global Head (Aerospace Practices), EOS GmbH, Germany on 'Aerospace and Automotive Applications of Additive Manufacturing' were delivered followed by detailed interaction between experts and industry representatives on establishing appropriate facilities in a consortium approach.

Participants at the discussion meet on Advanced Thermal Spray Processing and Reclamation Technologies

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 multi-ferroic composite thin films	IIT - Bombay	Tarun	16.07.2009	Ongoing
Poly 3,4-ethylen-edioxythiophene sheath over a SnO_2 hollow spheres/ graphene oxide hybrid for a dura-ble anode in Li-ion batteries	IIT- Hyderabad	A. Bhaskar	01.08.2010	Ongoing
Stable and highly efficient copper zinc tin sulphide (CZTS) thin film photovoltaics	IIT - Madras	Deepak Kumar	01.08.2012	Ongoing

Post Doctoral Fellows, Research Scholars, Senior/Junior Fellows, Post Graduate/Graduate Trainees and M.Tech/B.Tech Project Students Joined During the Year at ARCI

Post Doctoral Fellows	--
Research Scholars	02
Senior ARCI Fellows (SAF)	02
Junior ARCI Fellows (JAF)	08
Post Graduate Trainees	05
Graduate Trainees	26
M. Tech./B. Tech. Project Students	37

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

During the year, ARCI has been recognized as an external centre for carrying out Ph.D research by IIT-Kanpur, IIT-Madras, IIT-Hyderabad, and NIT-Thiruchirapalli and each of these institutes have signed a Memorandum of Understanding (MoU) with ARCI in this regard.

ARCI has already been recognized as an external centre for carrying out Ph.D research by IIT-Bombay, IIT- Kharagpur, Anna University, and NIT-Warangal.

Apart from the above, University of Hyderabad (UoH) has also recognized ARCI as an external centre for carrying out Ph.D research. In view of this, interested ARCI employees and Fellows can register for Ph.D (as per university norms) at the University.

Following Research Fellows are registered at UoH for their Ph.D studies:

Topic	Name of the Fellow	Status
Joining of aluminum alloy and steel by thermal joining techniques	Y. Krishna Priya	Ongoing
Structure - property correlations in nanostructured copper and copper nano-composite foils prepared by pulse and pulse-reverse electro deposition	Ch. Leela Pydi Pavithra	Ongoing
Development of TiCN - metal/ intermetallic based nanocomposites for cutting tool applications	M. S. Archana	Ongoing
Effect of individual layers and their microstructure on tribological behavior of cathodic arc deposition multilayer coatings	P. Sai V Pramod Kumar	Ongoing
Structure - property correlation in ODS 18 Cr steels	M. Nagini	Ongoing
Stabilization of cadmium chalcogenide based photo anode for photo electro chemical hydrogen production using solar light	Alka Pareek	Ongoing
Investigations on pressure casting and extrusion processing parameters and thermo-mechanical properties of low expanding ceramics	R. Papitha	Ongoing
Effect of dispersion of carbon nanotube/ graphene on aluminium alloys	N. S. Anas	Ongoing
Investigation of laser hybrid weldability of special steels	L. Subashini	Ongoing

Following Research Scholar is registered at Osmania University (O.U), Hyderabad for her Ph.D studies:

Topic	Name of the Scholar	Status
Synthesis and characterization of MFe_2O_4 (M:Zn, Ca, Mg) ferrites for photocatalytic and photo electro catalytic hydrogen generation applications	D. Rekha	Completed

Anna University, Chennai has recognized ARCI's Centre for Fuel Cell Technology (CFCT, Chennai) as a centre to conduct collaborative research for the purpose of pursuing Ph.D/M.S. (by research) programmes. This has been extended up to April 30, 2015.

Following Research Fellow is registered at Anna University, Chennai for her Ph.D studies:

Topic	Name of the Fellow	Status
Graphene as catalyst support for Polymer Electrolyte Membrane Fuel Cell (PEMFC) electrodes	P. Karthika	Completed

Following Research Fellows are registered at IIT-Hyderabad for their Ph.D studies:

Topic	Name of the Fellow	Status
Fabrication of $CuInSe_2$ and Cu (In, Ga) Se_2 absorber layers by pulse and pulse-reverse electrochemical techniques for solar photovoltaic applications	Mandati Sreekanth	Ongoing
Synthesis characterization and electrochemical performance of electrospun electrode materials for lithium ion batteries	K. H. Anulekha	Ongoing
Spherical indentation behaviour of porous copper and cold sprayed copper coatings	Bolla Reddy	Ongoing
Fuel contaminants on the anode side for PEMFC	Anusree Unnikrishnan	Ongoing

Following Research Fellow is registered at IIT-Madras for her Ph.D studies:

Topic	Name of the Fellow	Status
Air contaminants for PEMFC	J. A. Prithi	Ongoing

Following Research Fellows are registered at National Institute of Technology (NIT)-Warangal for their Ph.D studies:

Topic	Name of the Fellow	Status
Novel synthesis and electrochemical characterization of in-situ carbon coated lithium based electrode materials	V. V. N. Phani Kumar	Ongoing
Development of coated tools for high speed machining of hard to cut materials under dry conditions	Puneet Chandran	Ongoing
Electrospun inorganic materials for battery applications	P. Tejassvi	Ongoing
Development of high capacity nanostructured anode and sulphur cathode for lithium sulphur battery applications	E. Hari Mohan	Ongoing

Andhra University has recognized ARCI to carry out Extra - Mural Research (EMR) in the fields of Physics, Chemistry, Metallurgy, Chemical Engineering and Mechanical Engineering. With such recognition in place, ARCI can undertake research programmes leading to M.Phil and Ph.D degrees at Andhra University under EMR category.

Appointments

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

Employee Name	Designation	Date of Joining
Dr. N. Rajalakshmi	Senior Scientist (Contract)	April 4, 2013
Dr. K. Ramya	Senior Scientist (Contract)	April 4, 2013

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 2013-14:

Name of the Promotees	Effective Date	Promotion for the Post	
		From	To
Dr. K. Radha	April 1, 2013	Scientist "E"	Scientist "F'
R. Prabhakara Rao	May 1, 2013	Officer "D"	Officer "E"
Dr. R. Vijay	October 1, 2013	Scientist "E"	Scientist "F'
V. Balaji Rao	October 1, 2013	Scientist "E"	Scientist "F'
Dr. (Mrs.) B.V. Sarada	October 1, 2013	Scientist "D"	Scientist "E"
Dr. D. Siva Prahasam	October 1, 2013	Scientist "D"	Scientist "E"
S.M. Shariff	October 1, 2013	Scientist "D"	Scientist "E"
Dr. Ravi Nathuram Bathe	October 1, 2013	Scientist "D"	Scientist "E"
Dr. P. Suresh Babu	October 1, 2013	Scientist "C"	Scientist "D"
Dr. Krishna Valleti	October 1, 2013	Scientist "C"	Scientist "D"

Name of the Promotees	Effective Date	Promotion for the Post	
		From	To
Dr. M. Buchi Suresh	October 1, 2013	Scientist "C"	Scientist "D"
S. Nirmala	October 1, 2013	Scientist "C"	Scientist "D"
R. Senthil Kumar	October 1, 2013	Scientist "C"	Scientist "D"
A. Jyothirmayi	October 1, 2013	Technical Officer "C"	Technical Officer "D"
V. Mahender	October 1, 2013	Technical Officer "B"	Technical Officer "C"
B. V. Shalini	October 1, 2013	Technical Officer "A"	Technical Officer "B"
N. Venkata Rao	October 1, 2013	Technical Officer "A"	Technical Officer "B"
M. Srihari	October 1, 2013	Technical Officer "A"	Technical Officer "B"
P.V.V. Srinivas	October 1, 2013	Technical Assistant "A"	Technical Officer "A"
K. Ramesh Reddy	October 1, 2013	Technical Assistant "A"	Technical Officer "A"
B. Hemanth Kumar	October 1, 2013	Technician "B"	Technician "C"
Govinda Kumar	October 1, 2013	Technician "B"	Technician "C"
Prabir Kumar Mukhopadhyay	October 1, 2013	Technician "A"	Technician "B"
Shaik Ahmed	October 1, 2013	Technician "A"	Technician "B"
K. Ashok	October 1, 2013	Technician "A"	Technician "B"
J. Shyam Rao	October 1, 2013	Technician "A"	Technician "B"
E. Yadagiri	October 1, 2013	Technician "A"	Technician "B"
D. Manikya Prabhu	October 1, 2013	Technician "A"	Technician "B"
I. Prabhu	October 1, 2013	Technician "A"	Technician "B"
Aan Singh	October 1, 2013	Lab. Assistant "C"	Lab. Assistant "D"

Superannuation

Employee Name	Designation Held	Date of Superannuation
Dr. K. Radha	Scientist "F"	June 28, 2013

Visit by Students and Others to ARCI

01. 15 M.E. students of Industrial Metallurgy from PSG College of Technology, Coimbatore visited on April 5, 2013.
02. 20 M.Tech students of Nanotechnology from Visvesvaraya Technological University, Bangalore visited on April 9, 2013.
03. 12 Engineers from various Government Organizations, who participated in a workshop on "Trends in Corrosion, Tribology and Surface Engineering" organized by Engineering Staff College of India (ESCI), visited on May 10, 2013.
04. 32 M.Tech and M.Sc. students of Nanoscience & Nanotechnology from Jawaharlal Nehru Technological University (JNTU), Hyderabad visited ARCI on July 3, 2013.
05. A 31 member team consisting of Scientists and Technical Staff from various DRDO laboratories, who participated in a workshop on "Advanced Powder Metallurgical Process and Techniques for Defence Applications" organized by Administrative Staff College of India (ASCI), visited on July 10, 2013.
06. 17 Engineers from various Government Organizations, who participated in the "Welding Technologies and NDT Techniques Programme" organized by ESCI, visited on July 11, 2013.
07. A 15 member team consisting of Professors and Lecturers from various engineering colleges, who participated in sponsored refresher course on "Composite Materials" organized by JNTU-Hyderabad UGC, visited on July 31, 2013.
08. 15 M.Tech students of Nanotechnology from Sreenidhi Institute of Science & Technology-Hyderabad visited on September 10, 2013.
09. A 30 member team consisting of Scientists and Engineers from ISRO, who participated in "Management Development Programme" organized by ASCI, visited on September 23, 2013.
10. A 37 member team consisting of Faculty and Student members of SAE India, Southern Section visited on September 25, 2013.
11. 20 Engineers from various Government Organizations, who participated in the "Welding Technologies and

NDT Techniques Programme" organized by ESCI, visited on September 26, 2013.

12. A 20 member team consisting of Ph.D students and Faculty members from School of Engineering Science & Technology, UoH-Hyderabad visited on October, 8, 2013.
13. A 20 member team consisting of Engineers from various Government Organizations and Faculty from various universities, who participated in a workshop on "Creativity & Innovation Management in Research" organized by ESCI, visited on November 12, 2013.
14. A 33 member team consisting of Scientists and Technical Staff from DRDO Laboratories, who participated in the Continuous Education Programme (CEP) on "Joining of Advanced Materials" organized by DMRL, visited on November 20, 2013.
15. 75 B.E. students of Chemical Engineering from BITS Pilani-Hyderabad campus visited on January 04, 2014.
16. 50 M.Sc. and B.Sc. students of Chemistry from St. Francis College for Women, Hyderabad visited on January 08, 2014.
17. 56 M.Sc. and B.Sc. students of Chemistry from St. Francis College for Women, Hyderabad, visited on January 16, 2014.
18. 65 students of class V to XII from Andhra Pradesh Social Welfare Residential Schools, across Andhra Pradesh visited on January 27, 2014.
19. 36 B.E. students of Materials Science & Engineering from CARE Group of Institutions, Trichy visited on January 28, 2014.
20. A team of 11 Ph.D. Scholars and B.Tech students of Mechanical & Physics from Vellore Institute of Technology, Vellore visited on March 06, 2014.
21. A team consisting of 25 M.Tech students of Nanotechnology as well as Faculty members from Jawaharlal Nehru Technological University, Hyderabad visited ARCI on March 27, 2014.

Dr. Y. Srinivasa Rao with the students of class V to XII from Andhra Pradesh Social Welfare Residential School

Summer Training Programme

As in the previous year, this year too students from universities such as IITs, NITs, Banaras Hindu University and various other universities from all over the country were short-listed for availing Summer Training Programme at ARCI. 59 students were selected for the summer training programme, which was held during May 15 to June 28, 2013. The selected students initially underwent a week long orientation course so as to get familiarity with the activities being carried of at ARCI. Each student was guided by a scientist to carry out a mini project. The students were issued certificates on completion of the programme.

Reservations and Concessions

The Reservations and Concessions for SCs/STs/OBCs and persons with disabilities are followed as per Government of India orders from time to time. At ARCI, the representation of employees under SC is 16.88%, S.T is 3.75%, OBC is 25% and that of persons with disabilities is 1.88% as on March 31, 2014.

Dr. S. V. Joshi, Additional Director with summer training students

Indian and Foreign Visitors for Technical Discussion

1. Dr. A. V. Okotrub, Head, Department of Functional Materials, Nikolaev Institute of Inorganic Chemistry (NIIC), Novosibrisk, Russia; Dr. Luba Bulusheva, Senior Scientist, NIIC, Russia and Dr. Artem Guselinikov, Senior Scientist, NIIC, Russia visited during April 02-08, 2013.
2. Dr. Torsten Fischer, Programme Director, Humanities and Social Sciences, Deutsche Forschungsgemeinschaft (DFG), Germany visited on May 03, 2013.
3. Dr. T. Ramasami, Secretary, Department of Science and Technology (DST), New Delhi visited on May 04, 2013.
4. Mr. Uday Krishna, Senior Official L&T visited on May 10, 2013.
5. Dr. Amol Chandekar, Vice President, NanOptek, USA visited on June 11, 2013.
6. Prof. Subhakumar Kumpaty, Milwaukee School of Engineering, USA visited on July 25, 2013 and on August 08, 2013.
7. Prof. Paul Keyes, Department of Physics and Astronomy, Wayne State University, USA visited on August 08, 2013.
8. Mr. Kengo Saito, Manager, Olympus Corporation, Japan visited on August 30, 2013.
9. Prof. Amitava De, Indian Institute of Technology (IIT) Bombay, Mumbai visited on October 03, 2013.
10. Dr. Greert Vanhoyland, Product Manager, Bruker AXS Analytical Instruments Private Limited, Belgium visited on November 21, 2013.
11. Ms. Liudmila Kornaukhova, Deputy Director General, Indo-Russian Science and Technology Centre (IRSTC), Moscow and Prof. A. S. Shalumov, General Director of Scientific Research Institute 'ASONIKA', Moscow visited during November21-22, 2013.
12. Dr. Tomikatsu Kubo, Senior Staff, Rigaku Corporation, Japan visited on December 11, 2013.
13. Mr. J.A. Kamalakar, Director, Laboratory for Electro-Optic Systems (LEOS)-Indian Space Research Organization (ISRO), Bengaluru; Mr. P. Chakraborty, Deputy Director, LEOS-ISRO, Bengaluru and Dr. K. V. Sriram, Scientist G, ISRO, Bengaluru visited on December 26, 2013.
14. Dr. Eckhardt Schneider, Fraunhofer Institute for Non-Destructive Testing (IZFP), Saarbruken, Germany visited on December 28, 2013.
15. Mr. Rakesh Ghag, Associate Chief Manager, Tool Management Services, Godrej Tooling , Mumbai visited on January 20, 2014.
16. Mr. Udo Behrendt, Global Head (Aerospace Practices), EOS GmbH, Germany visited on February 21, 2014.
17. Dr. Alian Largeteau, Scientific Coordinator, Centre National De La Recherché Scientifique (CNRS), France and Ms. Mythili Prakasam, Researcher, CNRS, France visited on March 11, 2014.
18. Prof. Guillaume Racineux, Ecole Centrale de Nantes, France visited on March 16, 2014.
19. Dr. Amol Gokhale, Outstanding Scientist (OS) and Director, Defence Metallurgical Research Laboratory (DMRL), Hyderabad and team visited ARCI during 2013-14.

