# PERFORMANCE REPORT

# 2012-13

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ARCI

# ARCI

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**INTERNATIONAL ADVANCED RESEARCH CENTRE
FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)**
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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.

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- **Laser Materials Processing**
- **Fuel Cells**
- **Sol-Gel Coatings**
- **Solar Energy Materials**
- **Automotive Research**

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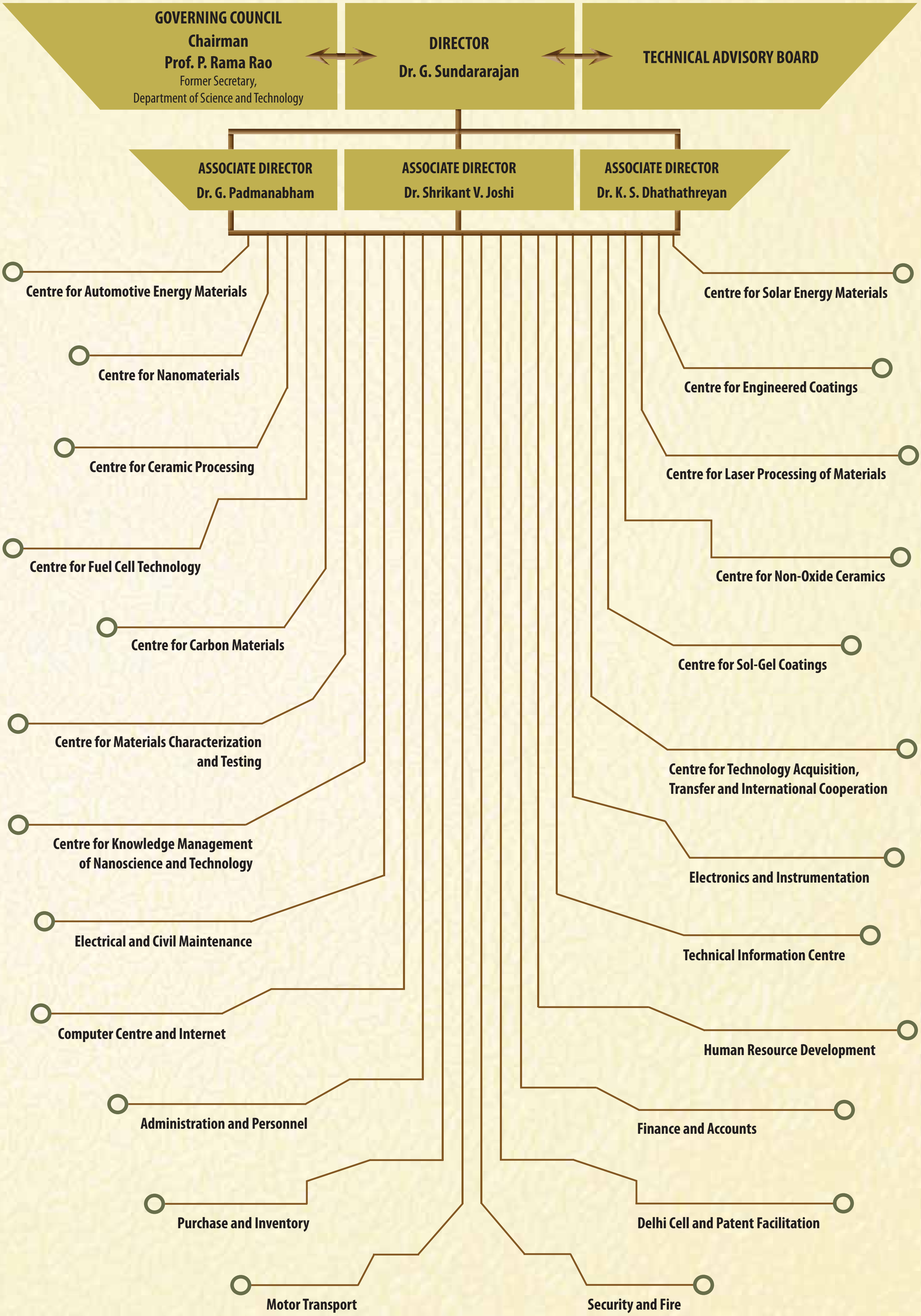

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# Director's Report

I am delighted to present the report of the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) for the year 2012-13. As usual, this report details the ongoing activities of the various Centres of Excellence operating in ARCI and also highlights the accomplishments of ARCI during the year, albeit in a slightly different format. Unlike the recent reports that described only select accomplishments of every Centre, each Scientist/ Technical Officer of ARCI, irrespective of whether he/she is associated with an R&D programme or the support services, has been requested to contribute an article focused on their core activity this year.

The Centres of Excellence that started recently, namely Centre for Solar Energy Materials (CSEM) and Centre for Automotive Energy Materials (CAEM), have made considerable progress during the past year. CAEM, located in the Indian Institute of Technology-Madras (IITM) Research Park in Chennai, has initiated major R&D programmes that focus on development of materials and components for Electric Vehicle (EV)/Hybrid Electric Vehicle (HEV) applications. The Centre is developing large format Lithium-ion cells and batteries for EVs/HEVs by setting up a comprehensive facility for Li-ion cells and battery packs at pilot plant scale. Li-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. Automobile manufacturers like Mahindra Reva and Ashok Leyland are already engaged in the manufacture of EVs based on Li-ion batteries and ARCI has initiated interactions to work closely with them to demonstrate its in-house Li-battery technology for EVs. The Centre has consciously decided to adopt a two-pronged approach for developing the Li-battery technology. The first involves establishment of state-of-the-art pilot scale facilities, including all processing equipment, dehumidified rooms etc., and demonstrating the Li-ion battery manufacturing technology with known commercial electrode materials. This is being simultaneously complemented by efforts to indigenously develop the technology for producing standard electrode materials/new materials, and test their electrochemical performance. The optimized process and/or the material technology, once ready, will be scaled up and tested in the Li-ion battery pilot plant facility set up at IITM-Research Park (Fig.1).

Fig. 1 Lithium-ion battery facility at CAEM, ARCI-Chennai

CAEM at Chennai has also launched major 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 being addressed through close technical collaborations with companies such as Lucas TVS (Chennai). In order to demonstrate the magnets technology at laboratory scale, ARCI has set up an array of all requisite process and characterization facilities (Fig. 2) to position CAEM such that it can extend the technology to the industries.

Consistent with its recent thematic focus, ARCI has also initiated solar energy related programmes in a big way. The most prominent progress on this front during the past year has been the establishment of a dedicated pilot line for CIGS thin film solar cells (Fig. 3), with an overall aim to develop new processes and to eventually maximize efficiency on glass as well as flexible substrates. The above line is capable of processing CIGS thin films on substrates of size 300 mm x 300 mm and, once the process qualification is complete, efforts will be made to make CIGS thin film solar cell devices of the above size. While the above pilot line will enable ARCI to become familiar with CIGS thin film device fabrication, it will also serve as a benchmark for the simultaneously ongoing R & D related to development of process routes that do not involve vacuum and selenization treatment.

Fig. 2 Various instruments for demonstration of magnets' technology at CAEM, ARCI, Chennai

In this context, in-house formulated CIGS inks combined with novel treatment techniques using a flash light or a laser have been used successfully to make CIGS films. Fabrication of stoichiometric single phase CIGS films with high density have also been achieved by the pulse electrodeposition technique. Efforts are currently in progress to prepare stoichiometric CZTS films with reduced porosity by the electrodeposition method in order to explore fabrication of solar cells with earth-abundant materials. The above processes represent exciting economic, environmentally friendly and scalable pathways for thin film solar cells.

Fig. 3 Pilot line for CIGS thin film solar cells

Another major initiave taken by ARCI is aimed at augmenting capabilities at the Centre for Laser Processing of Materials (CLPM). An ultrafast laser microprocessing system, comprising a Ti-sapphire regenerative laser source, is being developed jointly with National Research Council (NRC) of Canada under a collaborative arrangement. This versatile system will enable addressing diverse applications, such as micro/nano surface texturing, micro-scribing of thin film solar cells, micro-drilling of fuel injectors etc. Besides this, substantial capital expenditure of ARCI in the near future will be towards enhancement and replacement of its technical infrastructure. This has been necessitated by the fact that the critical infrastructure, such as electrical sub-stations/ transformers and fire-fighting facilities like water pipelines and fire-hydrants, has aged with time and needs to be in good operational condition.

**Table Comparing Performance Indicators**

| Parameters | | 2011-12 | 2012-13 |
|---|---|---|---|
| No. of Employees | | 170 | 173 |
| No. of Scientists | | 67 | 71 |
| No. of Publications* | | 129 | 131 |
| Indian Patents** | Granted | 22 | 23 |
| | Filed | 35 | 46 |
| International Patents** | Granted | 5 | 5# |
| | Filed | 4 | 4 |
| Scientists with Ph.D. | | 39 | 43 |
| Scientists Registered for Ph.D. | | 15 | 15 |
| No. of Deputations Abroad | | 41 | 47 |
| No. of ARCI Personnel who attended Conferences/ Seminars/Training Courses (in India) | | 243 | 217 |
| ARCI Fellows*** | | 30 | 42 |
| ARCI Trainees | | 33 | 21 |
| M.Tech./B.Tech. Project Students | | 26 | 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*
*# Includes same patent granted in multiple countries*

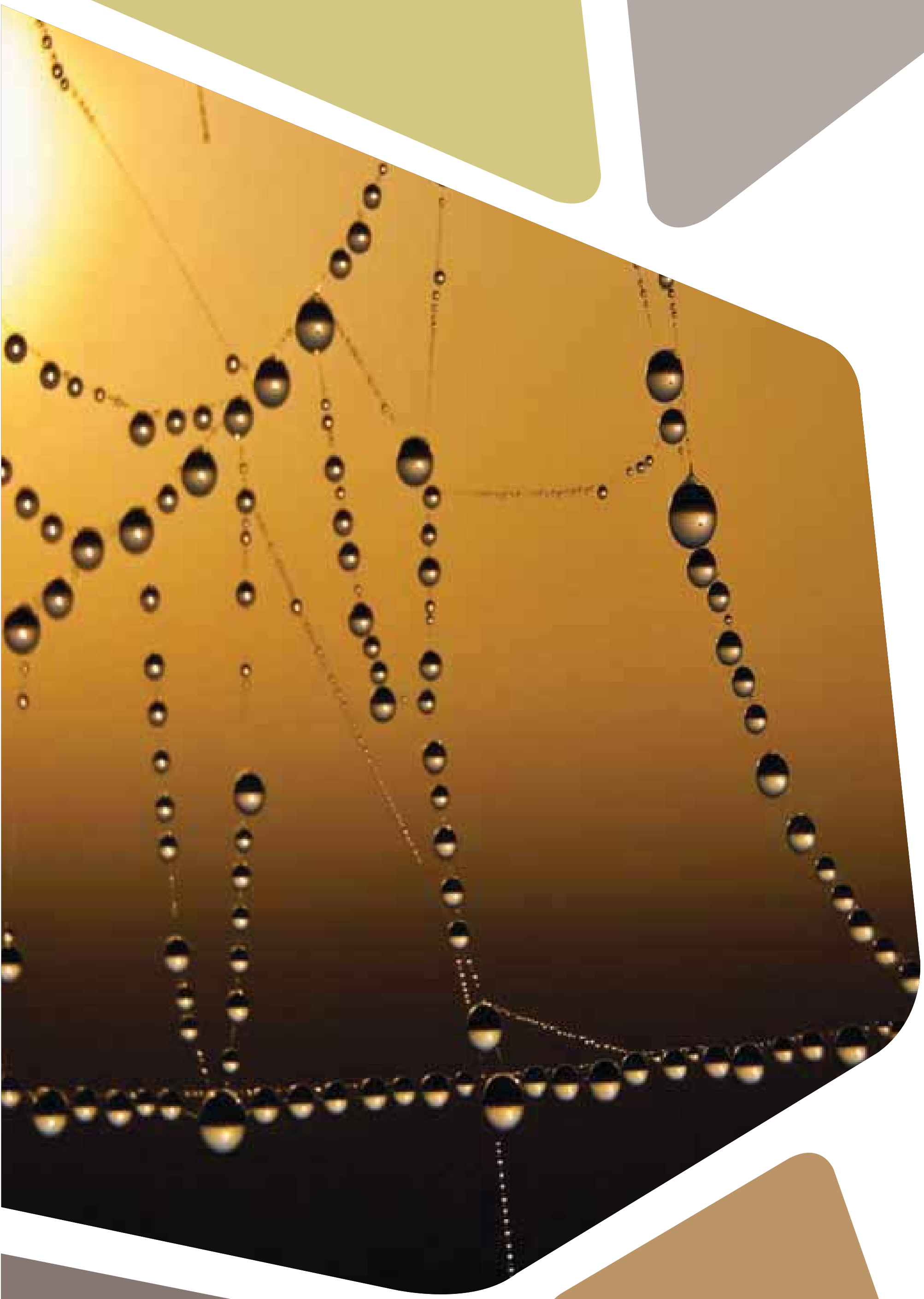
Consequently, the funds available for procurement of technical equipment will be substatially lower. The availability of adequate skilled/expert scientific and technical staff to implement various programmes of ARCI also continues to be a serious issue, with the Government not sanctioning any additional manpower. ARCI has been trying to solve this problem in a number of ways by attempting to attract senior and middle level scientists on contract basis, engaging Scientists and Technical staff for limited periods against positions indicated in externally sanctioned projects, hiring consultants with specific expertise and encouraging Post-Doctoral Fellows, Senior & Junior Research Fellows and undergraduate as well post-graduate project students to participate in our programmes.

As in the past, I would like to place on record the constant support that ARCI has received from DST and the Governing Council. I also take this opportunity to thank all the employees of ARCI for their unstinted cooperation and dedication to work. Without such support, ARCI could not have earned the reputation for being an institute that delivers what it promises.

G. Sundararajan

**( G. Sundararajan )**

# Research and Technology Highlights



# Ultrafast Laser Microprocessing

***Ravi Bathe, Centre for Laser Processing of Materials*** *ravi@arci.res.in*

ARCI's Centre for Laser Processing of Materials is currently involved in the development of processes and applications using high power industrial lasers with powers in kW range and minimum laser-material interaction times up to milliseconds. The emphasis has been on laser macro-processing. Recently, the Centre has embarked on building up capabilities in the micro-processing domain through the establishment of an ultrafast micromachining laser system. The red dotted lines in Fig. 1 depicts the extended regimes of laser processing envisaged at the centre.

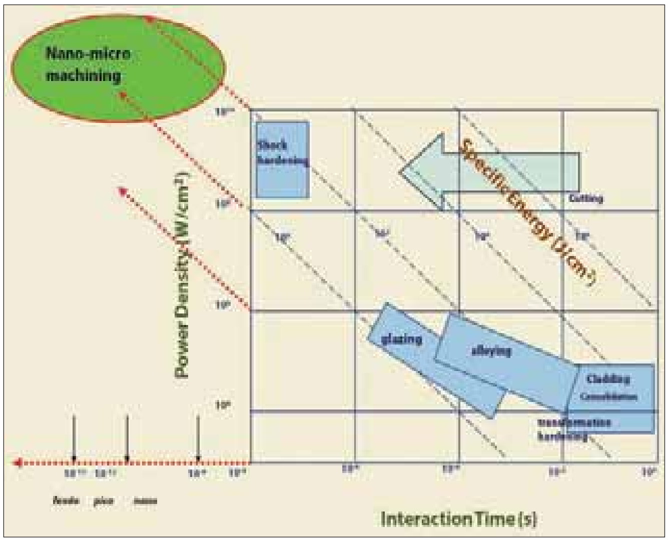
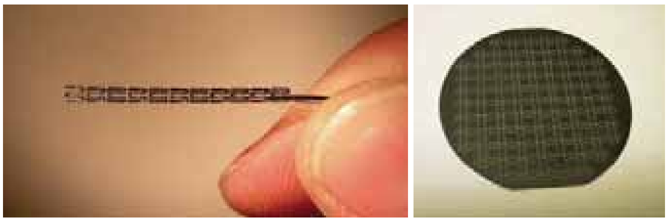


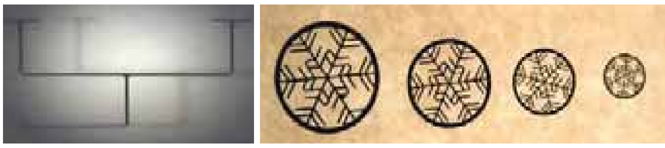
Fig. 1 Extended laser processing regimes

Laser microprocessing is one of the most flexible manufacturing technologies to create features in the sub-micron sizes. Its ability to accurately and reproducibly produce structures in a wide range of materials makes it an indispensible technology in a wide array of applications such as, microcutting of cardiac stents, microdrilling of PCB vias, microscribing of silicon/thin film solar cells, microlightography of electronic chips, microscribing/cutting of electrodes in flat panel displays, surface microtexturing of automotive engine parts, precision hole drilling in fuel injection nozzles, microfabrication of MEMS devices etc. The application domain of laser microprocessing is increasing steadily with more advanced ulltrafast lasers with millijoule/femtosecond combination at kHz repetition rates becoming commercially available. By the year 2015, the laser micromachining Market size is expected to be $725 M [ref: "The worldwide market for lasers market review and forecast 2012" report, Strategies Unlimited, 5th Edition, 2012]. The extreme flexibility and unique combination of characteristic advantages of laser micromachining include:

- Wide range of materials coverage - Almost any material can be machined using the correct laser light
- High precision - Material removal rate controllable down to the nanometer scale
- Non-contact machining – No mechanical loads and easy to reach inaccessible locations
- No damage - to the surrounding material due to the absence (minimal) of heat affected zone, redeposition, and resolidification. No pre- or post-processing required.



Stent Micromilling of semiconductor



Microfluidic channels in plastics Microfeatures cut in Alumina

Fig.2 Applications of laser micromachining

In laser micromachining, material removal is by ablation, which relies on strong absorption of laser photons by the material being processed. Ablation occurs by vaporization, molecular dissociation and/or ionization depending on the wavelength, pulse duration and fluence of the laser beam. A broad range of lasers is currently employed for laser micromachining such as carbon dioxide, solid state (Nd:YAG and Ti:sapphire), copper vapor, fiber, diode and excimer lasers. Most common wavelengths for microfabrication applications range from 1064 nm (fundamental Nd:YAG) to 248 nm (KrF excimer) and those provided by frequency doubled and tripled Nd:YAG (532 nm and 355 nm) and Ti:sapphire (800 nm) lasers. Two fundamental laser micromachining techniques exist, direct writing and mask projection. Direct writing method uses a focused beam as a pen to write structures on the material as it is moved over the surface. To achieve good results, a high spatial coherence from a Gaussian $TEM_{00}$ beam is required to produce a very small spot size of a focused beam. Typically Nd:YAG and Ti:sapphire lasers are employed in direct write machining. In contrast, mask projection makes use of multimode, spatially incoherent beams such as those of excimer lasers. Beam shaping and homogenizing is usually required prior to any mask plane, with a projection lens reducing the mask pattern to the required size.

Conventionally, lasers with pulse durations in the range of nanoseconds to microseconds are used. However, the level of precision and quality is limited due to thermal and mechanical damage (melting, formation of burrs and cracks, changes the morphology etc.) occurs during the process. In this context, femtosecond pulses offer great advantages over the nanosecond and picosecond pulses in their ability to deposit energy into a material and remove or modify it in a very short time, before thermal processes originate. As a result – the heat affected zone is reduced significantly. The ultrafast lasers essentially vaporize matter without generating heat ("cold" ablation). The energy deposition occurs on a timescale that is short compared to atomic relaxation processes. Also, the intensity of a femtosecond pulse is high enough to drive highly non-linear absorption processes in materials that do not normally absorb. At higher intensities (typically > $10^{13}$ W/cm$^2$) of femtosecond lasers, multiphoton ionization becomes significantly stronger. Also the high peak intensities of femtosecond pulses, new kinds of laser-matter interactions become possible. Smaller feature sizes, greater spatial resolution, and better aspect ratios can be achieved. With these advantages over conventional laser microprocessing, a wide variety of applications have opened up for femtosecond laser processing.


150 fs 12 ps 25 ns

Fig.3 Comparison of laser micromachining with laser pulses with different pulse durations

So, femtosecond laser microprocessing is characterized by: a) efficient, fast, and localized energy deposition, b) well-defined deformation and ablation thresholds, and c) minimal thermal and mechanical damage to the substrate material. At the same time, a combination of extremely low pulse durations, high intensities, high pulse repetition rates provides the capability to achieve high quality, high precision, high productivity in microprocessing. Wider the range of these capabilities wider will be the application domain.

At CLPM, it has been targeted to build up capabilities to process metals, semiconductors, polymers, and ceramics in bulk or thin film form with feature sizes ranging from 10s of micrometers to sub-micron. Accordingly, a high pulse energy ultrafast laser system has been conceived and being developed jointly with National Research Council (NRC) of Canada under a collaborative agreement. The system is built around Ti:Sapphire regenerative amplifier laser source, with shorter pulse duration (<120 fs); high average power (> 12 W) and pulse energy (1.2 mJ) at high repetition rate (10 kHz). Laser is designed according to industrial standards, which assures higher stability and reliability. It is integrated with a high resolution object positioning system (XYZ linear stages, AB tip/tilt stages) synchronized with galvanoscanners and a uniquely designed wavelength selector unit. Ultrafast variable attenuator enables full control in space, time and energy domains, allowing fabrication of difficult geometries with sub-micron resolution and repeatability. Also it is built with multiple beam delivery systems, which consists of four beam paths: 800 nm, 400 nm, 266 nm and pump laser beam (532 nm) with flip-mirrors arrangement which enables changing of beam path easily. Workstation vision system composed of high resolution CCD camera is synchronized with Aerotech linear stages and gives vision for whole system, allowing acquiring position, shape or any feature of the object and adjusting the beam. Overall it has been conceived as a versatile system for micro/nano machining research and production. Feasibility studies can be carried out to solve unique micro/nano machining needs.

Some of the R&D activities planned with this system include:

**Surface structuring**: The microstructuring of surfaces is interesting for several applications. One example is the structuring of cylinder walls in combustion engines. Small cavities are serving as a reservoir for the oil, preventing a breakdown of the oil-film. This results in significantly reduced particle emission.

**Sub-micron material processing**: Precision hole drilling, cutting and milling (Laser Scribing of transformer steel (cold-rolled grain oriented steel (CRGO)), Laser Drilling of Fuel Injector Nozzle, Laser cutting/drilling of Nb-alloys, Ti-alloys, Ni-alloys, Si, Glass, GaAs, etc.).

**Displays and solar**: Solar cell edge isolation, P1-P3 processing, thin-film ablation.

**Photonics devices**: Machining of optical waveguides in bulk glasses or silica, and inscription of grating structure in fibers.

**Microfluidics**: Microfluidic channels and devices.

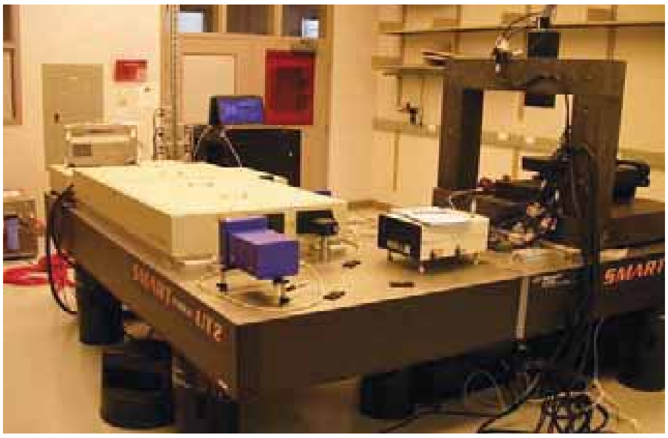


Fig.3 Ultrafast Laser Micromachining system

*Contributors: G. Padmanabham and Suwas Nikumb*

# Establishment of Lithium-Ion Battery Fabrication Line for Automotive Applications

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The dwindling fossil fuel resources necessitate the search for an alternative power sources especially in the automotive sectors. Li-ion battery (LIB) technology is projected to be the most efficient technology for this purpose due to its light weight, high energy and power densities compared to traditional lead acid and NiMH batteries. Globally, many leading automotive companies like Nissan, GM, Toyota, Honda, BMW, etc. have demonstrated electric vehicles using LIB technology which are on roads. On the contrary, in India no lithium ion battery manufactures are available. Interestingly, in 2010, Ashok Leyland demonstrated for the first time in India their hybrid electric bus (HYBUS) using imported lithium ion battery. At this juncture, ARCI has initiated the in-house development of LIB technology to produce large lithium ion cells and batteries. Meanwhile, REVA India has also introduced their REVA-e2o using this technology.

As a part of the developmental efforts, the Lithium-ion pilot plant facility is being established at IITM Research Park, Taramani, Chennai. The equipments for the fabrication line, according to the scheme 1, have been procured from various renowned suppliers. Since the battery fabrication process is highly sensitive to humidity, the processing equipments need to be placed inside the specially constructed dehumidified rooms. Two types of dry rooms are constructed, one for the electrode processing (RH~30%) and the other for the cell assembly (RH~1%) as shown in the Fig. 1. In the electrode processing room the high sheer mixer and coater/drier are placed, whereas all other equipments are housed inside the cell assembly room. Since most of these equipments are quite heavy and bulky, necessary safety measures have been taken to lift them to the 7th floor. The floors of the dehumidified rooms are reinforced appropriately to withstand the load of the equipments. In addition, the floors have been covered with copper in-laid vinyl mats (Electro static discharge) to prevent static electricity due to dehumidification (Fig. 2).

The dehumidified rooms are erected at the 7th floor using cam-lock panels. The dehumidifiers and the condensers needed for these rooms are placed at the terrace of the building (app. 14th floor). The ducts are made of GI (2 mm thick) with continuous welding to prevent any leakage. Each duct has been checked for leak proof by pressure test at their fabrication site. Four ducts (two supply and two return) emerge out from all the four utilities with each duct length of about 75 m. Currently the ducting work is in progress. Once the duct connection is established completely, the dehumidified rooms will be installed and their certified humidity level will be checked. After that, the equipments for the LIB fabrication would be commissioned for fabrication of Lithium-ion cells.

Scheme 1: Process for manufacturing LIB

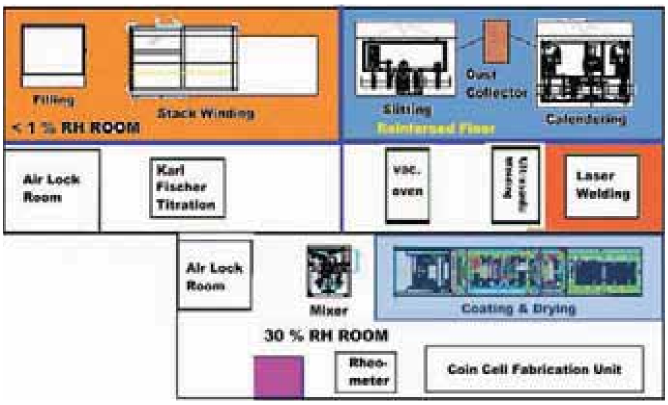

Fig. 1 Dehumidified rooms' layout showing the footprints of LIB processing equipment

Fig. 2 Reinforced dehumidified platform laid with earthed copper sheets and electrostatic discharge mats

***Contributors: Raju Prakash and R. Gopalan***

# Establishment of Pilot Scale Facility for CIGS Thin-Film Based Solar Cells

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The solar photovoltaic (PV) technology is considered most promising for power generation. Thin-film PV technology has the potential to provide significant advantage over traditional Si based solar cells and the thin-film cells can be deposited directly onto a substrate, usually glass, stainless steel, or plastic. Among all the thin-film solar cells, those based on Copper Indium Gallium Selenide (CIGS) are deemed to be attractive in terms of cost per watt and efficiency. Recently, the Swiss Federal Laboratories for Materials Science and Technology (EMPA) have developed CIGS thin-film solar cells on flexible polymer foils with a new record efficiency of 20.4% for converting sunlight into electricity. The current commercially available CIGS solar PV modules are known to have efficiency between 11.4 to 15.2 %, thereby making CIGS one of the most efficient, lowest cost PV technologies.

ARCI has initiated a major program in CIGS thin film solar cells with the objectives of improving existing manufacturing processes, developing new non-vacuum base process technologies, and systematically benchmarking the new processes developed by ARCI with existing ones. As a part of this program, installation and commissioning of various equipments has been done at Centre for Solar Energy Materials (CSEM) to establish a comprehensive pilot scale facility for complete fabrication of CIGS thin-film solar cells on substrate size of 300 mm x 300 mm. A schematic illustration of a typical CIGS thin-film PV device, including approximate film thicknesses and corresponding technology adopted in the CIGS line at ARCI is shown in Fig. 1. The special capabilities and tools available for CIGS thin-film solar cell fabrication include a sputter coater for the deposition of Mo, CuGa, In, i-ZnO and AZO; Evaporator-RTP for Se evaporation and selenization process; CBD tool for CdS deposition by chemical bath process; and laser and mechanical scriber for patterning the solar cells.

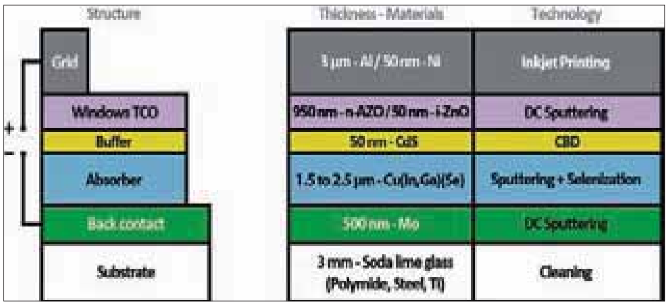

Fig. 1 Schematic illustration of a CIGS thin film PV device, including typical film thicknesses and the corresponding processing technologies adopted in the CIGS line

The present focus of the effort utilizing the CIGS pilot line is on comprehensively understanding the two-stage process, involving sputtering of the precursor layers followed by selenization. This process promises the formation of a CIGS thin-film layer that possesses the desired composition and structure to allow the charges generated by sunlight (i.e., electrons and holes) to exist long enough in the p-CIGS layer of the device so that they can be separated by forming a junction with n-CdS buffer layer, and collected at the front (i-ZnO/AZO) and back (Mo) contacts.

As the uniformity of various precursor and contact coatings is crucial for demonstrating high conversion efficiency on a substrate of size 300 mm x 300 mm, XRF mapping for thickness uniformity of all precursor and contact coatings deposited by sputtering has been done. The thickness maps for AZO, i-ZnO, In, CuGa and Mo shown in Fig. 2 reveal the uniformity across the 300 mm x 300 mm to be within the desired range. The electrical and optical properties, crystallographic phase constitution as well as, morphology of films are being comprehensively studied using various characterization tools such as four point probe, XRD, RAMAN, SEM, and UV-VIS spectroscopy. The fabrication of a complete thin-film solar cell device as illustrated in Fig. 1 is also underway.

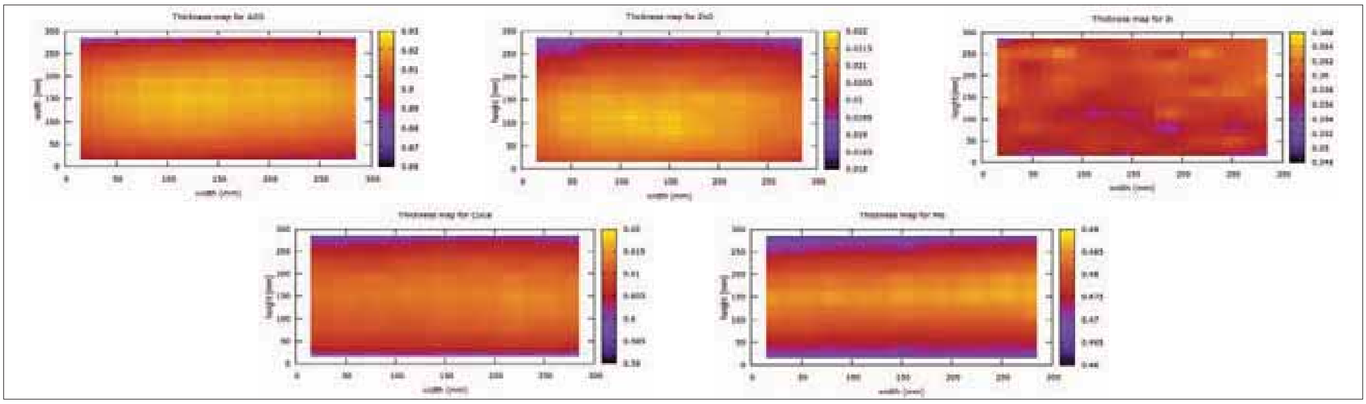

Fig. 2 Thickness maps of various precursor and contact coatings on 300 mm x 300 mm glass substrate

***Contributors: P. S. Chandra Sekhar, Ravi Mudike, P. Uday Bhaskar and S. Shiva Kumar***

# AC Magnetic Properties of Fe-P Soft Magnetic Alloy for Automotive Applications

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The rapid development in the automotive sector and ever increasing number of automobiles have meant the choice of materials for various applications has come under close scrutiny. A slight enhancement in property of the materials results in large amount of power savings due to the sheer numbers of automobiles involved. Soft magnetic materials are essential in the fabrication of motors and other electromagnetic devices for automotive and power sector applications. Presently non-oriented Si steel with a magnetic induction typically 17 - 20 kG is the widely used material. But recently with the advent of electric vehicles, there is a thrust to develop better soft magnetic materials with superior properties for high performance and energy saving. The increasing demand for these materials and the need to produce large quantities at industrial scale, calls for development of new soft magnetic materials.

Fe-P is a promising replacement for the conventional Si steel as stators and rotors in motors. Enhancement of resistivity of the Fe-P alloy without compromising on the saturation induction is the challenge to be addressed. Fe-0.4 wt.% P alloy with magnetic properties comparable to Si steel at low frequencies has been developed by a two-step heat treatment procedure. Fe-0.4 wt.% P alloy in the form of ingot was prepared by casting molten Fe with suitable amount of Fe3P. The ingot was forged and rolled at 900$^0$C. The rolled sheet was solution treated at 1000$^0$C/1h and was subsequently annealed at 500$^0$C/30 min.

Toroid shaped rings were punched (Fig. 1) out from these sheets for AC magnetic measurements up to 1 kHz. Fig. 2 (a & b) compares the permeability and total loss data of the Fe-P sample with standard Si steel. The permeability of Fe-P sample is about 4 times higher compared and loss equal to Si steel at low frequencies. At higher frequencies property deteriorates and Si steel exhibits better properties at 1 kHz. At low frequencies shown in Fig. 2 c) and d) (for motor application typical operating frequency is 50 Hz) the performance of Fe-P was better in terms of permeability and very comparable to Si-steel. The deterioration of property of Fe-P at higher frequencies is mainly due to the low resistivity of the samples.

The total loss comprises of two components namely the hysteresis loss and eddy current loss. The former depends on the magnetic property of the sample while the latter depends on the electrical resistivity of the sample. The eddy current loss is minimized by increasing the resistivity of the sample. The resistivity of the Fe-P sample was measured to be 22 μΩ cm compared to resistivity of Si steel which is about 50 μΩ cm. Hence the eddy current loss of Fe-P sample is higher explaining the deterioration of the AC magnetic properties at higher frequencies. Further work investigation is being carried out to optimize the microstructure by varying processing conditions and also by addition of various elements to increase the resisitivity of Fe-P sample thereby enhancing the suitability of the materials for automotive applications.