Seminars by Indian and Foreign Visitors

1. Prof. Vijay K. Vasudevan, University of Cincinnati, USA delivered a lecture on "Advanced Surface Treatment-Induced Changes in Residual Stress, Microstructure and Properties of Aero Engine and Nuclear Alloys" on April 04, 2013.
2. Dr. S. Devaraj, Post Doctoral Research Fellow, Department of Mechanical Engineering, National University of Singapore, Singapore delivered a lecture on "Zinc-Air Batteries: Challenges and Future Prospects" on April 29, 2013.
3. Dr. Vikram Gulati, Director, National Automotive Testing and R&D Infrastructure Project (NATRIP), New Delhi delivered a lecture on "National Mission for Electricity Mobility" on May 28, 2013.
4. Mr. Ramu Sunkara, Co-founder, QiK Inc., USA and Former Member, Oracle Architecture Board delivered a lecture on "Inventions to Market: Internet and Smartphone Cases" on June 18, 2013.
5. Dr. Raja Sekar, Manager, Engine and Emissions Research, Argonne National Laboratory, USA delivered a lecture on "Transportation Trends in the United States" on July 08, 2013.
6. Dr. A.K. Sharma , IIT Delhi, New Delhi delivered a lecture on "CZTS Thin Solar Cells by PVD" on July 14, 2013.
7. Dr. Kiran Kumar Challa, Chungnam National University, Korea delivered a lecture on "Nanomaterials Synthesis for Thin Film Solar Cells" on July 14, 2013.
8. Dr. Nandigam Padmavathi, IIT- Kharagpur, Khargpur delivered a lecture on "Micro-Structural Characterization of Carbon Fiber Reinforced Ceramic and Polymer Matrix Composites" on July 24, 2013.
9. Dr. Balachandran, Senior Scientist, Argonne National Laboratory, USA delivered a lecture on "Ferroelectric Films for Power Inverters in Electric Drive Vehicles and Applications" on July 30, 2013.
10. Dr. Sounak Roy, Assistant Professor at Birla Institute of Technology and Science (BITS)-Pilani, Hyderabad

delivered a lecture on "Environmental Catalysis: From Mechanism and Materials Properties to Catalytic Performance" on August 07, 2013.

11. Dr. K. Madhav Reddy, Research Associate, WPI Advanced Institute for Materials Research, Tohoku University, Japan delivered a lecture on "Atomic Structure and Deformation Behaviour of Light Weight Ceramics" on September 18, 2013.

12. Dr. Awadh B. Pandey, FASM Fellow - Cold Section Alloys, Pratt and Whitney, Materials and Processes Engineering, Florida, USA delivered a lecture on "High-Strength Elevated-Temperature Li_2 Aluminum Alloy for Aerospace Applications" on October 08, 2013.

13. Prof. Kazuhiro Hono, National Institute for Materials Science (NIMS) Fellow Director, Magnetic Materials Unit, NIMS, Japan delivered a lecture on "Progress in the Development of Dy-Free High Coercivity Nd-Fe-B Permanent Magnets" on November 12, 2013.

14. Prof. Horst Hahn, Director, Institute of Nanotechnology Karlsruhe Institute of Technology (KIT), Germany delivered a lecture on "From Tunable Properties of Nanostructures to Printed Devices" on November 20, 2013.

15. Dr. Pallavi Dhagat, Associate Professor, School of Electrical Engineering and Computer Science, Oregon State University, USA delivered a lecture on "Magnetic Recording with Acoustic Waves" on December 09, 2013.

16. Dr. Devesh Misra, Distinguished Professor and Director, Institute for Materials Research and Innovation, University of Louisiana, Lafayette, USA delivered a lecture on "Harnessing the Science of Nanostructured Metallic Materials for Structural and Functional Performance" on December 16, 2013.

17. Dr. Sudeshna Ray, Post Doctoral Scholar, National Chiao Tung University, Taiwan delivered a lecture on "Exploration of New Phosphors using a Mineral-Inspired Approach and Control of Photoluminescence Properties of Phosphor by Charge-Compensated Aliovalent Element Substitution" on December 23, 2013.

18. Dr. R. Mahendiran, Associate Professor, Department of Physics, National University of Singapore, Singapore delivered a lecture on "Magnetic Entropy Change and Magneto Thermopower in Perovskite Oxides" on December 24, 2013.

19. Dr. Satishchandra B. Ogale, Chief Scientist, National Chemical Laboratory (NCL), Pune delivered a lecture on "Advanced Functional Nanomaterials for Energy and Environment" on January 09, 2014.

20. Prof. Sanjay Sampath, Stony Brook, USA delivered a lecture on "Thermal Spray and Cold Spray as Materials Reclamation Technologies" on January 20, 2014.

21. Dr. Maddury V. Somayazulu, Lab Manager and Research Scientist, Carnegie/Department of Energy Alliance Centre (CDAC) at Geophysical Laboratory, USA delivered a lecture on "Synchrotron-based High Pressure Research" on January 22, 2014.

22. Prof. K.P. Karunakaran, IIT-Bombay, Mumbai delivered a lecture on "Additive Manufacturing and Allied Technologies" on January 28, 2014.

23. Dr. Jinsung Jang, Korea Atomic Energy Research Institute (KAERI), South Korea delivered a lecture on "Current Status and Perspectives of R & D on ODS Alloys at KAERI" on February 12, 2014.

24. Dr. P. Sudharshan Phani, Scientist, Nanomechanics Inc, University of Tennessee, Knoxville, USA delivered a lecture on "Is Smaller Stronger" on February 27, 2014.

25. Dr. Dimitry Bronin, Head, Laboratory of Kinetics, Institute of High Temperature Electrochemistry (IHTE) of the Ural Branch of Russian Academy of Sciences Akademicheskaya, Russia delivered a lecture on "Degradation Processes in Solid Oxide Fuel Cells (SOFC)" on March 03, 2014.

26. Prof. Surendar Marya, Emeritus Professor, Ecole Centrale de Nantes, France delivered a lecture on "Revisiting Manufacturing Technologies" on March 16, 2014.

Visits Abroad

1. Mr. P. Sai Venkata Pramod, Senior ARCI Fellow (SAF) visited USA to participate in the '40th International Conference on Metallurgical Coatings and Thin Films (40th ICMCTF-2013)' held at San Diego during April 29-May 03, 2013 and presented a paper on "Influence of Composition and Architecture on Mechanical Properties of Cathodic Arc Deposited Ti-Al-N Coatings".

2. Dr. D. Sivaprahasam visited VST (Services) Ltd, Israel during May 04-10, 2013 for pre-dispatch inspection and training on the 'Vacuum Arc Melting Furnace'.

3. Dr. G. Sundararajan visited France during May 11-20, 2013 to attend the Industrial Research Committee and Scientific Council Meetings of the Indo-French Centre for the Promotion of Advanced Research (CEFIPRA) held at Grenoble and Paris and also to visit various industries in France.

4. Dr. M. B. Sahana visited Germany during May 12-18, 2013 to participate in the '2nd International Conference on Materials for Energy (ENMAT-II)' held at Karlsruhe and presented a paper on "Structure Electrochemical Property Correlation of Carbon Free Mn Doped $LiFePO_4$ prepared by Hydrothermal Method".

5. Dr. Y. Srinivasa Rao visited PACT, Limoges, France during May 12-26, 2013 to attend the review meeting of the CEFIPRA sponsored project on 'Shaping of

Durable Thermal Shock Resistant High Volume Ceramic Containers'.

6. Dr. K. S. Dhathathreyan visited Taiwan during May 14-18, 2013 to participate in '2013 International Workshop on Environment and Resources Applications of Green Energy and Biotechnology/Biochemical Engineering' held at Ming Chi University of Technology, New Taipei City and delivered an invited lecture on "ARCI's Experience in Developing Hydrogen as an Energy Vector in the Context of Mitigating the Effects of Climate Change".

7. Dr. G. Padmanabham and Mr. K.V. Phani Prabhakar visited Germany during May 21-31, 2013 to a) attend the review meeting of the 'Multijoin Project' held at Fraunhofer Institute for Manufacturing Technology and Applied Materials (IFAM), Breman b) conduct joint experiments on Cold Metal Transfer and Cold Arc at Fraunhofer Institute for Machine Tools and Forming Technology (IWU), Chemnitz.

8. Dr. R. Easwaramoorthi visited Automax System Engineering, South Korea during May 25-June 03, 2013 for pre-dispatch inspection and training on the 'Semi-Automatic Screen Printer'.

9. Dr. K. S. Dhathathreyan visited United Kingdom during June 08-16, 2013 to a) attend the '2nd Meeting of the DST-UK Engineering and Physical Sciences Research Council (EPSRC) project' held at Imperial College, London and delivered an invited lecture on "Hydrogen Research at ARCI" and b) to attend the 'International Conference on Hydrogen and Fuel Cells (Hypothesis 2013)' held at Edinburgh during June 11-12, 2013.

10. Dr. N. Rajalakshmi visited United Kingdom during June 08-16, 2013 to a) attend the '2nd Meeting of the DST-EPSRC Project' held at Imperial College, London and b) to present papers on "Graphene based Pt Electrocatalyst for SO_2 Tolerance in PEMFC" and "Pt-Graphene Catalyst for Enhanced Electrochemical Performance Towards Methanol Oxidation in Fuel Cells" at 'Hypothesis 2013' held at Edinburgh during June 11-12, 2013.

11. Dr. S. V. Joshi visited USA during June 11-21, 2013 to participate in the '2013 Spring Consortium Meeting' held at Stony Brook and for technical discussions at Centre for Thermal Spray Research, New York.

12. Dr. H. Purushotham visited Sri Lanka during June 14-21, 2013 to participate in '2nd Journal Conference on Innovation, Management and Technology' held at Colombo and presented a paper on "Management of Technology Transfer from Indian Publicly Funded R&D Institutions to the Industry: Modeling of Factors Impacting Successful Technology Transfer".

13. Dr. M. Buchi Suresh visited Malvern Instruments Ltd, United Kingdom during July 09-13, 2013 for training on 'Particle Size Analyzer'.

14. Mr. B. Vishwanath Sasank visited Minneapolis, USA during July 12-21, 2013 to participate in '11th ASME Fuel Cell Science, Technology, and Engineering Conference' and presented a paper on "PEMFC Stack Activation through Thermal Management".

15. Dr. R. Vijay and Dr. K. Suresh visited PETRA III, Germany during July 31-August 06, 2013 to carry out X-Ray Diffraction and Scattering experiments on steel samples.

16. Dr. D. Sivaprahasam, Dr. Dibyendu Chakravarty and Mr. P. V. V. Srinivas visited Fuji Electronic Industrial Co Ltd, Japan during September 10-16, 2013 for pre-dispatch inspection and training on the 'Spark Plasma Sintering Equipment'.

17. Dr. S.V. Joshi visited Russia during September 11-16, 2013 to participate in the 'International Conference of Asia-Pacific Countries on Technologies of Science-based Business' held at Vladivostok and delivered invited lectures on "Development of Surface Engineering Technologies for Industrial Applications" and "Solar Energy Initiatives at ARCI".

18. Dr. G. Sundararajan visited China during September 21-24, 2013 to attend the 'International Union of Materials Research Society –International Conference on Advanced Materials (IUMRS-ICAM 2013)' held at Qingdao in the capacity as President of Materials Research Society of India (MRSI).

19. Mr. D. Srinivasa Rao visited, Russia during September 30-October 05, 2013 to i) participate in the meeting of the 'Indo-Russian Working Group for Science and Technology' held at Moscow and to ii) visit the Science and Technology Institutes in Moscow.

20. Dr. K. S. Dhathathreyan visited Taiwan during October 02-06, 2013 to participate in '2013 Hydrogen and Fuel Cell Seminar' held at National United University, Miaoli, and delivered an invited lecture on "Fuel Cell Activities in India".

21. Mr. B. Viswanath Sasank visited University College London, United Kingdom during October 06-31, 2013 to carry out the DST-EPSRC project activities on 'Stack Engineering and In Situ - Ex Situ Diagnostic Tools for Stack Assembly'.

22. Ms. Anusree Unnikrishnan, SAF visited Imperial College London, United Kingdom during October 10-31, 2013 to carry out DST-EPSRC project activities on 'Chloride Contamination at Bench Electrochemistry and Single Cell Diagnostics, Testing of Electrodes Contaminated by SO_2 and Recovery by Ozone Treatment'.

23. Dr. G. Sundararajan visited France during October 11-15, 2013 to participate in the '4th World Materials Summit'

held at Strasbourg and delivered an invited lecture on "Rare Earths : Present and Future - The Indian Scenario".

24. Dr. Ravi Bathe visited Canada during October 18-November 17, 2013 to participate in the system integration, assembling, testing and training of the 'Ultra Fast Micromachining System Facility' at the Industrial Materials Institute (IMI)- National Research Council (NRC).

25. Dr. G. Sundararajan visited Canada during October 27-31, 2013 to participate in the 'Materials Science and Technology (MS&T) Conference' held at Montreal and delivered an invited lecture on "Solid Particle Erosion Behaviour of Nanocrystalline Nickel Coatings".

26. Dr. G. Sundararajan visited USA during October 31-November 12, 2013 to deliver an invited lecture on "Cold Spray Coating Technologies at ARCI : An Overview" at Georgia Institute of Technology, Purdue University and Florida International University.

27. Dr. R. Gopalan visited USA during November 04-08, 2013 to participate in the '58th Annual Magnetism and Magnetic Materials (MMM) Conference' held at Denver and made poster presentations on "High Coercivity and Temperature Dependent Magnetic Properties of as-spun Mn-Bi Ribbons" and "AC Magnetic Properties of High Saturation Magnetization Fe-P Soft Magnetic Alloy Achieved by a Two-Step Heat Treatment".

28. Dr. Sanjay R. Dhage visited Ceradrop, Limoges, France during November 24-29, 2013 for pre-dispatch inspection and training on the 'Ink-Jet Printer for CIGS Ink Printing'.

29. Dr. G. Sundararajan visited USA during November 30-December 12, 2013 to participate in the 'International Conference on Processing and Manufacturing of Advance Materials (THERMEC 2013)' held at Las Vegas and delivered an invited lecture on "The Influence of Tungsten Addition and Grain Size on the Mechanical and Tribological Behaviour of Pulse Electro Deposited Ni Coatings".

30. Dr. S. V. Joshi visited Singapore during December 03-08, 2013 to participate in the '4th Trilateral Conference on Nanoscience: Energy, Water and Healthcare' jointly organized by Materials Research Society of Singapore and the School of Materials Science and Engineering and Nanyang Technological University, Singapore and delivered an invited lecture on "Nanotechnology-Based Initiatives for Energy Applications: Straddling Research and Technology Demonstration".

31. Mr. S. M. Shariff visited Fraunhofer Institute-IWS, Dresden, Germany during February 15-23, 2014 for technology demonstration of Laser Beam Brazing (using standard brazing head) as a part of the 'Multi-Join' project .

32. Dr. G. Sundararajan visited USA during February 15-24, 2014 to a) attend the 'The Minerals, Metals and Materials Society (TMS) 2014 Conference' and delivered two keynote lectures and an invited lecture on "Strengthening of Steels by Nanodispersoids", "Structure-Property-Performance Correlations in the Micro Arc Oxidation Coatings Deposited on 6061 T6 Al Alloy" and "Status of Advanced Manufacturing : Indian Perspective" respectively b) visited University of Utah and delivered an invited lecture on "Cold Spray Coating Technologies at ARCI : An Overview".

33. Dr. Dibyendu Chakravarthy has been deputed to USA during February 15, 2014 to February 14, 2015 to carry out research activities at Rice University, Houston under the Indo-US Science and Technology Forum fellowship programme.

Invited Lectures by ARCI Personnel in India

1. Dr. K. S. Dhathathreyan delivered an invited lecture on "Wind Energy and Hydrogen Integration" at the '10th International Training Course on Wind Turbine Technology and Applications' held at Chennai during March 20-April 12, 2013.

2. Dr. N. Rajalakshmi delivered an invited lecture on "PEMFC for Vehicular Applications" at the 'National Conference on Advances in Mathematics and its Applications (NCAMA 2013)' held at Trichy on April 05, 2013.

3. Dr. K. S. Dhathathreyan delivered an invited lecture on "Nanomaterials in Fuel Cells" at the 'Workshop on Alternative Energy in Perspective of Nanotechnology -An Event of QUANTA-13' held at Chennai on April 13, 2013.

4. Dr. T. N. Rao delivered an invited lecture on "Commercialization of Nanomaterials-based Technologies" at the 'VTU-International Caneus Symposium on Inclusive Innovation Projects for Aerospace and Energy Sectors (VICAS-2013)' held at Belgaum during April 19-20, 2013.

5. Dr. S. Sakthivel delivered an invited lecture on "Nano Functional Coatings for Solar Applications" at 'VICAS-2013' held at Belgaum during April 19-20, 2013.

6. Dr. G. Padmanabham delivered an invited lecture on "Coatings for Solar Energy Applications: Efforts at ARCI" at the 'Indo-Singapore Workshop' held at Kolkata during April 22-24, 2013.

7. Dr. R. Subasri delivered invited lectures on "Organic-Inorganic Hybrid Nanocomposite Coatings by Sol-Gel Process" and "Research Experience in Germany as a Max Plank India Fellow" at the 'Excellence on Tour- An Exhibition' held at Hyderabad on April 26, 2013.

8. Dr. S.V. Joshi delivered an invited lecture on "Emerging Surface Engineering Techniques to Combat Materials Degradation at High Temperatures" at the 'Prof. Brahm Prakash Birth Centenary Workshop on High Temperature Materials and Hot Structures (HTMHS)' held at Trivandrum during May 13-15, 2013.

9. Dr. S.V. Joshi delivered a plenary talk and an invited lecture on "Recent Developments in High Performance Coatings for Strategic Applications: Indian Scenario" and "Solution Precursor Plasma Spraying: A Versatile Technique for Deposition Diverse Functional Coatings" respectively at the 'International Conference and Exhibition on Heat Treatment and Surface Engineering (HT&SE 2013)' held at Chennai during May 16-18, 2013. Dr. S.V. Joshi conducted a full day course on 'Thermal Spray Coatings and Technologies for Industrial Applications' on May 19, 2013 as part of HT&SE-2013 Conference along with Prof. Per Nylen, University West, Sweden.

10. Dr. G. Padmanabham delivered an invited lecture on "Surface Engineering by Laser Processing" at 'HT&SE 2013' held at Chennai during May 16-18, 2013.

11. Mr. D. Srinivasa Rao delivered an invited lecture on "Exploring Detonation and Atmospheric Plasma Sprayed NiCoCrAlY Bond Coats for EB-PVD Thermal Barrier Coatings" at 'HT&SE 2013' held at Chennai during May 16-18, 2013.

12. Dr. G. Sundararajan delivered an inaugural lecture on "Materials and Surface Engineering Technologies at ARCI" at the 'Workshop on Surface Modifications of Structural Materials' held at Trichy on May 27, 2013.

13. Dr. G. Padmanabham delivered an invited lecture on "Laser based Joining and Surface Engineering" at the 'Technical Education Quality Improvement Programme (TEQIP) for Engineering Faculty Members' held at Hyderabad on June 03, 2013.

14. Dr. Neha Y. Hebalkar delivered an invited lecture on "Aerogels for Thermal Insulation" at the Hyundai R&D Centre, Hyderabad on June 05, 2013.

15. Dr. B.V. Sarada delivered an invited lecture on "Electrochemical Synthesis of CIGS Thin-Films for Solar Energy Applications" at the 'National Seminar on Solar Energy Harvesting through Photovoltaic Cells and Storage' held at Guntur during June 21-22, 2013.

16. Dr. S.V. Joshi delivered an invited lecture on "Surface Engineering for Wear Protection" at the '6th Summer School in Tribology' conducted by the Tribology Society of India' on June 26, 2013.

17. Dr. Sanjay Bhardwaj delivered invited lectures on "Managing IPRs in Technology-based Start-Ups" and "New Enterprise Creation: Technologies from ARCI" at the 'Technology based Entrepreneurship Development Programme' held at Hyderabad on June 27, 2013.

18. Dr. Sanjay Bhardwaj delivered an invited lecture on "Technologies from ARCI and Interaction Models" at the 'Workshop on Facilitating Technology Acquisition' held at Hyderabad on June 28, 2013.

19. Dr. G. Sundararajan delivered a keynote lecture on "Materials and Process Development Activities @ ARCI - An Overview" at the 'Workshop on Navigating New Frontiers in Materials' held at Warangal on July 02, 2013.

20. Dr. R. Gopalan delivered an invited lecture on "Microstructural Strategies for High Performance Magnetic Materials" at the 'International Conference on Electron Microscopy' held at Kolkata during July 03-05, 2013.

21. Dr. G. Ravi Chandra delivered an invited lecture on "Orientation Relationships in $YBa_2Cu_3O_7$-δ High-Tc Superconductor prepared by the Preform-Optimized Infiltration Growth Process" at the 'International Conference on Electron Microscopy' held at Kolkata during July 03- 05, 2013.

22. Dr. Dibyendu Chakravarty delivered an invited lecture on "Spark Plasma Sintering : An Emerging Technique for Developing Structural and Functional Components" at the 'Continuing Education Programme (CEP) on Advanced Powder Metallurgical Process and Techniques for Defence Applications' held at Hyderabad during July 08-12, 2013.

23. Dr. G. Padmanabham delivered an invited lecture on "Laser Welding" at the 'Training Programme on Advances in Welding Technology and Non-Destructive Testing' held at Hyderabad on July 11, 2013.

24. Dr. T. N. Rao delivered an award lecture on "Applications of Nanomaterials in Energy, Health and Environment" at the '1st Annual International Conference of Costal Chemical Research Society (CCRS)' held at Visakhapatnam during July 13-14, 2013.

25. Dr. R. Gopalan delivered an invited lecture on "Characterization Techniques for Advanced Materials" at the 'Refresher Course on Trends in Instrumental Analysis' held at Chennai on July 24, 2013.

26. Dr. G. Sundararajan delivered an keynote lecture on "Li-ion Batteries and Magnets for Electric Vehicle

(EV) Applications" at the 'Indo-Japan International Conference on Frontiers on Energy, Environment, Health and Materials Research' held at Bhubaneswar on August 12, 2013.

27. Dr. G. Padmanabham delivered an invited lecture on "Recent Developments in Laser based Joining of Materials" at a 'One Week Short Term Course on Joining of Materials (under TEQIP II)' held at Silchar on August 12, 2013.

28. Dr. H. Purushotham delivered an invited lecture on "Knowledge Management in Nanoscience and Technology: Key for Competitiveness of Academia, Research and Industry" at the 'International Seminar on Nanotechnology in Conventional and Renewable Energy: A Global Status and Pathway' held at Dehradun during August 12-13, 2013.

29. Dr. T. Mohan delivered an invited lecture on "Materials for Electrochemical Power Sources" at Vel Tech University, Chennai on August 21, 2013.

30. Dr. R. Gopalan delivered an invited lecture on "Materials and Components Technology of Li-ion Batteries and Motors for EV Applications" at the 'Central Electrochemical Research Institute (CECRI) Brainstorming Session on Rechargeable Energy Storage Systems for EVs' held at Chennai during August 22-23, 2013.

31. Dr. Raju Prakash made a video presentation on "Li-ion Battery Pilot Plant Situated at Centre for Automotive Energy Materials (CAEM)" at the 'CECRI Brainstorming Session on Rechargeable Energy Storage Systems for EVs' held at Chennai during August 22-23, 2013.

32. Dr. K. S. Dhathathreyan delivered an invited lecture on "PEMFC in Transportation- Status of Development at ARCI" at Ministry of New and Renewable Energy (MNRE), New Delhi on August 26, 2013.

33. Dr. P. K. Jain delivered an invited lecture on "Synthesis and Processing of Metal Matrix Composites, Synthesis and Application of Carbon Nanostructured Materials" at Vellore Institute of Technology (VIT), Vellore on August 28, 2013.

34. Dr. G. Ravi Chandra delivered an invited lecture on "Introduction to Materials Characterization" at the 'Workshop on Materials Characterization' held at Hyderabad on August 30, 2013.

35. Dr. T.N. Rao delivered an invited lecture on "Nano Batteries: Future Automotive Transportation" at the 'Workshop on Sustainable Energy Conversion and Storage Devices (SECSD- 2013)' held at Chennai on September 02-08, 2013.

36. Dr. K. S. Dhathathreyan delivered an invited lecture on "Hydrogen- A Sustainable Energy Vector" at 'SECSD-2013' held at Chennai during September 02-08, 2013.

37. Dr. S. Sakthivel delivered an invited lecture on "Important Role of Functional Nano Coatings for Solar Thermal and PV Applications" at 'SECSD-2013' held at Chennai during September 02-08, 2013.

38. Dr. K. S. Dhathathreyan delivered an invited lecture on "Integration of Wind Energy with Other Energy Sources- A Case of Sustainable Hydrogen through Wind Energy" at the '11th International Training Course on Wind Turbine Technology and Applications' held at Chennai during September 04- October 02, 2013.

39. Dr. R. Gopalan delivered an invited lecture on "Materials and Components Technology of Li-ion Batteries and Motors for EV Applications" at the '3rd workshop on Hybrid and Electric Vehicle Technologies' held at New Delhi during September 05-06, 2013.

40. Dr. R. Balaji delivered an invited lecture on "Hydrogen- The Fuel for Sustainable Living" at Thiagarajar College of Engineering, Madurai on September 06, 2013.

41. Dr. T.N. Rao delivered an invited lecture on "Commercial Prospects for Nanomaterials-based Technologies" at the 'DST Sponsored National Seminar on Futuristic Trends of Nanocomposites and their Fabrication (FTNCF)' held at Guntur during September 06-07, 2013.

42. Dr. K. S. Dhathathreyan delivered an invited lecture on "Status of Polymer Electrolyte Membrane Fuel Cell (PEMFC- Low/ High Temperature and with/ without Reformer) in India" at MNRE, New Delhi on September 09, 2013.

43. Dr. P. K. Jain delivered an invited lecture on 'Preparation and New Applications of Carbon Nanostructured Materials' at RVR JC College of Engineering, Guntur on September 09, 2013.

44. Dr. S. Sakthivel delivered an invited lecture on "Important Role of Functional Nano Coatings for Solar Conversion Technology" at the 'National Workshop on Nanotechnology–A Fuel for Chemical Industry' held at Guntur during September 20-21, 2013.

45. Dr. G. Ravi Chandra delivered an invited lecture on "Characterization of Nanomaterials" at the 'National Workshop on Nanotechnology – a Fuel for Chemical Industry' held at Guntur during September 20- 21, 2013.

46. Dr. Malobika Karanjai delivered an invited lecture on "Cerametallic Composites" at the 'International

Workshop on Ceramics, Carbon and Diamond' held at Nashik during September 22-26, 2013.

47. Dr. Neha Y. Hebalkar delivered a plenary lecture on "Aerogel based Thermal Insulation: Nanotechnology Development Case Study" at the 'National Conference on Nanotechnology's Invisible Threat: Small Science, Big Consequences' held at Hyderabad during September 26-27, 2013.

48. Dr. G. Sundararajan delivered an invited lecture on "Technology Transfer and Commercialization : ARCI's Experience" at the 'Workshop on Advances in Chemical and Materials Engineering' held at Hyderabad on October 01, 2013.

49. Dr. K. S. Dhathathreyan delivered an invited lecture on "Some Recent Developments in Hydrogen Research at ARCI" at the 'Lecture Series on Electrochemistry and Energy' held at Chennai on October 01, 2013.

50. Dr. S.V. Joshi delivered an invited lecture on "Solution Precursor Plasma Spraying: Opening New Vistas in Thermal Spraying" at the 'Workshop on Advancement and Futuristic Trends in Mechanical and Materials Engineering' held at Punjab during October 03-06, 2013.

51. Dr. S. Sakthivel delivered invited lectures on "Importance of Solar Energy Conversion Technology in India" and "A Role of Nano Functional Coatings in CSP and PV Applications" at the 'Workshop on Renewable Energy Sources' held at Tamilnadu during October 04-17, 2013.

52. Dr. G. Sundararajan delivered an invited lecture on "Characterization of Thermal Spray Coatings" at the 'Workshop on Thermal Spraying and Cladding' held at Chennai on October 08, 2013.

53. Dr. G. Padmanabham delivered an invited lecture on "Laser Processing of Materials and Sol-Gel Nano Composite Coatings Technologies" at the 'Workshop on Innovations in Materials and Processes and Transfer of Technology to Industries' held at Warangal during October 17-19, 2013.

54. Dr. L. Rama Krishna delivered an invited lecture on "How to Translate Invention Based Research into Exciting Technologies" at the 'Workshop on Innovations in Materials and Processes and Transfer of Technology to Industries' held at Warangal during October 17-19, 2013.

55. Dr. T.N. Rao delivered an invited lecture on "Nanomaterials-based Technologies: An Indian Perspective" at the 'Workshop on Innovations in Materials and Processes and Transfer of Technology to Industries' held at Warangal during October 17-19, 2013.

56. Dr. R. Vijay delivered an invited lecture on "Development of Oxide Dispersion Strengthened Steels- An Overview" at the 'Workshop on Innovations in Materials and Processes and Transfer of Technology to Industries' held at Warangal during October 17-19, 2013.

57. Dr. N. Rajalakshmi delivered an invited lecture on "Fuel Cells- Basics, Applications and Challenges" at the 'Workshop on Alternative Sources of Energy: Issues, Applications and Challenges' held at Chennai in October 18, 2013.

58. Dr. R. Balaji delivered an invited lecture on "An Overview on Hydrogen Fuel Cell Technology" at the 'National Seminar on Current Scenario of Renewable Energy Resources in India' held at Kancheepuram on October 19, 2013.

59. Dr. S. Sakthivel delivered an invited lecture on "Importance of Solar Energy Conversion Technology" at the 'National Seminar on Emerging Trend in Solar Energy' held at Chennai on October 23, 2013.

60. Dr. T.N.Rao delivered an invited lecture on "Nanomaterials-based Technological Research at International Advanced Research Center (ARCI)" at the 'India-France Technology Summit' held at New Delhi during October 23-24, 2013.

61. Dr. S.V. Joshi delivered an invited lecture on "Recent Development of High Performance Coatings at ARCI" at the 'India-France Technology Summit and Technology Platform' held at New Delhi on October 24, 2013.

62. Dr. S.V. Joshi delivered an invited lecture on "Solution Precursor Plasma Spraying: Bringing New Excitement to Thermal Spraying" at the 'DMRL Golden Jubilee Seminar on Materials Technologies for Defence Systems: Success Stories and Road Ahead' held at Hyderabad during October 25-26, 2013.

63. Dr. V. Chandra Sekaran delivered an invited lecture on "DMRL & Rare-Earth Permanent Magnets" at the 'DMRL Golden Jubilee Seminar on Materials Technologies for Defence Systems: Success Stories and Road Ahead' held at Hyderabad during October 25-26, 2013.

64. Dr. Y. Srinivasa Rao delivered an invited lecture on "Nanomaterials for Electronic Applications" at the '29th National Convention of Electronics and Communication Engineers' held at Hyderabad during October 29-30, 2013.

65. Dr. L. Rama Krishna delivered an invited lecture on "Surface Engineering: An Essential Approach for Tool Life Enhancement", at the 'National Workshop on Advanced Materials and Manufacturing (AMM)' held at Warangal during October 31 - November 02, 2013.

66. Dr. G. Ravi Chandra delivered an invited lecture on "Introduction to Nanoscience and Nanotechnology" at St. Anns College, Hyderabad on November 08, 2013.

67. Dr. R. Balaji delivered an invited lecture on "Hydrogen Generation by Electrolysis of Water- A Green Route" at the 'Seminar on Green Chemistry' held at Vellore on November 09, 2013.

68. Dr. K. S. Dhathathreyan delivered an invited lecture on "Fuel Cells in Power Generation and Transport Applications" at the '7th International Conference on Science, Engineering and Technology (SET-2013)' held at Vellore during November 14-15, 2013.

69. Dr. S.V. Joshi delivered an invited lecture on "Surface Engineering: An Interesting Canvas for Pursuing Cutting-Edge Research and Developing Industrial Applications" at the 'AP Science Congress' held at Hyderabad on November 15, 2013.

70. Dr. Malobika Karanjai delivered an invited lecture on "Composite Materials and their Processing" at the 'Powder Metallurgy Short Course 2013 (PMSC-13)' held at Hyderabad during November 18-21, 2013.

71. Dr. G. Padmanabham delivered an invited lecture on "Technology Transfer and Commercialization" at 'PMSC-13' held at Hyderabad during November 18-21, 2013.

72. Dr. Joydip Joardar delivered an invited lecture on "Particulate Materials: Grades and Applications" at 'PMSC-13' held at Hyderabad during November 18-21, 2013.

73. Dr. Roy Johnson delivered an invited lecture on "Advanced Ceramic Processing: Opportunities and Challenges" at 'PMSC-13' held at Hyderabad during November 18-21, 2013.

74. Dr. V. Chandra Sekaran delivered an invited lecture on "Powder Metallurgy Process for the Development of Technologically Important Magnetic Materials" at 'PMSC-13' held at Hyderabad during November 18-21, 2013.

75. Dr. K. S. Dhathathreyan delivered invited lectures on "Hydrogen in Transportation Applications and Energy Storage- System Performance and Analysis" and "PEMFC Stack Design and Development Various Issues for System Development and Integration" at the 'TEQIP-II Sponsored Faculty Development Programme on Incubating Potential Renewable Energy Technologies for Automotive Industry ' held at Coimbatore during November 18-24, 2013.