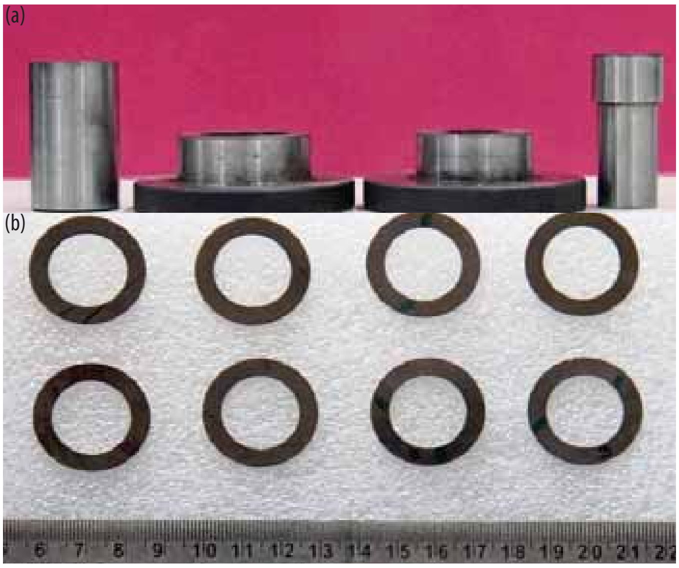

Fig. 1 a) Die fabricated for punching out toroid shaped rings and b) typical Fe-P rings used for AC magnetic measurements

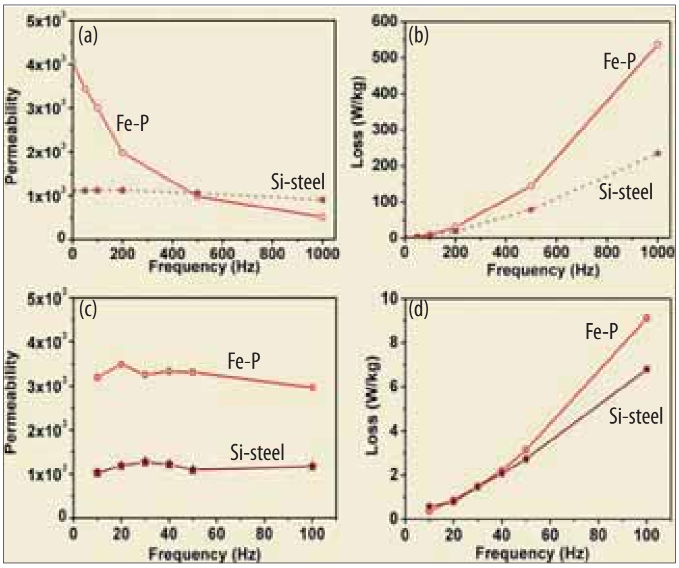

Fig. 2 Comparison of permeability and loss of Si steel with Fe-P samples synthesized at ARCI: (a) & (b) up to 1 kHz and (c) & (d)up to 100 Hz

***Contributors: D. Sivaprakasam, V.V. Ramakrishna, T.G.S.N. Rajkiran, S.B.Chandrasekhar, V.Chandrasekaran and R.Gopalan***

# Structure and Electrochemcial Property Correlation of Carbon Free Mn Doped LiFePO$_4$ Prepared by Hydrothermal Method

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Lithium-ion batteries are one of the main candidates for energy storage devices that can satisfy the power-energy requirements of electric-based transportation vehicles. LiFePO$_4$ cathode materials are showing promise towards developing high-energy and high-power density lithium ion batteries. In particular, LiFePO$_4$ with an olivine structure has many advantages such as low cost, nontoxicity, environmental friendliness, and high safety. Though it has a theoretical capacity of 170 mAh/g with a flat voltage profile at 3.4 V versus Li$^+$/Li, its low intrinsic electronic conductivity (~10$^{-9}$ S/cm) and low Li-ion diffusion coefficient (10$^{-11}$ to 10$^{-13}$ cm$^2$ S$^{-1}$) hinders its application in high power batteries. To circumvent these drawbacks, several approaches such as carbon coating, reducing particle size and doping with other transition metals have been extensively studied. Since electrochemically inactive carbon coating reduces the volumetric energy density, our research activities are focused on improving the electrochemical activity of carbon-free LiFePO$_4$ by Mn doping. Hydrothermal processing is one of the methods to produce large quantity of metal oxides. Accordingly, we are in the process of tuning the hydrothermal process parameters to obtain carbon-free Mn doped LiFePO$_4$, with high quality reproducible electrochemical properties.

Process parameters for hydrothermal synthesis, such as Li, Fe, Mn, P sources, ambient, and Li:Fe:P ratio are being optimized for the synthesis of phase pure Mn doped LiFePO$_4$. It is found that LiFePO$_4$ can only be synthesized in slight alkaline medium under inert atmosphere. Small percentage of Fe$_3$(PO$_4$)$_2$ impurity phase was detectable from Reitveld refinement of XRD and temperature dependent magnetic data (figure not shown) of Mn doped LiFePO$_4$ prepared with Li:Fe:P=1:1:1 stochiometry. Both pure LiFePO$_4$ and Mn doped LiFePO$_4$ have faceted growth and the particle size increases with increase in the Mn concentration as can asserted by the SEM micrographs given Fig.1. Doping of Mn at Fe site is evident from the increase in the lattice constant (Fig. 2) with increase in Mn concentration. Preliminary studies show that, the impurity phase Fe$_3$(PO$_4$) can be eliminated by taking higher concentration of lithium during hydrothermal synthesis. This also leads in the changes in the strength of P-O bond as can be observed in the shift in the stretching vibration of P-O bond, in the IR spectra (Fig. 3). The electrochemical performances of the samples are in progress; based on the results a comprehensive structure- property correlation will be evolved.

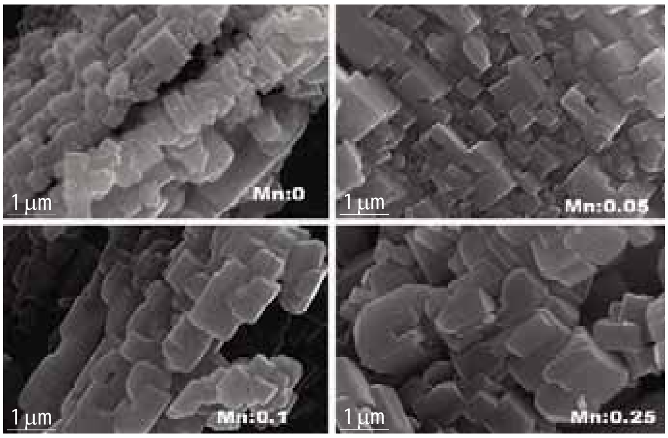

Fig. 1 SEM micrographs of Mn doped LiFePO$_4$ synthesized by hydrothermal method

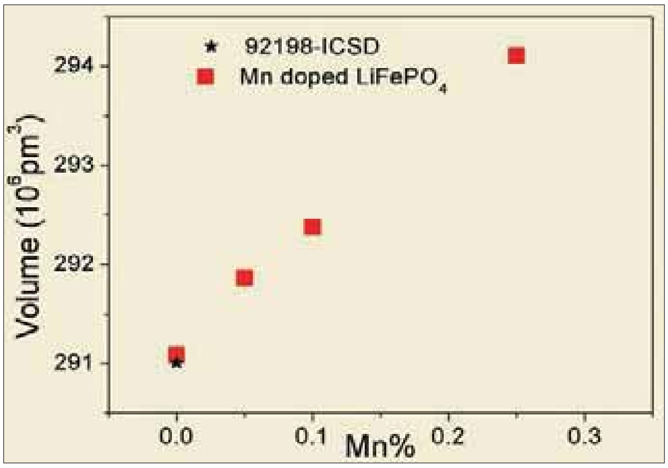

Fig. 2 Increase in the volume of the unit cell of LiFePO$_4$, as analyzed by the Reitveld refinement of XRD of Mn doped LiFePO$_4$

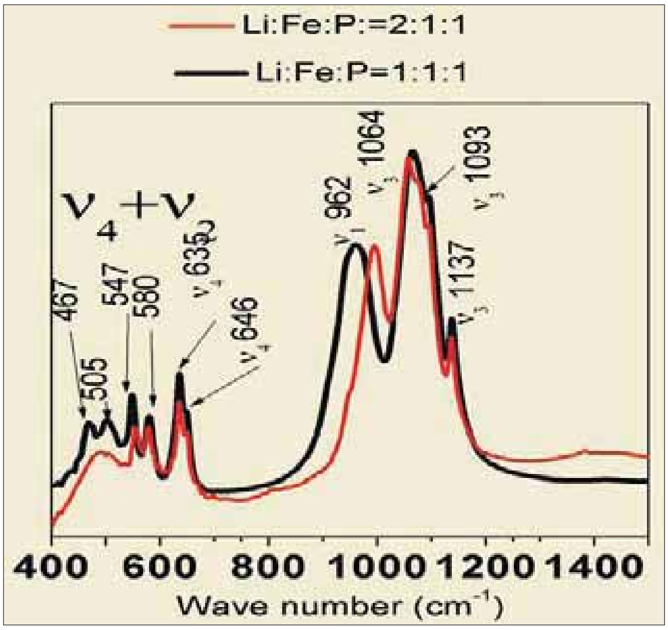

Fig. 3 IR spectra of LiFePO$_4$ depicting the shift in P-O stretching vibration of samples prepared using different Li concentration

***Contributors: Dipak Khatua, S. Anandan and R. Gopalan***

# Formation of LTP MnBi Phase for a Nanocomposite Bonded Magnet

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NdFeB based permanent magnets have been widely used owing to their excellent magnetic properties. However, their undesirable thermal stability is still a major concern for high temperature applications especially in automobile industries. Hybrid bonded magnet, in which two or more different kind of magnetic powders are mixed together, has been identified as a solution to the problem. MnBi with NiAs hexagonal structure exhibits unique magnetic properties. The ferromagnetic phase of MnBi is called low temperature phase (LTP). It has a positive temperature coefficient of coercivity. The coercivity of the LTP increases with temperature. Thus, it is considered as a potential candidate for permanent magnet application and automobile industry. Thus a composite of NdFeB/MnBi is expected to exhibit better magnetic properties than ferrite bonded magnets. Obtaining the single LTP phase in MnBi is very crucial through conventional methods. Mn tends to segregate from the MnBi liquid because of the peritectic reaction as the diffusion of Mn through MnBi is very sluggish. We initiated the work with the formation of MnBi LTP phase which will be mixed with NdFeB to obtain a composite of MnBi/NdFeB with a higher thermal stability.

$Mn_xBi_{1-x}$ ingots (X= 48, 50, 55) were prepared by using arc melting. The as-prepared ingots were subjected to melt spinning and brittle ribbons of the three compositions were obtained. The structures of the as-prepared ribbons have been studied by using X-ray diffraction. The structural transformation in the ribbons was independently monitored by using Differential scanning calorimeter (DSC). Magnetic properties of the ribbons have been studied by using 7T SQUID magnetometer.

XRD of the as-prepared ribbons show the existence of the signature peaks of LTP MnBi (Fig. 1). Apart from the LTP MnBi one can notice the impurity phases of Bi, Mn and $Mn_3Bi$ (metastable phase). The formation of LTP is evidenced in the DSC scans (Fig. 2). The broad peak at around 166°C is probably due to the crystallization of some small fraction of ferrimagnetic MnBi phase, and or metastable $Mn_3Bi$ phase as evidenced in the XRD pattern also. The next peaks in the DSC pattern at around 264°C and 355°C corresponds to the formation of LTP phase and the decomposition of LTP-high temperature phase (HTP) respectively. Hysteresis loops of the as-spun ribbons are non-saturating even at 7T indicating behaviour of hard magnets. The variation of coercivity with the Mn composition was studied. A coercivity of 0.8T was found in the $Mn_{55}Bi_{45}$ composition at room temperature. Microstructural analysis by Scanning Electron Microscopy would be helpful in correlating the magnetic and structural properties which is in progress.

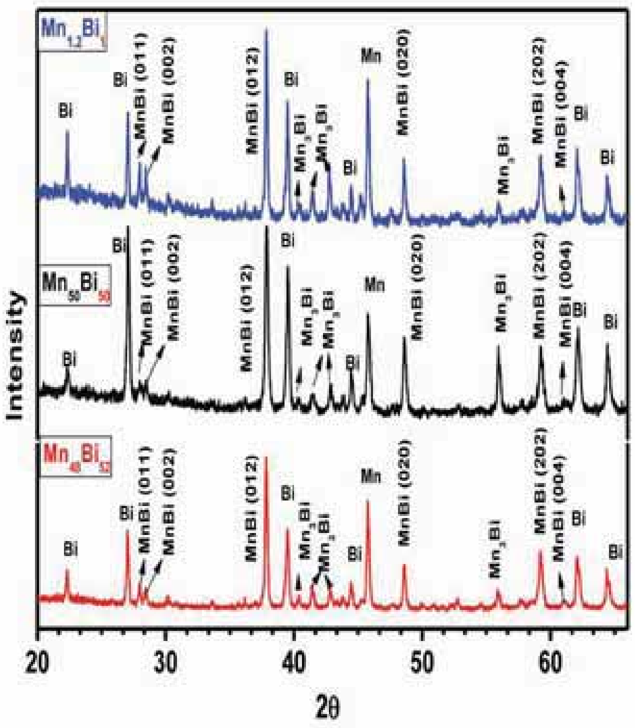

Fig. 1 X-ray diffraction patterns of as-spun ribbons

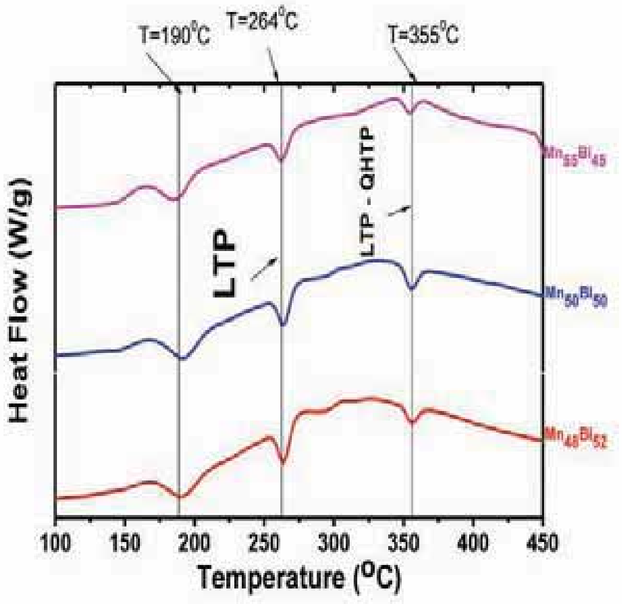

Fig. 2 DSC scans of as-spun ribbons

***Contributors: D. Prabhu and R. Gopalan***

# Development of High Thermal Stable Solar Selective Absorber Coatings

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In a concentrated solar power (CSP) system, the solar absorber receiver tubes play an important role in converting sunlight to electric power. A major objective of a vast majority of CSP programmes worldwide is to reduce the overall cost of parabolic trough solar thermal power technology.

One of the approaches is to operate the CSP system using cost effective solar receiver tubes in an open to air atmospheric condition instead of evacuated solar receiver tubes. To accomplish this, efficient novel solar selective coatings are needed that have both high solar absorptance and low thermal emittance at elevated temperatures at least up to 500$^0$C. For efficient photo-thermal conversion, the solar absorber tubes must have high solar absorptance (α) in the solar region (wavelength range 300-2500 nm) and low thermal emittance (ε) of IR radiation (wavelength range 3-25μm) at the operating temperature. Although present day designs are likely to use the coatings in evacuated environments, the coatings need to be stable in air, in case the vacuum is breached. Current coatings do not have the stability and performance desired for higher operating temperatures. While most of the coatings are thermally stable in air up to 300$^0$C, the selective properties are found to degrade beyond 300$^0$C due to oxidation or diffusion of the metal component or both.

To resolve the above mentioned problem, a novel composite coating (comprising Mn-Cu-Fe oxides) developed by a controlled oxidation process has been developed on a special variety of stainless steel substrate. The nanostructured oxide layer so obtained on the surface is found to possess excellent thermal stability (max. up to 500°C) and attractive optical properties (α/εC (500°C)= 91.5/0.19). The optical and structural characteristics of the coating, along with its thermal stability determined by measuring its thermal emissivity at varied temperatures, are shown here and indicate the promise of these coatings for use in solar thermal applications.

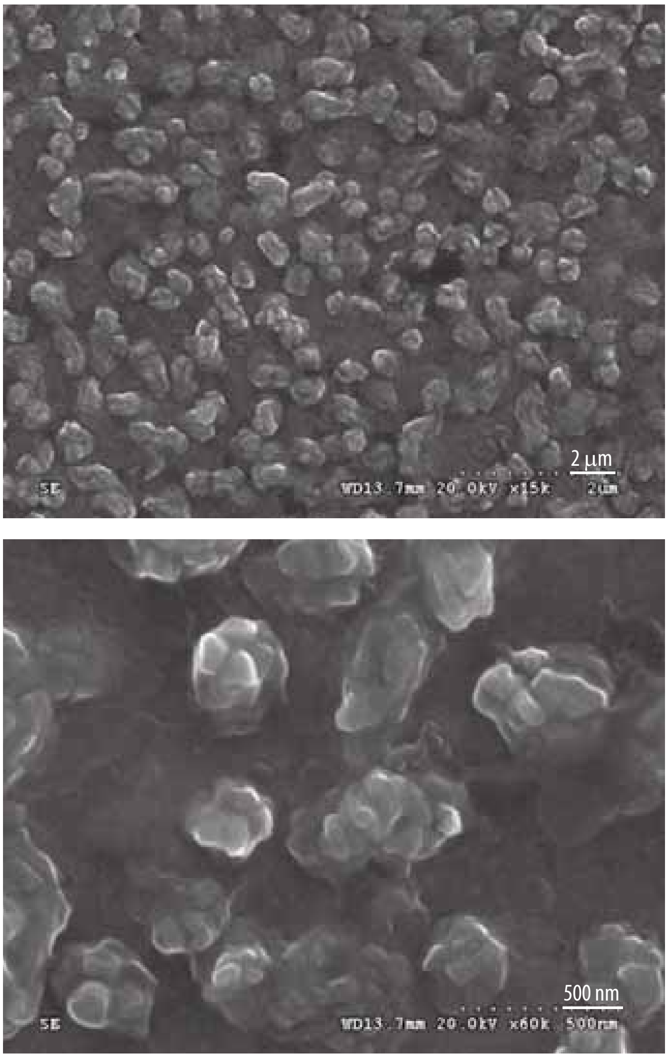

Fig. 2 FE-SEM images of the absorber layer revealing presence of nano-clusters determined to be comprised of oxides.

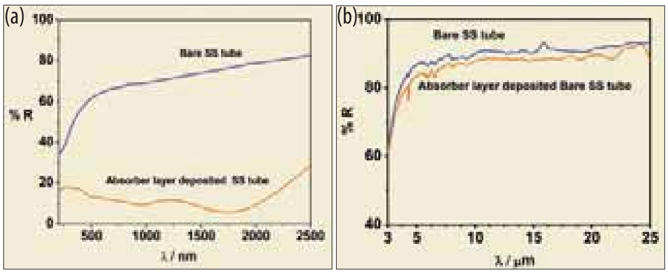

Fig. 1 (a) Reflectance spectra and (b) spectral emittance characteristics of the absorber layer generated by a controlled oxidation process in a special variety of stainless steel

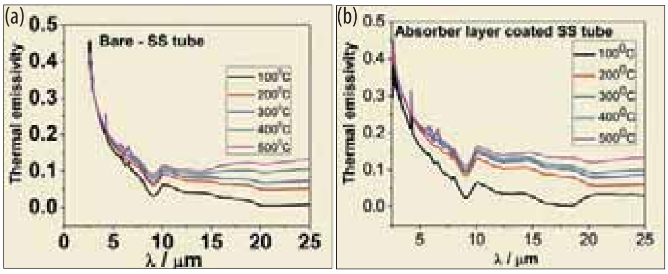

Fig. 3 Thermal emissivity spectra measured at different temperatures for (a) bare receiver tube material and (b) receiver tube material with an absorber layer formed by controlled oxidation

***Contributor: A. Srinivasa Rao***

# Two-stage Pulsed Current Electrodeposition of CIGS Thin-Films for Solar Cell Applications

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Thin film solar cells have attracted great interest due to their large absorption coefficient, low materials usage and high stability. CIGS ($CuIn_{1-x}Ga_xSe_2$) is one of the most promising semiconductor materials for the absorber layer in thin film solar cells with the potential to yield high efficiency, due to its suitable bandgap and large optical absorption coefficient (≈ $10^5$ $cm^{-1}$). Consequently, CIGS thin films have been extensively studied using several methods. A major focus of ARCI's solar PV programme involves development of non-vacuum techniques for reliable and reproducible deposition of CIGS thin films. In this context, an economical and simple method like electrodeposition, which can be conveniently scaled up to industrial level fabrication, is being actively pursued.

Pulsed Current (PC) technique is an advanced form of electrodeposition that offers better control over properties of the deposit by controlling the interfacial electrochemical reaction during formation of thin film. The PC technique is usually used to improve the quality of thin films via the application of current or potential, with high instantaneous densities, in pulses. This process has several advantages over DC electrodeposition since it lends itself to improved process control by virtue of the possibility of manipulating parameters such as deposition potential, duty cycle and period. Co-deposition of Cu-In-Ga-Se has been reported by several researchers for the fabrication of chalcopyrite CIGS thin films. However, the composition of the films has been found to deviate from the ideal stoichiometry and formation of undesired secondary phases has also been noted. Relatively easier control over the composition of individual elements was obtained in multi-step DC electrodeposited CIGS thin films, which also resulted in higher efficiencies. Bhattacharya et al., have explored multi-step deposition of CIGS to improve the film stoichiometry and have reported an efficiency of 10.4 %. Aksu et al., have performed four-step deposition to improve the composition of CIGS films and reported an efficiency of 15.36 %.

In the present work, two-stage pulsed current electro-deposition using a two electrode system has been being employed for the first time for the fabrication of CIGS thin films. In addition, use of additives (complexing agents) and the conventional additional step of selenization are avoided. The stoichiometric chalcopyrite CIGS films deposited employing this route have been found to possess a compact morphology without any undesired secondary phases and have shown an improved photoelectrochemical performance compared to the one-step electrodeposited CIGS films reported previously by our group. These results have provided the motivation for a more comprehensive study of the above process, which is presently ongoing.

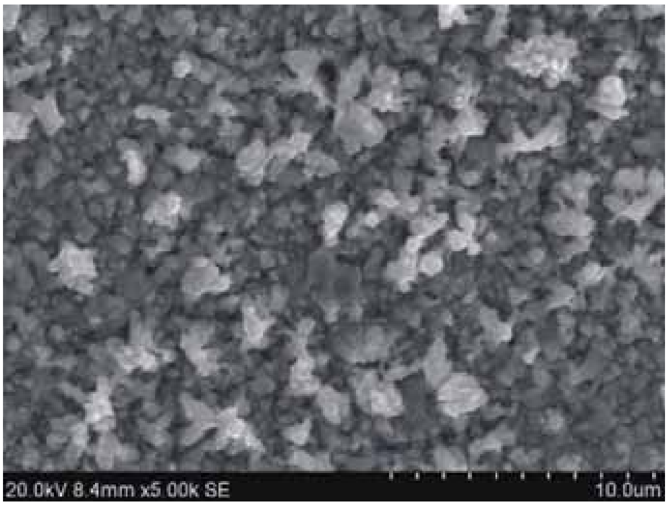

Fig. 1 SEM micrograph of two -stage pulsed current electrodeposited CIGS thin films

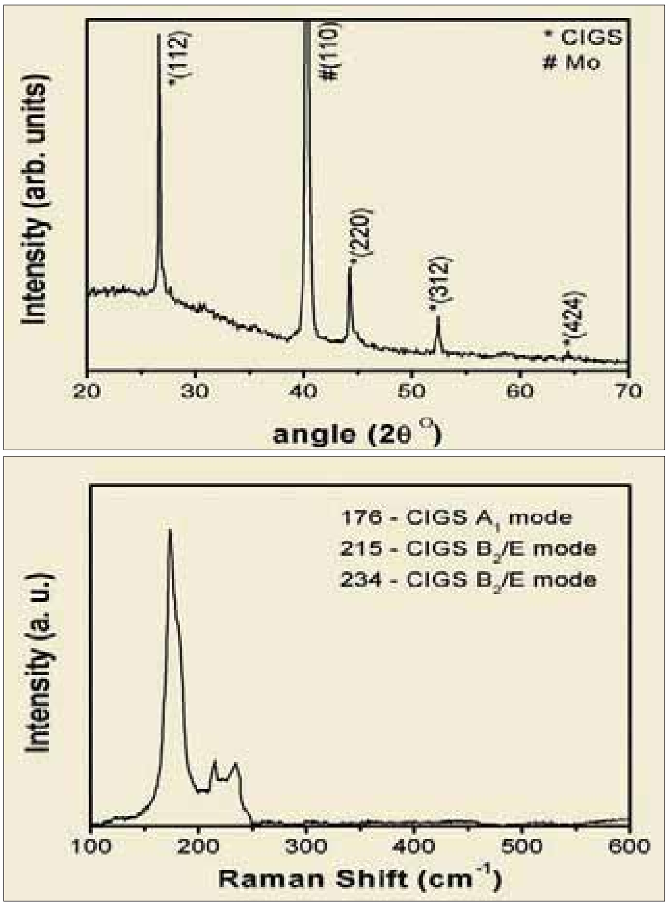

Fig. 2 (a) XRD pattern and (b) Raman spectrum of two stage pulsed current electrodeposited CIGS thin films

***Contributor: M. Sreekanth***

# Hierarchical $SnO_2$ Beads for High Performance Dye-sensitized Solar Cells

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Dye-sensitized solar cells (DSCs) based on nano-crystalline metal oxide photoanode and redox couple electrolyte have emerged as a low-cost, high-performance route to convert solar energy to electric energy. Champion devices based on nanoparticle $TiO_2$ photoanode, iodine/tri-iodide redox couple electrolyte and Pt counter electrode exhibit about 12% efficiency under standard test conditions (Air Mass 1.5G, 100 mW $cm^{-2}$). Notwithstanding the above, the energy conversion efficiency and long term stability need to be further improved to spur commercialization of these low-cost devices. Employing long wave length sensitive light absorbing dyes with high extinction coefficient, synthesis of high mobility hole transporting materials (HTMs) and hierarchical binary metal oxide photoanodes are few of the noteworthy approaches for the development of highly efficient and stable DSCs. The common issue in utilization of high extinction coefficient light absorbers and solid-state HTMs is the inefficient sensitization and pore-filling of nanoporous photoanodes. In this context, synthesis of surface-engineered hierarchical $SnO_2$ beads with large surface area and ordered pore structure by hydrothermal method was taken up and its potential application in DSCs studied.

Hierarchical $SnO_2$ beads were synthesized through self-assembly employing sucrose/$SnCl_4$ aqueous solution in the presence of urea. The carbon scaffold was gently removed by annealing the metal oxide/carbon composite in air. Fig. 1(a) shows an SEM image of pristine $SnO_2$ beads. Dye adsorption and charge carrier recombination were fine tuned by surface engineering of these $SnO_2$ beads. Introduction of 3 mol% Mg during the hydrothermal reaction was found to increase the isoelectric point without affecting bead morphology. A microscopic image of focussed ion beam (FIB) milled $SnO_2$ beads, although not shown here, indicates the presence of a loosely packed nanoparticle morphology throughout a bead.

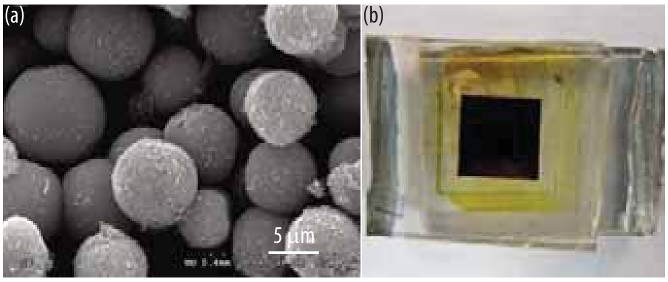

Fig. 1 (a) SEM image of hierarchical $SnO_2$ beads synthesized and (b) digital photograph of a 5mm x 5mm size dye-sensitized solar cell

A dye-sensitized solar cell with an active area of 0.25 $cm^2$ was prepared by doctor blading method. For this purpose, surface engineered $SnO_2$ beads were first formulated into a viscous paste by dispersing them in terpineol ethyl cellulose. A thin film of $SnO_2$ beads with a defined dimension (5 mm x 5 mm) was then coated on FTO glass substrate by the doctor blading method, followed by sintering at 500°C for 30 min. The freshly sintered electrode was sensitized with S2 dye and then assembled with Pt counter electrode. Liquid redox electrolyte with a composition of 0.5M 1-butyl-3-methylimidazolium iodide, 0.05M $I_2$ and 0.5M 4-tert-butylpyridine in acetonitrile was introduced into the cell. Fig. 1(b) shows a digital photograph of completely sealed DSC.

Current-voltage characteristics of DSCs were measured using a state-of-the-art class AAA solar simulator (Oriel, 94123A) and source meter. Fig. 2 shows the performance of DSCs measured under dark and 1 sun illumination conditions. The device was found to exhibit an open-circuit voltage ($V_{OC}$) of 0.640 mV and a photocurrent density ($J_{SC}$) of 3.3 mA.$cm^{-2}$. Considering the $SnO_2$ conduction band edge position and $I^-/I_3$-redox energy level, the obtained $V_{OC}$ is relatively high and may be attributed to surface passivation of electron trap sites. The large internal surface area and the favourable morphology of the $SnO_2$ beads could have plausibly increased the light harvesting efficiency and led to the DSC exhibiting 1.4% efficiency. Work is in progress to exploit the noted advantages of hierarchical $SnO_2$ beads to fabricate highly efficient organometallic perovskite sensitized solid state solar cells.

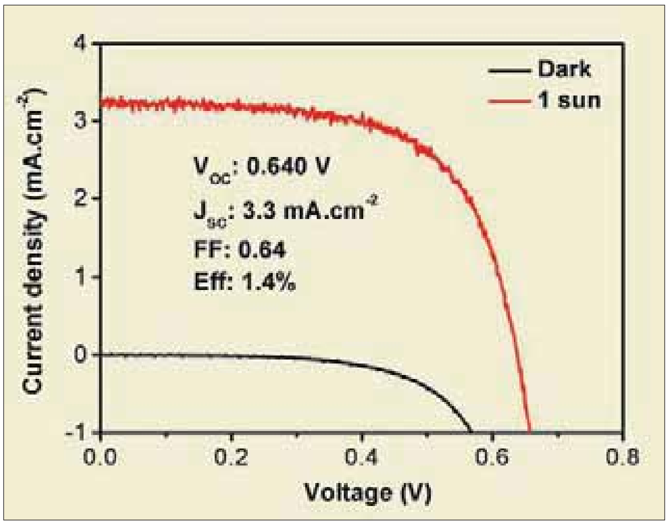

Fig. 2 Current-voltage characteristics of hierarchical $SnO_2$ bead photoanode dye-sensitized solar cell measured under dark and 1 sun (AM 1.5G, 100mW.$cm^{-2}$) illumination conditions

***Contributors: Anil Kumar Bharwal, S. Saroja and Islavath Nanaji***

# Growth Mechanisms in Pure ZnO Nanorod Synthesis by Flame Spray Pyrolysis Method

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ZnO nanorods in large quantities (> 3 kg/h throughput) were produced in the gas-phase by flame spray pyrolysis (FSP) of a zinc nitrate – ethanol precursor solution without employing any catalysts or dopants. The nanorods with diameters of 20-30 nm and aspect ratios as high as 7 were collected as a dry powder. The objective of this study was to understand the growth mechanism of pure ZnO nanorod in FSP.

ZnO nanorod particles synthesized from 0.94mol/l precursor solutions delivered at 12 l/h and dispersed with 80lit/min of oxygen exhibited monolithic, junction and terapod type nanorod. The junction zone of two rods as shown in Fig. 1a is magnified in Fig. 1b, which shows that the spacing between the lattice planes perpendicular to the length of the monolithic rods is 5.2Å. This corresponds to the (001) planes of the ZnO crystal and is in agreement with the value of lattice parameter "c" as determined by XRD. This indicates that the rods grow preferentially in [001] direction by stacking of materials on basal planes, which is typically observed in gas-phase synthesis of nanorods and nanowires. The 2.8 Å lattice spacing between (001) planes, as makred in Figure 2b, indicates (101) planes observed through the [12 l] zone axis with an angle of around 28° between the planes. The well-discernible interface region of 2-3 nm thickness (marked "1") shows a structure similar to slip bands that might have formed by slipping of a few (002) crystal planes. The lattice strain within the slip band structure appeared to be higher at the middle of the crystal compared to the area closer to the surface (marked "2"). Fig. 1c shows a TEM image and a selected area electron diffraction pattern of ZnO rods while Fig. 1d highlights the structure of ZnO tetrapod, which clearly shows single crystal and hexagonal rod cross section. The lattice spacing of 2.8 Å indicates (100) planes, confirming growth in [001] direction.

Based on our observation, we have proposed a growth mechanism of ZnO nanorod for FSP synthesis as illustrated in Fig. 2. This is an extension of the work by Strobel and Pratsinis. FSP synthesis of zinc oxide nanorods is mainly influenced by three aspects viz. (a) the flame temperature (b) the cooling rate and (c) the Zn concentration. The choice of solvent alters the flame temperature and cooling rate, which in turn had the strongest effect on the product powder morphology. Decreasing the precursor feed and increasing the dispersion oxygen flow rate are both known to decrease the flame temperature, increase the cooling rate and lead to nanorods with lower aspect ratio. The Zn concentration in the nitrate precursor solution has no significant effect on the flame temperature and cooling rate but influences the Zn supersaturation in the particle formation zone downstream the temperature maximum of the flame thereby controlling the contributions of condensation and coagulation to particle growth.

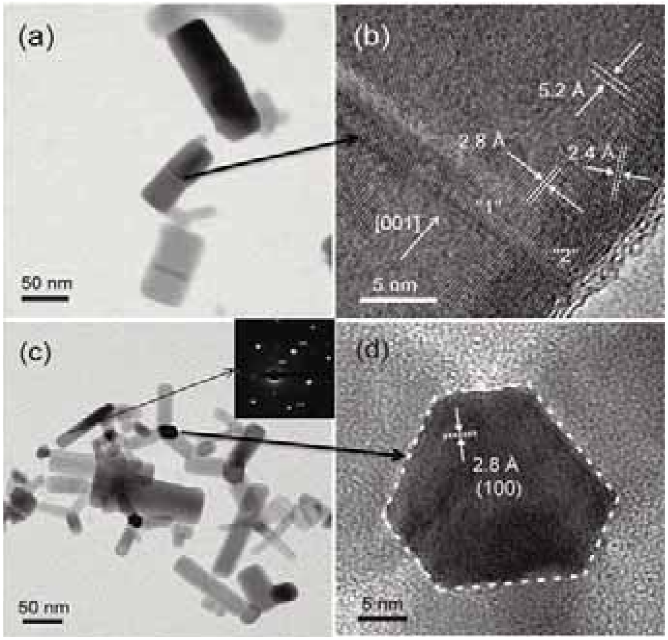

Fig. 1 HRTEM images highlighting the junction zone of two ZnO nanorods (a, b), confirming predominant growth in the [001] direction, (c) TEM and selected area diffraction pattern indicates (inset) that short rods are single crystals and tetrapods (d) revealing the hexagonal shape of rod cross-sections

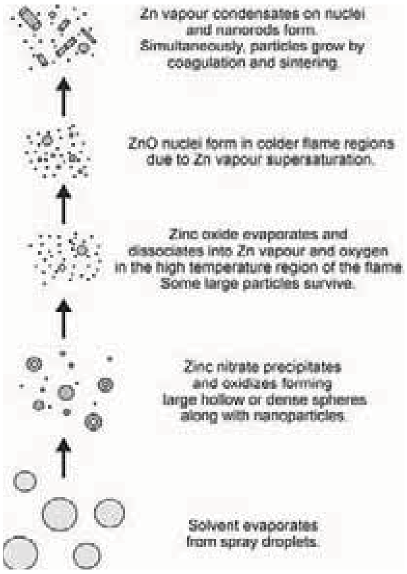

Fig. 2 Schematic of the proposed ZnO nanorod and nanoparticle growth mechanism in flame spray synthesis from nitrate precursors

***Contributors: D. Sivaprahasam and Tata Narasinga Rao***

# Efficient Visible-light-active $Cu^{2+}$-modified Rutile-$TiO_2$ for Self-cleaning Applications

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In recent years, self-cleaning technology has developed rapidly with photocatalytic paints being among the most promising applications. This technology is attractive and desirable as it can reduce labour costs and keep the environment clean. The self-cleaning effect has been known to be a combined effect of photocatalysis and hydrophilicity. Self-cleaning has industrially important applications, in which organic contaminant/bacteria residing on the surface of $TiO_2$ are removed by photocatalytic reaction. However, visible-light-active, high oxidation power, and long durability are essential for the photocatalyst to be effective for self-cleaning under visible-light illumination. Although N-doped $TiO_2$ has been explored for visible-light driven photocatalysis, its efficiency under visible light is much less than that under UV light due to slower hole mobility and low oxidation power of hole. Recently, co-catalyst (Cu, Pt) modified semiconductors are being considered as an efficient visible-light-driven photocatalyst contributed by interfacial charge transfer (IFCT) and multi-electron reduction via Cu (II)-ions. When visible-light illuminates on $Cu^{2+}$-modified $TiO_2$, the electrons are excited from valence band (VB) to surface $Cu^{2+}$-ions by IFCT resulting to a small visible-light absorption (~400-500 nm). The holes generated in the VB cause oxidation reaction, while the transferred electrons cause oxygen reduction. Thus the charge recombination is suppressed in $TiO_2$, which leads to large enhancement in the photocatalytic efficiency. This invention has triggered extensive research to improve the performance of co-catalyst modified semiconductors.

As part of nano-Titania project being implemented with a private sector company, ARCI is currently working on the design of highly active, visible-light-driven photocatalysts, which can be used in self-cleaning paints to remove odour from textiles. In this effort, co-catalyst modified rutile-$TiO_2$ is being investigated to increase the performance as rutile-$TiO_2$ in itself is able to absorb visible-light. We could successfully demonstrate that $Cu^{2+}$-modified rutile $TiO_2$ can serve as an ideal candidate to improve the photocatalytic efficiency under visible-light illumination.

The UV-vis. spectrum of rutile $TiO_2$ and $Cu^{2+}$-modified rutile $TiO_2$ are shown in Fig. 1. Rutile $TiO_2$ shows absorption onset ~380 nm, while $Cu^{2+}$-$TiO_2$ exhibit two additional absorption bands in addition to the inter-band transition of $TiO_2$ (Fig. 1). The small visible-light absorption at 450-500 nm corresponds to IFCT while the absorption at ~700-800 nm belongs to d-d transition of $Cu^{2+}$ ions. In order to evaluate the self-cleaning performance, photocatalytic decomposition of bacterial colony (E. coli) by $TiO_2$ and $Cu^{2+}$-modified $TiO_2$ was carried out under visible-light illumination (holding time of 1 and 5 h). The results are shown in Fig. 2. Bacterial growth using $TiO_2$ is confluent after 1 h exposure of visible-light illumination and subsequently underwent a slow decrease after 5 h. On the other hand, a significant growth reduction is observed for $Cu^{2+}$-$TiO_2$ within 1h of exposure time. At the end of 5 h exposure time, no bacterial growth was observed. The high photocatalytic activity of $Cu^{2+}$-$TiO_2$ is attributed to the strong oxidation power of hole, visible-light absorption by $Cu^{2+}$-ions, and retardation of electron-hole recombination by efficient oxygen reduction reaction.

In addition to the development of efficient $TiO_2$ photocatalysts in lab-scale, ARCI is also working on the up-scaling the production of $TiO_2$ by various processes.

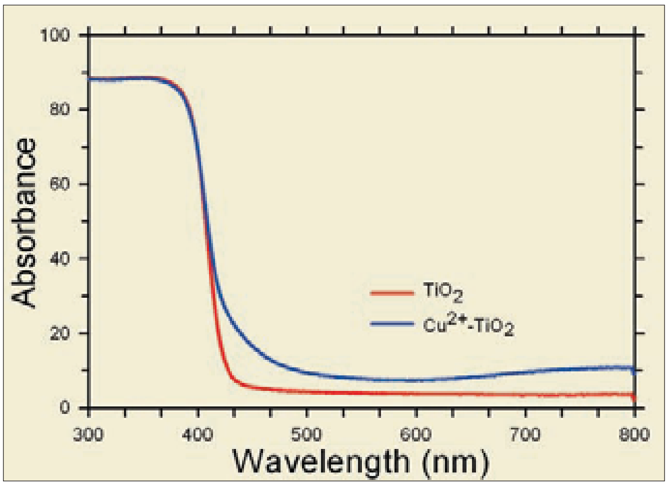

Fig. 1 UV-vis. spectrum of $TiO_2$ and $Cu^{2+}$-modified $TiO_2$

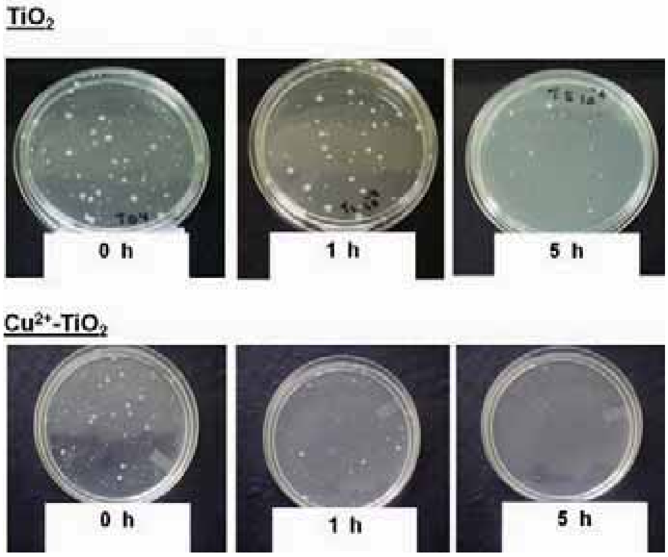

Fig. 2 Anti-bacterial activity of $TiO_2$ and $Cu^{2+}$-modified $TiO_2$ under visible-light

***Contributors: Raju Kumar and Tata Narasinga Rao***

# $Al_2O_3$-$ZrO_2$-TiCN Cutting Tool Inserts by Spark Plasma Sintering

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The specific objectives of the present study were to develop cutting tool inserts with $Al_2O_3$-$ZrO_2$-TiCN based nanocomposites and evaluate their machining performance. In addition, the microructure, wear behavior and tool life of the inserts were compared with commercial inserts of similar compositions in order to ascertain the feasibility of nanostructured material for cutting tool inserts.

$Al_2O_3$-$ZrO_2$-TiCN nanocomposites were developed by spark plasma sintering (SPS) for the first time. Complete densification was achieved at 1473 K with a dwell time of 5 mins under an applied stress of 100 MPa. TEM studies on the nanocomposites with composition of 9 wt.% $ZrO_2$ and 20 wt.% TiCN at 1473 K showed homogeneously distributed $ZrO_2$ and TiCN nanoparticles at the alumina grain boundaries (Figure 1). The average grain sizes of $Al_2O_3$, TiCN and $ZrO_2$ were 350 ± 10, 70 ± 2 and 50 ± 2 nm, respectively. These samples were subsequently machined to get the SNGN120408 insert configuration. Machining trials were performed on hardened steel workpieces of EN24 grade having hardness 40-42 HRC.

Due to homogeneous dispersion of the nanoparticles in the composites as mentioned above, cracks propagation along grain boundaries encountered a larger number of nanoparticles leading to enhanced toughness by crack arrest and crack deflection. As both TiCN and $ZrO_2$ have higher coefficient of thermal expansion when compared to alumina, these particles exert compressive stresses on the surrounding alumina matrix after sintering and thereby inhibit crack propagation. This leads to higher toughness in the nanocomposites.

The progress in wear for the ARCI nanocomposites and commercial inserts at different machining conditions is shown in Fig. 2. The tool life was considered to be over once the wear at the tool cutting edge reached 0.3 mm or the insert fractured. The ratio of tool life of the two types of inserts at different feed rates and depth-of-cut (doc) (Fig. 3) revealed a higher tool life for the ARCI nanocomposite inserts at high cutting speeds. This was attributed to differences in their failure modes. The commercial inserts fail by fracture due to their inability to withstand sudden impact due of their low toughness. In contrast, the higher toughness in nanocomposite inserts restricted fracture and led to failure by wear. Thus, toughness determines the mode of failure thereby influencing the tool life.

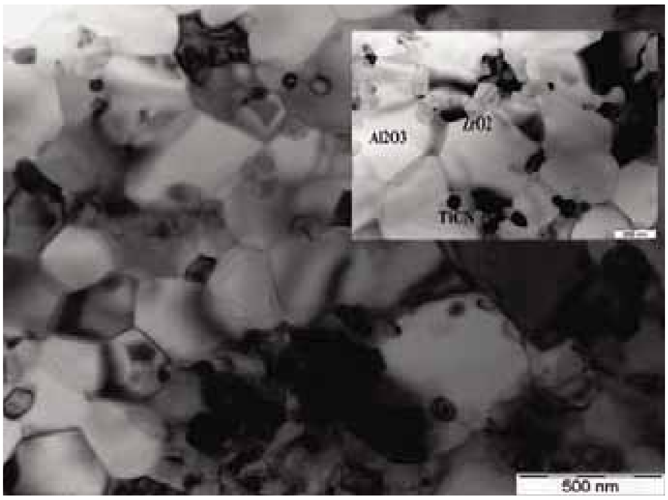

Fig. 1 Bright field TEM micrographs of samples sintered at 1473 K. Inset shows distribution of nanoparticles at alumina grain boundaries

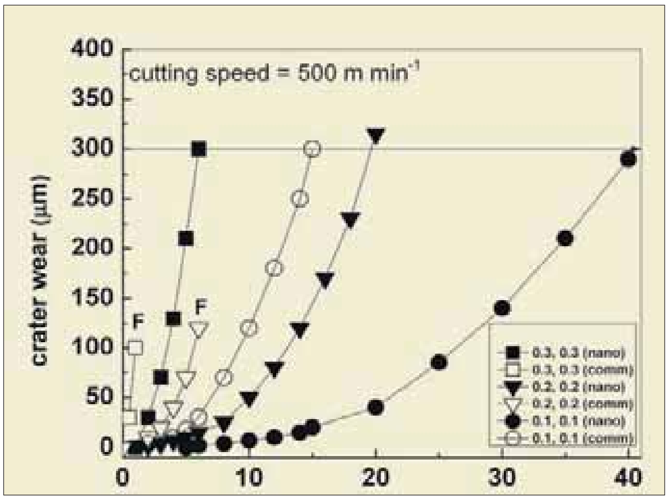

Fig. 2 Increase in crater wear with cutting time in nanocomposite and commercial inserts at a constant cutting speed of 500 m min$^{-1}$. Solid and hollow icons represent nanocomposite and commercial inserts at similar machining conditions, respectively; F indicates time of fracture

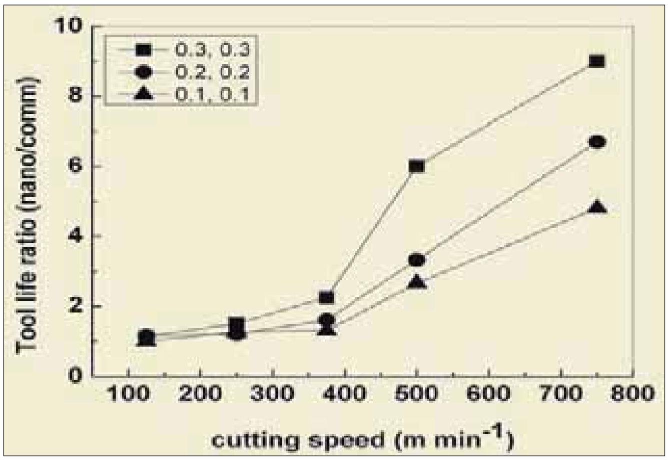

Fig. 3 Tool life ratio of ARCI nanocomposite and commercial inserts at different machining conditions (feed rate, doc = 0.3, 0.3; 0.2, 0.2; 0.1, 0.1)

# $WS_2$ Nanosheets for Potential Application as Automotive and Energy Material

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Nanosheet (NS) form of chalcogenides, in particular, tungsten disulfide ($WS_2$) and molybdenum disulfide ($MoS_2$) has enormous potential in the automotive, aerospace and energy materials sectors apart from, electronics industries (Figure 1).

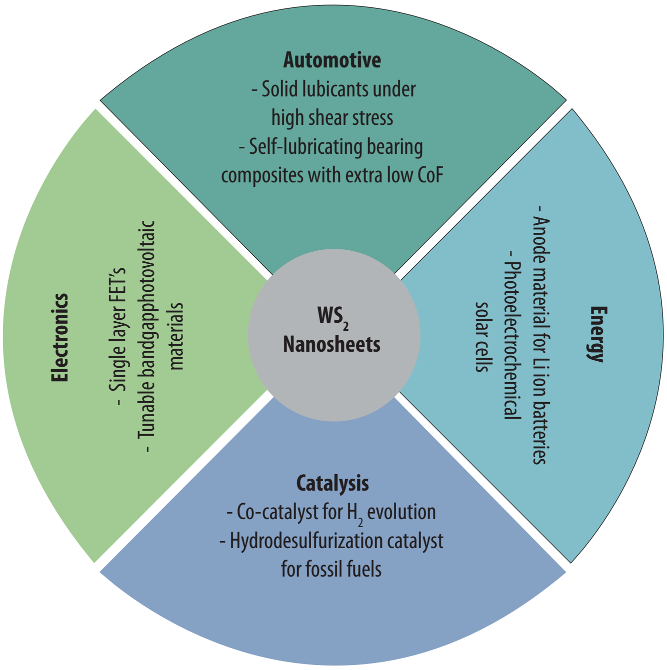

Fig. 1 Areas of application of $WS_2$ nanosheets

In addition, $WS_2$ and $MoS_2$ nanosheets have shown promising performance in the field of catalysis and fuel cells. One of the primary bottlenecks for commercial exploitation of these materials so far is the unavailability of a commercially viable large scale production method with reasonable degree of reproducibility.

At ARCI, we have developed a new route for the synthesis of $WS_2$ nanosheets in bulk quantity and reproducible quality. The method (patent pending) involves mechanically activated processing and at present the lab scale facility is capable of producing about 50-100 gm of powder per day. The process is easily scalable to 1kg/day and can be fine tuned to produce various fractions of nanosheets (NS: stack of more than 10 planes), inorganic fullerene (IF: layered spherical) and/or inorganic graphene (IG: stack of 10 or less number of planes). Figure 2a shows typical transmission electron microscopic (TEM) image of NS and IG like $WS_2$ produced by ARCI method while Figure 2b shows the XRD pattern confirming 100% conversion of $WO_3$ precursors to $WS_2$.

Currently, work is in progress to utilize these nano $WS_2$ phase(s) as solid lubricant, coatings and self-lubricating composites, e.g., cold sprayed $WS_2$-SS316L coating on steel, NiTi-$WS_2$ based composites by spark plasma sintering for application in automotive and other manufacturing industries; as cocatalyst to CdS for hydrogen generation. It is envisaged that the material after necessary optimization will find important application in energy sector e.g. in Li-ion battery electrodes as well as in strategic sectors like defence and space.

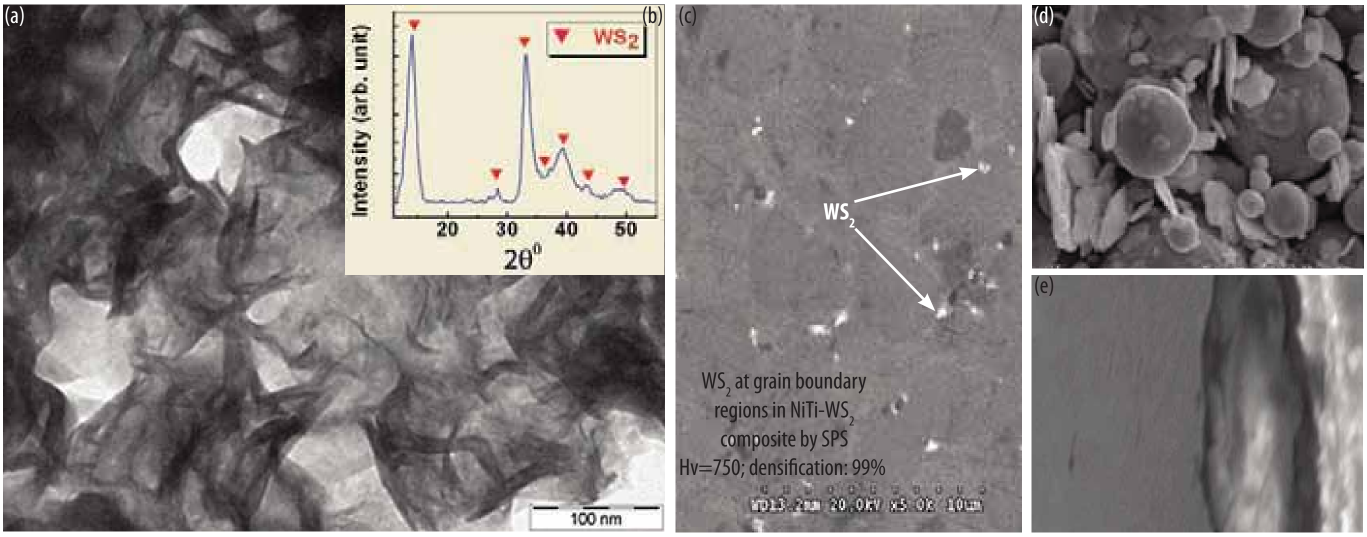

Fig. 2 (a) TEM micrograph and (b) XRD pattern of NS and IG-$WS_2$ synthesized by ARCI method; (c) dense NiTi-$WS_2$ composite by SPS (d) SS316L-$WS_2$ powder blend used for (e) cold sprayed composite coating on steel substrate

**_Contributor: M. Sylvester_**

# Preparation of IR Opacified Silica Aerogel Granules by a Novel Template Method

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Ultralow density nanoporous silica aerogels in various forms such as flexible sheets, monoliths and granules have been developed at ARCI for thermal insulation applications in various fields. Aerogels are known for their unique set of properties such as light weight and excellent insulation for heat, electricity and sonic energy.

The lowest thermal conductivity in silica aerogels is due to the very small solid content and nano meter size pores. Being transparent to some wavelengths of IR, aerogels show radiative heat transport to a certain extent. Suppression of this heat transport in aerogels has an added advantage if the temperature of thermal insulation application is above ambient. This is generally done by integrating silica aerogels with infra red opacifiers such as carbon black.

A novel method has been developed at ARCI to prepare thermally insulating silica aerogel granules which are IR opacified by in-situ trapping nano carbon particles into the aerogel network uniformly. A patent has been applied for this novel process. The process is pictorially shown in Figure 1.

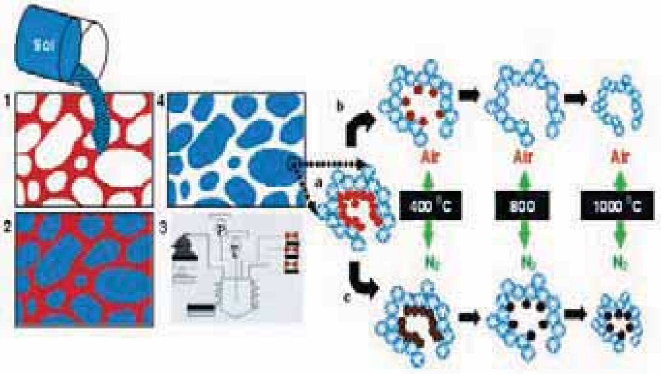

Fig. 1 Schematic showing synthesis of silica aerogel granules (1) organic sponge, (2) sponge-silica gel, (3) supercritical drying in ethanol, (4) formation of silica aerogel granules. (a) the structural changes in silica aerogel granule pore with respect to (b) heating in air (c) carbonization done in nitrogen atmosphere

The supercritical drying process of sponge-aerogel composite is carried out using ethanol as a solvent in a pressure vessel. During the process, the temperature of vessel is raised to 260$^0$C and pressure is increased to 80 bars. Under this condition, the organic sponge degrades completely to release granular gel and the organic molecules get trapped inside the gel network uniformly. The temperature and time maintained during this step determines the quantity of organic molecules in gel network and are utilized to control their loading. The drying process is completed by venting the vapours and cooling the vessel to get silica aerogel in granule form. These trapped organic molecules are then carbonized to obtain carbon containing silica aerogel. The totally carbon free aerogel granules was also prepared by heating them in air at 400$^0$C. The carbonization temperature was determined after evaluating the porous structure using nitrogen adsorption method.

The optimum carbon loading was decided where the aerogel porosity, which is a major cause for its thermal insulation property, is compromised to minimum and infra red absorption upto 15 $\mu$m wavelength is maximum due to carbon loading. It was found that 2% carbon loading could completely absorb the IR radiation of wavelength upto 18 micron. The important range of IR wavelength for opacification for suppression of radiative heat transfer is up to 15 microns. Fig. 2 depicts the IR absorption of pure silica aerogels and carbon loaded silica aerogels.

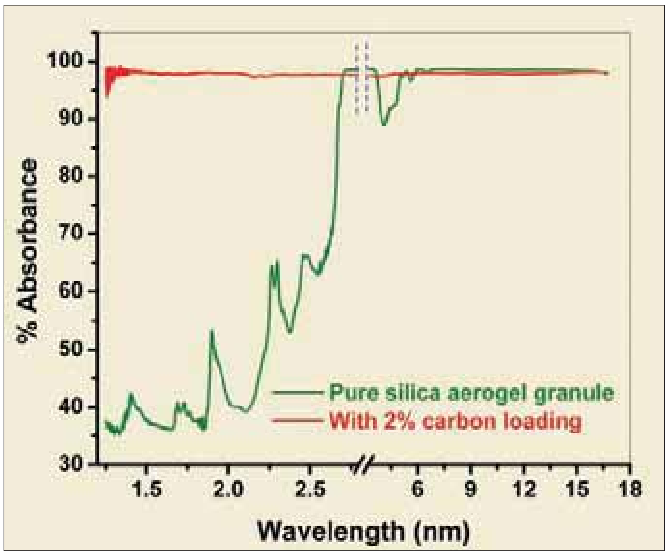

Fig. 2 IR absorbance in silica aerogel granules

The IR opacification in silica aerogels minimizes the radiative heat transport and hence shows good thermal insulation property even at higher temperatures. Such material is also expected to have application in concealing objects from thermal imaging devices which mainly work by detecting the IR radiation from the object. Thus, the aerogel material developed at ARCI is promising for strategic applications and for other users of surveillance cameras.

***Contributor: Ch. Swapna***

# Synthesis of Copper-Graphene Composite Foils with High Hardness by Pulse Reverse Electrodeposition

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Metal matrix nanocomposites reinforced with oxide and carbide nanopowders have witnessed significant attention during the past decade due to the feasibility of controlling the mechanical, electrical and thermal properties, which led to numerous commercial applications. Since the emergence of carbon nanotubes (CNT), composites reinforced with CNTs were soon to evolve due to remarkably enhanced features of CNTs when compared to the oxide and carbide nanopowders. Discovery of graphene has provided with a possibility to replace the CNTs in the composites. Graphene exhibits excellent physical, mechanical (Young's modulus of ~2TPa and tensile strength of ~130GPa), electrical (Electrical conductivity~$10^6$ $\Omega^{-1}cm^{-1}$) and thermal properties (K~ 5000 W $m^{-1}$ $K^{-1}$), which are superior to CNTs. In addition, its open structure/sheet like structure, high surface area and available contact area inhibits the entanglement unlike CNTs, when it is reinforced into the matrix making graphene as ideal filler. Metal matrix graphene reinforced composites have been studied very recently with Al, Mg, Cu and Ni by several methods.

In the present study, graphene reinforced copper (Cu-Gr) composite foils were prepared by pulse reverse electrodeposition (PRED) technique in order to enhance the mechanical properties of copper. PRED exhibits enhanced properties of the foils in terms of density, roughness and porosity due to the formation of minimal residual stresses, grain refinement etc. The presence of graphene was confirmed by FESEM and TEM (Figure 1). The hardness and elastic modulus of the copper and Cu-Gr foils prepared by PRED were studied by nanoindentation technique using a Hysitron Tribo Nanoindenter. Hardness and elastic modulus were estimated from the load-displacement curves (Fig. 2) for copper and composite foils by PRED revealed a significant enhancement in the hardness of the composite foils compared to that of pure copper foil. Graphene reinforced copper composite foils showed a higher hardness in the range of 2.2 - 2.5 GPa for different set of foils prepared by PRED compared to 1.5 – 1.6 GPa observed for pure PR deposited copper foils. Although a small increment in the hardness is observed for copper foils after annealing, probably due to the formation of twins, the values are much lower than those obtained for both as-deposited and annealed Cu-Gr foils. Decrement in the hardness upon annealing of Cu-Gr composite films was very less. This can be attributed to the effective inhibition of grain coarsening by graphene, which are uniformly distributed throughout the grain boundaries.

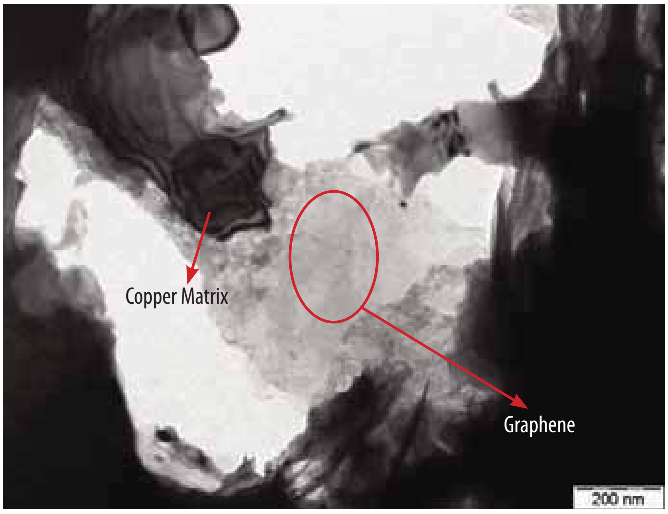

Fig. 1 TEM image of Cu-Gr foil

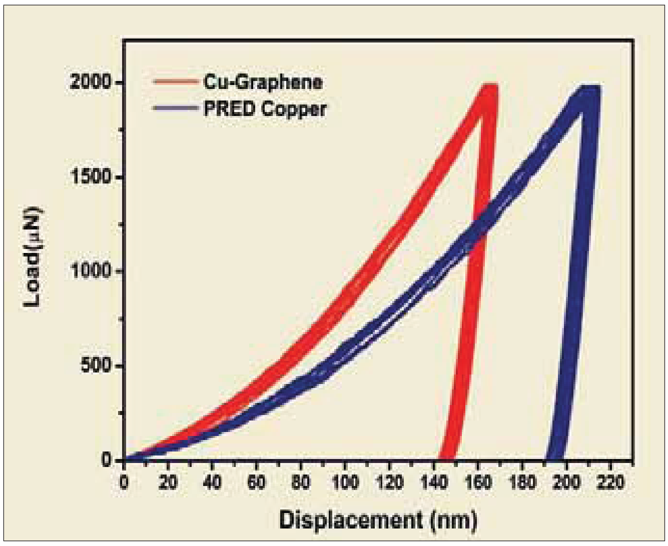

Fig. 2 Load-Displacement curves for Cu and Cu-Gr composite foils

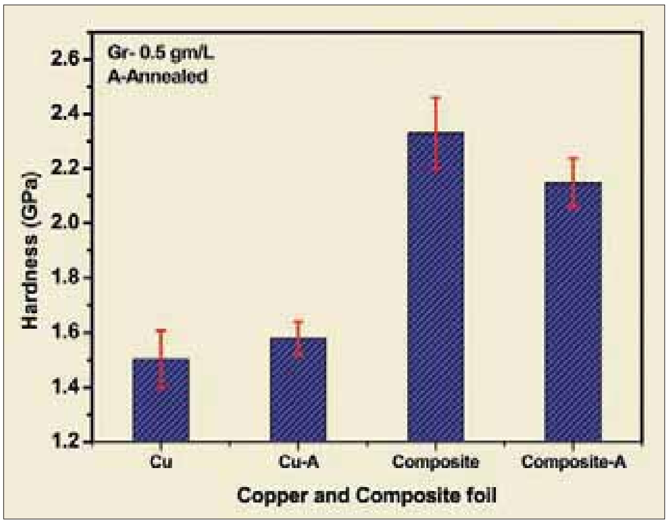

Fig. 3 Comparison of hardness for Cu and Cu-Gr foils prepared by PRED

***Contributors: Ch. L. P. Pavithra and B. V. Sarada***

# Development of Composite Coated Iron Powder for Soft Magnetic Applications

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Rapid progress has taken place in the development of hybrid and electric vehicles in order to reduce the environmental burden created by the automobile industry. A prime objective is to realize a high-performance and downsized motor or reactor, which is a crucial aspect of the electric/hybrid vehicles. A stator core or a rotor core, which constitutes a motor and a reactor, consists of a core storing energy from batteries in magnetic form for further transmission in requisite form. At present, the reactor cores comprise of either silicon steel sheet laminates or dust cores of iron-based soft magnetic powder. A variety of dust cores made of soft magnetic composites are being designed. As for example, pure Fe powder with resin, sintered iron-based powders, pure iron powder with additions of Zn stearate and carbon, iron-based powder alloys (P, Ni, Co, Si), commercially available iron powder "Somaloy 70 series". These have inherent design flexibility owing to particulate material processing and are advantageous in terms of magnetic properties that result in a high magnetic flux density with lower high-frequency iron loss when compared to electromagnetic steel sheets. In case of soft magnetic metal powder for dust cores, an electrically insulating coat is usually formed on the metal powder particle to inhibit the occurrence of iron loss. At ARCI, we are attempting to develop and consolidate coated composite Fe-based metal or alloy powders for reactor cores capable of working at moderate to high frequency applications. The outline of the process adopted and the evaluation is described below.

Electrolytic iron powder was coated with resin and resin-nano-silica using solution technique. Coated powders having two differential layers of resin and resin-silica were developed. The powders were then hot consolidated at different temperatures and pressures using indigenously developed hydrogen fed hot press 'SPHP' and also using spark plasma sintering technique into torroid shapes of 20 mm OD*15mm ID*2 mm thickness. The torroid samples had sintered densities ranging from 89-94%. Microstructure characterization using, SEM and magnetic property evaluation like induction, residual induction, coercivity, permeability and core loss were obtained under both DC and AC conditions at different fields (5-100 Oe) and different frequencies (50 Hz to 1 kHz) from the B-H hysteresis loop tracer. The comparison between the magnetic properties (B-H loop) in resin coated Fe based composite and resin-nano silica coated Fe powder composite under AC measurements @ 50 Hz is shown in the Figures 1 and 2. The resin-nano silica coated iron powders showed better induction (approx. 1T) and higher permeability (100) at 50 Hz when compared to resin-coated composite Fe powder. Further work is being carried out to measure DC properties at CAEM, Chennai in order to understand the effect of coercivity with respect to thermal treatment and annealing so that the core losses can be minimized.

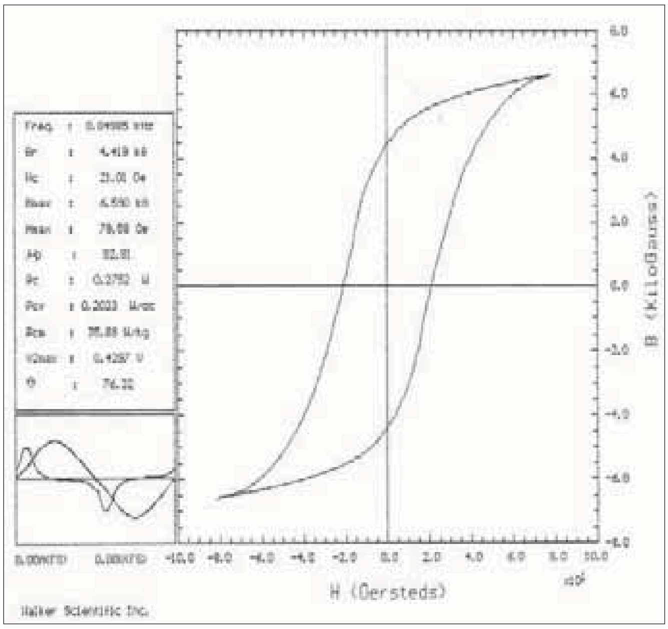

Fig. 1 B-H loop of resin-coated Fe powder

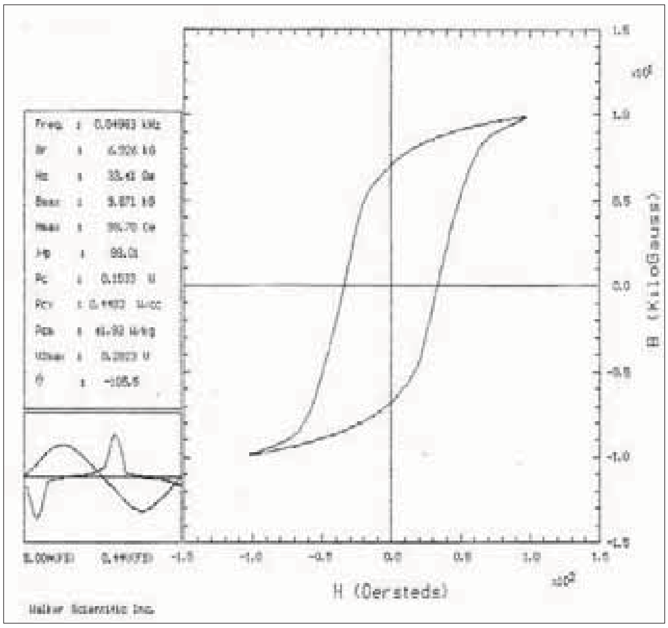

Fig. 2 B-H loop of resin-silica coated Fe powder

***Contributors: Neha Hebalkar, Dibyendu Chakravarty, V. Uma and R. Gopalan***

# MWCNT-Carbon Composite Nanofibers by Electrospinning for Li-ion Battery Applications

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Fabrication of nano graphitic carboneous material for Li-ion battery application by simple and commercially viable methods was evaluated. Carbon–carbon nanotube (CNT) composite nanofibers by electrospinning process were found to be one of the feasible and economical methods. It is known that the electrical conductivity of the carbon nanofibers can be increased by two orders of magnitude from 1.2 x $10^4$ S/m to 3.10 x $10^6$ S/m with the addition of 0.5 wt. % CNTs. A concomitant increase in tensile strength by 20 to 60% also takes place. According to the existing literature, the extent of graphitization also shows an increase during carbonization of the polymer in the presence of CNT. Based on such background information, experiments were performed to synthesize carbon–CNT composite nanofibers by electrospinning.

The synthesis of the nanofibers was carried out at ARCI using Nanospider electrospinning facility. The carbon/multi-wall (MW)-CNT composite nanofibers were produced from polymers for possible application in Li-ion batteries. For the synthesis of the composite fibers, polyacronitrile polymer was taken as the base polymer. About 0.5 to 2 wt.% of MWCNT was dispersed in N,N-dimethyl formamide (DMF). The Polymer was dissolved in CNT dispersed DMF solution. Subsequently, the PAN-CNT-DMF solution was electrospun for making the polymer nanofibers. Thereafter, the polymer nanofibers were calcinated at 600°C in argon atmosphere for converting it into the carbon-CNT composite fibers. Microstructure of the CNT-carbon composite nanofibers produced at ARCI were investigated by FESEM and TEM as shown in Figs. (1 and 2(a, b)).

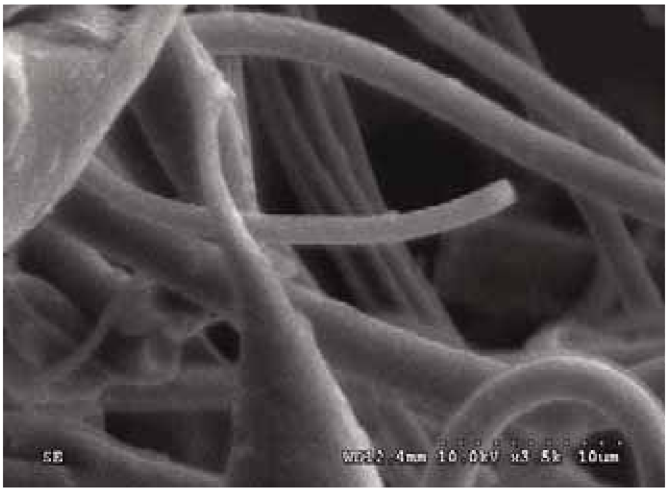

Fig. 1 FESEM image of MWCNT-Carbon nano-fiber composite

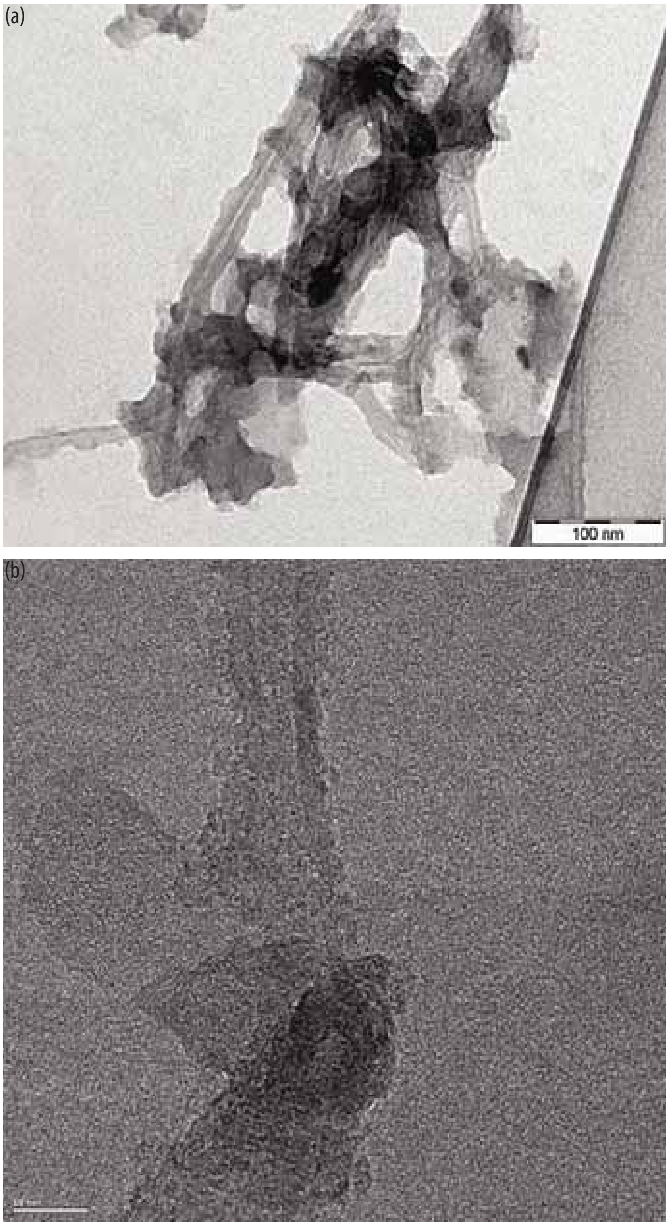

Fig. 2 (a, b) TEM images of CNT - Carbon nano-fiber composite

The microstructures clearly indicate the well distributed CNT incorporated in the fibers. Raman studies confirmed the significant fraction of $sp^2$ carbon in the fibers. Studies are currently in progress to improve the dispersion and graphitization to enable the material for Li-ion battery electrodes. It is worth mentioning that electrospinning provides safe, low cost and one step integrated processing assembly for production of composite nanofibers. With the Nanospider system, the production of fibers can be scaled to large volume. This is expected to bring down the overall production expenses.