76. Dr. G. Padmanabham delivered an invited lecture on "Laser based Joining of Materials' at the 'CEP for DRDO Scientists' held at Hyderabad on November 19, 2013.

77. Dr. K. S. Dhathathreyan delivered an invited lecture on "Fuel Cells- Present Status and Prospects" at the '3rd National Conference on Recent Advances in Bio-Energy Resources' held at Punjab during November 22-24, 2013.

78. Dr. K. S. Dhathathreyan delivered an invited lecture on "Recent Developments in PEMFC for Stationary and Transport Applications at Centre for Fuel Cell Technology (CFCT)- ARCI" at the '2nd International Hydrogen and Fuel Cell Conference' held at Goa during December 01-03, 2013.

79. Dr. H. Purushotham delivered an invited lecture on "Knowledge Management Services in Nanoscience and Technology for Researchers and Entrepreneurs" at the '6th Bangalore India Nano' held at Bengaluru during December 04-07, 2013.

80. Dr. T.N. Rao delivered an invited lecture on "Nanomaterials for Energy and Water Management: The Indian Perspective" at the '6th Bangalore India Nano' held at Bengaluru during December 04-07, 2013.

81. Dr. K. S. Dhathathreyan delivered an invited lecture on "Recent Developments in Electrocatalysts for Low Temperature Fuel Cells at ARCI" at the 'International Conference on Nanomaterials: Science, Technology and Applications (ICNM 13)' held at Chennai during December 05-07, 2013.

82. Dr. R. Gopalan delivered an invited lecture on "Magnetic Materials for Green Energy Applications" at the 'International Conference on Magnetic Materials and Applications (MAGMA 2013)' held at Guwahati during December 05-07, 2013.

83. Mr. T. Gururaj delivered an invited lecture on "Life Enhancement/Recovery of Tool Components by Laser Surface Engineering and Material Deposition Techniques" at the 'Aluminium Casters Association of India (ALUCAST) 2013 Conference and Exhibition - Die Casting' held at Bengaluru during December 06-07, 2013.

84. Dr. K. S. Dhathathreyan delivered an invited lecture on "Fuel Cell Activities in India" at the '1st Meeting

of Sub-Committee for Research, Development and Demonstration of Hydrogen Energy and Fuel Cells' held at New Delhi on December 09, 2013.

85. Dr. H. Purushotham delivered an invited lecture on "Patinformatics for Assessing Emerging Trends in Nanotechnology Applications in Cement Industry" at the 'Conference on Patinformatics for Corporate Planning and Business Development' held at Pune during December 09-11, 2013.

86. Dr. G. Ravi Chandra delivered an invited lecture on "Doing More with the SEM: Phase Identification Using a Combination of EDS and EBSD" at the 'Five-Day Workshop on Advances in Electron Microscopy' held at Warangal on December 10, 2013.

87. Dr. K. S. Dhathathreyan delivered an invited lecture on "Energy Next" at the 'Two Day Workshop on Energy Resources- Generation Next' held at Chennai during December 12-13, 2013.

88. Dr. R. Balaji delivered an invited lecture on "Hydrogen Fuel Cell Technology- An Introduction" at the 'Seminar on Renewable Energy' held at Gandhigramam on December 13, 2013.

89. Dr. T.N. Rao delivered an invited lecture on "Diamond based Electrochemical Sensors and Li Ion Batteries" at the 'National Workshop on Innovations in Electrochemical Science and Technology' held at Warangal on December 14, 2013.

90. Dr. Sanjay Bhardwaj delivered invited lectures on "Advanced Materials: Commercialization and IPR Issues" and "Growth Strategies for Technology based Start-ups" at the 'Entrepreneurship Development Programme' held at Hyderabad on December 16, 2013.

91. Dr. S.V. Joshi delivered an invited lecture on "Exciting Prospects for Hybrid Plasma Spraying of Composite Coatings Employing Powders and Solution Precursors" at the 'Symposia on Composites' held as part of the International Union of Materials Research Societies-International Conference in Asia (IUMRS-ICA 2013)' at Bangalore during December 16-20, 2013.

92. Dr. T.N. Rao delivered an invited lecture on "Electrodeposited Graphene-Metal Nanocomposites as High Performing Materials" at 'DST- Japan Society for the Promotion of Science (JSPS) Symposium on Nanotechnology based Innovation for Environmental, Energy and Biomedical Applications' held at Bengaluru on December 17, 2013.

93. Dr. G. Padmanabham delivered an invited lecture on "Lasers in Automotive Industry" at the 'Silver Jubilee Event of Optilase' held at Vellore on December 19, 2013.

94. Dr. Sanjay Bhardwaj delivered invited lectures on "Promoting Technology based Entrepreneurship in an R&D Environment" and "Developing IP Strategy for R&D Organizations" at the 'Faculty Development Programme' held at Hyderabad on January 08, 2014.

95. Dr. P. K. Jain delivered an invited lecture on "Synthesis and Application of Carbon Nano Materials" at the 'International Seminar on Nano, Bio, and Materials Sciences' held at Hyderabad during January 08-10, 2014.

96. Dr. S. Sakthivel delivered an invited lecture on "Future and Application of Nano Functional Coatings in Energy Harvesting Technology" at the 'International Conference on Nano-Bio and Material Sciences (ICONBMS-2014)' held at Hyderabad during January 08-10, 2014.

97. Dr. N. Rajalakshmi delivered an invited lecture on "Panel Discussion for Alternative Energy" at the 'International Conference on Emerging Trends in Energy and Environment (ICETEE)' held at Chennai during January 09-10, 2014.

98. Dr. H. Purushotham delivered an invited lecture on "Development of a Composite Index to Asses Renewability of Patents: A Case Study" at the '6th Global Intellectual Property Convention' held at Hyderabad during January 16-18, 2014.

99. Dr. Roy Johnson delivered an invited lecture on "Transparent Polycrystalline Ceramics: A New Class of Optical Materials" at the 'National Environmental Engineering Research Institute (NEERI)' held at Nagpur during January 17-18, 2014.

100. Mr. D. Srinivasa Rao delivered an invited lecture on "Detonation Spray Coatings: Applications Development at ARCI" at the 'Discussion Meeting on Advanced Thermal Spray Processing and Reclamation Technologies' held at Hyderabad on January 20, 2014.

101. Dr. S. Kumar delivered an invited lecture on "Cold Spray Activities in ARCI" at the 'Discussion Meeting on Advanced Thermal Spray Processing and Reclamation Technologies' held at Hyderabad on January 20, 2014.

102. Dr. G. Sivakumar delivered an invited lecture on "Solution Precursor Plasma Spray" at the 'Discussion Meeting on Advanced Thermal Spray Processing and Reclamation Technologies' held at Hyderabad on January 20, 2014.

103. Dr. Sanjay Bhardwaj delivered an invited lecture on "Commercialization of Innovations by SMEs in India"

at the 'National Conclave-cum-Exhibition on Igniting the Spirit of Innovation' held at Hyderabad on January 23, 2014.

104. Dr. Malobika Karanjai delivered an invited lecture on "Development and Consolidation of Silica Coated Iron Powder for Soft Magnetic Applications" at the 'International Conference on Powder Metallurgy and Particulate Materials (PM14)' held at Chennai during January 23-25, 2014.

105. Dr. K. S. Dhathathreyan delivered an invited lecture on "Gaps in Clean Energy Research, Development and Demonstration" at the 'Refresher Course for the Teaching Faculty' held at Chennai on January 24, 2014.

106. Dr. Y. Srinivasa Rao delivered an invited lecture on "Introduction and Applications of Advanced Ceramics and Processing of Advanced Ceramics-Few Case Studies" at PSG College of Technology, Coimbatore on January 25, 2014.

107. Dr. K. S. Dhathathreyan delivered an invited lecture on "Fuel Cell-Introduction" at the 'Course on Hydrogen and Fuel Cells for Students of M. E. (Energy Engineering)' held at Chennai on January 27, 2014.

108. Dr. Sanjay Bhardwaj delivered invited lectures on "The Technology Adoption Cycle" and "Technology Scouting" at the 'Training Programme on Technology Management for Executives and Engineers of Oil India Limited' held at Hyderabad on January 29, 2014.

109. Mr. T. Gururaj delivered an invited lecture on "Life Enhancement/Recovery of Tool Components by Laser Surface Engineering Techniques" at CASTALL Tech., Hyderabad on January 29, 2014.

110. Dr. R. Easwaramoorthi delivered an invited lecture on "Functional Nanomaterials for Next Generation Photovoltaics" at the 'National Conference on Advanced Functional Materials (NCAFM-2014)' held at Coimbatore during January 30-31, 2014.

111. Dr. K. S. Dhathathreyan delivered an invited lecture on "Materials on Membrane based Fuel Cells" at the 'National Conference on Advanced Materials for Energy Applications (NCAMEA-2014)' held at Hyderabad during January 31-February 01, 2014.

112. Dr. G. Ravi Chandra delivered an invited lecture on "Microstructural Issues in Energy Materials" at 'NCAMEA-2014' held at Hyderabad during January 31-February 01, 2014.

113. Dr. S.V. Joshi delivered an invited lecture on "Surface Engineering: A Vast Playground to Pursue Cutting-Edge Research and Realize Exciting Applications" at the 'Seminar Series' held at Kanpur on February 03, 2014.

114. Dr. Ravi Bathe delivered an invited lecture on "Laser Applications in Manufacturing" at a 'Programme on Precision Manufacturing Techniques and GD&T Principles' held at Hyderabad on February 05, 2014.

115. Mr. T. Gururaj delivered an invited lecture on "Additive Manufacturing -Future of Manufacturing" at the 'Sensitization Workshop on Additive Manufacturing' held at Warangal on February 10, 2014.

116. Dr. R. Gopalan delivered an invited lecture on "Science and Technology of Permanent Magnets" at the 'SERC School on Advanced Functional Magnetic Materials' held at Goa on February 11, 2014.

117. Dr. S.V. Joshi delivered an invited lecture on "Solution Precursor Plasma Spraying: Tailoring Microstructures through Improved Process Understanding" at the '25th MRSI Annual General Meeting (AGM)' held at Bengaluru on February 12-13, 2014.

118. Dr. R. Gopalan delivered an invited lecture on "Functional Materials in Automotive Applications-State-of-the-art and Prospects" at the '25th MRSI AGM' held at Bengaluru on February 12-14, 2014.

119. Dr. P. K. Jain delivered an invited lecture on "Carbon Nanomaterials and Fibers Reinforced Composites" at the 'Joint Raj Bhasha Seminar' held at Hyderabad during February 13-14, 2014.

120. Dr. Neha Y. Hebalkar delivered an invited lecture on "Amazing Nanomaterials" at Ravindra Bharti School, Hyderabad on February 14, 2014.

121. Dr. K. Ramya delivered an invited lecture on "Polymer Electrolyte Membrane based Supercapacitors" at the 'International Conference on Advancements in Polymeric Materials' held at Bhubaneswar during February 14-16, 2014.

122. Dr. S.V. Joshi delivered an invited lecture on "Advanced Techniques to Engineer Surfaces: Complementary or Competing?" at the 'International Workshop on Coatings and Surfaces for Biomedical Engineering (IWCSB 2014)' held at Chennai during February 16-19, 2014.

123. Dr. Sanjay Bhardwaj delivered invited lectures on "The Technology Adoption Cycle" and "Technology Scouting" at the 'Training Programme on Technology Management for Executives and Engineers of Oil India Limited' held at Hyderabad on February 18 and 25, 2014.

124. Dr. S.V. Joshi delivered an invited lecture on "ARCI's Research and Technology Demonstration Initiatives for Solar Energy Applications" at the 'International Conference on Advanced Functional Materials (ICAFM-2014)' held at Trivandrum during February 19-21, 2014.

125. Dr. R. Gopalan delivered an invited lecture on "Necessity of Tuning Functional Materials for Automotive Sector Applications" at 'ICAFM-2014' held at Trivandrum on February 19-21, 2014.

126. Dr. R. Easwaramoorthi delivered a keynote lecture on "Nanotechnology for High Performance Solar Cells" at the 'Vision Nano-2014 National Conference' held at Coimbatore on February 22, 2014.

127. Dr. G. Ravi Chandra delivered an invited lecture on "Introduction to Nanoscience and Nanotechnology" at the 'National Seminar on Recent Advances in Nanoscience and Nanotechnology' held at Nizamabad on February 26, 2014.

128. Dr. S.V. Joshi delivered an invited lecture on "Surface Engineering for Industrial and Strategic Applications: ARCI's Experience with Technology Development and Transfer" at the 'International Conference on Emerging Materials and Processes (ICEMP)' held at Bhubaneswar during February 26-28, 2014.

129. Dr. K. S. Dhathathreyan delivered an invited lecture on "Energy and Materials Science- Nanotechnology" at Bharathiyar University, Coimbatore on February 28, 2014.

130. Dr. P. K. Jain delivered an invited lecture on "Applications of Carbon Nano Materials" at the Department of Poultry, Hyderabad on February 28, 2014.

131. Dr. K. S. Dhathathreyan delivered an invited lecture on "Aspects of Materials Research in Hydrogen Technologies" at the 'Seminar on Materials for Energy Conversion and Storage (MECS-2014)' held at Pondicherry on March 08, 2014.

132. Dr. T.N. Rao delivered an invited lecture on "Nanomaterials-based Technologies for Energy and Water Applications" at 'International Conference cum Workshop on Nanomaterials with Special Reference to Energy Security (NMES-2014)' held at Varanasi during March 11-17, 2014.

133. Mr. N. Ravi delivered an invited lecture on "Effect of Substrate Roughness on Adhesion and Tribological Properties of Nanocomposite Coatings" at the 'All India Seminar on Emerging Technologies in Materials Sciences and Engineering' held at Hyderabad during March 18-19, 2014.

134. Dr. N. Rajalakshmi delivered an invited lecture on "Activated Carbons for Energy Storage" at the 'International Workshop on Advanced Materials (IWAM-2014)' held at Karaikudi on March 21, 2014.

135. Dr. K. S. Dhathathreyan delivered invited lectures on "Aspects of Fuel Cell Stack Design and Development" and "Materials Research as Relevant to Membrane based Fuel Cells" at the 'National Workshop on Fuel Cell Technology' held at Bhopal during March 24-25, 2014.

136. Dr. N. Rajalakshmi delivered an invited lecture on "Advanced Energy Storage Systems- Fuel Cells, Batteries and Supercapacitors" at the 'Workshop on Advances in Energy Storage and Broader use of Renewable Sources' held at Chennai on March 27, 2014.

137. Dr. K. S. Dhathathreyan delivered an invited lecture on "Essentials of Energy Storage" at the 'Workshop on Advances in Energy Storage and Broader use of Renewable Sources' held at Chennai on March 27, 2014.

Papers Presented at Indian Conference/ Symposia

1. Mr. E. Hari Mohan (Dr. T. N. Rao) made a poster presentation on "Scalable Synthesis of $LiFePO_4$ Composite Materials for Li-ion Battery Application by using Flame Spray Pyrolysis" at the 'VTU-International Caneus Symposium on Inclusive Innovation Projects for Aerospace and Energy Sectors (VICAS-2013)' held at Belgaum during April 19-20, 2013.

2. Dr. K. Suresh presented a paper on "Microstructural Studies of Oxide-Dispersion-Strengthened Austenitic Steel" at the 'Two Day Seminar on Microstructure - Diffraction (Microstructure-2013)' held at Mumbai during April 19-20, 2013.

3. Mr. T.K. Gireesh Kumar presented a paper on "Comparative Analysis of Search Features of Scopus and Web of Science" at the 'National Conference on Information Products and Services in the e-Environment (NACINPROSE-2013)' held at Tirupati during April 27-28, 2013.

4. Dr. K. Murugan made a poster presentation on "Self-Cleaning Functional Test on Nano TiO_2 Coated Glasses and Glazed Ceramic Tiles" at the 'International Conference and Exhibition on Heat Treatment and Surface Engineering 2013 (HT&SE 2013)' held at Chennai during May 16-18, 2013.

5. Mr. L. Venkatesh made a poster presentation on "Rapidly Solidified Microstructure of Laser

Clad Inconel-Chromium Carbide Layers" at the 'International Conference on Electron Microscopy' held at Kolkata during July 03-05, 2013.

6. Ms. Rekha Dom (Dr. P. H. Borse) presented a paper on "Investigation of Physico-Chemical Properties of MFe_2O_4 (M: Ca, Zn, and Mg) Photocatalysts Synthesized by Microwave Irradiation" at the 'National Conference in Applied Physics and Material Science(APMS)-2013' held at Hyderabad during July 19-20, 2013.