***Contributor: Tata Narasinga Rao***

# Modified Chalcogenide Photoanode for Sustainable Solar PEC $H_2$ Production

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Hydrogen energy from renewable sources has been predicted as the ultimate way of decreasing our dependence on the non-renewable resources like oil. It also has additional benefits with the reduction of carbon emissions and facilitating a clean and reliable power generation for energy and automotive sector. The photoelectrochemical (PEC) hydrogen generation using renewable sources like water and solar radiation is promising. However, this photo-assisted electrolysis needs efficient and stable electrode materials. In this regard, sulfides are known to be efficient though they lack stability. On the other hand, semiconducting metal oxides are highly stable but display poor activity under sunlight. The commercial fate of solar $H_2$-energy technology lies in achieving low-cost and stable PEC systems, which can sustainable for daily use.

At ARCI, we are in the process of developing low-cost nanostructured films with large area (10-30 cm x 10-30 cm) photoanodes for their direct implementation in a scaled-up PEC $H_2$ reactor.

Fig. 1 (a) displays a schematic for the fabrication of modified film exhibiting a nanostructured surface of the photoanode. Such surface structure enhances PEC performance due to improved absorption. Different semiconducting nanoparticles show the potential as modifier. Several interesting surface morphologies are achievable by using simple chemical and hybrid methodology. The nanoparticle modified electrode delivered several times enhanced PEC performance as shown in Fig. 1(b). Such photoanode is capable of generating $H_2$ as well as electricity. Figure 1(c) demonstrates how the sustainability can be improved with the stability. Currently, modified photoanodes of large area (>10-30cm length) are being targeted for $H_2$ production as well as energy application at ARCI. We have already demonstrated successfully a test case of hydrogen generation using large area electrode.

The utilization of simple chemical based technique is also being explored. A simple bath and spray method is especially important in context of development of economic deposition methodology. Figure 2 (inset) shows FESEM of a typical modified nanostructured chalcogenide photoanode developed at ARCI. Its performance demonstrates that a scalable technique can yield an efficient photoanode for producing $H_2$ as well as electric power under the renewable energy emanating from sun.

Development of efficient techniques with further modification of electrode and cell design is being pursued in order to scale-up the device capability.

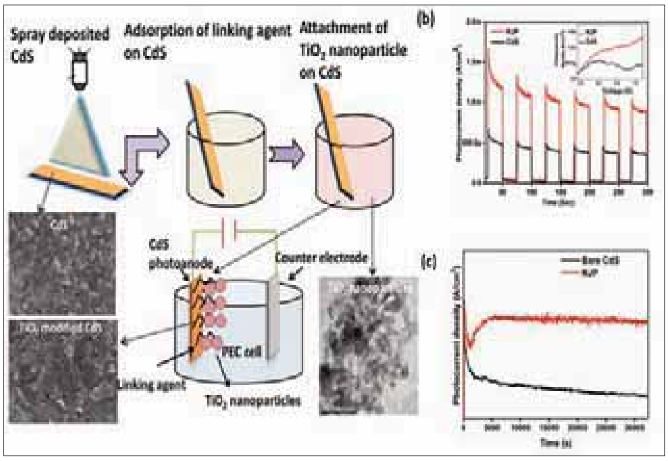

Fig. 1 (a) Schematic presentation of electrode modification using $TiO_2$ nanoparticles to fabricate modified photoanode; (b) Chronoampereometry and I-V plots of modified and bare CdS; (c) Stability testing in form of photocurrent versus reaction-time plot for ~10 hours on the modified nanostructure film

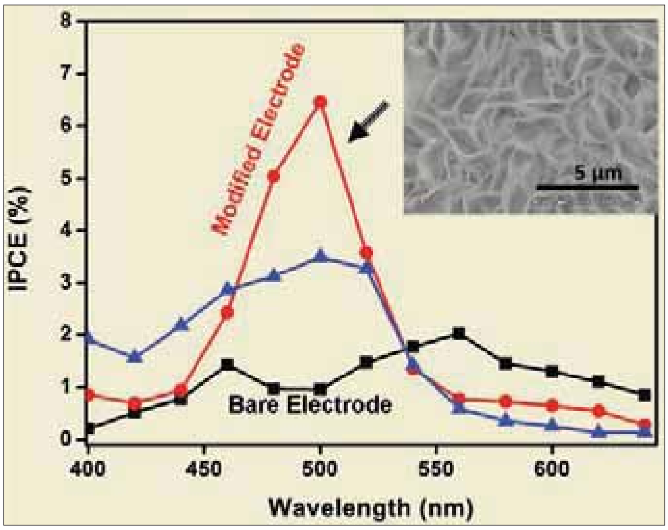

Fig. 2 Performance efficiency of nanostructure PEC electrode as deposited from the chemically controlled environment. Modified electrode showing a typical nanostructured surface exhibits maximum of 6% IPCE under visible light. Source-Monochromator (300Watts, Xe-lamp)

***Contributors: Rekha Dom and Alka Pareek***

# Microstructure and Properties of Hot Extruded Cu-1 wt% $Al_2O_3$ Nano-composites Synthesized by Various Techniques

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Alloys exhibiting high mechanical strength coupled with high electrical and thermal conductivity at elevated temperature have several commercial applications. Copper-based alloys are the most promising in this regard. However, for several design requirements in high temperature applications, additional strengthening is required. Conventional strengthening mechanisms such as cold working and precipitation hardening are inadequate for high temperature strength demands due to recrystallization and precipitate coarsening or dissolution, respectively. An alternative promising technique to get the desired properties is dispersion strengthening with $Al_2O_3$ in Cu. Applications for these materials include high-performance switches, spot welding electrodes and rotating-source neutron targets etc.

Non-equilibrium processing like mechanical alloying (MA), combustion synthesis (CS) and electrical explosion of wires (EEW) technique were employed to produce Cu-$Al_2O_3$ composite. In all the above three cases, the as-synthesized powders were subsequently reduced under hydrogen at a flow rate of 100 cc/s at 500$^0$C for 1 hr. The alumina loading was optimized to 1 wt.% in all the cases and extruded at 800$^0$C with an extrusion ratio of 9 using a 250 ton hydraulic press. Fig. 1 shows the TEM bright field image of the extruded Cu-$Al_2O_3$ samples from MA powders.

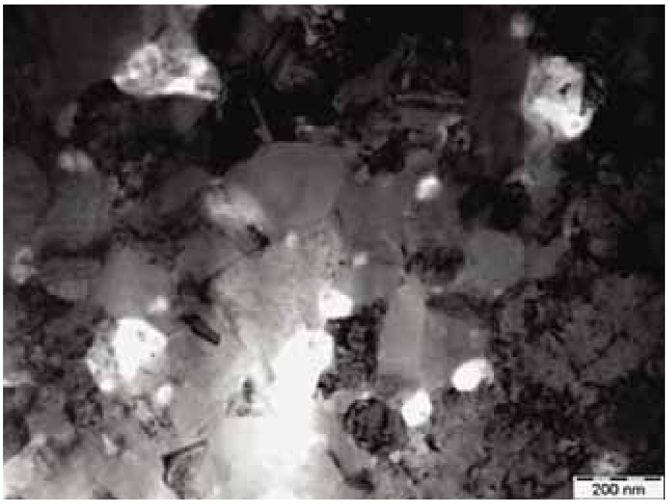

Fig. 1 TEM image of the extruded Cu–1 wt% $Al_2O_3$ from MA powders

The oxide particles were found to be mostly spherical in shape and predominantly located at the grain boundaries, although the finest particles are present in the grain interiors. A maximum compressive strength of 525 MPa was achieved in case of powders from MA, while it was 350 MPa for EEW powders upon consolidation. Fig. 2 shows the yield stress as a function of inverse square root of grain size for samples with different grain sizes obtained by different powder processing techniques. The values of Hall-Petch constant $k_y$ and friction stress $\sigma_{0y}$ are determined to be 117 MPa µm$^{0.5}$ and 201 MPa, respectively. Accordingly, the plot in Fig. 2 can be expressed by the equation:

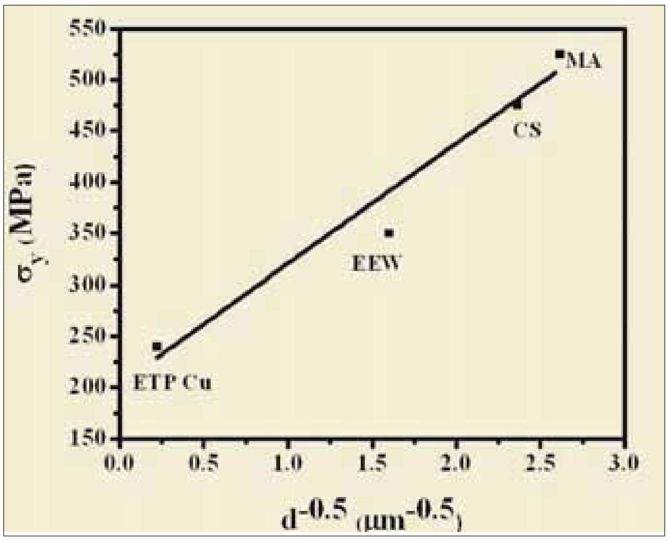

Fig. 2 Hall-Petch plot of yield stress ($\sigma_y$) vs inverse square root of grain size ($d^{-0.5}$) for extruded Cu-$Al_2O_3$ samples

$$\sigma_y = \sigma_{0y} + k_y d^{-0.5} = 201 + 117 d^{-0.5}$$

Efforts are underway to evaluate the effect of grain size on all the other properties like hardness, electrical conductivity and thermal conductivity. Preliminary results suggests a linear relationship between yield stress and electrical conductivity and also for yield stress and thermal conductivity (Fig. 3).

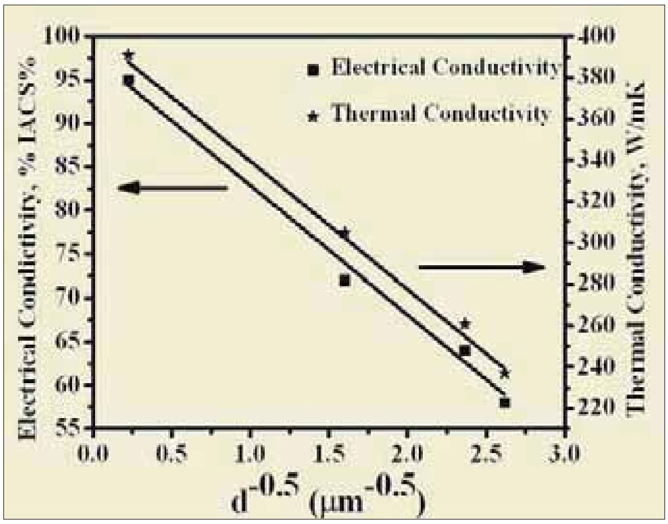

Fig. 3 Hall-Petch plot of physical properties for extruded Cu-$Al_2O_3$ samples

**Contributors: S. Sudhakar Sarma, M. Ramakrishna, P. Suresh Babu, B. P. Kashyap and Tata Narasinga Rao**

# Development of Nano Boron Powder by Mechanical Milling

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Elemental boron is a potential candidate as an additive to liquid propellant due to high volumetric energy density. The combustion rate of boron is low due to inherent heterogeneous process. The heterogeneous combustion can be accelerated by using nano particulate boron with high surface area/volume ratio. But the drawback to this approach is that boron forms a passivating native oxide layer exposed to air, which inhibits combustion and limits the effectiveness of reduced particle size. A protective coating on nano boron particles is expected to inhibit the formation of oxide layer and results in a better additive to the liquid propulsion system. At ARCI, we are working on the development of nano boron powder and protective coating on these particles.

High energy ball milling (mechanical milling) is employed to make nano particles of boron from micron sized powder. Boron powders of average particle size of 2 µm (supplied by HEMRL, Pune) are subjected to mechanical milling in a planetary ball mill in argon atmosphere with ball-to-powder ratio of 15:1 at 250 RPM for various milling times up to 15 h. BET Surface area analyzer, Laser particle sizer and FESEM are used to estimate the average particle size of the milled powder.

Various milling conditions employed on boron powder are given below:

1. Dry Milling (DM)
2. Dry Milling with Oleic acid (1% wt). (DMOA)
3. Dry Milling with Oleic acid (1% wt) followed by wet milling for 2 h with Ethyl Alcohol (DMOA+WM)
4. Wet Milling with Toluene (WMT)

Variation of BET surface area and the particle size measured using dynamic light scattering technique with milling time for various milling conditions are shown in Fig. 1 and 2.

It is evident from these figures that dry milling condition led to a decrease in the surface area without any change in the particle size. Wet milling with toluene, on the other hand, resulted in an increase in the surface area to some extent with only a marginal reduction in the particle size. Milling with oleic acid showed insignificant change in the surface area. However, additional milling with ethanol led to an increase in the surface area along with a drastic reduction in the particle size. Among all the aforementioned milling conditions, boron powder milled with oleic acid for 10 h followed by wet milling with ethanol for 2 h was found to give best result with an average particle size of 230 nm (Fig. 3).

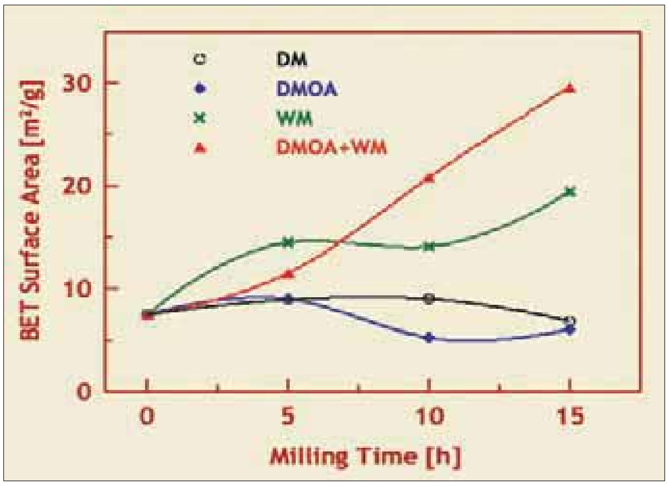

Fig. 1 Variation of BET surface area of boron with milling time

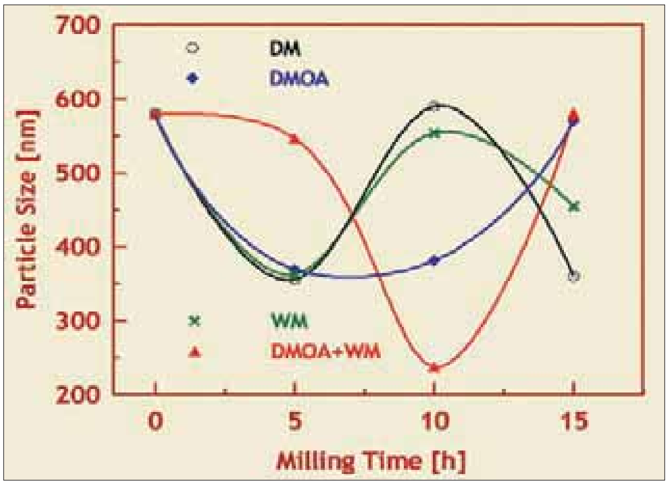

Fig. 2 Variation of particle size of boron with milling time

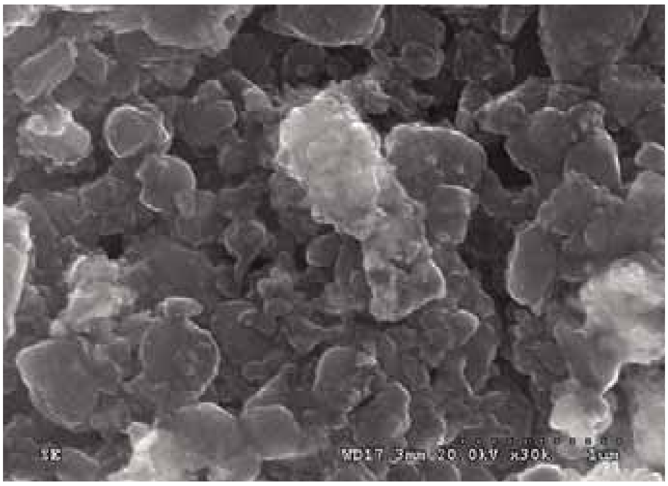

Fig. 3 FESEM image of boron powder milled for 10 h with oleic acid followed by wet milling with ethyl alcohol for 2 h

***Contributors: K. Sai Deepak Reddy and Tata Narasinga Rao***

# Role of Coating Thickness on Dry Machining Performance of TiCrN Coated HSS Drills

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The widely used transition metal nitride (TiN, TiAlN) coated tools have been in use for sometime now and meet the growing performance requirements to a certain extent. However, the increase in demand for higher performing tools has led to the development of new coatings such as TiCrN, TiAlCrN, etc. The addition of 'Cr' to TiN or TiAlN has been reported to increase high temperature stability and toughness. Hence, in the present study, deposition of TiCrN thin films (with varying thickness) on HSS drills by cylindrical Cathodic Arc Physical Vapor Deposition (c-CAPVD) technique has been investigated and the real time performance of coated tools evaluated. With a view to minimize the residual stresses, which otherwise tends to increase with increasing film thickness, the coatings were grown in stages with intermittent heating to 475° C for 30 minutes after each one micron thick film build up. In addition to TiCrN, the relatively well-understood TiAlN coating was also deposited for the purpose of benchmarking. Coating properties such as thickness, adhesion, surface roughness, crack propagation resistance (CPR), residual stress and hardness were evaluated for the coatings studied and the results are summarized in Table 1. Dry machining performance of bare and coated tools was evaluated on a 5-Axis (DMG HSC 55 linear) CNC machine with a feed rate of 120 mm/min (1200 RPM) against EN 24 steel (H - 2.8 GPa). Corner wear has been considered as the failure criterion and the results of machining trials are shown in Figs. 1 and 2.

The results presented in Table 1 and Fig. 1 clearly indicates the superiority of TiCrN over TiAlN coatings in many respects, barring the hardness value obtained. The observed higher tool life with TiCrN coatings may be due to the cumulative effect of reduced residual stresses, surface roughness and increased CPR. Furthermore, in case of the TiCrN coatings, an increase in coating thickness was found to significantly influence the results (Table 1). The increase in coating thickness was also accompanied by a considerable increase in surface roughness of the coating, which is attributable to the relatively more prolonged deposition which causes more droplets to be incorporated in the coating.

Table1: Mechanical properties of TiCrN coatings (at varied thicknesses) in comparison with already established TiAlN coating

| Coating | Adhesion (N) | CPR ($N^2$) | Hardness (GPa) | Modulus (GPa) | Stress (GPa) | Ra (μm) |
|---|---|---|---|---|---|---|
| TiAlN-4 μm | 98 | 2385 | 30.7±01 | 367±05 | 4.74 | 0.051 |
| TiCrN-5 μm | 113 | 3082 | 25.9±0.8 | 368±10 | 3.75 | 0.017 |
| TiCrN-8 μm | 132 | 4340 | 25.6 ± 0.4 | 426 ± 10 | 3.81 | 0.028 |
| TiCrN-10 μm | 132 | 4131 | 25.6 ± 0.6 | 429 ± 07 | 3.84 | 0.038 |

Although the TiCrN coated HSS tools clearly outperformed the bare HSS tools, with increase in TiCrN coating thickness up to 8 μm, no significant change in the tool life was observed (Fig. 2). However, beyond 8 μm, the coatings started exihibiting relatively poor tool life. From the microscopic analysis after the scratch test, it was found that at higher thicknesses the coatings exhibit chipping, leading to uneven tool wear due to increased friction. The increase in surface roughness with increasing coating thickness is another possible factor responsible for the noted performance degradation. In summary, a 5 μm thick TiCrN coating yields better mechanical properties and maximum tool life.

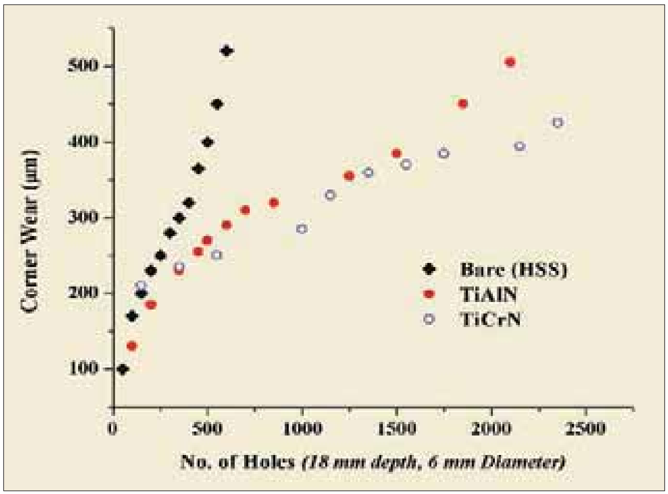

Fig. 1 Dry machining performance of bare as well as TiAlN and TiCrN coated HSS tools

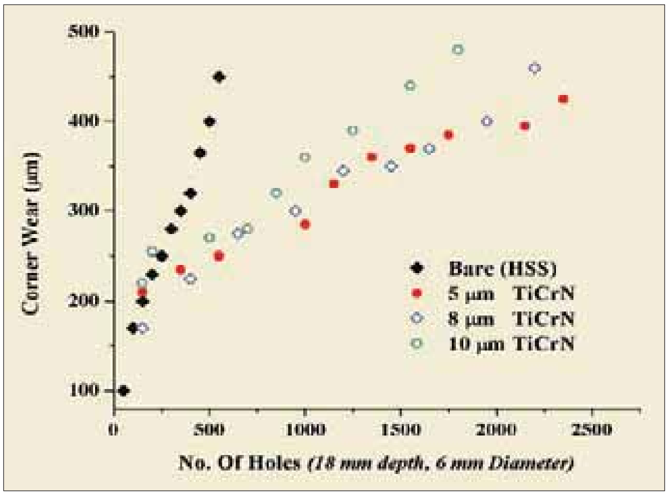

Fig. 2 Influence of coating thickness on dry machining performance of TiCrN coated HSS tools

***Contributors: Kadam Shirish and C. Puneet***

# Corrosion Studies on Textured Cold Sprayed Titanium Coatings

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Cold gas dynamic spray (CGDS) is a thermal spray variant in which kinetic energy, rather than thermal energy, of feedstock plays a major role in coating formation. A process gas (air/nitrogen/helium) is compressed to high pressures (8–30 bar) and heated to moderately high temperatures (RT-800 K) and is made to expand through a De-Laval convergent-divergent nozzle. Powder particles, introduced into the gas flow prior to the convergent section of the nozzle, are accelerated to ultra-high velocities by the gas. In the divergent section the temperature of the gas drastically falls thus cooling the particles to a temperature much lower than that in the convergent section. Thus, the temperature of the powder particles at impact is significantly lower than the melting point; unlike in the case of other thermal spray variants. Plastic deformation takes place at very high strain rates (>$10^7$/s) at which a major fraction of the kinetic energy is converted into heat energy, thereby heating up the deformed interface zone adiabatically.

In the present study, Titanium coatings were deposited at 10 bar, 15 bar and 20 bar pressure and at temperatures of 573 K, 648 K and 723 K, respectively using air as process gas. The Titanium powder used for coating deposition exhibited an irregular morphology. The porosity of the coatings was measured using optical microscopy and the results are shown in Fig. 1. The coatings were then also subjected to XRD analysis and found to have a strong basal texture. The relative texture of the basal plane in different coatings has been plotted against powder particle energy (kinetic energy + thermal energy) in Fig. 2. The texture development in the coatings is attributable to the favorable orientation of the slip plane (prismatic plane in the case of titanium) along the direction of highest degree of deformation.

The corrosion performance of the coatings has been evaluated in a 3.5% NaCl aqueous solution for 24 hours. Each coating was tested thrice and the average values reported herein. The observed $I_{corr}$ values have been compared to previous studies on cold sprayed titanium deposits reported in the literature and it has been found that the coatings deposited at ARCI using air have outperformed those deposited using nitrogen. Table 1 shows comparison of corrosion current and rest potential from tests conducted at ARCI and those reported by T. Hussain, D. G. McCartney, P. H. Shipway, and T. Marrocco, 'Corrosion Behaviour of cold sprayed titanium coatings and free standing deposits', Journal of Thermal Spray Technology, 260-Vol.20(1-2) January 2011. The corrosion performance seems to vary as a function of porosity (inter-splat bonding), grain refinement and the basal texture. It has been reported that the basal texture acts as a positive factor in enhancing corrosion performance. Even though the porosity and finer grains present in the coating is expected to have a deleterious effect on the corrosion rate, in the case of titanium it promotes faster passivation thus reducing further corrosion. This is reflected in the corrosion performance of the coatings deposited at 15 bar (0.52438MPY) which performed better than bulk Ti (0.56 MPY). It is worth noting that coating deposited at 20 bar, 375°C shows better corrosion performance than the coating deposited at 20 bar, 450°C, due to the presence of more refined grains at the inter-splat boundary.

Table 1: Corrosion performance of Ti coating

| **Coating Conditions (Process gas, $P_{stag}$, $T_{stag}$)** | **Corrosion Current ($I_{corr}$) (Amp/cm$^2$)** | **Rest Potential (V)** |
|---|---|---|
| Nitrogen @ 40 bar, 600°C (T. Hussain et al) | $1.9 \times 10^{-3}$ | -0.565 |
| Air @ 20 bar, 450°C | $2.27 \times 10^{-3}$ | -0.368 |
| Air @ 20 bar, 375°C | $1.04 \times 10^{-3}$ | -0.534 |
| Air @ 15 bar, 375°C | $0.71 \times 10^{-3}$ | -0.529 |

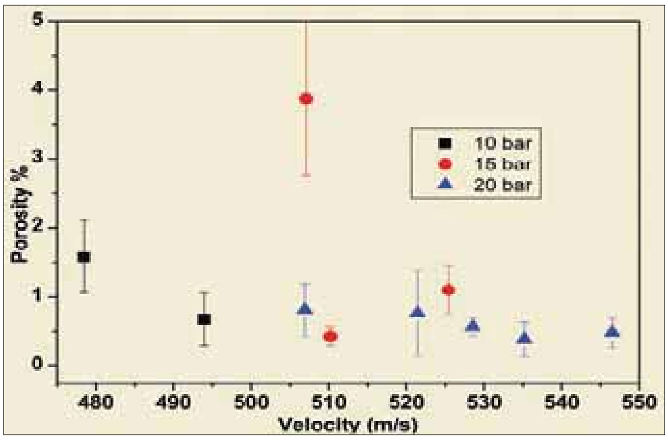

Fig.1 Variation of porosity levels in the coatings as a function of velocity

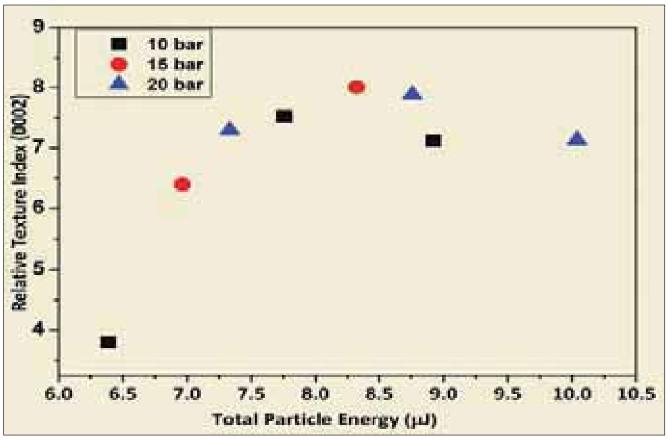

Fig. 2 Variation of the relative texture index of the basal plane as a function of total energy of the powder particle

***Contributors: Anil Kumar Prathuru and A. Jyothirmayi***

# Duplex Coatings for Corrosion Protection of Magnesium Alloys

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Micro arc oxidation (MAO) of Mg alloys usually results in a porous coating, with the open pores extending down to the substrate-coating interface, thereby exposing the underlying substrate material to corrosion. An attempt has been made to combine two radically different techniques, namely Cold gas dynamic spray (CGDS) and MAO, wherein the former is employed to deposit Aluminium on an AZ91 Mg alloy substrate while the latter results in formation of oxides of metallic constituents present to enhance overall corrosion resistance.

Commercially available spray grade Al powder was sprayed using CGDS at an inlet gas (air) pressure of 20 bar and a gas temperature of 150°C, with a stand off distance of 15 mm. Two different coating thicknesses, namely 12±2 μm and 22±3 μm, were deposited on different samples. The Al-coated AZ91 substrate with Al top coat was then subjected to MAO treatment in an electrolyte comprising sodium silicate, potassium hydroxide and sodium aluminate at a total concentration of 10 g/ltr. The MAO treatment of the above samples resulted in duplex coating thickness of 16±3 μm and 28±4 μm, respectively.

The typical mechanism of coating formation by material coming out of discharge channels onto the coating surface and forming pancakes appears to be valid even in the present case, as illustrated by the pancake features observed in plain MAO (Fig. 1a) and CGDS+MAO duplex coatings (Fig. 1b). However, it is to be noted that the duplex coatings are denser than the plain MAO coatings. This observation has also been verified through SEM examination of the coating cross-sections.

XRD and SEM-EDS analysis of the coatings has revealed that the plain MAO coating contains mainly the MgO (periclase) phase, with the less predominant $MgAl_2O_4$ phase being uniformly distributed throughout the coating thickness. However, in the case of duplex coatings, there exists a clear composition gradient across the coating thickness, with coating top layer predominantly comprising the $MgAl_2O_4$ (spinnel) phase and the inner sub-layer mainly of MgO phase, with the $Mg_2SiO_4$ (fosterite) phase being nearly constant throughout the coating thickness. Such a compositionally gradient nature of the duplex coating is attributed to the presence of metallic Al (CGDS) coating on the Mg substrate prior to the MAO treatment. With the above phase distribution, the MAO+CGDS duplex coating offers significantly higher corrosion protection (Fig. 2) compared to bare AZ 91 as well as with MAO or CGDS alone.

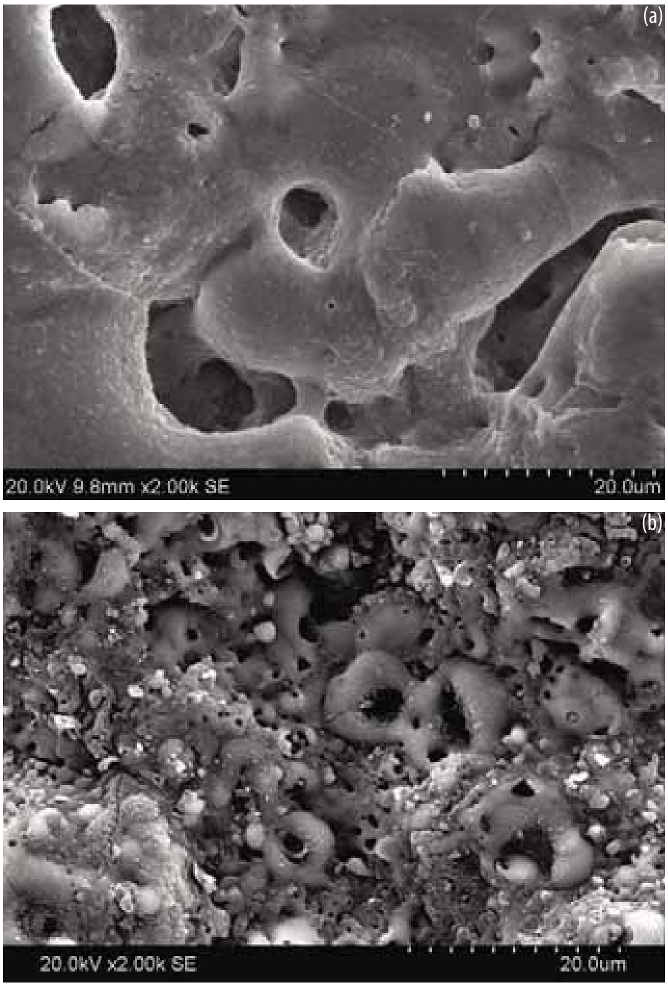

Fig.1 Surface SEM images of plain MAO and CGDS+MAO duplex coatings at identical magnification

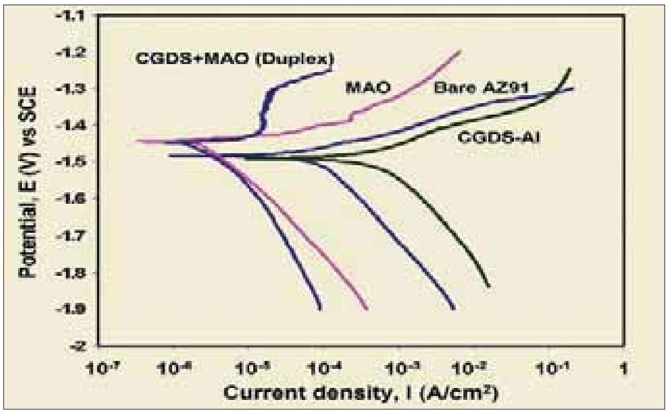

Fig.2 Polarization curves for AZ91 magnesium alloy untreated and coated using different methods (as indicated on figure), recorded after 60 min of immersion in aerated 3.5 wt.% NaCl solution (scan rate 1.0 mV/s)

***Contributor: A. Jyothirmayi***

# Hybrid Plasma Sprayed Thermal Barrier Coatings Using Powder and Solution Precursor Feedstock

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High-performance TBCs are being increasingly sought in gas turbines, as improved fuel economy and enhanced efficiency demands push operating temperatures closer to design limits of component materials. While electron beam physical vapour deposition (EB-PVD) and atmospheric plasma spraying (APS) are the more popular techniques in vogue for depositing TBCs, the solution precursor plasma spray (SPPS) technique has been the subject of growing recent attention. The porosity and micro-cracks inherently present in APS TBCs ensure reduced heat transfer to the bond coat. However, the top yttria stabilized zirconia (YSZ) layer has a propensity to sinter during service, thus not only increasing the effective thermal conductivity but also leading to increase in stiffness and accelerated spallation. In this context, SPPS based nanostructured YSZ coatings have been found to exhibit better sintering resistance. *In situ* particle generation and splat formation studies previously carried out at ARCI have provided an improved understanding of the process and provide basis for an attempt to hybridize the SPPS and APS processes, by enabling simultaneous or sequential feeding of spray-grade powders and solution precursors employing a set-up as shown in Fig. 1. This approach is extremely versatile, enabling production of diverse architectures such as multi-layered, composite and graded coatings to potentially yield improved TBC performance.

A YSZ forming precursor and a commercially available YSZ powder were deposited sequentially as well as simultaneously to form layered and composite coatings, respectively. Cross-sectional microstructures of these two architectures are shown in Fig. 2 along with standalone APS and SPPS YSZ coatings. Although SPPS and APS YSZ coatings exhibited similar porosity levels, the former exhibited a fine distribution of nano-sized pores along with vertical cracks compared to larger voids and distinct splat boundaries associated with conventional APS. The layered coatings showed good integrity at the interface and appear promising, as the top nano-porous SPPS YSZ layer can effectively slow down the ingress of oxidizing/corrosive species while retaining the larger pores in the underlying APS YSZ that serve to reduce the effective thermal conductivity and improve strain tolerance. The composite YSZ coating possesses a unique microstructure, comprising distributed nano-pores along with micron-sized features typical of APS. The nano-zones provide better sintering resistance due to the differential sintering characteristics of bimodal YSZ splats. Microhardness measurements reveal marginal improvement in hardness of composite YSZ coatings over both APS and SPPS YSZ coatings, which is attributable to strengthening by *in situ* formed nanosized YSZ particles from solutions, within the matrix of relative larger YSZ powder splats.

Fig. 3 depicts the thermal cycling life of the different TBCs studied which reveals that the SPPS YSZ coatings are most durable, closely followed by the layered YSZ coatings. Although the thermal cycling life of composite YSZ coating was shorter than that of the SPPS and layered YSZ coatings, they outperformed the conventional APS YSZ coatings. Therefore, the hybrid approach combining SPPS and conventional APS processes has yielded promising results, demonstrating significant improvement in durability of TBCs compared to APS TBCs. The higher hardness noted in composite YSZ coatings also appears to suggest that this architecture could be promising for TBCs that encounter erosive wear during routine operation.

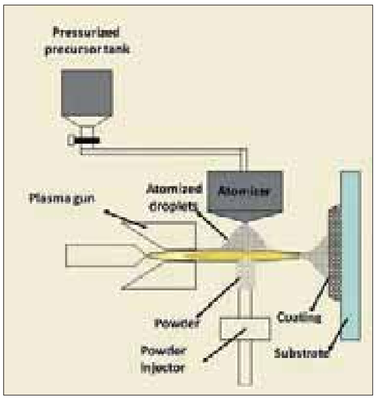

Fig. 1 Schematic of hybrid solution precursor plasma spray process

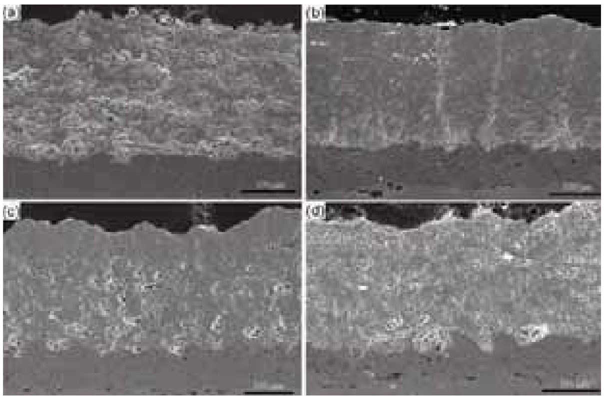

Fig. 2 Typical cross-sectional microstructures of (a) APS, (b) SPPS, (c) layered and (d) composite YSZ coatings

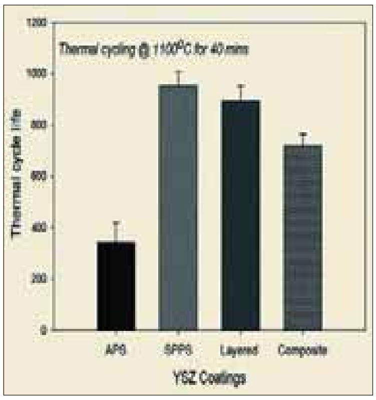

Fig. 3 Thermal cycling performance of yttria stabilized zirconia coatings

**Contributor: D. Srinivasa Rao**

# Pulsed Electrodeposition of Ni-P Alloy Coatings: Influence of Deposition Parameters

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Electrodeposition has evolved over the years to now be considered a techno commercially attractive technology for development of a variety of coatings. The synthesis of nanostructured materials by electrodeposition has also advanced from being merely a laboratory scale phenomenon to a practical industrial materials technology. Electrodeposition is industrially relevant because of its low cost and flexibility. Pulsed current 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 and producing deposits with unique structure and properties. Many nanocrystalline metals, alloys and composites have already been produced by PED successfully.

The present investigation deals with a study of the influence of electrodeposition parameters on micro hardness, surface roughness and composition of Ni-P coatings. In particular, pulse reverse current (PRC) has been employed during deposition. The forward current density was maintained at 0.05 A/cm$^2$ while the reverse current density was varied at three levels: 0, 0.05 and 0.1 A/cm$^2$. The effect of heat treatment on hardness and phase composition of Ni-P was investigated using Energy Dispersion Spectroscopy (EDS), X-ray diffraction and TEM analysis. A hardening mechanism has been proposed to correlate the structure and mechanical properties of Ni-P coatings. Electrodeposition was carried out in a two liter capacity beaker kept in a water bath maintained at 60°C. The electrolyte comprised of nickel sulphate, nickel chloride, phosphoric acid and phosphorus acid. The pH of the solution was maintained at 1.05. The surface microstructure of as deposited coatings consisted of numerous fine colonies of Ni-P. The cross section of the deposited coatings depicted a clear interface between the coating and the substrate. The compositional analysis (EDS) of the coatings suggested an increase in the P content of Ni-P alloy coatings with increase in reverse current density due to higher dissolution of Ni from the coating compared to P during current reversal. This effect was confirmed using XRD analysis as shown in Fig. 1(a). The appearance of amorphous peaks with increase in reverse current density is indicative of the increase in P content. The hardness of the coating, measured in the cross section, is presented in Fig. 1(b). The increase in hardness with increase in reverse current density is due to increase in P content of the coating. In order to study the influence of heat treatment on microhardness, the coatings were heated to 500°C for 1 hour under vacuum. The microhardness after heat treatment was found to be higher compared to that of deposited coatings. TEM analysis (Fig. 1(c)) of heat treated coatings suggested precipitation of Ni3P phase in the Ni-P matrix, thereby causing Orowan type hardening. In conclusion, Ni-P coatings with controlled phosphorus content can be deposited using pulsed current deposition.

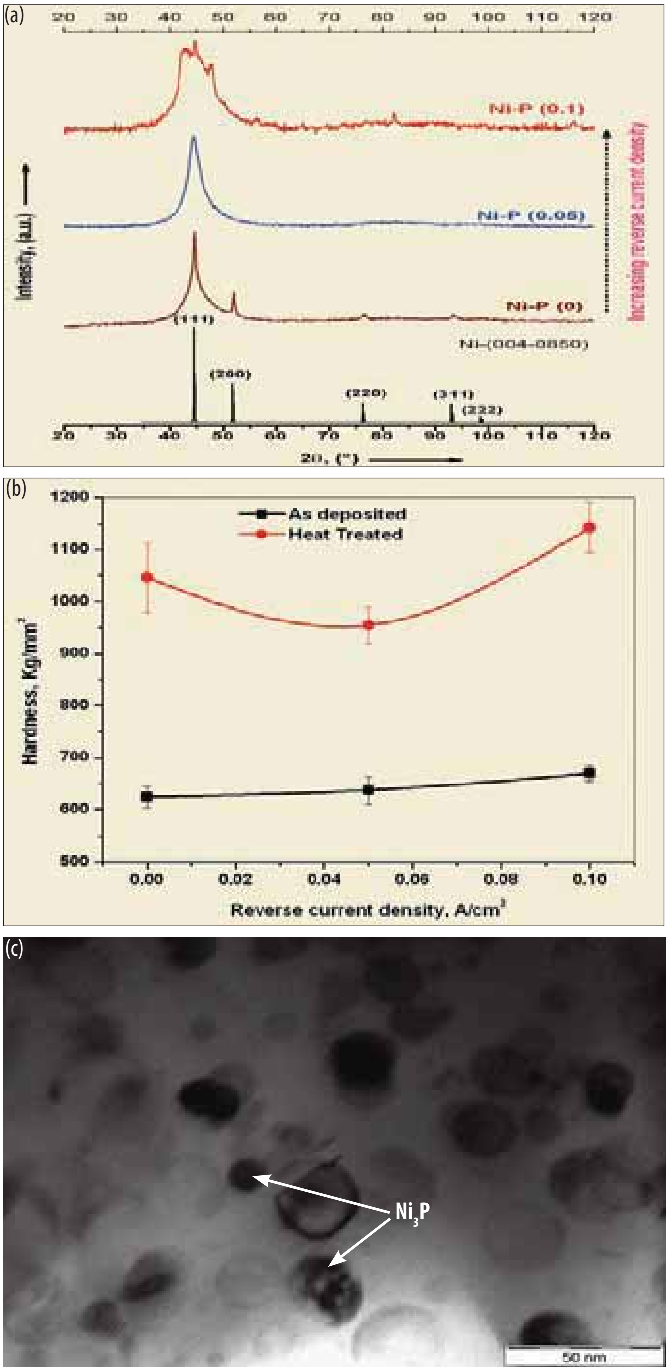

Fig. 1 Influence of reverse current density on (a) phase constitution (b) micro-hardness of the Ni-P coatings (c) TEM analysis of heat treated coatings reveals precipitation of Ni$_3$P

***Contributor: D. Srinivasa Rao***

# Heterogeneous Deformation Strain and Strain rate Induced Grain Size and Hardness Gradient in Cold Sprayed Coatings

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Cold gas dynamic spray (CGDS) involves high strain rate (or high velocity) impact of micron sized metallic/alloy/composite powder particles (10-45 µm) on the substrate as well as themselves in solid state. However, the coating formation is based on successful bonding between particle/substrate and particle/particle that is generally confined to localized areas at the respective interfaces due to the phenomena of adiabatic shear instability. The aforementioned features give rise to a microstructure that is quite inhomogeneous in terms of the strain, strain rate and heat rise due to high velocity impact.

In this study, local hardness mapping (using nano indentation at low loads) has been carried out on a composite Cu-30Ag coating and compared to the initial hardness of the feedstock powders. A maximum load of 10 mN was used and indentation was carried out in matrices numbered sequentially (Fig. 1). Individual hardness data was obtained from the indent number and its actual location (Ag or Cu, center or edge of splat etc.) as shown in Fig. 1. All hardness calculations were made as per the Oliver and Pharr method. Higher values of local hardness, significantly higher than that of the feedstock and moderately higher than the coating (Vickers number at higher loads), were observed and an attempt was made to correlate this finding with the induced microstructures. It can be observed from Fig. 2 that the cold spray process induces a significant change in grain size and morphology especially at the interface (Fig. 2c) vis-à-vis the initial feedstock particles (Fig. 2b). This is, in turn, reflected in the local hardness data obtained in the silver component of the composite coatings as shown in Fig. 2a. It can be observed that there is significant grain refinement induced by the cold spray process especially at particle/particle boundary. However, it would be premature to attribute the local hardness distribution, with values as high as 3.2 GPa and 2.8 GPa (for copper and silver respectively), to the grain refinement alone. There could also be contributions from the strain/strain rate hardening and dislocation density variations that are induced by the process. Hence, we can broadly represent the observed hardness values as follows:

$$H_{coat} = H_{i} + H_{cold\ spray}$$

where $H_i$ = feedstock hardness and

$H_{coldspray} = H_{g}b + H\varepsilon + H\rho$

$H_{gb}$ - grain boundary strengthening

$H\varepsilon$ - Strain hardening component

$H\rho$- Dislocation density component

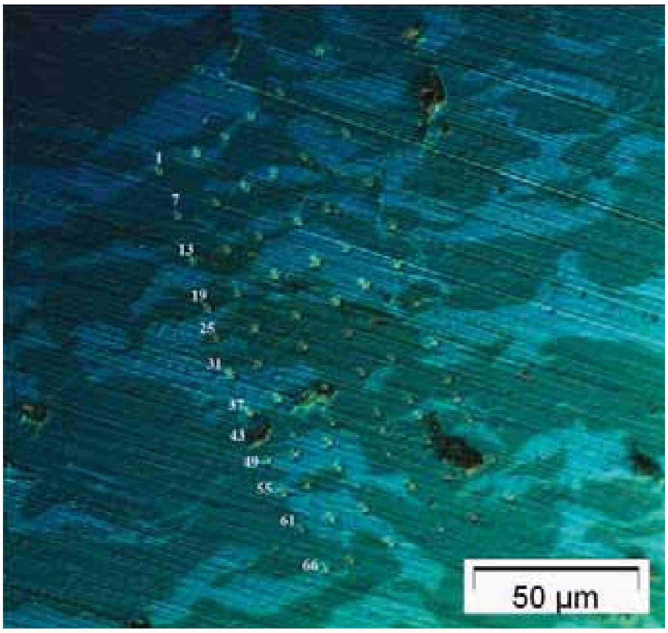

Fig 1. Local hardness mapping using nano indentor

Fig 2. Hardness distribution (a) along with microstructure of feedstock and single splat in case of silver (b, c)

**Contributor: Sumeet Somani**

# Effect of Substrate Surface Roughness on Adhesion and Tribological Properties of Cathodic Arc PVD Coatings

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The surface roughness of a coated component is critical for its functionality and reliability as it can affect friction, wear, and fatigue characteristics of the tribosystem. The properties of the deposited coatings are significantly influenced by the substrate's surface characteristics like its roughness, chemistry, cleanliness etc. Physical vapour deposition of superhard nanocomposite coatings, typically of the nc-TiAlN/$\alpha$-$Si_3N_4$ type, represents a significant recent development as mechanical properties of these coatings, such as hardness and elastic modulus, are reported to be superior to those of conventional hard coatings like TiN and TiAlN. The present study is aimed at investigating the effect of substrate surface roughness on the adhesion and subsequent tribological behaviour of the above nanocomposite coatings as well as the conventional TiN hard coatings.

HSS specimens in as-received condition, after emery polishing with papers of different grit size and with diamond-polishing were used as substrates to ensure different surface roughness values prior to coating deposition. 2 µm thick TiN and nc-TiAlN/$\alpha$-$Si_3N_4$ coatings were deposited on all the above pre-treated substrates by cathodic arc physical vapour deposition (PVD). Adhesion of the coatings was assessed by determining the critical loads, Lc1 and Lc2, using a scratch tester. The coatings were then subjected to tribological tests using a pin-on-disc tester at a load of 10 N using a 2 mm dia. WC-6%Co pin as the counter material. Wear volume was calculated using an optical profilometer to study the wear bahaviour of the coatings.

The critical loads, Lc1 and Lc2, determined for the TiN and nc-TiAlN/$\alpha$-$Si_3N_4$ coatings are plotted against substrate roughness in Fig. 1. It is clearly observed that the softer TiN is more strongly adherent to the substrate compared to the harder nc-TiAlN/$\alpha$-$Si_3N_4$. It is also evident that the critical loads decrease as the surface roughness increases for both the coatings studied. It is plausible that, with increase in surface roughness, the ridges that act as stress raisers also increase, thereby resulting in higher probability of coating failures at lower loads due to higher contact pressures.

The wear volume of the coated disc, in a sliding wear test, depends on the contact area of the sliding pin. Therefore, the wear volume of the coated disc per unit pin contact area has been plotted against substrate roughness in Fig. 2 and it is observed that the wear volume decreases with the substrate roughness. The decrease in wear volume with roughness is expected because, at lower roughness values, the contact area between the disc and the counterface pin material increases due to the presence of a larger number of surface asperities on the coated disc, thereby increaseing the shear-force for a given applied load. As the roughenss increases, the contact area correspondingly decreases, leading to a reduction in wear volume. From the figure, it also appears that the wear volume is higher in case of the harder nc-TiAlN/$\alpha$-$Si_3N_4$ than TiN, presumably on account of the higher toughness of the latter. The higher wear volume in case of nc-TiAlN/$\alpha$-$Si_3N_4$ may also be due to the higher elastic modulus mismatch between the substrate and nc-TiAlN/$\alpha$-$Si_3N_4$ coating. The possibility of higher abrasive action of the wear debris also contributing to the observed high wear rate in case of nc-TiAlN/$\alpha$-$Si_3N_4$ is currently being investigated.

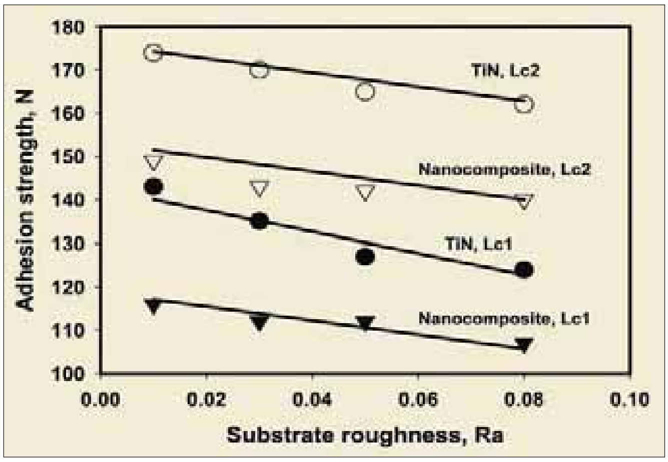

Fig. 1 Scratch adhesion strength of TiN and nc-TiAlN/$\alpha$-$Si_3N_4$ coatings as a function of substrate roughness; Lc1 – load at first cracking and Lc2 – load at catastrophic failure

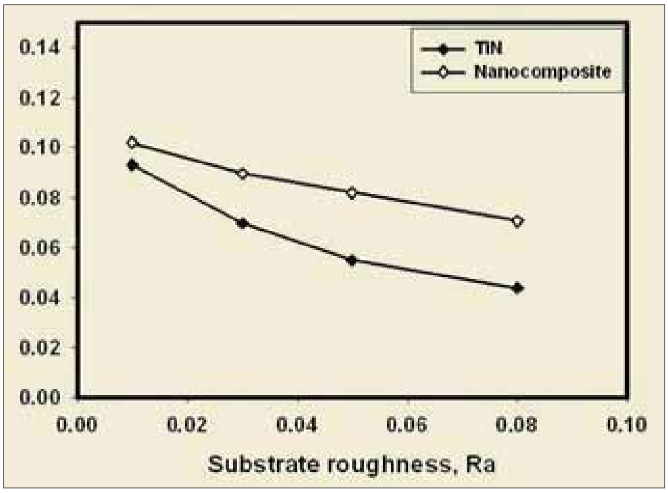

Fig. 2 Wear volume/pin contact area of TiN and nc-TiAlN/$\alpha$-$Si_3N_4$ coatings as a function of substrate roughness

***Contributor: R. Markandeya***

# Comparative Studies Between Modified and Existing Detonation Spray Coating (DSC) Systems

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Successful technology transfer and implementation of indigenously built DSC systems at different private entrepreneurs in India and considering the further demand for DSC technology, ARCI has decided to improve the existing DSC system's design by replacing mechanically moving devices with electrical/electronic systems to automate the gases and powder injection with an objective to simultaneously enhance firing frequency such that coating productivity and efficiency could be improved.

In view of the above, the gases mixing chamber responsible for four steps of operation to obtain a detonation wave has been redesigned with precise valves for controlling the gas feeding such that several mechanical parts those undergo wear damage during prolonged operation periods like cams, gears, carbon seals, piston, rollers, bearings, rings were completely replaced. Graphite seal assemblies in existing system [Fig. 1(a)] causes extensive heat generation due to graphite seals expansion and being in continuous contact with piston and seal leads to seizer of piston assembly in turn. The redesigned mixing assembly is expected to minimize the heat generation during continuous operation.

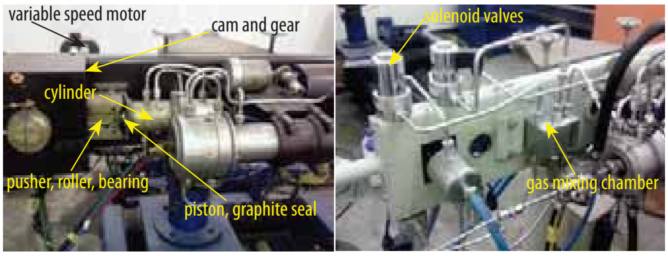
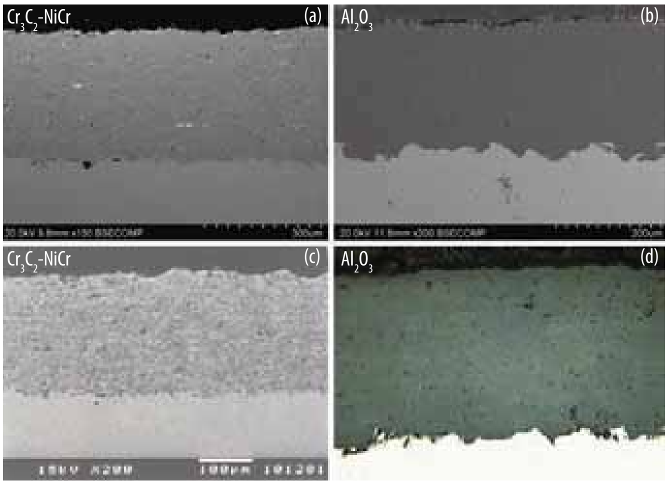


Fig. 1(a) Existing DSC mixing chamber (b) Modified DSC mixing chamber

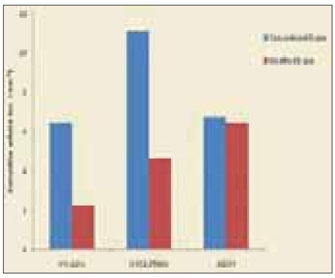
The new DSC gas mixing system has only electronically controlled solenoid valves and gas mixing chamber. The main function of solenoid valves i.e. to control the valve opening time using Lab view software. Exact time required to fill the oxy-fuel gas in new mixing chamber has been accomplished by calculating the old system cam profile. After integrating the new gas mixing mechanism with the existing spray system and successful coating trial runs with regard to overall function of the DSC system, the essential coating characterization studies were carried out and compared with the coating properties of old DSC systems.

The quality of the coatings in terms of microhardness, porosity and microstructure are very similar and infact marginally better. The DSC system with new gas mixing chamber has also been subjected to continuous operation to assess the performance and to addressed the other technical issues such as overheat or seizure which in general found to happen during prolonged hours of operation. The outcome of these studies led to a major breakthrough in terms of extended operational duration thereby permitting the deposition of DSC coatings on larger size parts with improved efficiency and overall productivity. Deposition efficiency/rate is higher in modified system in case of carbide coatings and similar observation is noticed in the case of oxide coatings too. The detailed performance and validation tests are also planned to carry out with the incorporation mass flow controllers, PLCs and the monitor for the online process monitoring.

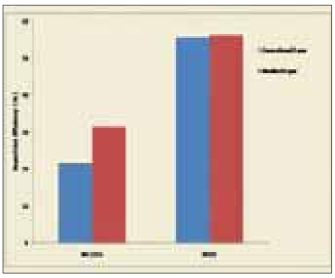
With its improved overall productivity, the newly designed and fabricated gas mixing mechanism is thus found to be more energy efficient and therefore do not require regular maintenance work and frequent replacement of worn out spare parts.



Comparison of coatings with new (a,b) and old systems (c,d)



Comparative abrasion results of coatings



Comparative deposition efficiency of coatings

***Contributors: S. Nirmala and D. Srinivasa Rao***

# Development of $MgAl_2O_4$ Spinel Transparent Honeycomb Structures

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Cellular materials are receiving renewed attention as structural and functional components. Material scientists and engineers are therefore trying to mimic cellular structures with a wide variety of engineered configurations and material classes. Opaque honeycomb structures are generally produced by the process of extrusion and these honeycombs are inherently porous and transparency could not be achieved due to scattering. Recently developed thermally induced methyl cellulose (MC) based colloidal forming technique by the ARCI team permits shaping of defect free and high density parts which are the essential prerequisites for transparency. In the present study the process was explored for the development of transparent honeycomb structures, which is attempted for the first time.

$MgAl_2O_4$ spinel powder procured from M/s. Baikowski, France was dispersed in aqueous medium to form slurries having solid loading of 56 wt% using Darvan 821A as a dispersant. The suspension was then milled for 4 hrs in polypropylene bottles in a jar mill using high purity alumina balls of 2 mm diameter as the grinding media with 1:1 charge to ball ratio. An aqueous solution of 0.20 wt% methyl cellulose (MC) was added into the slurry as mentioned above and then milled for an additional period of 2 hrs for uniform mixing. The slurry was then used for further processing of honeycomb as well as flat specimens by thermal gelcasting. Rheological behaviour of the slurries was measured at varying shear rates to determine the flow properties.

MC added slurry was then cast into prefabricated Teflon mould provided with uniform circular rods projecting from the base for forming parallely aligned circular channels. A part of the slurry was also cast into round molds to get the flat specimens. The mould containing the slurry was exposed to a gelation temperature of 45-60°C in an oven. The samples were then dried and characterized for their green densities. Samples with ~50% green density were sintered in the temperature range of 1650 - 1700ºC in a muffle furnace at a ramp rate of 100°C/h to achieve 98 - 99% of the theoretical density. These processing conditions were optimized based on several trials. The samples sintered were further HIPed at 1800°C for 5 hrs under an argon gas pressure of 195 MPa. Typical specimens fabricated are shown in Fig. 1(a) and (b). Sintered density and the cellular properties such as relative density, surface to volume ratio (S/V) of the honeycomb are shown in Table 1. Microstructure and visible transmission (0.4 – 0.8 µm) pattern of specimens are also shown in Fig. 2. Specimens processed through the methyl cellulose based colloidal forming process exhibited a density of 3.58 g/cc and optical transmission of 84% which are close to theoretical values.

Fig. 1 Photographs of transparent (a) honeycomb and (b) flat sample

Table I: Densities and cellular properties

| Sample ID | Density (g.cm$^{-3}$) | TD (%) | Relative density | S/V ratio |
|---|---|---|---|---|
| Transparent honeycomb | 3.58 | ~100 | 0.69 | 0.65 |

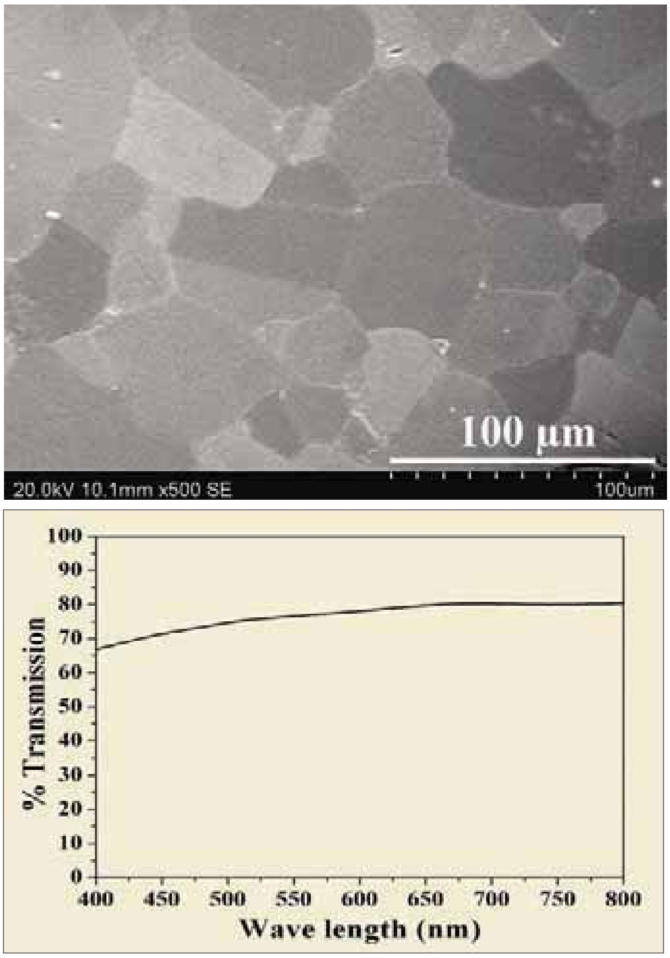

Fig.2 Microstructure and visible transmission (0.4 – 0.8 µm) pattern of spinel specimens

***Contributors: Papiya Biswas, K. Rajeshwari and P. Ramavath***

# Development and Demonstration of Honeycomb Based Anode Supported Solid Oxide Fuel Cell (H-SOFC)

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Honeycomb-supported Solid Oxide Fuel Cell (SOFC) is a novel concept with inherent advantages such as large electrode area per unit volume, miniaturization of module, low thermal inertia and faster warm up which enables quick start, a major disadvantage of SOFC in general. A schematic of the honeycomb SOFC concept is shown in Fig. 1(a). Honeycomb structures are generally produced by extrusion of formable dough through a specially designed die. It is a complex process involving lateral flow of the dough followed by the knitting with adjacent cross section within the die. The rheological properties of the dough play a major role. The extruded honeycombs after shaping are dried and sintered at various temperatures. Honeycomb extruded in the present study is shown in Fig. 1(b). The channels are 35 mm in length and cross section of the cell is 4.5 mm x 4.5 mm with a wall thickness of 0.95 mm.

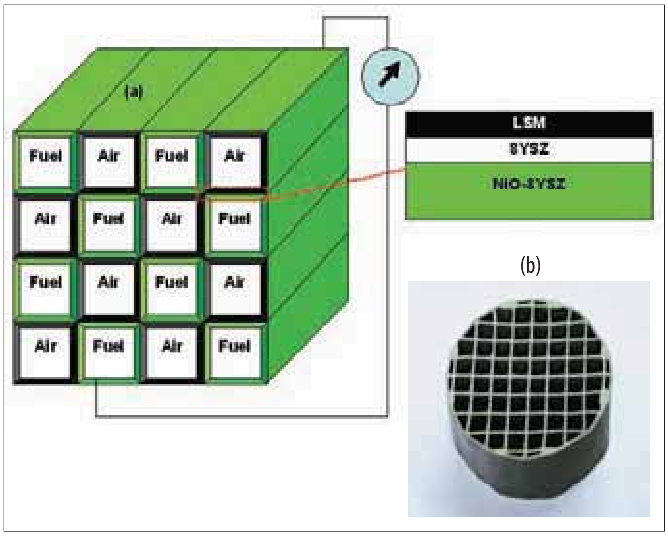

Fig. 1 (a) Concept of honeycomb SOFC (schematic) & (b) NiO-8YSZ anode honeycombs

As schematically shown, in the present concept 66 wt% NiO & 34 wt% 8YSZ as an anode honeycomb (support structure), 8YSZ as an electrolyte and $La_{0.8}Sr_{0.2}MnO_3$ as a cathode were used. The cell with 4 x 4 channels is having an active cathode area of 25 cm$^2$. Pure $H_2$ was used as a fuel in the flow rate of 0.5 cc/min and air as an oxidant. Platinum wires were fixed using platinum paste on the cathode and anode channels for collecting the current. Module is further integrated with manifolds and current collectors to form the prototype as shown in Fig. 2(a). Electrolyte coating, good electrolyte-electrode adhesion and better sealing resulted in negligible leakage of the gas. Innovative concept of manifold design is found to be suitable for SOFC application as the system remained intact during the prolonged stay at the working temperature (>800°C).

Module is evaluated by feeding fuel and oxidants from opposite sides of the honeycomb and exhausted from the other sides, accordingly. Fig. 2(b) shows the electrochemical performance of the HC SOFC at 800°C. The open circuit voltage is approximately 0.8 V and peak power density is 1.6 mW/cm$^2$ (50% of the estimated output). The lower output observed in the present run has been attributed to less concentration of the available active sites for the reactions to take place. Attempts are in progress to improve the electrochemical performance of the honeycomb SOFC since the system is conceptually proven for the workability.

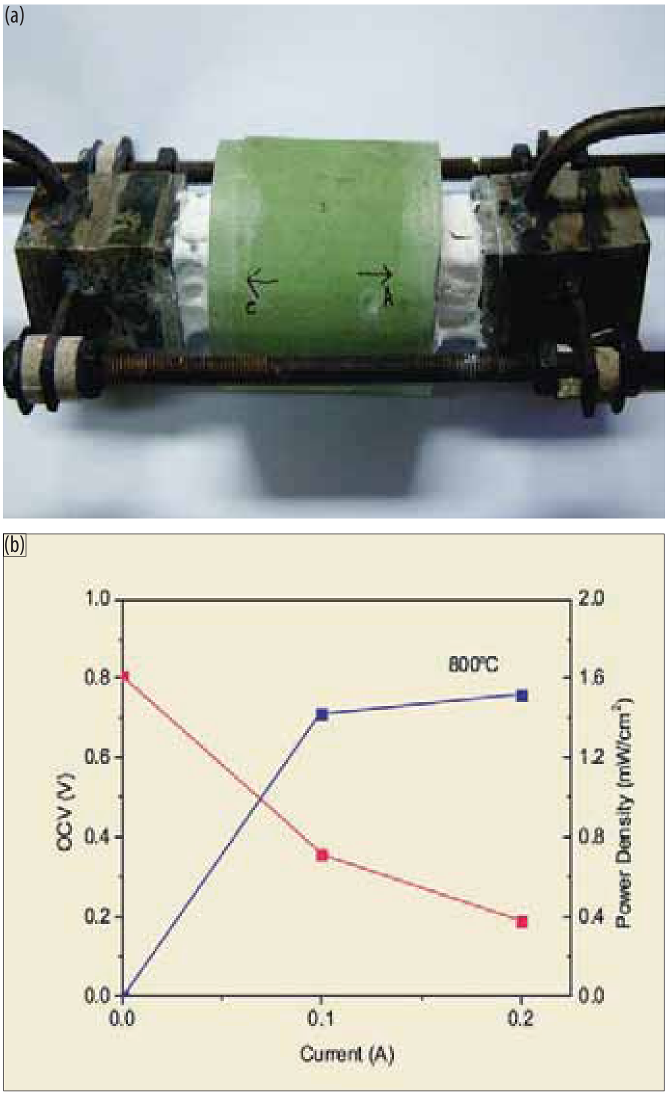

Fig. 2(a) Prototype module and (b) electrochemical performance

***Contributors: Y. S. Rao and Roy Johnson***

# Pressure Slip Casting of Advanced Ceramics

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Pressure slip casting of traditional ceramics have several advantages such as high green density, better green strength/ability to handle, productivity and low shrinkage. However, inspite of several advantages, only limited attempts have been made for pressure slip casting of advanced ceramics. The objective of the current work is therefore to explore possibility of pressure slip casting (PSC) of alumina, a commonly used advanced ceramic material. Commercially available high purity alumina powder with 99.95 % purity and average particle size ($D_{50}$) of 1.0 µm (MR grade, HINDALCO, India) was used in this study. The powder was made into an aqueous slurry in distilled water using Darvan 821A (R. T. Vanderbilt Co., Inc., Norwalk, CT, USA) as a dispersant. The suspension was then milled for 2 hrs in a rubber lined ball mill using alumina balls at 1:1 charge to balls ratio to achieve solid loading of alumina in the range of > 75%. Rheological behavior of the slurries was measured at varying shear rates using a MCR 51, Anton Paar Rheometer. Fig.1 (a) presents the viscosity measurements with shear rates of alumina slurry with varying shear rates. It is evident that the slurry is pseudo-plastic at lower shear rates and as the shear rate is increased beyond 200 $S^{-1}$ the slurry exhibit close to Newtonian behavior adaptable for casting of the slurry.

The slurry was cast into prefabricated polymer based (SAMA-pore) macro porous moulds by proprietary techniques of M/s. SAMA maschinenbau GmbH. The split mould has two parts with a cross section each of >400 $cm^2$ capable of casting a specimen of 80-100 mm diameter. The castings were carried out using a pressure casting machine model PCM 100 N (SAMA GmbH) with a closing force of (max) 1000 N. The slurry was pumped into the polymer mould with a feed pressure of 2 bars for a filling time of 15 second, both of which can be varied if desired. After filling the slip, pressures of 10-35 bar were obtained with an increment of 5 bar and pressure attained was maintained (dwelling) for 30-90 second to determine the effect of the pressure on build up of the cast. When the pressure is applied on the slurry, the volume fraction increases the inter-particle repulsion and the osmotic pressure of the suspension increases. However, the optimum amount of surfactant layer allows a gradual increase in volume fraction under compressive stress field. It is well known that compressive properties of colloidally stable suspensions are reversible. Nevertheless, as the isostatic stress (30–35 bar) is above the compressive yield stress of the slurry, the particle network forms resulting in consolidation. The green density Vs casting pressure is shown in Fig. 1(c). The samples were further sintered at temperatures of 1600°C achieving > 99 % of the theoretical densities and the samples (Fig.1 (b) exhibited a hardness of 18 GPa confirming the adaptability of processing of alumina ceramics by pressure slip casting.