7. Dr. Sanjay Bhardwaj presented a paper on "Role of Partnerships and Collaborations in Technology Development and Transfer: Materials and Processes Case" at the 'Indian Technology Congress (ITC)' held at Bengaluru during July 24-25, 2013.

8. Dr. R. Balaji presented a paper on "Hydrogen Generation via Urea Electrolysis using Nickel Alloy Electrode" at the 'National Symposium on Electrochemical Science and Technology (NSEST-2013)' held at Bengaluru during August 23-24, 2013.

9. Ms. S. Nirmala presented a paper on "A Virtual Instrument for Thermal Fatigue Testing of Die Casting Tool Steels" at the 'National Symposium on Instrumentation NSI-38' held at Hubli during October 24-26, 2013.

10. Dr. D. Prabhu presented a paper on "Development of Fe-P Alloy with High Saturation Induction for Automotive Applications" at the 'Indian Institute of Metals - 51st National Metallurgists Day - 67th Annual Technical Meeting (IIM-NMD-ATM 2013)' held at Varanasi during November 12-15, 2013.

11. Dr. D. Sivaprahasam made a poster presentation on "High Performance Nanostructured beta Zn_4Sb_3 Thermoelectric Materials by High Pressure Ball Milling" at the 'IIM-NMD 2014' held at Varanasi during November 12-15, 2013.

12. Mr. T. Gururaj presented a paper on "Structure-Property Correlation of Laser Surface Engineered AISI HI3 Hot Work Tool Steel for Improved Mechanical Properties" at the 'IIM-NMD 2014' held at Varanasi during November 12-15, 2013.

13. Mr. A. V. B. Subrahmaniam (Dr. P. K. Jain) presented a paper on "Effect of Nitrogen Doping Concentration on Morphology and Microstructure of Nitrogen Doped Super Aligned Carbon Nanotubes Forest" at the 'International Conference on Chemical and Bio Process Engineering (ICCBPE2013)' held at Warangal during November 16-17, 2013.

14. Mr. Ravi Gautam (Dr. R. Gopalan) made a poster presentation on "Thematic Unit of Excellence on Nanomaterials based Technologies for Automotive Applications" at the '6th Bangalore India Nano' held at Bengaluru during December 04-06, 2013.

15. Ms. K. H. Anulekha (Dr. T. N. Rao) made a poster presentation on "A Facile Method to Synthesize Nanostructured $Li_4Ti_5O_{12}$ as Anode Materials for Lithium Ion Battery", at the '6th Bangalore India Nano' held at Bengaluru during December 04-06, 2013.

16. Dr. S. Kavita presented a paper on "Temperature Dependent Coercivity of Meltspun MnBi Ribbons" at the 'International Conference on Magnetic Materials and Applications (MagMA 2013)' held at Guwahati during December 05-07, 2013.

17. Mr. T.K. Gireesh Kumar presented a paper on "Open Source Software for Integrated Library Systems: Relative Appropriateness in the Indian Context" at the 'Doctoral Student Consortium and International Workshop on Global Collaboration of Information Schools co-located with 15th International Conference on Asia-Pacific Digital Libraries (ICADL 2013)' held at Bengaluru during December 09-11, 2013.

18. Mr. S. Vasu (Dr. Gopalan) made a poster presentation on "Structure Electrochemical Property Correlation of $LiFePO_4$ prepared by Hydrothermal Synthesis" at 'IUMRS-ICA 2013' held at Bengaluru during December 16-20, 2013.

19. Mr. M. Sreekanth (Dr. B.V. Sarada) presented a paper on "Fabrication of Stoichiometric CIGS Thin Films by Pulse Reverse Electrodeposition" at 'IUMRS-ICA 2013' held at Bengaluru during December 16-20, 2013.

20. Ms. Alka Pareek (Dr. P.H. Borse) presented a paper on "Stability Improvement of CdS Photoanode by Control over Adsorbed Titania Nanoparticle Phase" at the 'IUMRS-ICA 2013' held at Bengaluru during December 16-20, 2013.

21. Ms. M. Nagini (Dr. R. Vijay) presented a paper on "Effect of Milling on Microstructural Evolution of ODS18Cr Nanoferritic Steels" at the 'IUMRS-ICA 2013' held at Bengaluru during December 16-20, 2013.

22. Mr. P. V. S. Krishna (Dr. K. S. Dhathathreyan) presented a paper on "Development of Anion Exchange Membrane based Supercapacitors" at the 'IUMRS-ICA 2013' held at Bengaluru during December 16-20, 2013.

23. Mr. Balaji Padya presented a paper on "Reduction of Thermo-Kinetics in De-Oxygenation of Free Standing Graphene Oxide Paper" at 'IUMRS-ICA 2013' held at Bengaluru during December 16-20, 2013.

24. Mr. Pandu Ramavath presented a paper on "Evolution of Microstructure of ZnS Transparent Ceramics Processed

through Powder HIPing and CVD + HIPing Routes" at the '77th Annual Session of the Indian Ceramic Society' held at Jamshedpur during December 19-20, 2013.

25. Ms. Papiya Biswas presented papers on "Polymer Sponge Replication of Dense Spinel Cellular Foams" and "Fabrication of Transparent $MgAl_2O_4$ Spinel Hollow Spheres by Drain Casting" at the '77th Annual Session of the Indian Ceramic Society' held at Jamshedpur during December 19-20, 2013.

26. Ms. R. Papitha (Dr. R. Johnson) presented a paper on "Pressure Slip Casting of Alumina and Titania Raw Mix with Aluminium Titanate Stoichiometry" at the '77th Annual Session of the Indian Ceramic Society' held at Jamshedpur during December 19-20, 2013.

27. Mr. V. Ashok Kumar (Dr. P. K. Jain) presented a paper on "Effect of Magnetic Field on Synthesis of CNTs by Arc Discharge under De-Ionized Water" at the 'International Seminar on Nano, Bio and Materials Sciences' held at Hyderabad during January 08-10, 2014.

28. Dr. Sanjay Bhardwaj presented a paper on "Strategic Alliances for Advanced Materials Technologies' Value Chain: Research and Technology Organizations (RTOs) Perspective" at the '2nd International Conference on Management of IPRs and Strategy (MIPS2014)' held at Mumbai during January 30-February 02, 2014.

29. Mr. V. Ashok Kumar (Dr. P. K. Jain) presented a paper on "Synthesis, Purification and Dispersion of CNTs" at the 'National Conference on Advanced Materials for Energy Applications (NCAMEA- 2014) held at Hyderabad during January 31-February 01, 2014.

30. Dr. Rekha Dom (Dr. P. H. Borse) presented a paper on "Deposition of Nanostructured Metal Oxide Film using Solution Precursor Plasma Spray (SPPS) Technique for Photoanodic Water Oxidation" at 'NCAMEA-2014' held at Hyderabad during January 31-February 01, 2014.

31. Ms. Alka Pareek (Dr. P.H. Borse) presented a paper on "Characterization of Nano-Titania Modified CdS/Polysulphide Electrolyte Interface by Utilizing Electrochemical Impedance Spectroscopy" at the 'Eleventh Indian Society for Electro-Analytical Chemistry (ISEAC) International Discussion Meet on Electrochemistry and its Applications (11th ISEAC-DM-2014)' held at Amritsar during February 20-25, 2014.

32. Ms. K.H. Anulekha (Dr. T. N. Rao) presented a paper on "Electrochemical Performance of Lithium Titanate Submicron Rods Synthesized by Sol-Gel/Electrospinning" at the '11th ISEAC-DM-2014' held at Amritsar during February 20-25, 2014.

Participation in Indian Conferences/Symposia/Seminars/Workshops/Exhibitions

1. Mr. V. Balaji Rao and Mr. P. Ramakrishna Reddy attended a 'Programme on Green Building Concept Towards Greener World Tomorrow' held at Bengaluru during June 14-15, 2013.

2. Mr. Anirban Bhattacharjee attended a 'Management Development Programme on Accounting, Financial Management and Governance for Autonomous Bodies' held at Faridabad during August 05-08, 2013.

3. Ms. Kumari Konda attended a 'Two Day Rheology Workshop' held at Bengaluru during August 19-20, 2013.

4. Mr. Arun Seetharaman attended the '4th National Conference and Exhibition-MSME Linkages 2013' held at Ahmedabad during August 30 - September 01, 2013.

5. Mr. M. Srinivas and Mr. N. Venkat Rao attended a 'Seminar on Latest Developments in Multi-Axis Machining Technology' held at Hyderabad on September 04, 2013.

6. Ms. S. Nirmala, Ch. Sambasiva Rao and N. Aruna attended the 'National Instruments Technical Symposium 2013' held at Hyderabad on September 13, 2013.

7. Mr. D. Srinivasa Rao attended a 'Workshop on Vigilance for Executives of Science and Technology Institutions' held at Hyderabad during October 22-26, 2013.

8. Mr. A. Srinivas attended the 'Technical Workshop on Roster Writing and Reservation in Services Government Policy for SCs, STs and OBCs and PH and Recruitment Rules' held at New Delhi during October 23-25, 2013.

9. Dr. G. Padmanabham attended a 'Workshop on IPR and TOT' held at Bengaluru on October 26, 2013.

10. Ms. K. Shakuntala attended a 'Training Programme on Service Rules for LDCs/UDCs/Section Supervisors in CG Offices' held at Bengaluru during October 28-30, 2013.

11. Dr. S.V. Joshi attended the 'Indian Institute of Metals - 51st National Metallurgists Day - 67th Annual Technical Meeting (IIM-NMD-ATM 2013)' held at Varanasi during November 12-15, 2013.

12. Dr. K. Murugan participated in the 'India International Trade Fair-2013' held at New Delhi during November 14-20, 2013.

13. Mr. Shakti Prakash Mishra, Mr. Aan Singh and Mr. Gaje Singh participated in the 'India International Trade Fair-2013' held at New Delhi during November 14-27, 2013.

14. Dr. P. H. Borse attended the 'International Conference on Chemical and Bioprocess Engineering' held at Warangal during November 16-17, 2013 and chaired a technical session on 'Nano and Environment'.

15. Dr. R. Subasri participated in a 'Training Programme on the Sexual Harassment of Women at Workplace (Prevention, Prohibition and Redressal) ACT, 2013' held at Hyderabad during November 18-19, 2013.

16. Mr. P. Barick and Mr. Pandu Ramavath attended the 'Powder Metallurgy Short Course (PMSC-13)' held at Hyderabad during November 18-21, 2013.

17. Mr. Arun Seetharaman, participated in the 'India International Trade Fair-2013' held at New Delhi during November 21-27, 2013.

18. Dr. P. K. Jain, Dr. G. Ravi Chandra, Mr. V. Balaji Rao, Dr. Y. S. Rao, Dr. R. Subasri, Dr. S. S. Sakthivel, Mr. K.V. Phani Prabhakar, Mr. S. B. Chandra Sekhar, Dr. Neha Y. Hebalkar, Dr. Nitin P. Wasekar, Dr. Sanjay Dhage, Dr. D. Siva Prahasam, Ms. S. Nirmala, Mr. S. Arun, Mr. Prasanjit Barick, Dr. R. Easwaramoorthy, Dr. K. Ramya, Dr. R. Balaji, Mr. S. Vasu, Mr. B. Amol Chintaman, Mr. R. Prabhakara Rao, Ms. A. Jyothirmayi, Ms. V. Uma, Mr. V. C. Sajeev, Mr. K. Srinivasa Rao, Mr. D. Sreenivas Reddy, Mr. V. Mahender, Ms. B. V. Shalini and Mr. A. R. Srinivas attended the 'Two Day In-House Training on Industrial Safety' held at Hyderabad during December 05-06, 2013.

19. Mr. Vivek Patel and Mr. Ratnesh Kumar Gaur attended a 'Conference on Patinformatics for Corporate Planning and Business Development' held at Pune during December 09-11, 2013.

20. Mr. L. Venkatesh attended a 'Two-Day Course on Quantitative Microscopy' held at Chennai during December 12-13, 2013.

21. Mr. V. Balaji Rao and Mr. A. R. Srinivas attended the '9th International Conference on Transformers- Trafotech 2014 (Transformers for Smart Grid)' held at Bengaluru during January 08-12, 2014.

22. Dr. K. Samba Sivudu attended the '6th Global Intellectual Property Convention (GIPC)' held at Hyderabad during January 16-18, 2014.

23. Dr. T. N. Rao attended the 'DST-GoI Sponsored Study on Developing Performance-Related Incentive Scheme (PRIS) for Promoting Basic Research-Stakeholder Consultation Workshop' held at Hyderabad during January 18-19, 2014.

24. Dr. P. Suresh Babu attended a 'National Workshop on Fatigue, Fracture and Life Extension (FFLE-2014)' held at Hyderabad during January 29-31, 2014.

25. Mr. T. Gururaj attended the 'Workshop on 3D Printing and Allied Technologies' held at Mumbai during February 19-21, 2014.

26. Dr. H. Purushotham attended the 'International Conference on Nanoscience and Technology (ICONSAT – 2014)' held at Mohali during March 03-05, 2014.

27. Ms. N. Aruna, Mr. M. R. Renju, Mr. T. K. Gireesh Kumar, Mr. Siddartha Sankar Pal, Mr. P. Anjaiah, Mr. A. Janga Reddy, Mr. A. Jayakumaran Thampi, Mr. E. Konda, Mr. D. Krishna Sagar, Mr. D. Kutumba Rao, Mr. A. Praveen Kumar, Mr. A. Ramesh, Mr. A. Sathyanarayana, Mr. K. Satyanarayana Reddy, Mr. K. Subba Rao, Mr. B. Subramanyeswara Rao, D. Surya Prakash Rao, Mr. K. V. B. Vasantha Rayudu, Mr. B. Venkanna, Mr. K. Venkata Ramana, Mr. G. Venkata Rao, Mr. Ch. Venkateswara Rao, Mr. J. Venkateswara Rao, Mr. K. Vigneswara Rao, Mr. G Venkata Reddy, Mr. Govinda Kumar, Mr. A. Jagan, Mr. M. Satyanand, Mr. B. Hemanth Kumar, Mr. Sushanta Mukhopadhyay, Mr. P. Suri Babu, Mr. G. Anjan Babu, Mr. D. Manikya Prabhu, Mr. S. Narsing Rao, Mr. P. K. Mukhopadyay, Mr. Shaik Ahmed, Mr. K. Ashok, Mr. J. Shyam Rao, Mr. E. Yadagiri, Mr. I. Prabhu, Mr. Ch. Jangaiah and Mr. Lingaiah Mothe attended the 'Two Day In-House Training on Industrial Safety' held at Hyderabad during March 06-07, 2014.

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	29/06/2007 (Dt. of Publication of Grant)
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
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
A Method of and an Apparatus for Continuous Humidification of Hydrogen Delivered to Fuel Cells	670/ CHE/2007	30/03/2007	247547	22/04/2011 (Dt. of Publication of Grant)
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

Indian Patents Filed

Title of Patent	Patent Application No.	Date of Filing
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
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 the Preparation of Doped Zinc Oxide Nanopowder useful for the Preparation of Varistors and an Improved Process for the Preparation of Varistors Employing the said Nano Powder	1669/DEL/2006	20/07/2006
An Improved Test Control System Useful for Fuel Cell Stack Monitoring and Controlling	1989/DEL/2006	06/09/2006
An Improved Process for Preparing Nano Tungsten 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 Therefor	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	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 Electrodeposit 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	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

Title of Patent	Patent Application No.	Date of Filing
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
An Improved Process for the Preparation of Nano Silver Coated Ceramic Candle Filters	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 Submicron Alumina Article	1358/DEL/2011	10/05/2011
An Improved Hybrid Methodology for Producing Composite Multi-Layered 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 Compositions	3324/DEL/2011	22/11/ 2011
A Process and a Multi-Piston Hot Press for Producing Powder Metallurgy Components, such as Cerametallic Friction Composites	3844/DEL/2011	28/12/ 2011
A Novel Process for Producing IR Transparent Polycrystalline Alumina Articles and the Articles so Produced	365/DEL/2012	08/02/2012
A Process for Preparing Nano-Crystalline Olivine Structure Transition Metal Phosphate Materials	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

Title of Patent	Patent Application No.	Date of Filing
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	1129/DEL/2013	16/04/2013
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
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
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

International Patents 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	

Title of Patent	Country	Patent Number	Date of Grant	Date of Filing	Indian Patent Details
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	
	Germany	DE102009044256.1	--	15/10/2009	
	France	0957102	--	12/10/2009	
	Brazil	PI0904232-6	--	15/10/2009	
Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity	United Kingdom	1303768.4	--	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
	USA	13/484613	--	31/05/2012	
	Japan	2012-093888	--	17/04/2012	
	United Kingdom	1206843	--	18/04/2012	
	Germany	102012218448.1	--	10/10/2012	
	France	1259820	--	15/10/2012	
	Brazil	102120221209	--	31/08/2012	
	Canada	2784395	--	31/07/2012	

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. S.S. Arbuj, S.R. Bhalerao, S.B. Rane, Neha Y. Hebalkar, U.P. Mulik and D.P. Amalnerkar, "Influence of Triethanolamine on Physico-Chemical Properties of Cadmium Sulphide", Nanoscience and Nanotechnology Letters, Vol. 5(12), p 1245-1250, 2013.

2. S.S. Basha, V.M. Periasamy, M. Kamaraj and S.M. Shariff, "Improvement of Slurry Erosion Wear Resistance of 16Cr-5Ni Martensite Stainless Steel by LSA and LTH", Journal of Materials Engineering and Performance, Vol.22(12), p 3689-3698, 2013.

3. G. Sundararajan, N.M. Chavan and S. Kumar, "The Elastic Modulus of Cold Spray Coatings: Influence of Inter-Splat Boundary Cracking", Journal of Thermal Spray Technology, Vol.22(8), p1348-1357, 2013.

4. K. Murugan, R. Subasri, T.N. Rao, A.S. Gandhi, and B.S. Murty, "Synthesis, Characterization and Demonstration of Self-Cleaning TiO_2 Coatings on Glass and Glazed Ceramic Tiles", Progress in Organic Coatings, Vol. 76(12), Special Issue, p 1756-1760, 2013.

5. P. Biswas, M.K. Kumar, K. Rajeswari, R. Johnson and U.S. Hareesh, "Transparent Sub-Micrometre Alumina from Lanthanum Oxide Doped Common Grade Alumina Powder", Ceramics International, Vol. 39(8), p 9415-9419, 2013.

6. P. Biswas, K. Rajeswari, V. Mahendar and R. Johnson, "Extrusion Processing of Dense $MgAl_2O_4$ Spinel Honeycombs with Low Relative Density", Ceramics International, Vol. 39(8),p 9819-9821, 2013.

7. L. Rama Krishna, G. Poshal, A. Jyothirmayi and G. Sundararajan, "Compositionally Modulated CGDS Plus MAO Duplex Coatings for Corrosion Protection of AZ91 Magnesium Alloy", Journal of Alloys and Compounds, Vol. 578, p 355-361, 2013.

8. S. Seetharaman, R. Balaji, K. Ramya, K.S. Dhathathreyan and M. Velan, "Graphene Oxide Modified Non-Noble Metal Electrode for Alkaline Anion Exchange Membrane Water Electrolyzers", International Journal of Hydrogen Energy, Vol. 38(35), p 14934-14942, 2013.

9. P. Karthika, N. Rajalakshmi and K.S. Dhathathreyan, "Flexible Polyester Cellulose Paper Supercapacitor with a Gel Electrolyte", Chemphyschem, Vol. 14(16), p 3822-3826, 2013.

10. K. Ramya, K.S. Dhathathreyan, J. Sreenivas, S. Kumar and S. Narasimhan, "Hydrogen Production by Alcoholysis of Sodium Borohydride", International Journal of Energy Research, Vol. 37(14), p 1889-1895, 2013.

11. P. Saravanan, J.H. Jen-Hwa, D. Sivaprahasam and S.V. Kamat, "Structural and Magnetic Properties of Gamma-Fe_2O_3 Nanostructured Compacts Processed by Spark Plasma Sintering", Journal of Magnetism and Magnetic Materials,Vol.346, p 175-177, 2013.

12. S.B. Chandrasekhar, D. Prabhu, M. Gopinath, V. Chandrasekaran, M. Ramakrishna, V. Uma and R. Gopalan, "High Saturation Magnetization in Fe-0.4 wt% P Alloy Processed by a Two-Step Heat Treatment", Journal of Magnetism and Magnetic Materials, Vol. 345, p 239-242, 2013.

13. P. Saravanan, R. Gopalan, D. Sivaprahasam and V. Chandrasekaran, "Effect of Sintering Temperature on the Structure and Magnetic Properties of $SmCo_5$/Fe Nanocomposite Magnets prepared by Spark Plasma Sintering (vol 17, pg 517, 2009)", Intermetallics, Vol. 42, p 198-204, 2013.

14. D. Chakravarty and G. Sundararajan, "Microstructure, Mechanical Properties and Machining Performance of Spark Plasma Sintered Al_2O_3-ZrO_2-TiCN Nanocomposites", Journal of the European Ceramic Society, Vol.33 (13-14), p 2597-2607, 2013.

15. G. Sivakumar, R.O. Dusane, and S.V.Joshi, "A Novel Approach to Process Phase Pure Alpha-Al_2O_3 Coatings by Solution Precursor Plasma Spraying", Journal of the European Ceramic Society, Vol. 33(13-14), p 2823-2829, 2013.

16. B. Shanmugarajan, J.N. Chary, G. Padmanabham, B. Arivazhagan, S.K. Albert and A.K. Bhaduri, "Studies on Autogenous Laser Welding of Type $304B_4$ Borated Stainless Steel", Optics and Lasers in Engineering, Vol. 51(11), p 1272-1277, 2013.

17. G. Sundararajan, R. Vijay and A.V. Reddy, "Development of 9Cr Ferritic-Martensitic and 18Cr Ferritic Oxide Dispersion Strengthened Steels", Current Science, Vol.105(8),p 1100-1106, 2013.

18. P. Biswas, K. Rajeswari, P. Ramavath, R. Johnson and H.S. Maiti, "Fabrication of Transparent Spinel Honeycomb Structures by Methyl Cellulose based Thermal Gelation Processing", Journal of the American Ceramic Society, Vol.96(10), p 3042-3045, 2013.

19. R. Lalitha Sridhar and Ramya Krishnan, "PEMFC Membrane Electrode Assembly Degradation Study based on its Mechanical Properties", International Journal of Materials Research, Vol. 104(9), p 892-898, 2013.

20. S.M. Shariff, T.K. Pal, G. Padmanabham and S.V. Joshi, "Influence of Chemical Composition and Prior Microstructure on Diode Laser Hardening of Railroad Steels", Surface and Coatings Technology, Vol. 228, p 14-26, 2013.

21. K. Vijayasankar, Neha Y. Hebalkar, H.G. Kim and P.H. Borse, "Controlled Band Energetics in Pb-Fe-Nb-O Metal Oxide Composite System to Fabricate Efficient Visible Light Photocatalyst", Journal of Ceramic Processing Research, Vol. 14(4), p 557-562, 2013.

22. S. Nirmala, G. Sivakumar, A.S. Joshi, N. Aruna, D.S. Rao and G. Sundararajan, "A Computer-Based Approach for Developing Functionally Graded and Layered Coatings with Detonation Spray Coating Process", Journal of Scientific and Industrial Research, Vol.72(8), p 477-480, 2013.

23. P.H. Borse and D. Das, "Advance Workshop Report on Evaluation of Hydrogen Producing Technologies for Industry Relevant Application ARCI, Hyderabad, India, 8-9 February 2013", International Journal of Hydrogen Energy, Vol. 38, p 11470-11471, 2013.

24. Ch. Sujatha, K.V. Reddy, K.S. Babu, A. R. Reddy, M.B. Suresh and K.H. Rao, "Effect of Mg Substitution on Electromagnetic Properties of NiCuZn Ferrite", Journal of Magnetism and Magnetic Materials Vol.340, p 38-45, 2013.

25. P. Sai Pramod, K.V. Rajulapati, M. Ramakrishna, K. Valleti, G. Ravi Chandra and S.V. Joshi, "Characterization of Multilayer Nitride Coatings by Electron Microscopy and Modulus Mapping", Materials Characterization, Vol. 81, p 07-18, 2013.

26. K. Rajeswari, S. Padhi, A.R.S. Reddy, R. Johnson and D. Das, "Studies on Sintering Kinetics and Correlation with the Sinterability of 8Y Zirconia Ceramics based on the Dilatometric Shrinkage Curves", Ceramics International, Vol.39(5), p 4985-4990, 2013.

27. P. Kathirvel, J. Chandrasekaran, D. Manoharan and S. Kumar, "Formation and Characterization of Flame Synthesized Hexagonal Zinc Oxide Nanorods for Gas Sensor Applications", Ceramics International, Vol.39 (5), p 5321-5325, 2013.

28. Ch. Sujatha, K.V. Reddy, K.S. Babu, A. R.C. Reddy, M.B. Suresh and K.H. Rao, "Effect of Co Substitution of Mg and Zn on Electromagnetic Properties of NiCuZn Ferrites", Journal of Physics and Chemistry of Solids, Vol.74(7), 917-923, 2013.

29. P.Divya, T.T. Baby, V.B. Parambhath, N. Rajalakshmi and S. Ramaprabhu, "Carbon Nanostructure Grown using Bi-Metal Oxide as Electrocatalyst Support for Proton Exchange Membrane Fuel Cell", International Journal of Hydrogen Energy, Vol. 38(15),p 6460-6468, 2013.

30. B. Palanisamy, C.M. Babu, B. Sundaravel, S. Anandan and V. Murugesan, "Sol-Gel Synthesis of Mesoporous Mixed Fe2O3/TiO2 Photocatalyst: Application for Degradation of 4-Chlorophenol", Journal of Hazardous Materials, Vol. 252, p 233-242, 2013.

31. D. Sreekanth, N. Rameshbabu, K. Venkateswarlu, C. Subrahmanyam, L. Rama Krishna and K.P. Rao, "Effect of K2TiF6 and Na2B4O7 as Electrolyte Additives on Pore Morphology and Corrosion Properties of Plasma Electrolytic Oxidation Coatings on ZM21 Magnesium Alloy", Surface and Coatings Technology, Vol. 222, p 31-37, 2013.

32. P. Ramavath, M. Swathi, M.B. Suresh and R. Johnson, "Flow Properties of Spray Dried Alumina Granules using Powder Flow Analysis Technique", Advanced Powder Technology, Vol. 24(3), p 667-673, 2013.

33. M. Sreekanth, B.V. Sarada, S.R. Dey and S.V. Joshi, "Improved Photoelectrochemical Performance of Cu(In,Ga)Se-2 Thin Films Prepared by Pulsed Electrodeposition", Journal of Renewable and Sustainable Energy, Vol.5(3), Article Number: 031602, 2013.

34. L. Sowntharya, G. Ravi Chandra, K.R.C. Soma Raju and R. Subasri, "Effect of Addition of Surface Modified Nanosilica into Silica-Zirconia Hybrid Sol-Gel Matrix", Ceramics International, Vol.39(4), p 4245-4252, 2013.

35. L. Sowntharya and R. Subasri, "A Comparative Study of Different Curing Techniques for SiO_2-TiO_2 Hybrid Coatings on Polycarbonate", Ceramics International, Vol. 39(4), p 4689-4693, 2013.

36. P. Karthika, H Ataee-Esfahani, H.J. Wang, M.A. Francis, H. Abe, N. Rajalakshmi, K.S. Dhathathreyan, D. Arivuoli, and Y. Yamauchi, "Synthesis of Mesoporous Pt-Ru Alloy Particles with Uniform Sizes by Sophisticated Hard-Templating Method", Chemistry-An Asian Journal, Vol. 8(5), p 902-907, 2013.

37. A. Bhaskar, M. Deepa and T.N. Rao, "MoO_2/Multiwalled Carbon Nanotubes (MWCNT) Hybrid for use as a Li-Ion Battery Anode", ACS Applied Materials and Interfaces, Vol.5(7), p 2555-2566, 2013.

38. P. Karthika, H Ataee-Esfahani, Y.H.Deng, K.C.W. Wu, N. Rajalakshmi, K.S. Dhathathreyan, D. Arivuoli, and Y. Yamauchi, "Hard-Templating Synthesis of Mesoporous Pt-Based Alloy Particles with Low Ni and Co Contents", Chemistry Letters, Vol.42(4), p 447-449, 2013.

39. B. Palanisamy, C.M. Babu, B. Sundaravel, S. Anandan and V. Murugesan, "Visible-Light Active Mesoporous Ce Incorporated TiO_2 for the Degradation of 4-Chlorophenol in Aqueous Solution", Journal of Nanoscience and Nanotechnology, Vol. 13(4), SI- p 2573-2581, 2013.

40. N.M. Chavan, B. Kiran, A. Jyothirmayi, P.S. Phani and G. Sundararajan, "The Corrosion Behavior of Cold Sprayed Zinc Coatings on Mild Steel Substrate", Journal of Thermal Spray Technology, Vol.22(4),p 463-470, 2013.

41. P. Suresh Babu, B. Basu and G. Sundararajan, "A Comparison of Mechanical and Tribological Behavior of Nanostructured and Conventional WC-12Co Detonation-Sprayed Coatings", Journal of Thermal Spray Technology, Vol. 22(4), p 478-490, 2013.

42. B. Nagaraj, T.K. Divya, M. Barasa, N.B.Krishnamurthy, R. Dinesh, C.C. Negrila and D. Predoi, "Phytosynthesis of Gold Nanoparticles using Caesalpinia Pulcherrima (Peacock Flower) Flower Extract and Evaluation of their Antimicrobial Activities", Journal of Optoelectronics and Advanced Materials, Vol.15(3-4), p 299-304, 2013.

43. P. Karthika, N. Rajalakshmi and K.S. Dhathathreyan, "Phosphorus-Doped Exfoliated Graphene for Supercapacitor Electrodes", Journal of Nanoscience and Nanotechnology, Vol. 13(3), p 1746-1751, 2013.

44. V. Dhand, J.S. Prasad, M.V. Rao, S. Bharadwaj, Y. Anjaneyulu and P.K. Jain, "Flame Synthesis of Carbon Nano Onions using Liquefied Petroleum Gas without Catalyst", Materials Science and Engineering C-Materials For Biological Applications, Vol.33(2), p 758-762, 2013.

45. R. Vijay, M. Nagini, J. Joardar, M. Ramakrishna, A.V. Reddy and G. Sundararajan, "Strengthening Mechanisms in Mechanically Milled Oxide-Dispersed Iron Powders", Metallurgical and Materials Transactions A-Physical Metallurgy and Materials Science, Vol. 44A(3), p 1611-1620, 2013.

46. K. Jeevajothi, R. Subasri and K.R.C. Soma Raju, "Transparent, Non-Fluorinated, Hydrophobic Silica Coatings with Improved Mechanical Properties", Ceramics International, Vol. 39(2), p 2111-2116, 2013.

47. M. Maidhily, N. Rajalakshmi and K.S. Dhathathreyan, "Electrochemical Impedance Spectroscopy as a Diagnostic Tool for the Evaluation of Flow Field Geometry in Polymer Electrolyte Membrane Fuel Cells", Renewable Energy, Vol. 51, p 79-84, 2013.

48. K. Latha, S. Vidhya, B. Umamaheswari, N. Rajalakshmi and K.S.Dhathathreyan, "Tuning of PEM Fuel Cell Model Parameters for Prediction of Steady State and Dynamic Performance under Various Operating Conditions", International Journal of Hydrogen Energy, Vol. 38(5), p 2370-2386, 2013.

49. P. Balaji, D. Kalita, P.K. Jain, G. Padmanabham, M. Ravi, and K.S. Bhat, "Nitrogen Incorporated Highly Aligned Carbon Nanotube Arrays Thin Film Grown from Single Feedstock for Field Emission", Journal of Nanoelectronics and Optoelectronics, Vol.8(2), p 177-181, 2013.

50. K. Hembram, D. Sivaprakasam, T.N. Rao and K.Wegner, "Large-Scale Manufacture of ZnO Nanorods by Flame Spray Pyrolysis", Journal of Nanoparticle Research, Vol. 15(2) Article Number: 1461, 2013.

51. I. Jeong, C. Jo, A. Anthonysamy, J.M. Kim, E. Kang, J. Hwang, E. Ramasamy, S.W. Rhee, J.K. Kim, K.S. Ha, K.W. Jun and J. Lee, "Ordered Mesoporous Tungsten Suboxide Counter Electrode for Highly Efficient Iodine-Free Electrolyte-Based Dye-Sensitized Solar Cells", Chemsuschem, Vol. 6(2), p 299-307, 2013.

52. P. Sathiya, M.K. Mishra, R. Soundararajan and B. Shanmugarajan, "Shielding Gas Effect on Weld Characteristics in Arc-Augmented Laser Welding Process of Super Austenitic Stainless Steel", Optics and Laser Technology, Vol.45, p 46-55, 2013.