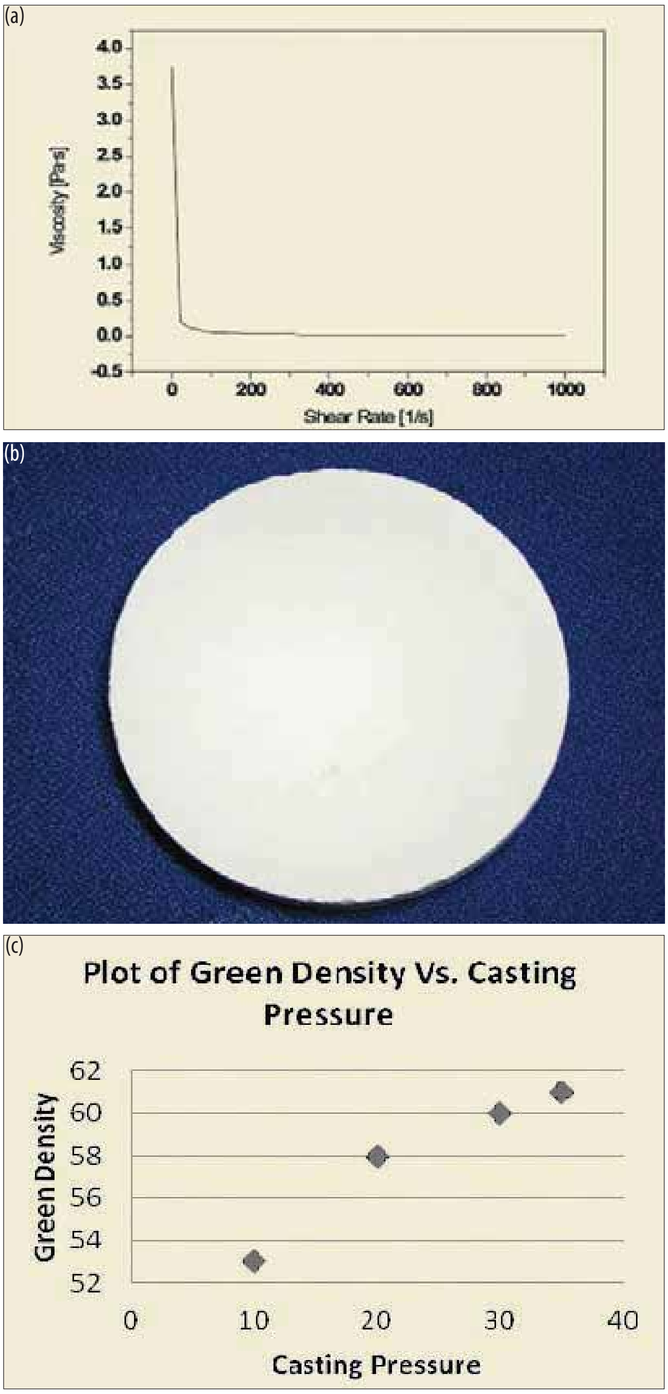

Fig. 1 (a) Plots of viscosity with shear rates for alumina slurries of varying shear rates (b) pressure cast alumina sample and (c) the effect of casting pressure on the green density

***Contributor: Roy Johnson***

# Shaping and Properties of Submicron Transparent Alumina Ceramics Processed Through Sol-Gel Route

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Transparent alumina is proposed as an ideal material for a wide range of applications such as discharge lamp envelops, orthodontic parts, artificial gems apart from strategic uses. The prerequisites for obtaining transparency in combination with superior mechanical properties is to achieve the final sintered average grain sizes less than a micron and a density close to near theoretical (99.95%) values. This necessitates the use of commercially available alumina powder having purity above 99.95% with an average particle size ranging between 200 and 300 nm as starting material leading to exorbitant costs.

In an attempt to address the above issue, in the present process, stable boehmite sol was prepared by dispersing commercially available boehmite powder in water followed by acid peptisation using nitric acid to reach the pH between 2 and 3. MgO up to 0.5 % to the total weight of the alumina was added to the sol for assisting the densification during sintering. Appropriate quantity between 5 and 20 % of alpha phase alumina having purity above 99.97 % with an average particle size of 250 nm was seeded into the sol for enhancing the sintering and packing factor during shaping. Gelation was carried out by drop-wise addition of ammonia. The gel was dried and calcined at 1000°C and the resulting powder was milled to produce alumina powder. The powder was further mixed with binders such as poly vinyl alcohol and shaped through uniaxial pressing followed by cold isostatic pressing at 200 MPa. The samples were sintered at temperatures between 1350 and 1450°C in air and the sintered samples were further pressed hot isostatically at 1350°C using argon atmosphere at 195 MPa to produce transparent alumina articles.

Fig. 1 shows the image of the in-house produced sol-gel derived alumina powder suitable for producing transparent alumina ceramics. It can be observed that the size of the alumina particles formed through sol-gel process between 40 – 60 nm and the size of the alumina seed remains same as 200 – 250 nm. Fig. 2 shows the polished and thermally etched surface of sintered and HIPped transparent alumina sample. It can be observed that the distribution of the grain sizes ranges between 0.2 and 1.7 µm with the mean size of 1.0 µm. Fig. 3 shows the percentage of real in-line transmission measurements obtained for 0.8 mm thick sintered and polished transparent alumina sample. The sample exhibited broad band transparency greater than 83% between 2 µm and 5 µm wavelength region and has shown almost theoretical transparency for wavelength 4.2 µm to 4.8 µm. Hardness was measured by Vickers indentation at 1 Kg load and the samples showed an average hardness of 20 GPa.

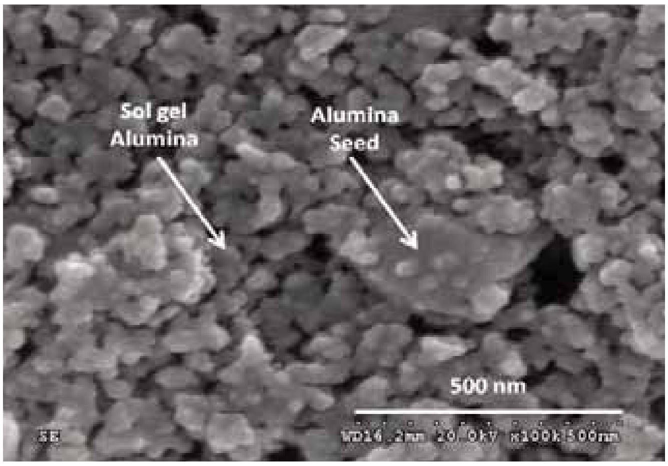

Fig.1 SEM image of sol-gel alumina powder suitable for producing transparent alumina

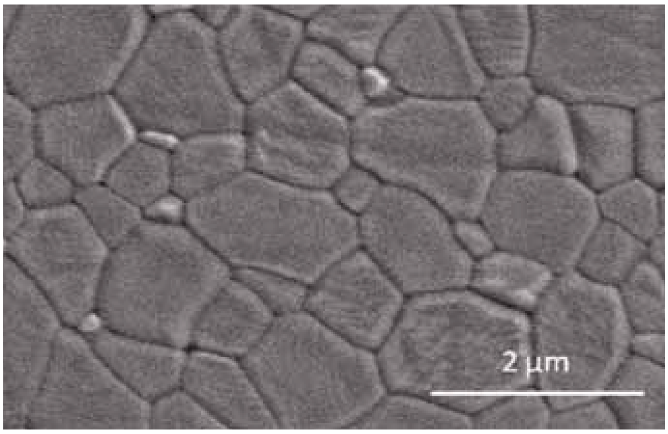

Fig.2 Microstructure of sintered and hipped transparent alumina

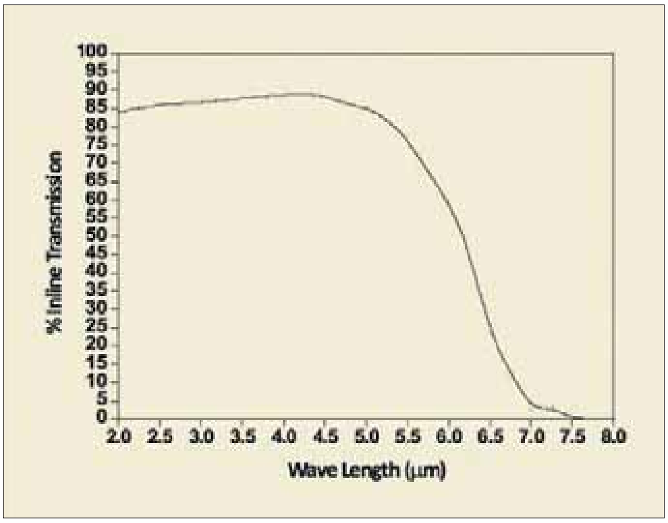

Fig.3 Percentage of real inline transmission v/s wavelength

***Contributor: Roy Johnson***

# Alumina Shaping: Correlation of Quasi Elastic Neutron Scattering and Rheological Measurements

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Alumina slurry containing 0.1wt% methylcellulose is subjected to Quasi Elastic Neutron Scattering (QENS) and rheological measurements in gelation temperature regimes to understand and evolve a possible mechanism of the forming process. High purity alumina powder was made into an aqueous slurry with >75wt% of solid loading using Darvan as the dispersant. Thus obtained alumina slurry was further mixed with 0.1wt% of methylcellulose and was subjected to viscosity and QENS measurements. Variation in viscosity as a function of temperature was studied at low shear rates of $10^{s-1}$ in the temperature range of 25-70°C at a heating rate of 1°C/min using a rheometer. Neutron scattering measurements were carried out by using the QENS spectrometer (at Dhruva reactor, BARC, Trombay) on alumina slurry samples after exposing them to gelation points at 50°C and 55°C designated as sample 1 and 2 respectively. Variation in complex viscosity with respect to temperature is shown in Fig. 1 and QENS spectra for the samples are shown in Fig. 2(a-b).

The viscosity remains unchanged or with marginal decrease till the slurry reaches a temperature of 50°C which demonstrated a very prominent increase in viscosity to 50000 Pa-s revealing the gelation. It is evident from Fig. 2 that the sample 2 has shown a larger quasi-elastic broadening compared to sample 1. This indicates that the water molecules in the slurry exposed at 55°C experience a different environment while diffusing, compared to that in other sample exposed at 50°C. In neutron scattering experiment the scattered intensity is analyzed as a function of both energy and momentum transfer. In the present case of both the samples, the elastic intensity is found to be negligible and a single Lorentzian function is good enough to describe the data, indicating that the observed dynamics correspond to the translational diffusion of the adsorbed water molecules.

The simplest model of translational motion is Brownian diffusion, which is described by Fick's law, in which HWHM ($\Gamma$) of the quasi-elastic component (Lorentzian function) varies linearly with Q2, $\Gamma$(Q) = DQ2, where D is the self-diffusion coefficient of fluids. Diffusivity of sample 1 is estimated to be $2.16\times10^{-5}$ cm$^2$/s which is close to that of water $2.5\times10^{-5}$ cm$^2$/s. However, sample 2 has shown a reduction in diffusivity to $1.92\times10^{-5}$ cm$^2$/s complementing the steep increase in viscosity in the same temperature regime. The observed phenomena of steep increase in viscosity in combination with decrease in diffusivity in the range of 50-55°C explains the cross-linking of methyl cellulose polymer network formation which aids in defect free processing of ceramics.

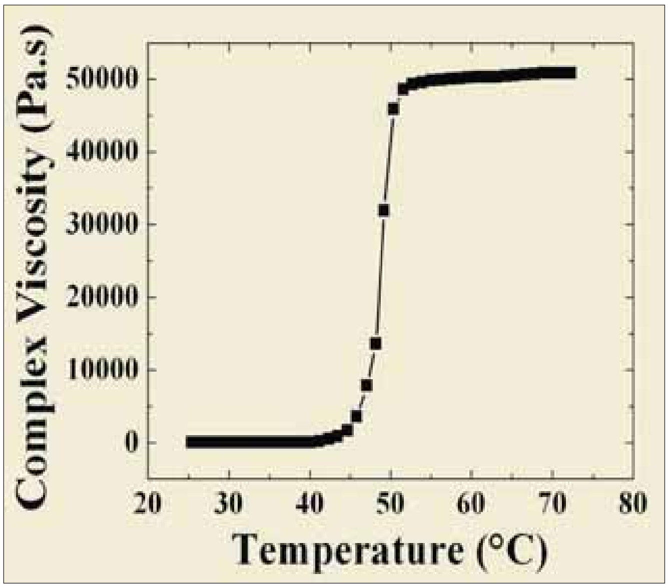

Fig. 1 Complex viscosity versus temperature for alumina slurry

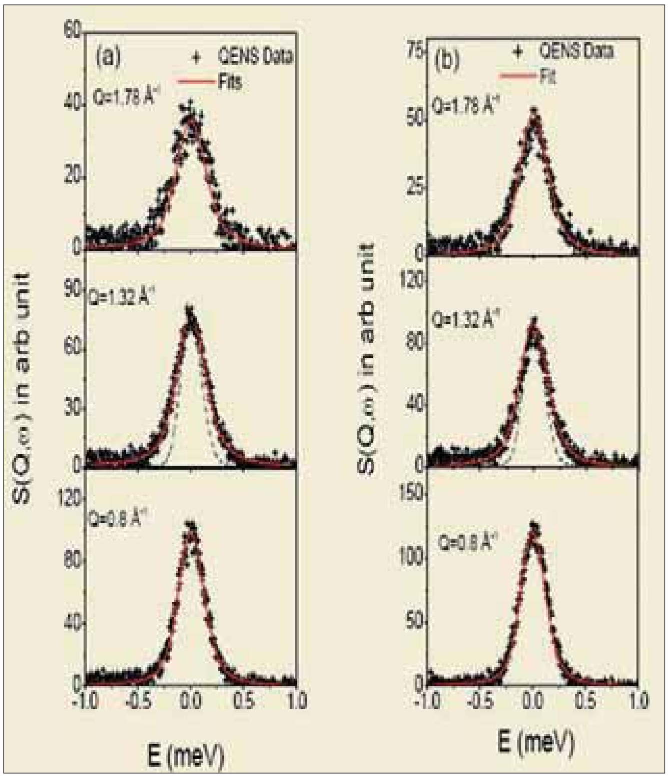

Fig.2 Fitted QENS spectra for samples (a) sample-1 and (b) sample-2

***Contributors: K. Rajeswari and Roy Johnson***

# Flowability and Compaction Behavior of Spray Granulated Submicron Alumina Granules

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Compaction process of ceramic powders primarily involves die filling and particle rearrangement under applied stress and is very sensitive to the flow behavior of the powder. Flow properties of powders are dictated by the collective factors acting on an individual particle, such as Vander waal and electrostatic forces, surface tension, interlocking as well as friction. This makes it difficult to predict the flow behavior of powders. In an attempt to quantify the powder flow behavior, a powder flow analyzer attached to a texture analyzer has been successfully employed for measuring the cohesion index which can be correlated with the flow behavior of the powder.

Commercially available high purity alumina powder was spray granulated using a spray drier (BUCHI B 290/295, lab model) under a given set of parameters. Table 1 shows the spray parameters along with average granule sizes and the distribution achieved with spray drying. Scanning electron micrographs of as-received powder (Fig.1a) and spray dried granules with 20% and 40% solid loadings with minimum flow rate of 3.75 ml/min and maximum flow rate of 7.5 ml/min are shown in Fig. 1(b-c) and Fig. 1(d–f).

Cohesion index measurements were carried out by the powder flow analyzer which involves the programmed motion of the blade in the cylinder confining the granules, that ensures flow modes of compression while moving downwards in clock-wise and slicing while moving in anti-clockwise direction. It is very interesting to note that a cohesion Index value of 28.45 for as-received alumina could be modified significantly by spray drying, to 6.45 for SG-40(e) granules indicating the free flowing behavior. Transformation of very cohesive to free flowing (cohesion index <11) behavior can be attributed to the narrow distribution of granules in combination with the spherical morphology as is evident from the micrographs depicted in Fig. 1 SG-40(f). In order to have a better understanding on behavior of spray dried granules under uni-axial compaction, compressibility curves were recorded for the granules SG-40(e). Compressibility curves of the spray dried granules are shown in Fig. 2. There is a distinct slope change in the plot of relative density vs. compressive strength. Due to the free flowing nature of the granules as shown by the powder flow analysis, rearrangements to fill the intergranular voids are expected to take place at very low pressures.

A steep increase in densification rate marks the reach of agglomerate strength and breakage of individual highly porous soft granules with high porosity. As the compaction pressure increases, porosity within the granules is continuously eliminated and exceeds the yield strength of all the granules. The compressibility curve almost plateaued and the relative density reaches a maximum without lamination defects.

Table 1: Spray drying variables adopted for processing

| Sample I.D | Solid Loading % | Feed Rate (ml/min) | Average size of the granule (μm) | Size distribution (μm) |
|---|---|---|---|---|
| SG-20 b | 20 | 3.75 | 18 | 10 – 30 |
| c | 20 | 5.00 | 15 | 15 – 30 |
| d | 20 | 6.25 | 12 | 10 – 20 |
| SG-40 e | 40 | 7.50 | 20 | 10 – 20 |
| f | 40 | 3.75 | 12 | 10 – 20 |

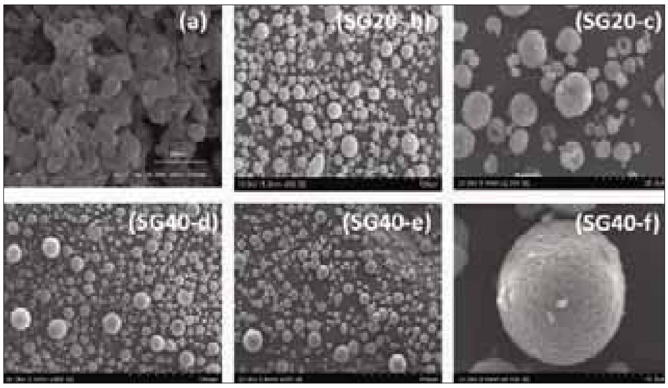

Fig.1 Micrographs of (a) as received (b-c) SG-20 and SG-40 3.75ml/min and (d-f) SG-20 and SG-40 7.5ml/min

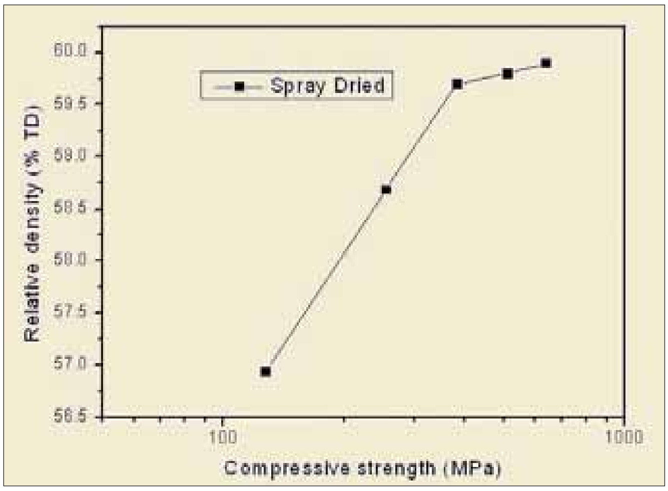

Fig. 2 Compressibility curve of spray dried granules

***Contributors: Abhisek Choudhary, N. Ravi and Roy Johnson***

# Rheological Characterization of $MgAl_2O_4$ Spinel Pastes

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$MgAl_2O_4$ spinel powder (Baikowski, France) having average particle size of 200 nm was blended with 2.5 wt% of methylcellulose binder to obtain a homogeneous mixture. The mixture was subsequently kneaded in a vacuum sigma kneader with 1 wt% of polyethylene glycol as the plastsizer and 35-40% water. The dough was characterized for their rheological properties using an indigenously designed and fabricated capillary extrusion rheometer shown in Fig. 1.

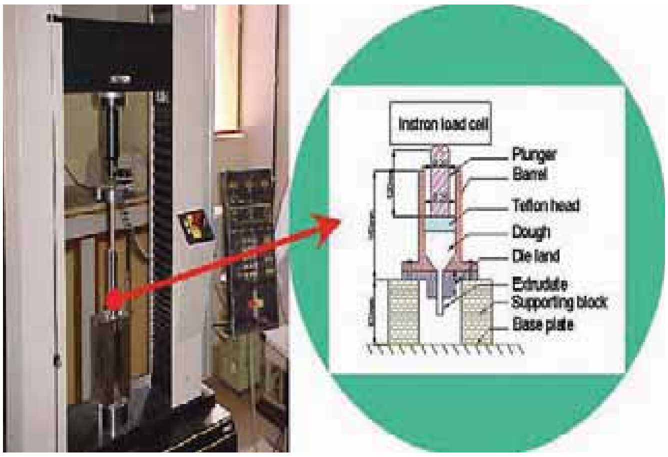

Fig. 1 Capillary extrusion rheometer mounted on Instron-4483

Extrusion pressures, P, required for maintaining stable flow through the capillary die were calculated from the steady state load values corresponding to the plateau region of the load displacement curve, as load per unit cross sectional area of the barrel, $(4F/\pi.D^2)$ - Eq. (1), where F is the load and D is the diameter of the barrel. Similarly, the extrusion velocities, V, corresponding to these pressures were calculated from the ram rates scaled for the relative change in the cross sectional area from the barrel to the capillary, as $v.(D^2/d^2)$ - Eq. (2), where v is the ram rate and d is the diameter of the capillary die.

Extrusion pressure versus extrusion velocity data obtained from the capillary extrusion rheometry was translated as shear rate vs. shear stress data using the equations (1) and (2) and the apparent viscosity was calculated as $\eta = \tau / \gamma$. Fig. 2 shows the variation of viscosity with shear rates for two (L/d) ratios of 15 and 25 calculated from the extrusion data for the spinel dough. The trend is clearly non-linear, suggesting that the mix exhibits a shear thinning behavior. Such shear thinning behavior can be analyzed using the Power Law Model, $\eta = m * \gamma^{n-1}$ where, $\eta$ – viscosity, m - consistency constant, $\gamma$ - shear rate and n - shear rate exponent or power law index from the plot of ln $\eta$ vs. ln $\gamma$ (Fig. 3). The deviation of flow properties from the Newtonian behavior can be estimated based on the deviation from the shear rate exponent "n". A shear rate exponent of "n" 0.74 corresponds to a strong non-Newtonian behavior (Fig. 3), indicates the suitability of rheological properties adaptable for extrusions.

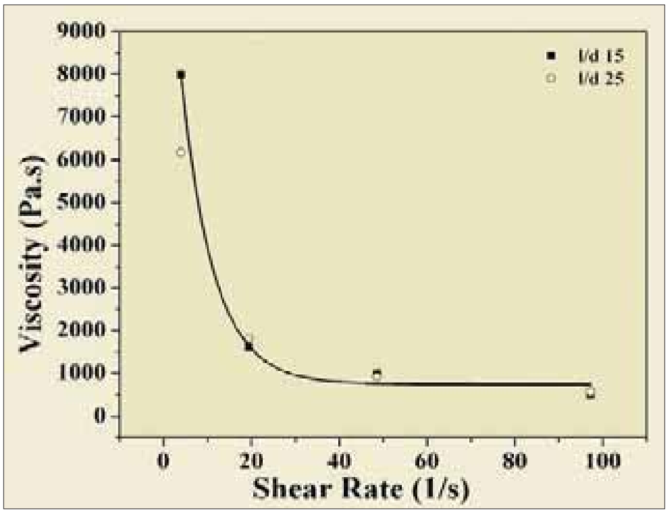

Fig. 2 Variation of viscosity as a function of shear rate using capillary dies of two l/d ratios 15 and 25

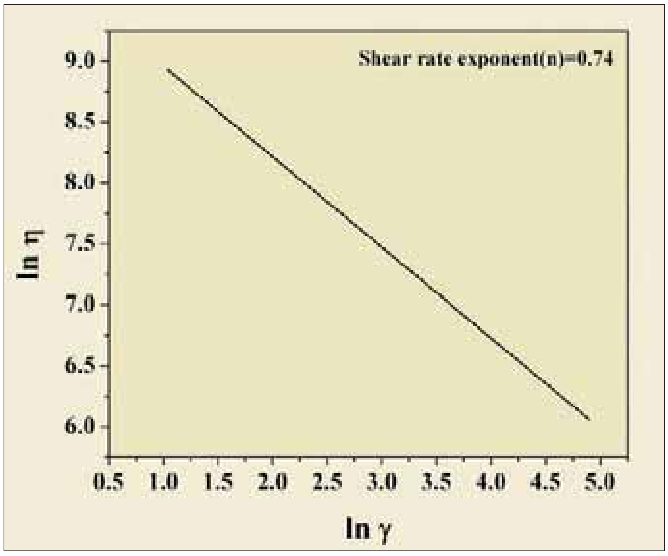

Fig. 3 Plot of ln $\eta$ vs. ln $\gamma$ showing an n value of 0.74

***Contributors: A. Rajashekar Reddy, P. Biswas and Roy Johnson***

# Laser Surface Treatment of Hot Work Die Steel

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Laser surface hardening involves laser assisted heating of the surface of steel substrate to austenizing temperature and quenching to induce martensitic transformation. This is widely used for improving surface hardness and wear resistance in a variety of hardenable steels. H-13 is a hot work tool steel (0.4 wt.% C, 0.4 wt.% Mn, 5.2 wt.% Cr, 1.5 wt.% Mo, 1.0 wt.% V, Fe balance) with high hardenability and excellent toughness and is commonly used for high temperature applications like dies for pressure die casting of aluminium alloys. This tool steel is heat treated by hardening followed by tempering to achieve a hardness of 44 to 48 HRc. During aluminium alloy pressure die casting, dies get exposed to severe operating conditions like thermal and mechanical fatigue (up to 700$^{o}$C), high pressure and high speed of the molten alloy, resulting in surface damages like heat checks, erosion and chemical attack in select locations, limiting the service life of tools. Thermal fatigue cracking may be reduced by incorporating increased amount of carbide forming alloys in solid solution without affecting the toughness significantly. This can be achieved by rapid cooling from austenizing temperature leading to a fine distribution of alloy carbides which is possible by laser treatment.

In this study, laser surface treatment of H-13 tool steel (heat treated and tempered) has been undertaken using a 6-kW fiber-coupled high power diode laser with a spot size of 20 mm x 5 mm (with top-hat intensity distribution). With increase in laser specific energy there is increase in depth of the treated layer. Surface melting occurs when a very high laser specific energy (>80 J/mm$^2$) is used. Melted surface results in formation of inhomogeneous microstructure across the depth of the processed zone. Different zones are observed from the surface to the laser affected/unaffected base metal interface. In top melted layer, formation of retained austenite, carbides along the grain boundary and martensite have been observed. In the zone below some kind of partial melting is observed, followed by a hardened zone and over tempered zone towards the interface. Depending on the peak temperature experienced by the individual layer, the amount of the carbides dissolved in to the austenite also varied. Subsequent rapid quenching leads to fine carbide precipitation inside the martensite lath and pinning of dislocation network, resulting in increase in hardness and residual compressive stress. Application of intermediate laser specific energy (from 50 to 80 J/mm$^2$) causes formation of hardened layer with the dispersion of nano-carbides (Fig. 1) of $M_{23}C_6$, $M_7C_3$, MC and $M_2C$ with the processed layer surface hardness ranging between 650 – 700 $HV_{0.2}$ (Fig. 2). At a very low laser specific energy (less than 50 J/mm$^2$), an over tempered microstructure with low carbon martensite and coarse carbide precipitates (with 420 - 450 $HV_{0.2}$ hardness) were observed. Wear test against alumina ball at 100 N test load showed significant improvement in specific volume loss, in case of laser surface hardened H13 tool steel (1.3 x $10^{-5}$ mm$^3$/N. m) as compared to heat treated and tempered (7.2 x $10^{-5}$ mm$^3$/N.m). Laser surface treatment parameters with specific energy ranging between 50 - 80 J/mm$^2$ are expected to show best performance against severe application conditions.

Fig. 1 Bright field TEM image of laser treated H13 tool steel with laser specific energy of 62 J/mm$^2$

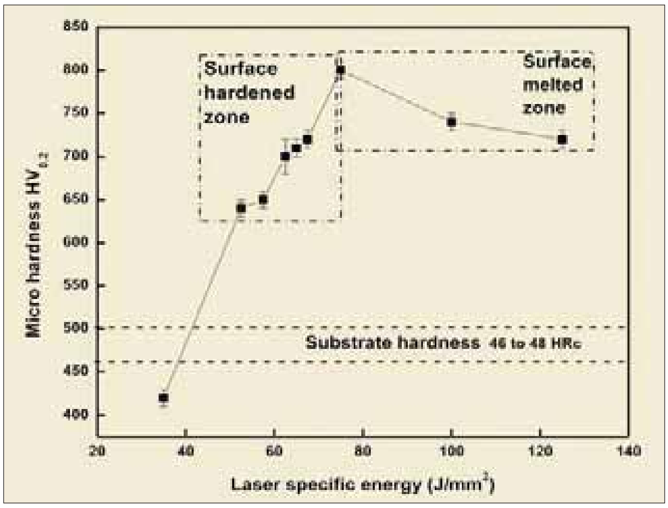

Fig. 2 Average top surface microhardness of laser surface treated H13 as a function of laser specific energy

***Contributor: G. Padmanabham***

# Aluminium-Steel Joining by Cold Metal Transfer (CMT) Brazing: Effect of Filler Wire Composition and Joint Fit-up

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Cold metal transfer (CMT) is an energy reduced arc technique with short circuiting metal transfer coupled with low heat input characteristics as the electrode wire motion is integrated into the process control. Investigations are being carried out at ARCI to examine the suitability of CMT process as joining technique on identified materials/profiles in bus body and car bodies.

Fig. 1 Experimental set-up for joining studies using CMT process

In the present work, comparative study is carried out to understand the effect of gap between lapped sheets (of 2 mm thick Aluminium alloy 6061-T6 and 1.2 mm thick galvanized interstitial free steel) and effect of silicon content of filler wire (5% vs 12%) on mechanical properties of brazed joint. The arc is run along the edge of the aluminium sheet. A gap of 200 µm is maintained between the lapped sheets. Fig. 2 shows transverse cross-sectional macrostructures of the lap fillet joints made with 5% silicon & 12% Silicon wire and also with and without gap.

Macrostructural analysis indicated that for similar welding parameters, the bead profiles and wetting behavior is different. It further indicates that the gap between lapped sheets led to more spreading of aluminium melt on steel sheet which is manifested with increase in wetting width and decrease in wetting angle (i.e., increase in wetting width to angle ratio). The gap between the lapped sheets paved way for venting out evaporated zinc else, the zinc stands entrapped in the seam and acts as point of crack initiation during lap sheared test under tension. It also appeared that 12% silicon wire promotes better wetting action than 5% silicon wire probably due to high fluidity and low melting point of 12% silicon filler wire. Figure 3 shows graphical representation of tensile lap shear test results. It indicates that in case of 12% silicon filler wire, gap between the lapped sheets improved the load carrying capacity from 200 N/mm (without gap) to 236 N/mm by 20%. Whereas, in case of 5% silicon filler wire, gap between lapped sheets improved the load carrying capacity to the extent of 6%. Further optimization of strength and ductility with change in filler wire is underway.

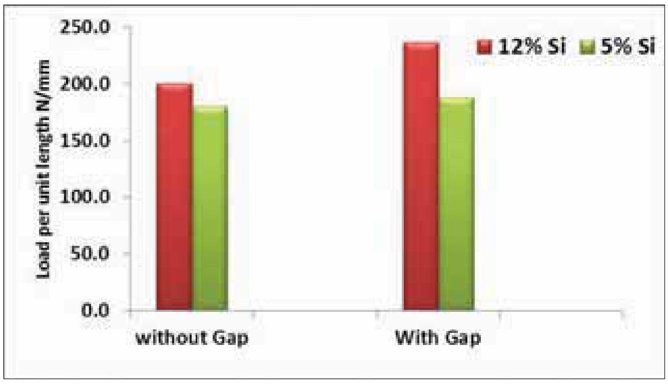

Fig. 3 Variation of load per unit length with/without gap & filler wire

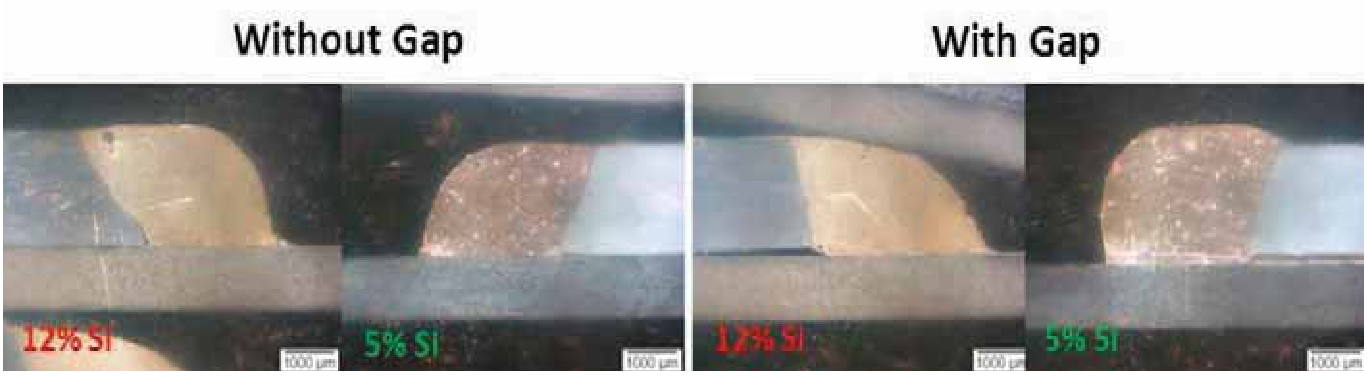

Fig. 2 Transverse cross-sectional macrostructures of lap fillet joints

***Contributors: G. Padmanabham and Y. Krishna Priya***

# Wear Performance of Laser-Hardened and Carburized-Hardened Bearing Steel

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Large-sized bearings used in engineering and railroad industry are generally made of low-carbon-low-alloyed steels and subjected to case-hardening treatment to impart sufficient load-bearing capacity and wear resistance. Although various conventional surface treatments like carburizing with hardening, carbo-nitriding, plasma-nitriding etc have been tried and tested on various bearing steels, laser-surface hardening (LSH) is yet to be explored. In the present work, conventionally case-hardened and diode-laser hardened processes are compared in terms of microstructural changes and sliding-wear performance of SAE-8620 steel. Diode laser treatment has been carried out on SAE-8720 steel under three different prior-treatment conditions, namely, untreated (UT), carburized (CU) and carburized-hardened and tempered (CHT). Fig. 1 illustrates cross-sectional micrographs of laser-treated layers processed under similar conditions. The laser hardened zone (LHZ) depth of treated layer is 700-µm, 780-µm and 890-µm when processed with prior conditions of UT, CU and CHT respectively. The LHZ depth increased with reduced carbon-diffusion distances associated with prior-treatment microstructures. The low carbon content in UT results in non-uniform martensitic transformation whereas uniformly distributed martensite was observed in layer with CU and CHT conditions. Indeed refinement of martensitic microstructure in LHZ region of CHT layer is higher as compared to that of CU layer and could be due to prevailing higher cooling rate in laser treatment cycle than that of conventional case-hardening treatment. Hardness in LHZ regions of CU and CHT conditions increased by a factor of 3 in the range of 690 – 840 HV and 830 – 920 HV as compared to substrate steel hardness of 240-260HV. Also, 15-20% improvement in hardness of LHZ regions could be observed in laser-treated layer with CHT condition as compared to conventionally treated CHT and is attributable to the relatively higher cooling rates that prevail in laser-treatment cycles. Residual stress analysis of laser-treated layers showed compressive stress levels being increased from 370–510 Mpa in surfaces of prior-treatment conditions (UT, CU and CHT) to 630–1100 MPa in laser hardened surfaces due to martensitic transformation.

Comparative tribological performance of laser-treated and untreated surfaces was assessed by subjecting to unlubricated dry ball-on-disk sliding wear testing. Fig. 2 shows the evaluated specific wear rate obtained at the end of wear test in each case. It is clear that wear resistance improved vastly with laser-treatment owing to hard martensitic transformations in the treated layers. A ten-fold reduction in wear rate of laser-treated CHT could be observed as compared to untreated steel.