53. A. Pareek, R. Dom and P.H. Borse, "Fabrication of Large Area Nanorod like Structured CdS Photoanode for Solar H-2 Generation using Spray Pyrolysis Technique", International Journal of Hydrogen Energy, Vol.38(1), p 36-44, 2013.

54. S. Anandan, T.N. Rao, M. Sathish, D. Rangappa, I. Honma, and M. Miyauchi, "Superhydrophilic Graphene-Loaded TiO_2 Thin Film for Self-Cleaning Applications", ACS Applied Materials and Interfaces, Vol. 5(1), p 207-212, 2013.

55. N. Sivanandham, A. Rajadurai, S.M. Shariff, J. Senthilselvan and A. Mahalingam, "Mechanical Properties and Microstructure Analysis of Laser Surface Melting of EN32B Low Carbon Steel", International Journal of Surface Science and Engineering Vol.7(4), p 329-344, 2013.

56. A. Pareek, Neha Y. Hebalkar and P.H. Borse, "Fabrication of a Highly Efficient and Stable Nano-Modified Photoanode for Solar H-2 Generation", RSC Advances, Vol. 3(43),p 19905-19908, 2013.

57. R. Dom, Lijin R. Baby, H.G. Kim and P.H. Borse, "Enhanced Solar Photoelectrochemical Conversion Efficiency of ZnO:Cu Electrodes for Water-Splitting

Application", International Journal of Photoenergy, Article Number: 928321, 2013.

58. R. Dom, G.S. Kumar, Neha Y. Hebalkar, S.V. Joshi and P.H. Borse, "Eco-Friendly Ferrite Nanocomposite Photoelectrode for Improved Solar Hydrogen Generation", RSC Advances, Vol.3(35), p 15217-15224, 2013.

59. S. Thirumalairajan, K. Girija, Neha Y. Hebalkar, D. Mangalaraj, C. Viswanathan and N. Ponpandian, "Shape Evolution of Perovskite $LaFeO_3$ Nanostructures: A Systematic Investigation of Growth Mechanism, Properties and Morphology Dependent Photocatalytic Activities", RSC Advances, Vol.3(20), p 7549-7561, 2013.

60. S. Mandati, B.V. Sarada, S.R. Dey and S.V. Joshi, "Pulsed Electrodeposition of $CuInSe_2$ Thin Films with Morphology for Solar Cell Applications", Journal of the Electrochemical Society, Vol.160(4), p D173-D177, 2013.

61. P. Barick, D.C. Jana and N. Thiyagarajan, "Effect of Particle Size on the Mechanical Properties of Reaction Bonded Boron Carbide Ceramics", Ceramics International, Vol.39(1), p 763-770, 2013.

62. S. Nagarajan, P. Sudhagar, V. Raman, W. Cho, K.S. Dhathathreyan and Y.S. Kang, "A PEDOT-Reinforced Exfoliated Graphite Composite as a Pt- and TCO-Free Flexible Counter Electrode for Polymer Electrolyte Dye-Sensitized Solar Cells", Journal of Materials Chemistry A, Vol.1(4), p 1048-1054, 2013.

63. G. Sundararajan, P. Biswas, and N.E. Prasad, "Mechanical Properties of Transparent Polycrystalline Alumina Ceramics Processed using an Environmentally Benign Thermal Gel Casting Process", Experimental Mechanics, Vol.53(1),SI p 123-129, 2013.

64. S. Polaki, R. Ramaseshan, F. Jose, S. Dash, A.K. Tyagi and N. Ravi, "Evolution of Structural and Mechanical Properties of TiN Films on SS 304LN", International Journal of Applied Ceramic Technology, Vol.10(1), p 45-50, 2013.

65. S. Pandiyan, A. Elayaperumal, N. Rajalakshmi, K.S. Dhathathreyan and N. Venkateshwaran, "Design and Analysis of a Proton Exchange Membrane Fuel Cells (PEMFC)", Renewable Energy, Vol. 49-SI, p 161-165, 2013.

66. R. Papitha, M.B. Suresh, D. Das and R. Johnson, "Effect of Micro-Cracking on the Thermal Conductivity and Thermal Expansion of Tialite (Al_2TiO_5) Ceramics", Processing and Applications of Ceramics, Vol.7(3), p 143-146, 2013.

67. R. Papitha, M.B. Suresh, Y. Srinivasa Rao, B. P. Saha, D. Das and R. Johnson, "Pressure Slip Casting and Cold Isostatic Pressing of Aluminium Titanate Green Ceramics: A Comparative Evaluation", Processing and Applications of Ceramics, Vol.7(4), p 159-166, 2013.

68. N. Kumar, A. Jyothirmayi, K. R. C. Soma Raju, V. Uma and R. Subasri, "One Step Anodization/Sol-Gel Deposition of Ce^{3+}-Doped Silica-Zirconia Self-Healing Coating on Aluminum", ISRN Corrosion, Article ID 424805, 2013.

69. R. Subasri, G. Reethika and K.R.C. Soma Raju," Multifunctional Sol-Gel Coatings for Protection of Wood", Wood Material Science and Engineering, Vol. 8(4), p 226-233, 2013.

70. S. Nirmala, G. Telasang, N. Aruna, A. S. Joshi and G. Padmanabham, "A Virtual Instrument for Thermal Fatigue Testing of Die Casting Tool Steels", Journal of Instrument Society of India, Vol.43(4), p 261-262, 2013.

71. Priya A. Mathews, K.R.C. Soma Raju, S. Bhardwaj and R. Subasri, "Sol-Gel Functional Coatings for Solar Thermal Applications: A Review of Recent Patent Literature", Recent Patents on Materials Science, Vol.6(3), p 195-213, 2013.

72. H. Purushotham, V. Sridhar and Ch. Shyam Sundar, "Management of Technology Transfer from Indian Publicly Funded R&D Institutions to Industry-Modeling of Factors Impacting Successful Technology Transfer", International Journal of Innovation Management and Technology, Vol.4(4), p 422-428, 2013.

73. V. Senthilvelan, P Karthika, N. Rajalakshmi and K.S. Dhathathreyan, "A Novel Graphene Based Cathode for Metal – Air Battery", Graphene, Vol.1(2), p 86-92, 2013.

74. P. Karthika, N. Rajalakshmi and K.S. Dhathathreyan, "Synthesis of Alkali Intercalated Graphene Oxide for Electrochemical Supercapacitor Electrodes with High Performance and Long Cycling Stability", Graphene, Vol.1(1), p 16-24, 2013.

75. S. Naveen Kumar, N. Rajalakshmi and K. S. Dhathathreyan, "Efficient Power Conditioner for a Fuel Cell Stack-Ripple Current Reduction using Multiphase Converter", Smart Grid and Renewable Energy, Vol. 4(1), p 53-56,2013.

76. A. Venkateswarlu, V.K. Sharma and L. Rama Krishna, "Evaluation of Microstructure and Texture of Alloy-90

Sheets", International Journal of Latest Trends in Engineering and Technology, Vol. 2(3), p 01-10, 2013.

77. S. Bhardwaj, K. Jain and S.V. Joshi, "Technology Commercialization by Micro, Small and Medium Enterprises (MSMEs) in Indian Context: Challenges and Governmental Support Systems", Indian Journal of Economics and Business, Vol.12(1), p 57-71, 2013.

78. T.K. Gireesh Kumar and M. Jayapradeep, 'Knowledge Management and Electronic Theses and Dissertations in Libraries: Perils and Solutions in Indian Perspective' IASLIC Bulletin Vol.58 (4), p 206-227, 2013.

79. H. Purushotham, "Transfer of Nano-Technologies from R&D Institutions to SMEs in India: Opportunities and Challenges", Tech Monitor, p 23-33,Oct-Dec 2013.

80. T.N Rao and Raju Prakash, "Nano Batteries: Future of Automotive Transportation", Nano Digest, Vol. 4, p 28 -31, 2013.

81. S. Sudhakara Sarma and T.N. Rao, "A Novel Method for Measurement of Porosity of Nanofiber Mat Using Pycnometer in Filtration", Journal of Engineering Fibers and Fabrics, Vol. 8(4), p 132-137, 2013.

82. G. Padmanabham and R.N. Bathe, "Applications of Laser Processing of Materials", KIRAN, Vol. 24(2), p 03-14, 2013.

83. G. Telasang, J.D. Majumdar, G Padmanabham and I. Manna, "Refurbishment of AISI H13 Die Materials by Laser Cladding", KIRAN, Vol. 24(2), p 33-37, 2013.

84. I. Ganesh, "A Review on Magnesium Aluminate ($MgAl_2O_4$) Spinel: Synthesis, Processing and Applications", International Materials Reviews, Vol. 58(2), p 63-112, 2013.

85. A. V. B. Subrahmanyam, B. Padya and P.K. Jain, "Influence of Nitrogen Doping Concentration on Morphology and Microstructure of Nitrogen Doped Super Aligned Carbon Nanotubes Forest", Journal of Advanced Microscopy Research, Vol.8(4), p 300-302, 2013.

86. R. Vijay, M. Nagini, S.S. Sarma, M. Ramakrishna, A.V. Reddy and G. Sundararajan, "Structure and Properties of Nano Scale Oxide Dispersed Iron", Metallurgical Materials Transactions A, Vol. 45, p 777-784, 2014.

87. P. Ramavath, P. Biswas, K. Rajeshwari, M.B. Suresh, R. Johnson, G. Padmanabham, C.S. Kumbhar, T.K. Chongdar and N.M. Gohkale, "Optical and Mechanical Properties of Compaction and Slip Cast Processed Transparent Polycrystalline Spinel Ceramics", Ceramics International, Vol. 40, p 5575-5581, 2014.

88. K. Mamatha and R. Subasri, "Investigations on Coatings Generated from Silica-Zirconia Hybrid Sols Synthesized through Hydrolytic/Non-Hydrolytic Wet Chemical Route on PMMA Substrates", Ceramics International, Vol.40, p 10615-10619, 2014.

89. S. Pavithra and R. Subasri, "Sol-Gel Derived Single Layer Zeolite-MgF_2 Composite Antireflective Coatings with Improved Mechanical Properties on Polycarbonate", Journal of Coatings Sciences and Technology, Vol.1, p 08-16, 2014.

90. G.V. Ramana, B. Padya, V.V.S.S. Srikanth and P.K. Jain, "Rapid Mixing Chemical Oxidation Polymerization: An Easy Route to Prepare PANI Coated Small Diameter CNTs/PANI Nanofiber Composite Films", Bulletin of Materials Research, Vol. 37(3), p 585-588, 2014.

91. V. Senthilvelan, G. Velayutham, N. Rajalakshmi and K.S. Dhathathreyan, "Influence of Compressive Stress on the Pore Structure of Carbon Cloth Based Gas Diffusion Layer Investigated by Capillary Flow Porometry", International Journal of Hydrogen Energy, Vol. 39, p1752- 1759, 2014.

92. N. Sasikala, K. Ramya and K.S. Dhathathreyan, "Bi-Functional Electrocatalyst for Oxygen/Air Electrodes", Energy Conversion and Management, Vol. 77, p 545-549, 2014.

93. S. Seetharaman, R. Balaji, K. Ramya, K. S. Dhathathreyan and M. Velan, "Electrochemical Behaviour of Nickel-Based Electrodes for Oxygen Evolution Reaction in Alkaline Water Electrolysis", Ionics, Vol. 20 (5), p 713-720, 2014.

94. V. Krishna, D. Murali Krishna and S.V. Joshi, "Functional Multilayer Nitride Coatings for High Temperature Solar Selective Applications", Solar Energy Materials and Solar Cells, Vol. 121, p 14-21, 2014.

95. M. Sandhyarani, N. Rameshbabu, K. Venkateswarlu and L. Rama Krishna, "Fabrication, Characterization and In-Vitro Evaluation of Nanostructured Zirconia/Hydroxyapatite Composite Film on Zirconium", Surface and Coatings Technology, Vol. 238, p 58-67, 2014.

96. P. Kathirvel, J. Chandrasekaran, D. Manoharan and S. Kumar, "Preparation and Characterization of Alpha Alumina Nanoparticles by In-Flight Oxidation of Flame Synthesis", Journal of Alloys and Compounds, Vol. 590, p 341-345, 2014.

97. I. Ganesh, P.P. Kumar, I. Annapoorna, J.M. Sumliner, M. Ramakrishna, Neha Y. Hebalkar, G. Padmanabham and G. Sundararajan, "Preparation and Characterization of Cu-doped TiO_2 Materials for Electrochemical,

Photoelectrochemical, and Photocatalytic Applications", Applied Surface Science, Vol.293, p 229-247, 2014.

98. S. B. Chandrasekhar, S. Sudhakara Sarma, M. Ramakrishna, P. Suresh Babu, T.N. Rao and B.P. Kashyap, "Microstructure and Properties of Hot Extruded Cu-1wt% Al_2O_3 Nano-Composites Synthesized by Various Techniques", Materials Science and Engineering A, Vol. 591, p 46-53, 2014.

99. R. Dom, H.G. Kim and P.H. Borse, "Efficient Hydrogen Generation over (100)-Oriented ZnO Nanostructured Photoanodes under Solar Light", CrystEngComm , Vol.16(12), p 2432-2439, 2014.

100. A. Pareek, R. Purbia, P. Paik, Neha Y. Hebalkar, H. G. Kim and P.H. Borse, "Stabilizing Effect in Nano-Titania Functionalized CdS Photoanode for Sustained Hydrogen Generation", International Journal of Hydrogen Energy, Vol. 39, p 4170-4180, 2014.

101. P.H. Borse, K.T. Lim, J.H. Yoon and H.G.Kim, "Investigation of the Physico-Chemical Properties of $Sr_2FeNbWxO_6$ $(0.0<x<0.1)$ for Visible Light Photocatalytic Water Splitting Applications", Journal of the Korean Physical Society, Vol. 64, p 295-300, 2014.

102. P. Suresh Babu, B. Boesl, C. Zhang, D. Lahiri, A. Nieto, G. Sundararajan and A. Agarwal, "Dry Sliding Wear Behavior of Cold Sprayed Aluminum Amorphous/ Nanocrystalline Alloy Coatings", Surface and Coatings Technology, Vol. 238, p 118-125, 2014.

103. P. Suresh Babu, Debrupa Lahiri, G. Sundararajan and Arvind Agarwal, "Scratch Induced Deformation Behavior of Cold Sprayed Aluminum Amorphous/ Nanocrystalline Coatings at Multiple Load Scales", Journal of Thermal Spray Technology, Vol. 23, p 502-513, 2014.

104. S.V. Joshi, G. Sivakumar, T. Raghuveeer and R.O. Dusane, "Hybrid Plasma – Sprayed Thermal Barrier Coatings using Powder and Solution Precursor Feedstock", Journal of Thermal Spray Technology, Vol. 23(4), p 616-624, 2014.

105. Bhuvaneswari, P.M. Pratheeksha, S. Anandan, R. Dinesh, R. Gopalan, and T.N. Rao, "Efficient Reduced Graphene Oxide Grafted Porous Fe_3O_4 Composites as a High Performance Anode Materials for Li-Ion Batteries", Physical Chemistry Chemical Physics, Vol. 16, p 5284-5294, 2014.

106. S. Anandan, T. N. Rao, R. Gopalan and Y. Ikuma, "Fabrication of Visible-Light-Driven N-Doped Ordered Mesoporous TiO_2 Photocatalysts and their Photocatalytic Applications", Journal of Nanoscience and Nanotechnology, Vol. 14, p 3181-3186, 2014.

107. K.H. Anulekha, S.S. Chandra, V. Sritharan and T.N. Rao, "Fabrication and Surface Functionalization of Electrospun Polystyrene Submicron Fibres with Controllable Surface Roughness", RSC Advances, Vol.4, p 12188-12197, 2014.

108. R. Papitha, M.B. Suresh, D. Chakravarty, A. Swarnakar, D. Das and R. Johnson, " Eutectoid Decomposition of Aluminium Titanate (Al_2TiO_5) Ceramics under Spark Plasma (SPS) and Conventional (CRH)", Ceramics International , Vol. 40(1), p 659-666, 2014.

109. M. Sreekanth, B.V. Sarada, S.R. Dey and S.V. Joshi, "Two-Step Pulsed Current Electrodeposition of CIGS Absorber Layers for Thin Solar Films", Materials Letters, Vol. 118, p 158-160, 2014.

110. R.N. Bathe, A.K. Singh and G. Padmanabham, "Effect of Pulsed Laser Dressing of Metal Bonded Diamond Wheels on Cutting Performance", Materials and Manufacturing Processes, Materials and Manufacturing Processes, Vol. 29, p 386-389, 2014.

111. G. Telasang, J.D. Majumdar, G. Padmanabham and I. Manna, "Structure-Property Correlation in Laser Surface Treated AISI H13 Tool Steel for Improved Mechanical Properties", Materials Science and Engineering A, Vol. 599, p 255–267, 2014.

112. I. Ganesh, "Conversion of Carbondioxide into Methanol- A Potential Liquid Fuel: Fundamental Challenges and Opportunities", Renewable and Sustainable Energy Reviews, Vol. 31, p 221-257, 2014.

113. I. Ganesh, P. P. Kumar, I. Annapoorna, J. M. Sumliner, M. Ramakrishna, N. Y. Hebalkar, G. Padmanabham and G. Sundararajan, "Preparation and Characterization of Cu-doped TiO_2 Materials for Electrochemical, Photoelectrochemical & Photocatalytic Applications", Applied Surface Science, Vol. 293, p 229-247, 2014.

114. I. Ganesh, "The Latest State of the Art on Artificial Photosynthesis", Chem Express, Vol. 3(4), p 131-148, 2014.

115. Ch L. P. Pavithra, B.V. Sarada, R.V. Koteswararao, T. N. Rao and G. Sundararajan, "A New Electrochemical Approach for the Synthesis of Copper-Graphene Composite Foils with High Hardness", Scientific Reports, Vol.4, Article No 4049, 2014. (doi:10.1038/ srep04049)

116. R. Kumar, S. Anandan, K. Hembram and T.N. Rao, "Efficient ZnO-based Visible-Light-Driven Photocatalysts for Antibacterial Applications", ACS

Applied Materials and Interfaces, DOI: 10.1021/am502915v.

117. K. Rajeshwari, P. Biswas, R. Johnson, S. Prabhudesai, V. K. Sarma, S. Mitra and R. Mukhopadhayay, "Effect of Surface Passivation in Spinel Slurry Toward Hydrolysis: Neutron Scattering and Rheological Studies", Journal of Dispersion Science and Technology, doi:10.1080/01932691.2013.850718.

118. R. Papitha, M.B. Suresh and R. Johnson, "High Temperature Flexural Strength and Thermal Stability of Near Zero Expanding Doped Aluminium Titanate Ceramics for Diesel Particulate Filters Applications", International Journal of Applied Ceramic Technology, doi:10.1111/ijac.12092.

119. G. Sivakumar, R. O. Dusane and S. V. Joshi, "Understanding the Formation of Vertical Cracks in Solution Precursor Plasma Sprayed Yttria-Stabilized Zirconia Coatings", Journal of American Ceramic Society, doi:10.1111/jace.13129.

120. A. Lohia, G. Sivakumar, M. Ramakrishna and S. V. Joshi, "Deposition of Nanocomposite Coatings Employing a Hybrid APS+SPPS Technique", Journal of Thermal Spray Technology, doi:10.1007/s11666-014-0071-8.

121. S. R. Dhage, M. Tak and S. V. Joshi, "Fabrication of CIGS Thin Films Absorber by Laser Treatment of Pre-Deposited Nano-Ink Precursor Layer", Materials Letters, doi:10.1016/j.matlet.2014.07.107

122. R. Bathe and G. Padmanabham, "Evaluation of Laser Drilling of Holes in Thermal Barrier Coated Superalloys", Materials Science and Technology. (In Press)

123. R. Bathe, V.S. Krishna, S. K. Nikumb and G. Padmanabham, "Laser Surface Texturing of Gray Cast Iron for Improving Tribological Behavior", Applied Physics A . (In Press)

124. D. Narasimhachary, R. Bathe, G. Padmanabham and A. Base, "Influence of Temperature Profile during Laser Welding Alloy 6061 T6 on Microstructure and Mechanical Properties", Materials and Manufacturing Processes. (In Press)

Conference Proceedings

1. Rekha Dom, A. S. Chary and P. H. Borse, "Investigation of Physico-Chemical Properties of Nano Crystalline MFe_2O_4 (M:Ca,Zn and Mg) Photocatalysts Synthesized by Microwave Irradiation", Proceedings of the APMS Conference, ISBN:978-93-82570-10-3, p 32, 2013.

2. K. Prashant, "Solid Oxide Fuel Cells as Alternative Energy Source for Sustainable Development", Proceedings of International Conference on Advanced Nanomaterials and Emerging Engineering Technologies (ICANMEET 2013), Chennai, p 459-463, 2013.

3. G. Padmanabham, Y. K. Priya, K. V. P. Prabhakar, K. V. Phani, R.N. Bathe, K. B. S. Rao, "A Comparison of Interface Characteristics and Mechanical Properties of Aluminium-Steel Joints made by Pulsed-MIG and Cold Metal Transfer (CMT) Processes" (eds. DebRoy T; David SA; DuPont JN; Koseki T; Bhadeshia HK), Trends in Welding Research: Proceedings of the 9th International Conference, p 227-234, 2013.

4. J. Bensingh, S. Ilangovan, S. K. Nayak, L. Sowntharya, K. Murugan, R. Subasri, Neeraj Kumar, Keshva Nand, V. Mishra, G. S. Singh and S. V. Rama Gopal, "Integrated Optimization Efforts to Improve Surface Quality In Injection Molded, Sol-Gel Coated High Precision Bi-Aspheric Polycarbonate Lenses (20D and 28D) for Indirect Ophthalmoscopy", Proceedings of the International Conference on Advancements in Polymeric Materials (APM 2013), CIPET, Lucknow, p177-178, 2013.

5. R. C. Gundakaram and S. P. Pemmasani, "Characterization of Coatings by SEM Based Microdiffraction", Textures of Materials, Pts 1 and 2 (Proceedings of 16th International Conference on the Textures of Materials (ICOTOM 16), Mumbai), Materials Science Forum, Vol. 702-703, p 570-573, 2013.

6. M. Sreekanth, B. V. Sarada, S. R. Dey and S. V. Joshi, "Pulsed Electro Deposition and Characterization of CIGS Thin Films for Solar Cells Applications", Proceedings of 5th ISEAC Triennial International Conference on Advances and Recent Trends in Electrochemistry, p 558-661, 2013.

7. Rekha Dom, G. Siva Kumar, S. V. Joshi and P. H. Borse, "Photoelectrochemical Characterization of Fe_2O_3, $ZnFe_2O_3$ and Composite Photoelectrodes for Hydrogen Generation Application", Proceedings of the Fifth ISEAC Triennial International Conference on Advances and Recent Trends in Electrochemistry (ELAC-2013), p 368-371, 2013.

8. A. Pareek and P. H. Borse, "Photoelectrochemical Characterization of Metal-Semiconductor Nanoparticle Modified Nanostructured Cds Photoelectrodes", Proceedings of the Fifth ISEAC Triennial International Conference on Advances and Recent Trends in Electrochemistry (ELAC-2013), p 372-375, 2013.

9. S. Sabareeswaran, R. Balaji, K. Ramya, N. Rajalakshmi and K.S. Dhathathereyan, "Carbon Assisted Water Electrolysis for Hydrogen Generation", American Institute of Physics (AIP) Conference Proceedings, Vol. 1538, p 43-47, 2013.

10. B. Padya, P.K. Jain, G. Padmanabham, M. Ravi and K.S. Bhat, "Highly Ordered Nitrogen Doped Carbon Nanotube Novel Structures of Aligned Carpet for Enhanced Field Emission Properties", AIP Conference Proceedings, Vol.1538, p 196-199, 2013.

11. M. Kota, B. Padya, G.V. Ramana, P.K. Jain and G. Padmanabham, "Role of Buffer Gas Pressure on the Synthesis of Carbon Nanotubes by Arc Discharge Method", AIP Conference Proceedings, Vol.1538, p 200-204, 2013.

12. G.V. Ramana, B. Padya, V.V.S.S. Srikanth and P.K. Jain, "Thermal Properties of Multi-Walled Carbon Nanotubes-Graphite Nanosheets/Epoxy Nanocomposites", AIP Conference Proceedings, Vol.1538, p 205-208, 2013.

13. M. Ali, G.V. Ramana, B. Padya, V.V.S.S. Srikanth and P.K. Jain, "Synthesis of Amorphous Carbon Nanofibers using Iron Nanoparticles as Catalysts", AIP Conference Proceedings, Vol.1538, p 237-239, 2013.

14. S. Seetharaman, K. Ramya and K. S. Dhathathreyan, "Electrochemically Reduced Graphene Oxide/ Sulfonated Polyether Ether Ketone Composite Membrane for Electrochemical Applications", AIP Conference Proceedings, Vol.1538, p 257-261, 2013.

15. R. Naresh Kumar, B. Padya, S. B. Chandrasekhar, P.K. Jain, V.V.S.S. Srikanth and Bhanushankar Rao, "Morphological, Structural and Phase Characteristics of Conventionally Sintered MWCNTs/Cu Composites", Proceedings of International Conference on Advanced Nanomaterials and Emerging Engineering Technologies (ICANMEER)., p 190-192, 2013.

16. T. K. Gireesh Kumar, "Comparative Analysis of Search Features of Scopus and Web of Science", Proceedings of the National Conference on Information Products and Services in the e-Environment (NACINPROSE-2013)', p 373-377, 2013.

17. Muruli and T.K. Gireesh Kumar, "Marketing of Library Products and Services through Social Media: An Evaluation", Proceedings of the National Conference on Inspiring Library Services (NCILS-2013)', p. 144-154, 2013.

18. S. Bhardwaj, G. Padmanabham, K. Jain, K. Momaya and S. V. Joshi, "Strategic Alliances for Advanced Materials Technologies Value Chain: Research and Technology Organization (RTO)'s Perspective", Proceedings of the 2nd International Conference on Management of IP and Strategy, p 177-183, 2014.

19. T. K. Gireesh Kumar, "Open Source Software for Integrated Library Systems: Relative Appropriateness in the Indian Context" in the Doctoral Student Consortium and International Workshop on Global Collaboration of Information Schools Session of the 15th International Conference on Asia-Pacific Digital Libraries (ICADL 2013) Bangalore. (In Press)

20. S. R. Dhage, P. S. Chandrasekhar, S. B. Chandrasekhar and S. V. Joshi, "CIGS Absorber Layer by Single Step Non Vacuum Intense Pulsed Light Treatment of Inkjet Printed Films", Proceedings of 40th IEEE Photovoltaics Specialist Conference (IEEE-PVSC-40), Colarodo, USA .(In Press)

Books Chapters

1. 'Journal of Thermal Spray Technology', editorial K. Ogawa, H. Katanoda, C.J. Li, C. Lee, K.A. Khor, M. Hyland, G. Sundararajan and S. Kuroda , Vol. 22(8), p 1259-1260, 2013.
2. G. Sundararajan, D. Srinivasa Rao, G. Siva Kumar and S. V. Joshi, "Detonation Spray Coatings" a chapter in 'Encyclopedia of Tribology', p 736-742, 2013.
3. T.K. Gireesh Kumar and Muruli, "Information and Communication Technology Literacy (ICTL): Essential Skills for Library Professionals in the Digital Era" a chapter in 'Information Management Today and Tomorrow : Volume II', Festschrift in Honor of Prof. S. Sudarshan Rao, B. R. Publishing Corporation, New Delhi, p 353-366, 2013.
4. T. K. Gireesh Kumar "Wikis: Tool for Altering Tacit Knowledge Explicit", a chapter in 'Challenges of Library and Information Science in Digital Era', Festschrift in Honor of Dr. B. Sathaiah, PST University, Hyderabad, p 340-348, 2013.
5. S. Yadagiri and T. K. Gireesh Kumar, "Knowledge Management: Changing Role of LIS in the Digital Environment" a chapter in 'Libraries in the Changing Dimensions of Digital Technology', Festschrift In Honor of Prof. D. Chandran, B. R. Publishing Corporation, New Delhi, Vol. II, p 476-481, 2013.
6. I. Ganesh, P. S. C. Sekhar, G. Padmanabham and G. Sundararajan, "Preparation and Characterization of Li-doped ZnO Powders for Photocatalytic Applications", a chapter in 'Material Science Forum' Transtech Publications, Vol. Photocatalytic Materials and Surfaces for Environmental Cleanup-II, p 90-116, 2013.
7. Rekha Dom and P.H. Borse, "Photocatalytic and

Photoelectrochemical Study of Ferrites for Water Splitting Applications: A Comparitive Study" a chapter in 'Material Science Forum' Transtech Publications, Vol. Photocatalytic Materials and Surfaces for Environmental Cleanup-II, p 334-348, 2013.

8. I. Ganesh, "Conversion of Carbondioxide into Several Potential Chemical Commodities Following Different Pathways - A Review" a chapter in 'Material Science Forum' Transtech Publications, Vol. Photocatalytic Materials and Surfaces for Environmental Cleanup-III, p 01-82, 2013.

9. Rekha Dom, H.G.Kim and P.H. Borse, "Investigation of Solar Photoelectrochemical Hydrogen Generation Ability of Ferrites for Energy Production" a chapter in 'Material Science Forum' Transtech Publications, Vol. Photocatalytic Materials and Surfaces for Environmental Cleanup-III, p 97-115,2013.

10. I. Ganesh, Rekha Dom, P.H.Borse, I. Annapoorna, G. Padmanabham and G. Sundararajan, "Fabrication and Photoelectrochemical Characterization of Fe, Co, Ni and Cu-doped TiO_2 Thin Films", a chapter in 'Material Science Forum' Transtech Publications, Vol. Photocatalytic Materials and Surfaces for Environmental Cleanup-III, p 266-283,2013.

11. Rekha Dom, G. Sivakumar, H.G. Kim, S.V. Joshi, A.S. Chary and P.H. Borse, "Design and Development of Ferrite Composite Film Electrode for Photochemical Energy Application" a chapter in 'Materials Science Forum', Transtech Publications, Vol. 781, p 45-61, 2014.

12. K.R.C. Soma Raju and R. Subasri, "Sol-Gel Nanocomposite Hard Coatings" a chapter in the handbook entitled "Anti-Abrasive Nano Coatings: Current and Future applications", Elsevier Publishers. (In press)

Awards and Honours

1. Dr. G. Sundararajan was honoured the 'Padma Shri', the fourth highest Civilian Award, by the President of India for his outstanding contribution in the field of Science and Engineering.

Dr. G. Sundararajan being honoured the 'Padma Shri' by the President of India

2. Dr. K. Murugan received the 'Best Poster Award' for the poster presentation on 'Self-Cleaning Functional Test on Nano TiO_2 Coated Glasses and Glazed Ceramic Tiles' at the 'International Conference and Exhibition on Heat Treatment and Surface Engineering 2013 (HT&SE 2013)' held at the Chennai Trade Centre, Chennai during May 16-18, 2013 .

3. Dr. T. N. Rao received the 'Coastal Chemical Research Society (CCRS-2013) Award' under the research category at the '1st CCRS International Conference' held at Sanketika Vidya Parishad Engineering College, Andhra Pradesh during July 13-14, 2013.

4. Dr. G. Sundararajan was conferred the 'National Metallurgist Award' by the Indian Institute of Metals at 'NMD-ATM 2013' held at Varanasi during November 13-15, 2013.

Dr. G. Sundararajan receiving the National Metallurgist Award

5. Dr. R. Gopalan was conferred the 'Metallurgist of the Year Award' by the Indian Institute of Metals at 'NMD-ATM 2013' held at Varanasi during November 13-15, 2013.

Dr. R. Gopalan receiving the Metallurgist of the Year Award

6. Dr. G. Sundararajan was conferred the 'Shri Om Prakash Bhasin Award-2013' by the Shri Om Prakash Bhasin Foundation for Science and Technology.

7. Dr. S. V. Joshi received the 'MRSI-ICSC Superconductivity & Materials Science Annual Prize' for the year 2014 during the 25th Annual General Meeting of Materials Research Society of India held at IISc., Bangalore during February 12-14, 2014.

Dr. S. V. Joshi receiving the MRSI-ICSC Superconductivity & Materials Science Annual Prize

8. Dr. R. Gopalan was conferred the 'MRSI Medal' by the Materials Research Society of India at the Annual General Meeting of the Materials Research Society of India held at IISc, Bengaluru on February 12, 2014.

9. Ms. Alka Pareek (Dr. P. H. Borse) received the 'First Prize' for oral presentation of the paper on 'Characterization of Nano-Titania Modified CdS/polysulphide electrolyte interface by utilizing electrochemical Impedance spectroscopy' at the '11th ISEAC-DM-2014' held at Amritsar during February 20-25, 2014.

Ms. Alka Pareek receiving the First Prize for oral presentation

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