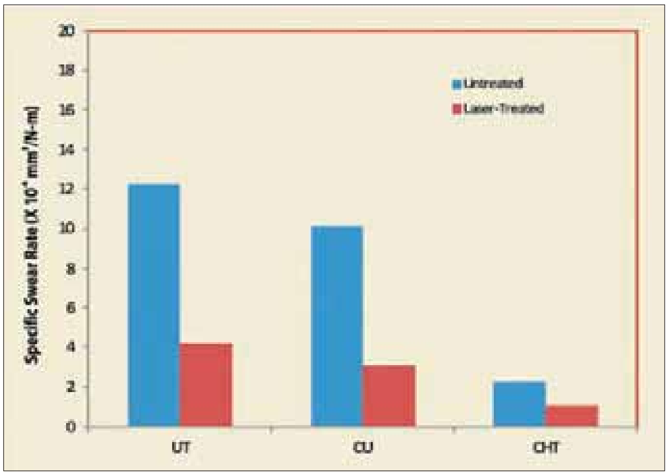

Fig. 2 Comparative sliding wear performance of laser-treated and untreated steel surfaces

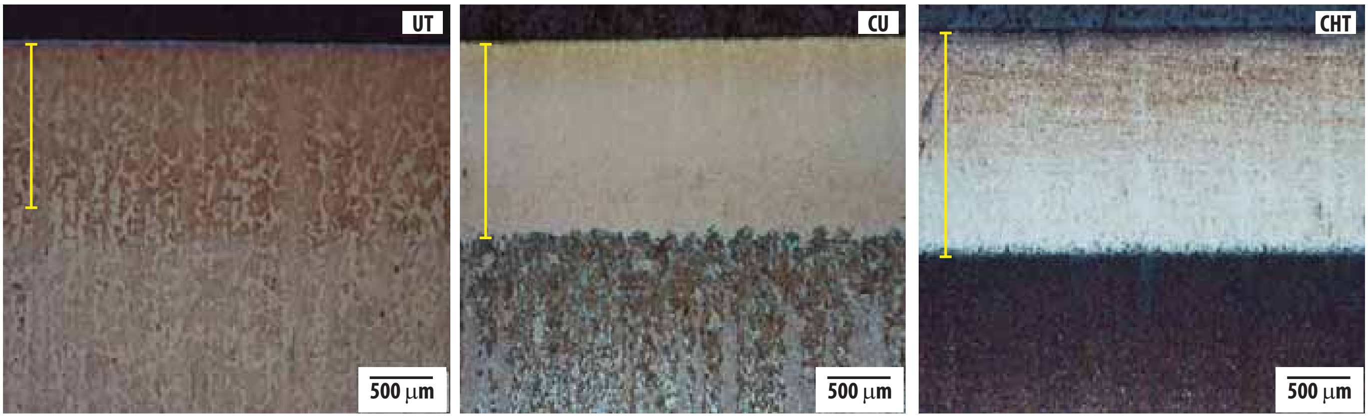

Fig. 1 Cross-sectional micrographs of laser-treated layers

***Contributors: Manish Tak and Kirti Singh***

# Effect of Preheating on Cracking Susceptibility of NiCrBSi Laser Clad-coatings

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In applications where components come in contact with each other under liquid metal environment under high pressure, severe galling and wear over a period of time are observed. One of the solutions is hard-facing of the surfaces with Ni-based alloys. Presently used, plasma transfer arc cladding process is resulting in large heat affected zone and distortion. Laser cladding with controlled and localized heat input is expected to avoid these problems. Initial experiments of laser cladding of Ni based alloy on SS316L showed transverse cracking of the clad. This seems to be due to thermal stresses associated with rapid solidification in laser cladding. In order to investigate this cracking tendency, studies were undertaken by pre-heating the substrate to different temperatures.

Laser cladding experiments were performed using a 6kW high power diode laser system by varying substrate pre-heat temperature (PrHT) from room temperature (RT) to 400°C. A 4mm x 4mm laser spot was used with an off-axis powder feeding nozzle under Ar atmosphere. NiCrBSi alloy powder of average particle size 45µm was used for the experiments. Single track clads and multiple track overlap clads were generated and subjected to dye penetration test. Cracking susceptibility (measured in terms of number of cracks per unit length of clad) for single track clads reduced with increase in PrHT, from 4 when processed under RT to zero when processed under PrHT 200$^0$C beyond (Fig.1). Base metal dilution in clad increased with PrHT and resulted in reduction in micro-hardness (Fig. 2).

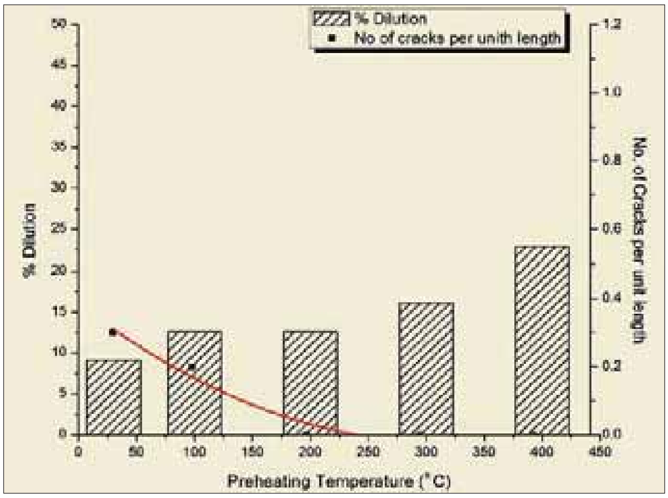


Fig. 1 Effect of preheating on dilution and cracking

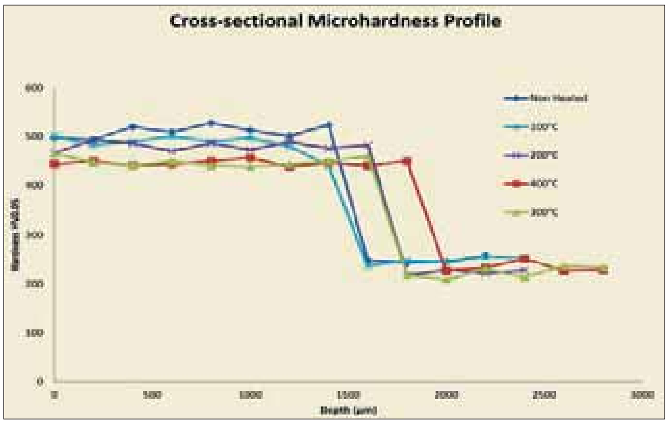


Fig .2 Cross-sectional hardness profile

While the above behavior was observed on single-track clads, experiments on overlap clads revealed increased tendency for cracking under similar temperature conditions (Fig. 3). This could be due to enhanced heat input requirement for melting of existing clad material. SEM analysis of clad surface of RT and 400°C PrHT shown in Fig. 4 further illustrates coarsening of dendrites of $\gamma$-Fe (Ni) in clad prepared with PrHT 400$^0$C as compared to that of RT. This possibly is due to reduction in cooling rate associated with PrHT. Although not mentioned here, EDS analysis showed depletion of Cr-rich phases in interdendritic zones with reduction in cooling rates associated with increase in PrHT. In summary, crack-free clads with desired properties were successfully achieved by optimizing the pre-heat temperature.

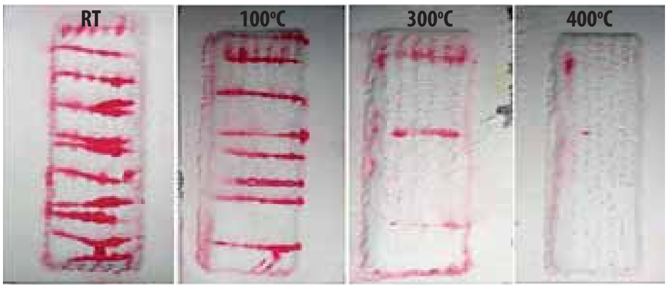


Fig. 3 Die penetration test of overlapped laser clads made at different pre-heating temperatures

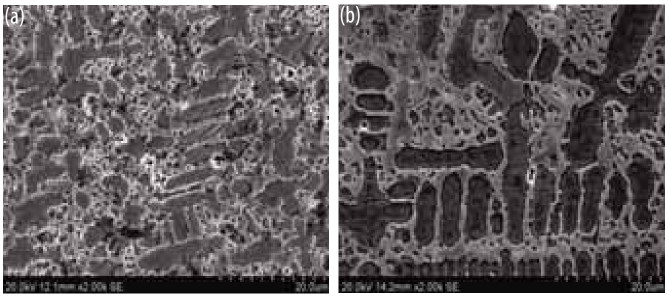


Fig. 4 SEM microstructure of clad surface made at a) RT b) PrHT 400$^o$C

**Contributor: S.M. Shariff**

# PEM Fuel Cell Development for Stationary Applications

***K. S. Dhathathreyan , Centre for Fuel Cell Technology*** *ksdhatha@arci.res.in*

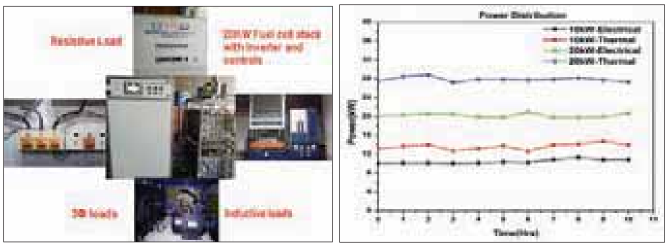
During the year, Centre for Fuel Cell Technology (CFCT) developed and tested Grid Independent Power Supply System, GIPS-20000 which comprises of two 10 kW stacks (built with bipolar plates made from exfoliated graphite), inverter delivering three phase 415 V AC and control system. The unit has been operated for nearly ~275 hrs intermittently. The efficiency of the inverter is close to 84% at 0.82 power factor at peak load and is capable of taking different types of electric loads.

To address the issue of surge current in fuel cell applications, CFCT has been engaged in developing supercapacitors. Several materials which show high capacitance have been prepared. Rigorous research on optimising the method for fabrication of the electrode has resulted in the devlopment of a super capacitor of 10F capacity using indigenouly avaiable materials. The "ARCI Cap 10F" shows true super capacitance behaviour.

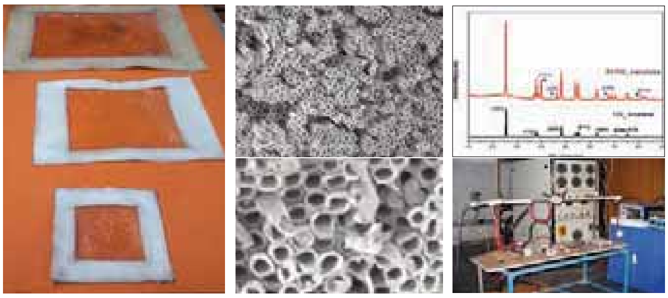
CFCT has initiated work on demonstrating a "DC Lab" with a view to reduce the overall power losses wherein all the appliances including lighting loads will operate on 48 V DC power as fuel cells produce DC power. As part of this programme, CFCT has now developed 3 kW DC-DC converters which use either "Buck-Boost topology" or a "Booster Topology" to accommodate the variable DC voltage available from the fuel cell stack. These topologies offer the advantage of using either a high current – low voltage fuel cell stack or low current – high voltage fuel cell stack.

To improve performance of the fuel cells and reduce cost, several attempts are being made. These developments include development of a semi-automated process for making composite membranes, flow reactor for preparing fuel cell catalyst, catalysts supported on nano structured $TiO_2$, Graphene and catalyst with mesoporous structures. CFCT has developed ePTFE/Nafion® composite membranes for application in Polymer Electrolyte Membrane Fuel Cell (PEMFC) and had demonstrated their use by fabricating a 1kW fuel cell stack. While initially developed process involved time-consuming spraying and brushing techniques, recently the centre has developed a semi-automated coating method. These composite membranes find applications not only in fuel cells but also in membrane based water electrolysers. Having established the process for fabrication of the membrane, efforts are on to produce the membranes in large numbers and fabricate PEMFC and PEMWE stacks using the same. The process developed suggests a saving of nearly 60% of the electrolyte cost.

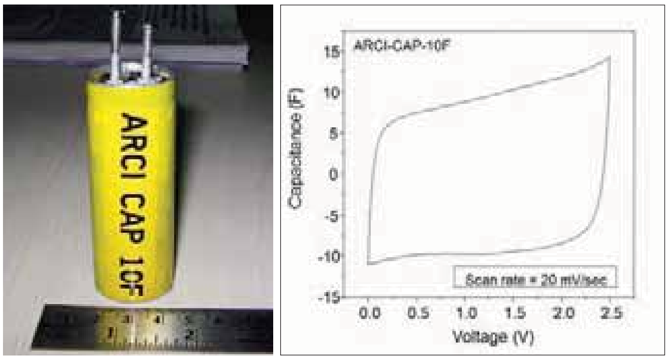
The centre has also initiated work in the area of electrically rechargeable metal – air battery as the air electrode for fuel cells with some minor modification can be used for this purpose. Graphene based materials are used in the electrode fabrication. REDOX battery development is another thrust area.



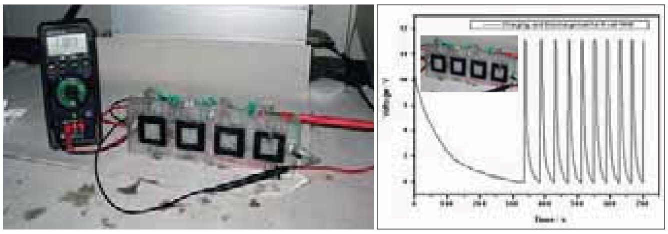
GIPS 20000 with various electrical loads and performance curves



Cost reduction and performance improvement: composite membranes, catalyst on $TiO_2$ nanotubes, flow reactor



ARCI cap 10 F



12 V Zn-air battery

***Contributors: N. Rajalakshmi, K. Ramya, Jiflin Das, R. Imran Jafri, K. N Manoj Krishna, P. Karthika and M. Maidhily***

# PEMFC for Transport Applications

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One of the mandates for the CFCT is to demonstrate fuel cells in transportation application. Towards these objective, a M&M Bijlee fitted with a 3 kW PEMFC stack and all other accessories were demonstrated during 2008-10 where the fuel cell is used as a range extender. Based on the experience gained, CFCT has now fitted a Mahindra Bijlee vehicle with a 5 kW PEMFC stack. A thermal management module, which is suitable for 1 hour operation and can handle ~7.2 kWhr thermal energy, has been developed and integrated. A DC-DC converter, which delivers a constant 72V DC and also a power sharing control device, was developed and fitted into the vehicle dashboard. Use of one 6 NM3 cylinder of hydrogen gas provided a range extension of ~17 kms. The vehicle has been operated for about 100 hrs.

**Mahindra Bijlee**

**Bench Test and Lab**

**Demonstration**

Mahindra Bijlee with 5kW PEMFC stack

CFCT has also developed a Go-Kart, the "ARCI FuGo" for use as test vehicle in many of its development. "ARCI FuGo" was designed in house and fabricated using tubular structural materials. The drive control has also been designed in-house. One of the unique features of the vehicle is the use of hub motor. The fuel for the fuel cell stack is supplied form a metal hydride bed and the oxidant is supplied through a DC air blower. The Go-Kart has been tested with 1 kW PEM fuel cell stack and can attain a maximum speed of 30kmph with two passengers.

The operation experience of the various fuel cell vehicles developed at CFCT over the past few years has clearly identified the requirement of an auxiliary power system to address the surge current requirement during vehicle operation. After various studies, CFCT has identified supercapacitors as an ideal option for this purpose. Optimising the super capacitor capacity is an important activity and scientists at CFCT have addressed this issue. CFCT is engaged in designing an optimised supercapacitor bank for hybrid vehicle applications. Due to the wide variety of driving profiles, the selection of the power ratio between primary and secondary power sources is a matter of judgment. For multiple step applications, the discharging profile can be pre-determined and depending upon the determined discharge time, one can size the capacitance value required and thereby size the super capacitor bank. Modelling studies with two super capacitors with cell capacitance 2700F and 50F were considered to support a fuel cell stack of 400 watts operating at 40V with a variable voltage range of 16-10V.

Go-Kart with 1 kW PEM fuel cell stack

The theoretical studies have been validated by experiments with a 20 cell PEMFC stack and the response of the system was noted. It was observed that a bank with 50F supercaps transferred load in 3 secs. while that with 2800F supercap in 200 secs. The results indicate that for applications with power requirement of less than 500W, 2700F capacitor bank is over-rated and hence the capacitance size can be reduced. Since the equations have simple linear relationship, depending upon the application, operating voltage level, transient response time the optimum super capacitor required can be predetermined and thus reducing the size and improving the fuel cell response rate.

***Contributors: B.Sasank Viswanath, Jiflin Das and K. S. Dhathathreyan***

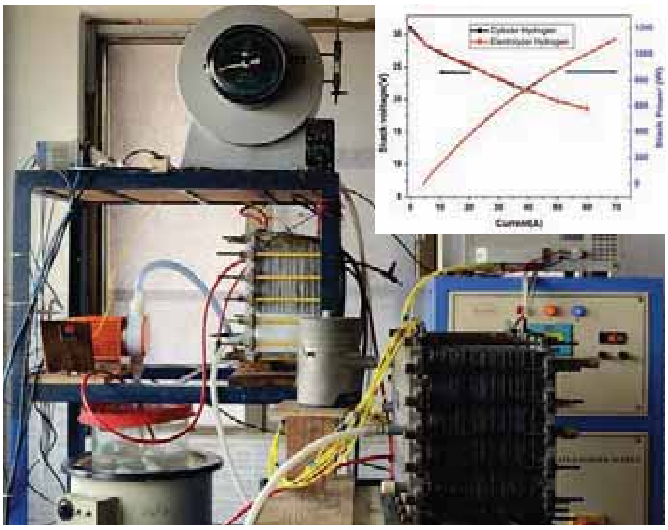
# Development and Demonstration of PEM Based Hydrogen Generator using Exfoliated Graphite Material as Bipolar Plates

*R. Balaji, Centre for Fuel Cell Technology*

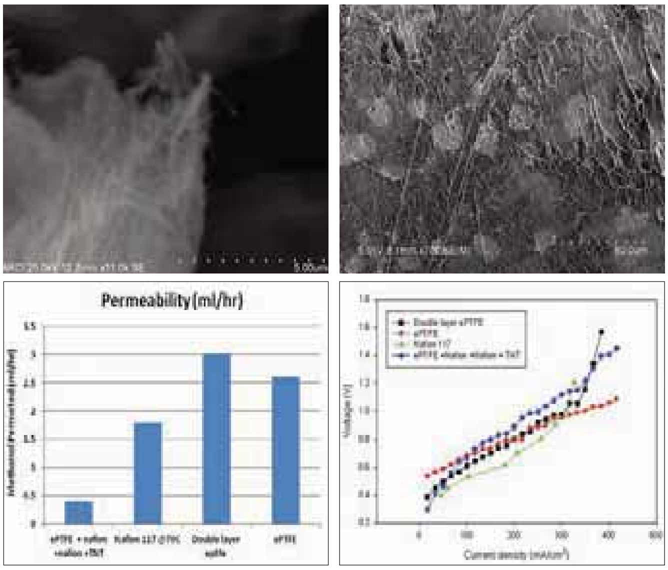
CFCT has continued its work on developing PEM based hydrogen generators by electrochemical reforming of methanol - water mixture and has now successfully devloped a 1000 l/hr capacity hydrogen generator. Based on the optimisation stuides carried out earlier , an electrolyzer stack made of 32 cells of 770 $cm^2$ electrode area was fabricated using exfoilated graphite material as flow field plate. Use of carbon materials as bipolar plate has been one of the significant achivement replacing the titanium plates normally used hetherto in electrolyser units. The energy consumption is about 1.40 $kWhr/Nm^3$ and the corresponiding average cell voltage is 550 mV. The performance of the stack was tested for extented duration and it was stable for more than 100 hrs. Further duartion test is underway. Use of exfoliated plates in the stack assembly offers a conservative cost benefit of about 30%. The hydrogen produced is highly pure and can be directly used in fuel cells.

The electrolyser unit was successfully integrated with an indigenouly devloped 1.2 kW PEM fuel cell stack which delivered the rated power at the hydrogen flow rate delivered by the electrolyser.

In addition to electrochemical reformation of methanol to produce hydrogen, scientists at CFCT are also investigating sea water electrolysis, membrane based alkaline electrolysis and Photo electrochemical route to produce hydrogen at low cost. Development of composite Polymer electrolyte membranes to reduce cost is another development objective.



Operation of PEM fuel cell stack using Hydrogen (1000 ltrs/hr) produced from PEM based electrolyser



SEM images of ePTFE-Naflon®, Titania nanotubes and ePTFE/Naflon®-$TiO_2$ composite membrane for electrolyser appliction, their permeability and hydrogen production data

1000 l/hr PEM based Hydrogen generator and performance data

***Contributors: K. Ramya, S. Seetharaman, N. Rajalakshmi and K. S. Dhathathreyan***

# Development of High Temperature Membrane Fuel Cell Stack using Bipolar Plates Made from Exfoliated Graphite

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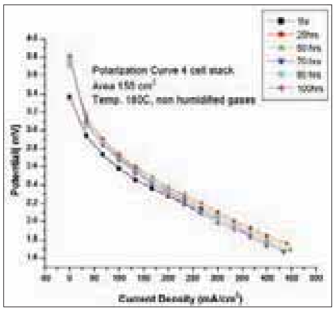
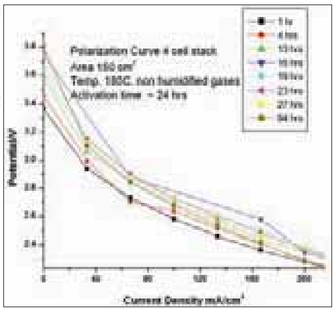
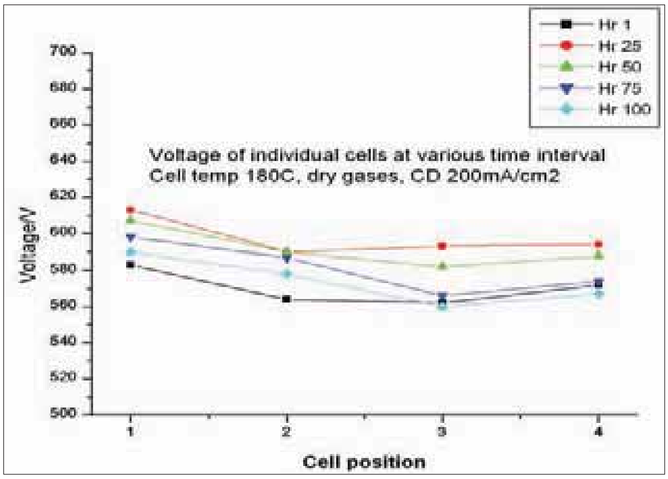
High temperature PEM Fuel Cell (HTPEMFC) offers many advantages for both stationary and automotive applications. Higher tolerance to impurities leading to elimination of some of fuel processor components, better water management and performance characteristics make them extremely attractive for stationary applications. Potential reduction in the size of the radiators by 50% makes them suitable for automotive applications. CFCT had initiated development of HTPEMFC systems with commercial HTPEMFC membrane electrode assemblies for optimization of stack components, operating parameters etc. Single cell studies revealed that exfoliated graphite plates developed by ARCI are suitable for development of HTPEMFC stacks. A 70W stack comprising of 4 cells of area 150 cm$^2$ was developed to carry out the preliminary studies. The stack has been operated for 100 hrs., continuously using exfoliated plates as gas distribution and current collection plates. The time taken for activation of the stack was about 24 hrs. and the stack delivers stable peak performance. The stack developed does not require any special external humidification system thus simplifying the water management. The stack was operated at a high temperature of 180°C which promises tolerance to many of the known anode and cathode impurities. The demonstration of the use of exfoliated graphite for high temperature applications has provided scope for mass reduction in stack components due to the use low density material and cost reduction due to the use of moulded plate compared to the machined graphite plate conventionally used in high temperature stacks.



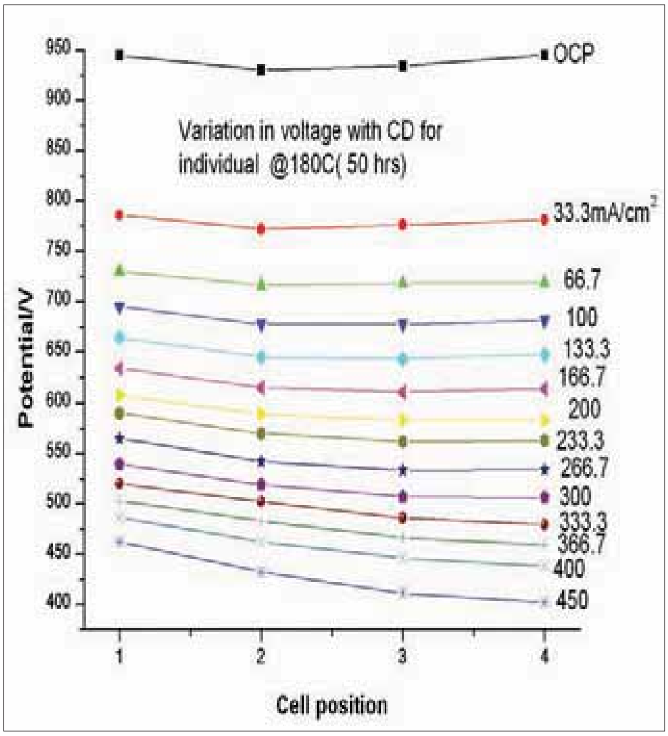
Polarization curve



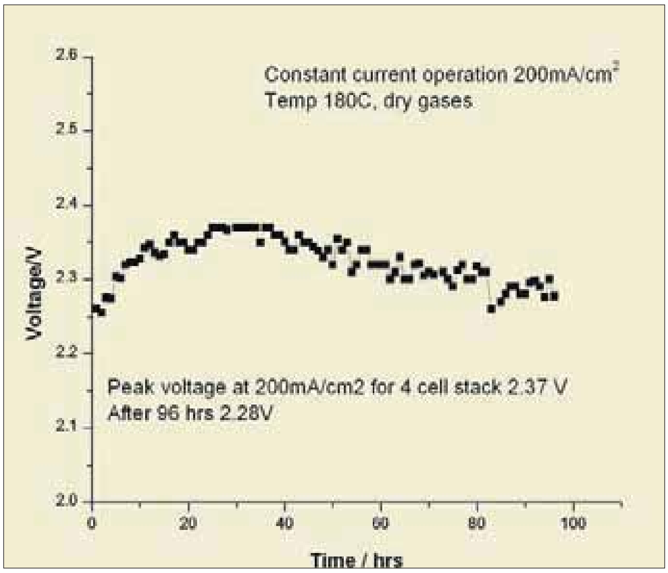
Activation time



Variation of individual cell voltage as function of time



Variation of individual cell voltagesas function of CD



Life test for 4 cell stack

*Contributors: N. Rajalakshmi and K. S. Dhathathreyan*

# Effect of Porosity on Microstructure of Closed Cell Silicon Carbide Foams

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Porous silicon carbide (SiC) ceramics attract considerable interest because of their great potential for a number of industrial applications, including catalytic supports, molten metal filters, diesel particulate filters, membrane supports for hydrogen separation, gas-burner media etc. Several processing routes have already been developed for preparing SiC-based porous ceramics depending on the nature of targeted applications, such as requirement of pore size, amount of porosity, and degree of interconnectivity of the pores. The mechanical properties of such porous bodies are known to primarily depend on the density and microstructure of the struts. While developing porous SiC with high percentage porosity, the solid content in the body reduces as the strut, thus lowering the mechanical properties. Porosity dependent mechanical properties have also been predicted using theoretical models, which assume that the strut properties remain unchanged with increase in porosity. The present investigation is aimed at, experimentally assessing the influence of porosity on the microstructure of closed-cell SiC foams.

An aqueous gel-casting process was adopted to fabricate porous SiC bodies using sacrificial templates. SiC powder, without any binder or sintering additives, was used as the raw material. SiC slurries were prepared in aqueous medium in the presence of methacrylamide ($C_2H_3CONH_2$, MAM) and N, N'-mithylenebisacrylamide [$(C_2H_3CONH_2)_2CH_2$, MBAM,] as gel-casting monomers. N, N, N, N-tetramethylammonium hydroxide [$(CH_3)_4NOH$, TMAH] was used as a dispersant to improve the dispersion of SiC powder and increase the fluidity of the slurry. Externally added boron and carbon residue, obtained through decomposition of the gelcasting monomers, were the sintering additives for solid-state sintering of SiC. Polystyrene micro-beads (d50 = 0.23 mm), constituting the sacrificial pore template, were also mixed with the slurry. The slurry was then cast in aluminium molds and gelled at 60°C in the presence of ammonium per-sulphate [$(NH_4)2S_2O_8$, APS] and tetramethylethylenediamine [$C_6H_{16}N_2$, TEMED] as initiator and catalyst, respectively. Gelled parts were then dried, subjected to low temperature heat treatment for the removal of sacrificial pore template and other organic volatiles, and finally sintered at 2150°C for an hour in a controlled atmosphere furnace in presence of stagnant argon atmosphere. Micrographs of SiC bodies with different porosity made with varying amounts of sacrificial template are shown in Fig. 1, while Table 1 depicts the role of sacrificial template on porosity in the SiC bodies. As expected, porosity in sintered SiC increases with amount of sacrificial template initially present. SiC bodies with maximum porosity of 80 % can be made using 60 wt. % sacrificial templates. As seen from the micrographs, the porous SiC bodies are comprised of uniformly distributed mono-size pores. It is also seen from the micrographs that the increase in porosity is also accompanied by an increase in the pore population in sintered SiC, which leads to decrease in strut thickness.

The microstructure of the struts for SiC bodies with different porosity is also shown as insert of the respective micrographs (Fig. 1). The differences in microstructures of struts with 45 % and 80 % porosity [insets in Figs. 1 (a) and (d)] are clearly noticeable. The strut in case of 45 % porous body consists of densely packed angular grains with a sharp interface, whereas the strut with 80 % porous body consists of uniformly distributed equiaxed and elongated grains with a smooth interface. The enhanced surface diffusion and related phenomena during sintering may be the reason for formation of smooth interface grains as the mass transport phenomena in low thickness struts are influenced by the large surface area generated in the bodies by use of a sacrificial template. The changes in microstructure of struts for SiC bodies with higher porosity are gradual, which is evident from micrographs [insets in Figs. 1 (b) and (c)] of struts for bodies with 57 % and 66 % porosity.

Table 1: Effect of sacrificial template on porosity

| Sacrificial template (wt %) | 25 | 34 | 48 | 60 |
|---|---|---|---|---|
| Porosity in sintered SiC (vol. %) | 45 | 57 | 66 | 80 |

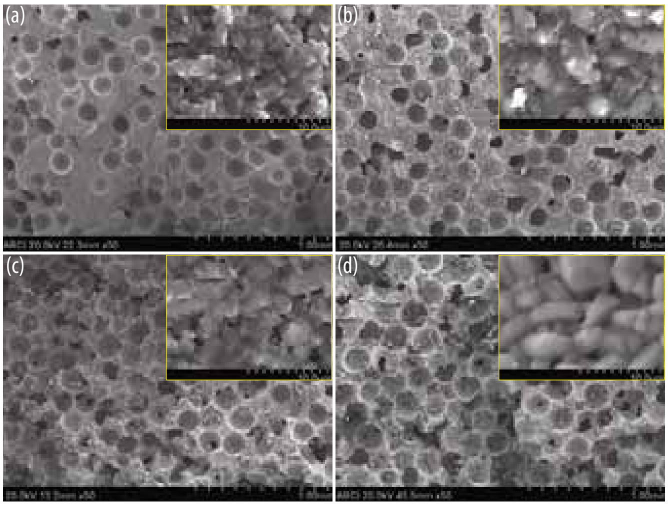

Fig. 1 Micrographs of sintered SiC with different porosity (vol. %) (a) 45 (b) 57 (c) 66 , and (d) 80 . Inset in respective foam micrograph is the grain morphology of the strut

***Contributors: Prasenjit Barick and Bhaskar Prasad Saha***

# Load Dependent Hardness Behaviour of β-SiAlON and α-Silicon Carbide

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Hardness is an important property of material, which depends on grain size, indenter load, loading rate, geometry, and surrounding environment. Generally, hardness decreases with increase in indenter load due to indentation size effect (ISE). This load-dependent hardness phenomenon occurs due to elastic recovery of indentation, cracking and stress relaxation, work hardening, dislocation pinning at the indentation area, and frictional effect between indenter facets and test specimens. Two prominent structural ceramic materials, viz. β-SiAlON with hardness of 15-17 GPa and fracture toughness of 6.50-7.88 MPa.m$^{1/2}$ and α-SiC with hardness of 22-35 GPa, and fracture toughness 2.5-5 MPa.m$^{1/2}$ were selected in the present study to investigate the load dependent hardness behaviour. These materials find applications in ballistic armor, abrasives, space, and cutting tools.

In this present study, experiments were carried out at eight different loads within the range 0.49-29.4N, beyond which the indents on α-SiC specimen were found to shatter indicating higher brittleness index (B). Both materials were found to exhibit decrease in hardness as load increases (Fig.1 and Fig.2) due to indentation size effect and, beyond a critical load (Pc), the load vs. hardness plot was found asymptotic. A mixed elastic / plastic deformation (EPD) model for hard and strong material proposed by Bull et. al., was chosen to analyse the ISE phenomenon in case of β-SiAlON and α-SiC. According to this model, plastic deformation occurs in a discrete manner progressively to relieve stresses created by elastic flexure of the surface at the edges of the indentation. During unloading of the indenter, recovery of the elastic increment of deformation, which precedes each new band of plastic deformation, results in the indentation appearing smaller than expected. Thus, the hardness calculated from the residual indentation imprints increases with decreasing load. Under very low load, prior to the nucleation of first plastic band, surface flexure remains elastic, and fully recoverable on unloading, leaving no residual impression. At higher load (generally beyond transition-point indicated by arrow mark in Fig. 1 and Fig. 2), indentations are associated with both elastic deformation and cracking. Fracture and cracking dominate as load increases. Thus, the recovery effect of elastic deformation becomes negligible, which eventually makes the load to diagonal ratio (used for calculating hardness) nearly identical at each load. Thus, load-hardness plot becomes almost horizontal beyond transition point.

Based on the above result, it can be summarized that ISE effect in α-SiC is more pronounced than in β-SiAlON, as the brittleness index of α-SiC is significantly higher than that of β-SiAlON. The higher brittleness index of α-SiC compared to β-SiAlON, is attributed to its higher hardness at transition load.

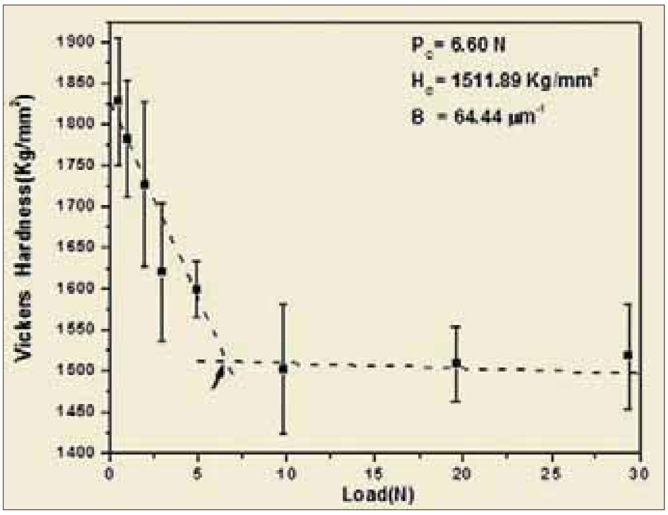

Fig. 1 Load vs. hardness for β-SiAlON

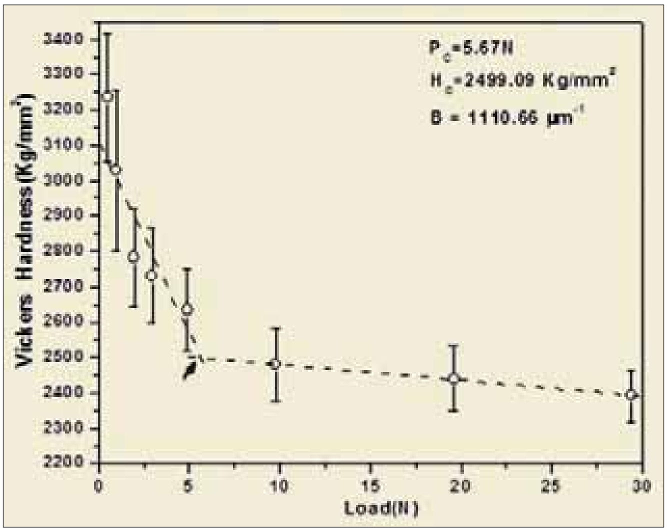

Fig. 2 Load vs. hardness for α-SiC

***Contributors: Dulal Chandra Jana and Bhaskar Prasad Saha***

# Influence of Gas Pressure on CNTs Yield in Arc Discharge Method

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Carbon nanotubes (CNTs) are certainly one of the most striking materials discovered in recent years with great potential for new and exotic products based on them. There are several methods like arc discharge, chemical vapor deposition and laser ablation for the synthesis of CNTs depending on the applications. Each one has its own advantages and disadvantages. Arc discharge is one of the popular methods for synthesis of good quality carbon nanotubes. Growth kinetics of CNTs synthesis involves many process parameters but one of the important parameters is buffer gas pressure. In the present study, the role of buffer gas pressure on the yield of the CNTs was investigated.

A DC arc discharge set up was employed for production of multiwall CNTs. The chamber is evacuated to a base pressure of 100 mTorr and then helium gas is purged at different partial pressures from 80 to 600 Torr. The cathode deposit, which is mainly multiwall CNTs, is collected at the cathode. During the arcing, the evaporation rate of anode and current density varies with partial gas pressure which shows that when the gas pressure is high current drawn is less. The rate of evaporation of anode also varies with the partial gas pressure which is due to the fact that Helium gas has very good ionization energy. SEM studies showed that the yield of CNTs is influenced by partial pressure of gas. It was observed that there are almost no CNTs at low partial pressure of He gas and the yield of CNTs was observed more when the partial pressure of gas was high. However, the very high partial pressure of Helium also does not yield high CNTs. It was observed that CNTs synthesized at 450 Torr give the highest yield as compared to other pressures. CNTs synthesized at 450 Torr with 8 to 10 graphene layers with outer diameter around 16-20 nm are shown in the Fig.1. An increase in pressure has enhanced the yield and number of layers of CNTs. However, beyond the critical pressure the yield and crystallinity of CNTs decreases. The possible reason could be that lower pressure decreased the dynamic viscosity of helium gas and could not enhance the dynamics of carbon clusters on the formation of CNTs, thus delaying the diffusion speed of carbon clusters. While the pressure reaches a restrained value or higher, the yield of CNTs decreases. The foremost reason is that higher pressure increases the density of gas thus decreasing the diffusion speed of carbon clusters.

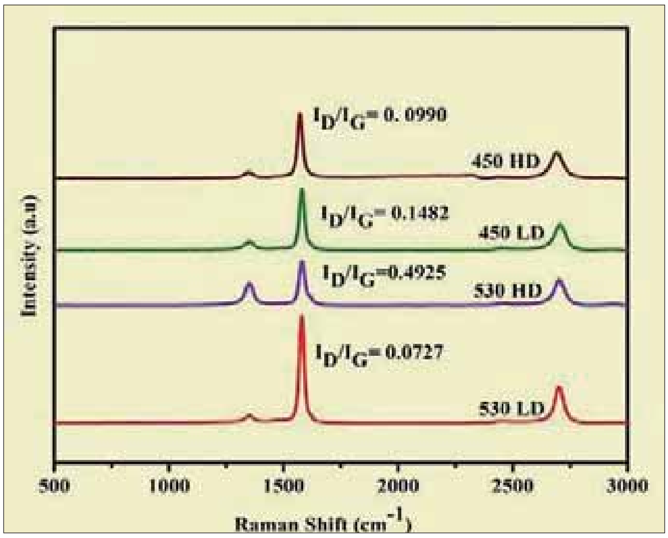

Fig. 2 Raman spectrum of cathode deposits with different partial pressure

Raman studies of samples produced at 450 Torr (Fig. 2), show that the main G peak appears at 1577cm$^{-1}$, which indicates the formation of graphitic sheet. The less intensity peak 'D' obtained at 1351cm$^{-1}$ in case of CNTs produced at 450 Torr indicates that the CNTs are free from impurities and defects. The CNTs yield is relatively higher at moderate pressure of 450 Torr with good crystallinity.

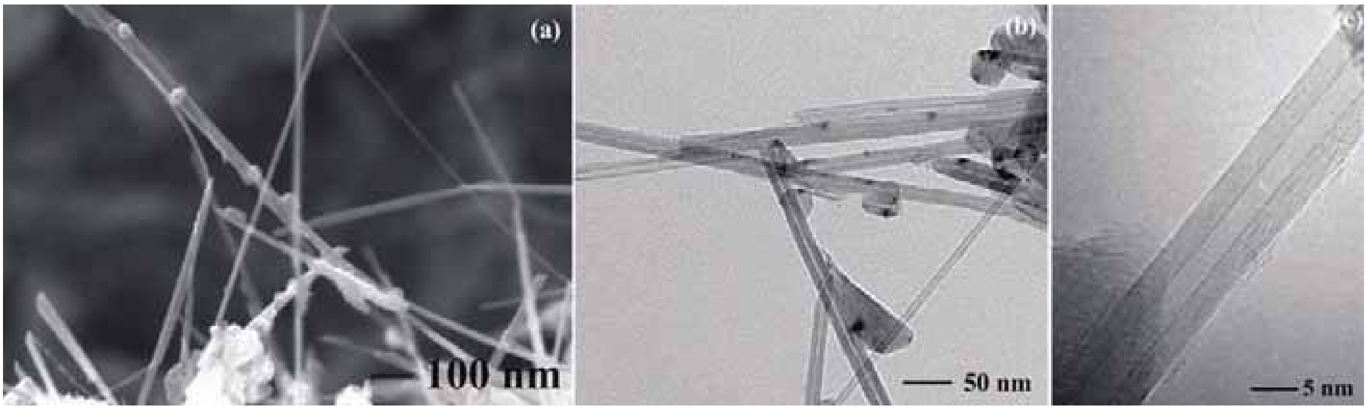

Fig.1 Micrographs of CNT (a) SEM (b-c) TEM

***Contributors: Manikantan Kota and Balaji Padya***

# Controlled Growth of Nitrogen Content Modulated Carbon Nanotubes

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Due to their remarkable properties and potential in various applications, carbon nanotubes (CNTs) have attracted considerable attention. A great interest has been lately observed towards improving and controlling their properties through heteroatom incorporation including B, N, I and P. Among various doped CNTs, nitrogen doped carbon nanotubes (NCNTs) exhibit novel chemical reactivity, electronic, optical and mechanical properties that are not found in pure form of CNTs paving the way to the creation of nano-scale devices.

A facile method was deployed to tune the nitrogen content as well as graphitic/pyridinic type of nitrogen in nanotubes by controlling the growth temperature. The pentagonal and heptagonal rings exist in the $sp^2$ carbon lattice, which are responsible to cause the distort-walled CNT formation.

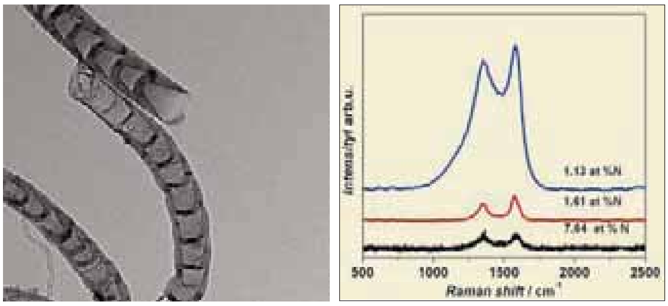

Fig.1 (a) Doped CNTs TEM micrograph (b) Raman spectrum

Nitrogen substitution in carbon network will take place by replacing the carbon atom mainly in two forms i.e., graphitic-like nitrogen and pyridinic-like nitrogen. The main peak at 398.3 eV is attributed to the carbon bonded to two C atoms (C-N=C) is the pyridine-like nitrogen which is responsible for the bamboo type structure in the CNTs and 400.5 eV for graphite-like nitrogen. According to XPS, the CNTs produced at 900°C, 850°C and 800°C from acetonitrile precursor exhibited 1.13 at%, 1.61 at%. 7.64 at% nitrogen, respectively. It implies that the nitrogen content and amount of pyridinic nitrogen doped in CNTs decreases as the growth temperature increases and same is shown in Table 1.

Table 1: Effect of growth temperature on Nitrogen content

| Temperature (°C) | N content (at%) | N1s (eV) [% Area] |
|---|---|---|
| 800 | 7.64 | 398.40 (56.85 % A)<br>401.03 (43.15 % A) |
| 850 | 1.61 | 398.37 (37.42 % A)<br>400.95 (62.58 % A) |
| 900 | 1.13 | 388.16 (32.61 % A)<br>400.71 (67.39 % A) |

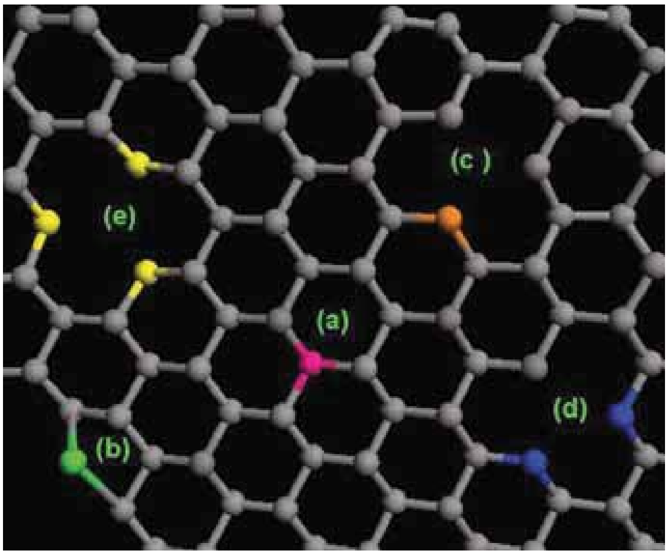

Fig.2. Possible defects in substitutional nitrogen doping in carbon network (a) pyrrolic nitrogen (b) graphitic nitrogen (c) pyridynic N1-vacancy (d) pyridinic-N2 vacancy and (e) pyridinic-N3 vacancy

The defects in doped nanotubes can originate either due to defects in the curved graphitic sheets or tube ends of the N-CNTs, atomic displacement and finite particle size. The possible defects in hexagonal carbon network are shown in Fig. 2. Fig.1b shows G-band at 1582 $cm^{-1}$, 1575 $cm^{-1}$ and 1568 $cm^{-1}$ and D-band at 1352 $cm^{-1}$, 1350 $cm^{-1}$ and 1347 $cm^{-1}$ for the nanotubes with nitrogen content 1.13 at%, 1.61 at% and 7.64 at%, respectively. Raman spectrum indicated that the D-band becomes stronger and broader at lower growth temperature as compared to higher temperature.

Due to enhanced electron transfer from valence band to conduction band, electronic structure of the nanotubes will be altered and results in downshift of G-band position as the nitrogen content increases. The additional free electron donated by the nitrogen makes the C-C bond weaker, and thus G-band shifts down (indicates red shift phenomenon). The change in the electronic structure of NCNTs relative to CNTs depends on the amount and type of the incorporated nitrogen.

CNT arrays with tuneable N content finds application in many areas such as field emission display devices, nano-electrodes, gas sensors, electron guns and gas ionizers.

***Contributor: P. K. Jain***

# One Step Anodization/Sol-Gel Deposition of Ce$^{3+}$-doped Silica-Zirconia Self-Healing Coating on Aluminium

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Aluminium and aluminium alloys are widely used as structural materials due to their high strength-to-weight ratio and low cost. They are highly susceptible to corrosion attack in chloride containing environments. Chromate conversion coatings have been the most widely used self-healing, anti-corrosion treatments for aluminium and aluminium alloys. However, there is an increasing demand for the development of environmentally friendly and cost-effective method for corrosion protection, due to the toxicity involved in use of hexavalent chromium. Anodization is an electrochemical oxidation process employed to increase the thickness of the native oxide layer. The anodized layer is porous, and usually, a sol-gel coating is deposited over the anodized layer to render good barrier properties. The present work involved a novel one-step anodization/sol-gel deposition from a Ce$^{3+}$-doped silica-zirconia sol to obtain a self-healing coating on aluminium by optimization of electrodeposition parameters like current density, voltage, time of deposition and pH. The coated substrate after curing at 130°C reveals a ~ 20 micron thick crystalline aluminosilicate layer along with an amorphous sol-gel coating. The X-ray diffraction (XRD) patterns acquired at normal and grazing angle incidence (GI) as shown in Fig. 1 confirm that the coating is crystalline corresponding to an aluminosilicate phase of the formula $Al_2SiO_5$ (JCPDS 44-0027).

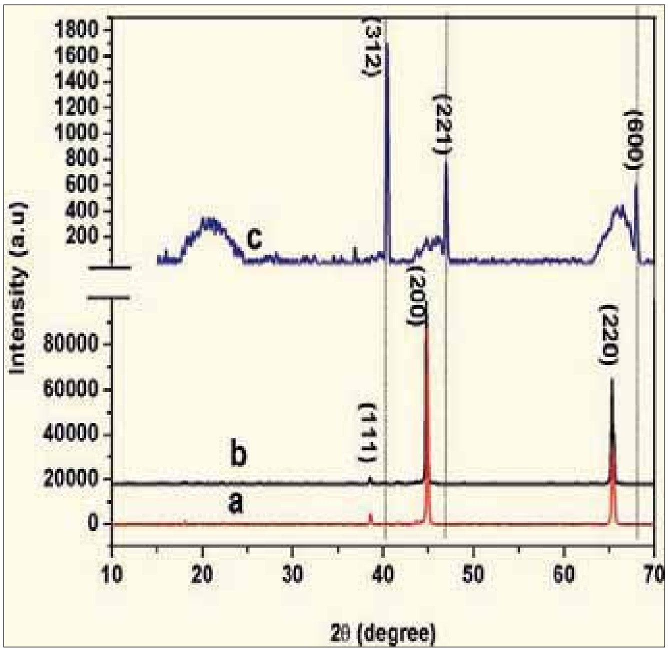

Fig.1 Comparison of XRD patterns of (a) bare aluminium; (b) coated aluminium cured at 130°C both acquired at normal incidence and (c) of coated aluminium, cured at 130°C, acquired at GI of 1 degree.

Neutral salt spray tests (NSST) on the coatings carried out for 400 h showed that the electrodeposited coatings provided a dense barrier on the substrate and provided a self-healing effect, when compared to a simple dip coated layer deposited from the same sol composition. It could be discerned from the scratch test results (as shown in Fig. 2) that the simple dip coated specimen started showing visible cracks and delamination even at the bare minimum load of 0.9 N applied during point of contact whereas, there were no cracks in the electrolytically coated specimens until the normal load increased to 2 N. These results show that the electrolytically deposited coating exhibits a higher scratch hardness than the coating derived from a simple deposition. This novel one step anodizing/ sol-gel deposition process provides a dense, crystalline and a self-healing coating on the anodizable metal substrate, that renders prolonged corrosion protection.

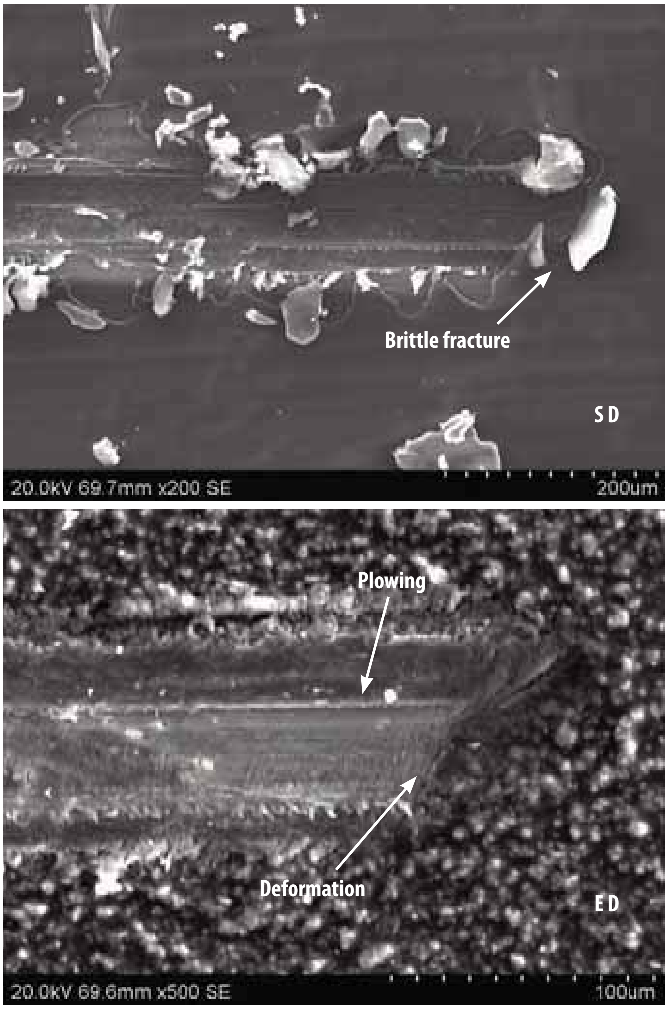

Fig. 2 SEM images of scratch in a) simple dip coated (SD) and b) electrolytically deposited (ED) specimens

***Contributors: Nirmal Kumar, K.R.C. Soma Raju and V. Uma***

# Durable Single Layer Anti-reflective $SiO_2$ Coatings on Glass Substrates

*K. Murugan, Centre for Sol-Gel Coatings* *murugan@arci.res.in*

Reflection of light is a basic phenomenon when light propagates across a boundary between two media having different refractive indices. In order to reduce the magnitude of reflection, anti-reflection coatings (ARCs) are extensively used in various applications. ARCs are prepared by applying a single or multiple layers of material onto a highly transmissive, ultra-clear glass. Coatings are engineered to reduce reflection at the air/glass interface so that more energy producing photons can enter the energy conversion devices. Most commercial AR coated glasses for the solar industry feature a layer of uniform or graded low refractive index material that is applied to a glass substrate by various deposition processes, including wet techniques or dry processes, such as vacuum deposition. In this report, ARCs on glass substrates have been made using thermal decomposition and sol-gel processing techniques.

Thermal decomposition of silicon precursor above 400°C generates 95% average transmittance from 400 to 1200 nm on various glass substrates such as soda lime glass (SLG), borosilicate glass (BSG), and fused silica glass (FSG). The sol-gel process by using organic catalysts and pore forming agent improves the transmittance to 97%. To compare, bare BSG thermal decomposed thin film shows 95% avg. transmittance (Fig. 1) whereas film prepared using sol-gel process exhibits 97% (Fig. 1).

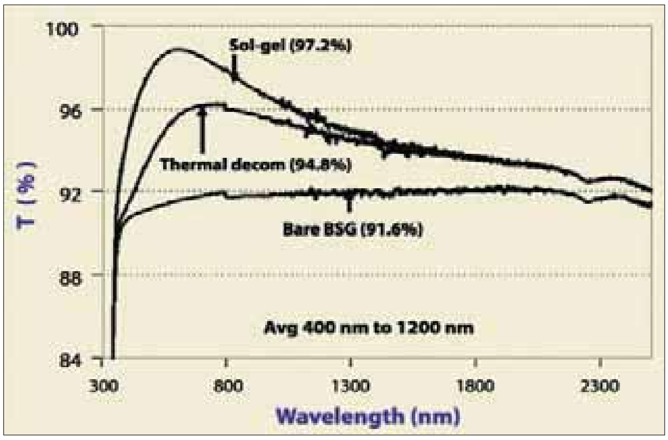

Fig. 1 Transmittance spectrum of $SiO_2$ thin film prepared by thermal decomposition of silicon precursor and modified sol-gel process on BSG slides

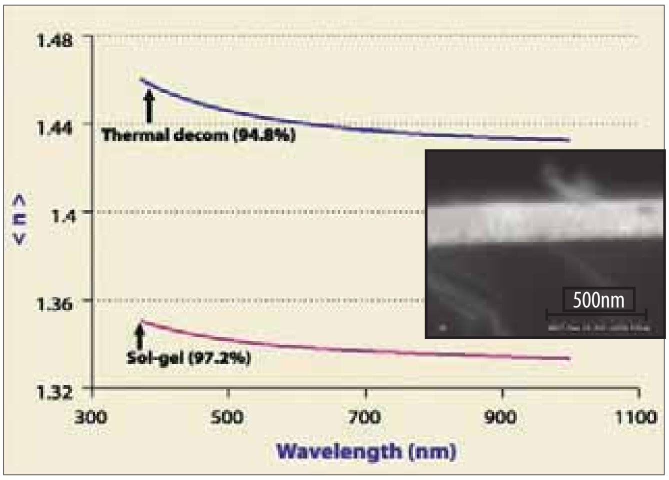

Fig. 2 Refractive index of the $SiO_2$ film prepared by thermal decomposition of silicon precursor and modified sol-gel process on BSG slides (Inset: Cross section SEM image of Sol-Gel $SiO_2$ film)

The improved transmittance in the sol-gel base process is mainly due to formation of 20% closed porosity as estimated by ellipsometry data analysis. Fig. 2 shows the variation in refractive index of film prepared by the above method. Lower refractive index in the film prepared using sol-gel method indicates the contribution of 20% air and 80% $SiO_2$. The film thickness and refractive index was estimated using ellipsometric parameters such as ψ and Δ as a function of wavelength from 400 to 1000 nm using variable angle spectroscopic ellipsometer (VASE). The data generated using variable angle spectroscopic ellipsometer (VASE) was fitted using two layer Cauchy model (convert into EMA) by varying single parameter (thickness). The result obtained from VASE is reliable and trustworthy, by the excellent corroboration obtained with the HR-SEM cross section analysis. The root mean square error value of the experimental and estimated values of ellipsometry parameter is 2. The estimated coating thickness from the ellipsometry parameter is 137 ± 0.3 nm which is in very good agreement with the SEM cross sectional analysis of 145 nm as shown in inset (Fig. 2) with the closed pores. The durability of the above coatings was analyzed by change in the haze and loss of transmittance after 1000 cycles on crock meter. Table 1 shows the crock meter analysis after 1000 cycles which shows less than 2% of haze.

Table 1: Change in haze upon dry abrasion crock meter test using cotton at 9N load

| **Sample** | **Haze value at 550 nm** | | | **% of haze after 1000 cycles** |
|---|---|---|---|---|
| | ***Initial*** | ***After 500 cycles*** | ***After 1000 cycles*** | |
| Bare BSG | 0.04 | 0.31 | 0.32 | 0.28 |
| Thermal decomposition | 0.13 | 1.5 | 2.17 | 2.04 |
| Sol-Gel | 0.035 | 0.95 | 1.35 | 1.315 |

***Contributor: M. Syamala Rao***

# Effect of Plasma Pre-treatment on the Mechanical Properties of Sol-gel Derived Hard Coatings on Transparent Plastics

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Plastics such as polycarbonates (PC) and polymethylmethacrylate (PMMA) find many applications in automotive and aerospace fields due to their low density and transparency. Prominent applications include windshields, window glazing and headlamp bodies etc. Mechanical impacts such as scratches and abrasion on these parts lead to loss in transparency thereby leading to a reduction in the performance of the material. There are various surface engineering techniques such as physical and chemical vapour deposition processes to improve the hardness, scratch and abrasion resistance of these polymers. But the coatings deposited by these processes are expensive requiring huge infrastructure and often result in poor adhesion due to difference in coefficient of thermal expansion and crack formation due to difference in moduli of elasticity between the polymer substrate and the inorganic coatings deposited by these techniques.

Sol-gel coating technique, on the other hand is a suitable wet chemical process in which an organic-inorganic flexible hybrid coating can be deposited to improve the mechanical properties to a considerable extent without compromising on the transparency. Plasma surface pre-treatment is known to improve the adhesion of sol-gel coatings on plastic substrates. Hence, the effect of an atmospheric air plasma surface pre-treatment on mechanical properties of a low temperature curable sol composition was investigated.

The hybrid sol was synthesized by the hydrolysis and co-condensation of an epoxy silane along with titanium tetraisopropoxide in the presence of water and an acid catalyst. Uniform coatings of 15 $\mu$m wet film thickness were deposited using optimized parameters on PC substrates of dimensions of 100 mm x 100 mm with the help of a manual spray gun. Some of the coatings were deposited after an atmospheric air plasma surface pre-treatment using the equipment supplied by M/s Plasmatreat GmbH, Germany. The coatings were cured using UV radiation within 10 minutes of deposition, followed by further densification using an air circulating drying oven at temperatures between 100-130°C for 1 h.

The sol-gel synthesized nanocomposite coatings were very smooth with an average surface roughness as low as 0.02 $\mu$m (Ra). The pencil scratch hardness could be substantially increased from 2B for uncoated PC to 2H even with such low temperature curing. Both coated and uncoated samples were subjected to abrasive wear using a taber tester with harder CS10 abrasive wheels and as could be seen from the Fig. 1, the effect of plasma treatment is clearly visible with a lower haze change of 10% on plasma treated substrate as against 12% of untreated but coated substrate.

Fig. 2 shows wear tracks of coated PC after plasma treatment with an inset of uncoated PC after 500 cycles of abrasion testing. Dark circles were marked to identify the wear track on coated substrate. As can be seen, there is no visible track on the coated substrate while the uncoated PC shows a prominent wear track indicating excellent wear resistance of the coating.

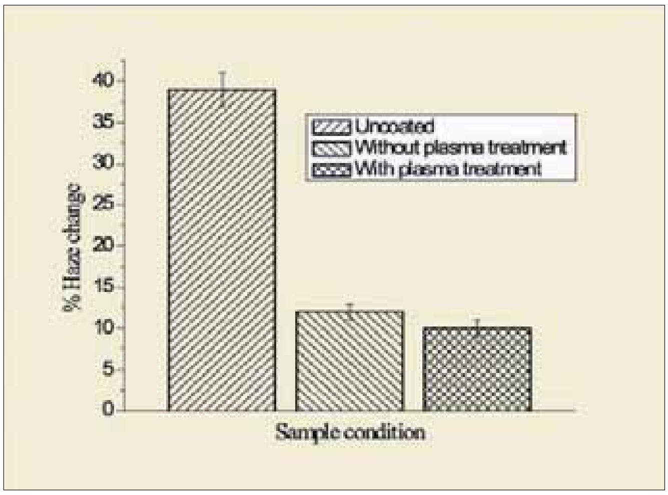

Fig. 1 Bar chart showing comparison of change in haze of bare with that of coated PC, Wheels used: CS-10, Load: 2 x 500 g after 500 cycles

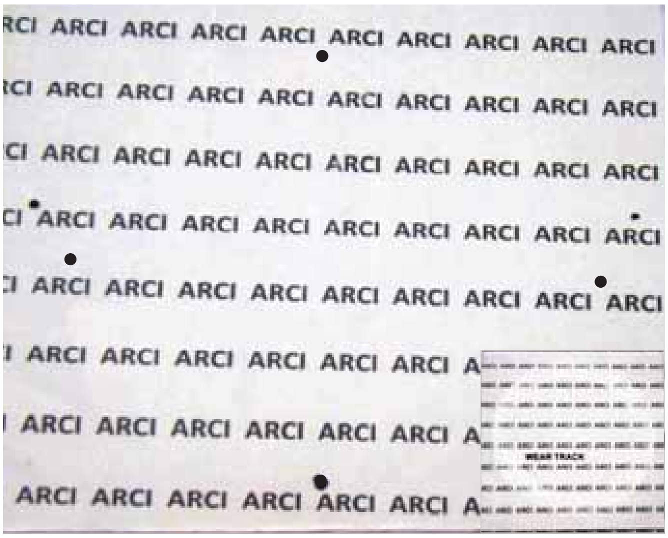

Fig. 2 Wear track of coating on plasma treated substrate with inset showing wear track on un-coated substrate

***Contributors: D. Sreenivas Reddy and R. Subasri***

# Near-infrared Curing of Easy-to-clean Coatings on Chlorinated Polyethylene Electrical Cable Jackets

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Centre for Sol-Gel Coatings has been working on demonstration of a variety of applications of sol-gel derived organic-inorganic hybrid nanocomposite coatings on glass, plastics, metals/stainless steels, glazed tiles to obtain functionalities like anti-microbial, easy-to-clean, photo catalytic, solar selective, antireflective etc. The important advantages of using hybrid nanocomposite coatings are possibility of low temperature curing when deposited on temperature sensitive substrates like plastics and use of alternate curing techniques like ultraviolet (UV) radiation or near-infrared (NIR) radiation for coating densification. UV or NIR radiation induce the polymerization of the organic groups in the organic-inorganic hybrid coatings thereby leading to coating densification. The coating technology (coating deposition plus curing process) has to necessarily be amenable to scale-up for use by the industry, which can be either a batch or a continuous production. However, the coating technology when scaled-up should be able to be incorporated into the existing production line and should be optimized in such a way that the production rate is unaltered.

In an attempt to develop easy-to-clean, anti-bacterial coatings on chlorinated polyethylene [CPE-chemical formula $(-CH_2-CHCl-)_n$] cable jacket material, which is normally produced at a rate of approximately few hundreds of feet per minute in the industry, the applicability of NIR radiation for rapid curing of the coatings was investigated. The performance with regard to easy-to-clean property was compared with the coatings cured using a conventional drying oven. Coatings from a sol formulation that could yield hydrophobic easy-to-clean coatings were deposited on CPE coupons using a dip coating technique. These coatings were either cured in a drying oven at 130°C for 1 h (total process time - 4 hours) or using a near infra-red curing chamber. The NIR curing times were varied from 10-30 minutes and optimized in such a way that coatings are completely cured, which was found to be 15 minutes.

In order to test the easy-to-clean property, the coated and cured CPE coupons were dipped into carbon black suspension and dried overnight. They were then wiped off with a water soaked sponge to see if the carbon black layer can be removed easily.

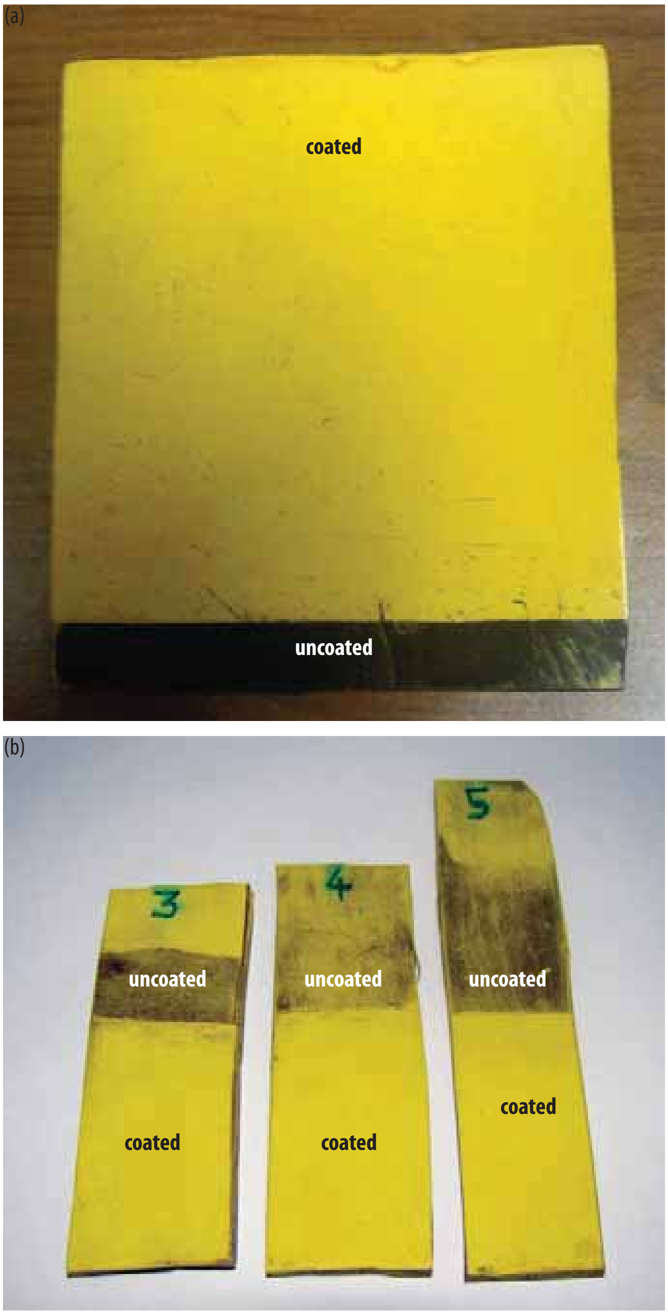

Fig. 1 Demonstration of easy-to-clean property on coated CPE coupons that are (a) conventionally cured coated and (b) NIR cured

Fig. 1 shows that the carbon black coating on uncoated area is not removed with just a simple wipe with water whereas, the same gets removed easily from the coated area. It can also be seen that a fast curing of coatings using NIR radiation yields similar results as obtained when conventional curing is employed, which proves that NIR radiation can be used for a fast and efficient curing of sol-gel derived easy-to-clean coatings on CPE coupons. The present work demonstrated that a conveyorized NIR curing technology can be introduced into the production line to generate easy-to-clean coated CPE jackets for electrical cable applications.

***Contributors: D. Sreenivas Reddy and R. Subasri***

# Multifunctional, Decorative Hybrid Sol-Gel Coatings on Aluminium

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Multifunctional, i.e. hydrophobic, corrosion resistant, scratch resistant and decorative single layer sol-gel coatings on aluminium find lot of applications, especially for use on blades of ceiling fan. Generation of such a single layered multifunctional coating obviates the need for chromating, painting followed by deposition of transparent multifunctional hydrophobic corrosion resistant and scratch resistant coatings. However, aluminium being a soft metal gets easily scratched during handling. Hence, in order to obtain a single layer multifunctional coating as a substitute to conventional paints which usually conceal the scratches on aluminium, a thick decorative coating similar to a paint layer, has to be deposited. Organic-inorganic hybrid coatings have the advantages of being thick and able to be densified at low temperature or by using alternative curing techniques like ultraviolet (UV) irradiation. Multifunctional hybrid sol-gel coatings that are transparent, thick and hydrophobic were generated by varying the precursor contents of a base sol composition comprising acrylic modified silane (M), vinyl modified silane (V), zirconium alkoxide (Z) and a fluorosilane (F). Different sol compositions with varying contents of M and F in the base sol composition were synthesized to determe an optimized composition that would yield coatings with maximum thickness and hydrophobicity simultaneously when deposited on aluminium substrates.

Tables 1 and 2 give the thickness and water contact angles of the transparent coatings obtained by varying either the composition of one of the polymerizable precursor (M) and fluorosilane (F) respectively. The optimized sol compositions yielding transparent coatings with maximum thickness and hydrophobicity were then combined with inorganic pigments to generate pigmented sols. The pigmented sols were directly deposited on aluminium substrates by spray coating, densified using UV radiation/ conventional curing and characterized with respect to their thickness, roughness, contact angles and surface morphology.

It could be seen from Tables 1 and 2, that MVZF20 could yield a sufficiently thick coating with very good hydrophobicity. Hence, this composition was used to generate the pigmented coating on aluminium substrate (Fig. 1).

Table 1 Thickness of coatings generated by varying content of M in the coating

| Sl. No. | Composition | Thickness [μm] | Water contact angle $[^{0}]$ |
|---|---|---|---|
| 1 | MVZF | 1.3 | 87±5 |
| 2 | M2VZF | 1.5 | 83±7 |
| 3 | M3VZF | 1.8 | 88±6 |
| 4 | M4VZF | 1.9 | 91±2 |
| 5 | M5VZF | 2.5 | 78±1 |

Table 2 Water contact angles coatings generated by varying content of F in the coating

| Sl. No. | Composition | Water contact angles $[^{0}]$ | Thickness [μm] |
|---|---|---|---|
| 1 | MVZ | 78±1 | 1.2 |
| 2 | MVZF | 87±5 | 1.3 |
| 3 | MVZF3 | 87±3 | 1.7 |
| 4 | MVZF5 | 93±14 | 1.9 |
| 5 | MVZF20 | 104±13 | 2.1 |

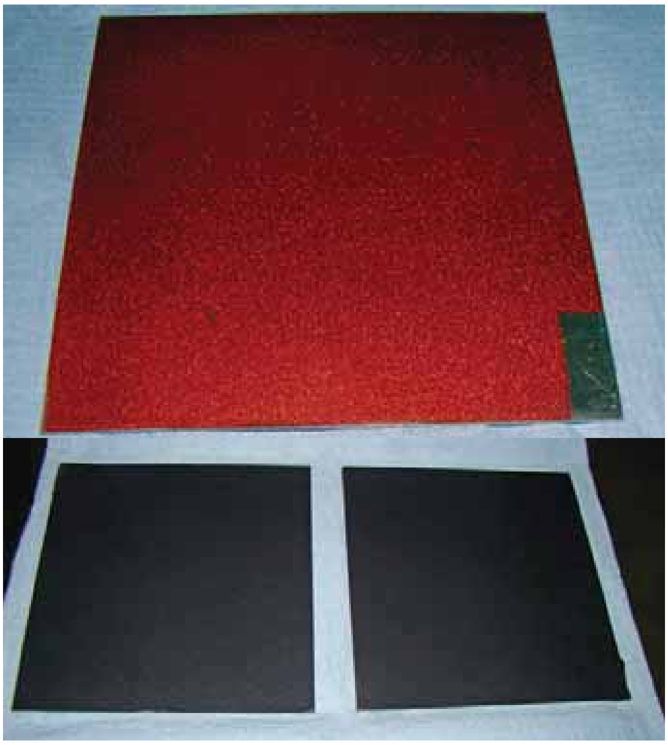

Fig. 1 Photographs of pigmented MVZF20 coatings on aluminium substrates (a) red colored coating and (b) black colored coating

The thickness of the pigmented coatings ranged between 18-20 μm. These coatings were found to be thick, decorative, hydrophobic and scratch/corrosion resistant and could well conceal the scratches on the aluminium substrate. The coatings were found to be an eco-friendly substitute to the toxic chromate and paint layers.

**Contributor: S. Shanthini**

# Phase Analysis of Inconel-Chromium Carbide Powder and Rapidly Solidified Laser Clad Layers by EBSD and XRD

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Laser cladding is one of the promising methods of coating deposition due to its immense versatility in depositing a wide array of materials. The denser microstructures and enhanced interfacial bond strength are presumed to be responsible for the superior tribological behaviour of the laser clad layers. Chromium carbide based metal matrix composites are popular choices as coating materials for erosive-corrosive environments at service temperatures up to 800°C. In this study Inconel which has a better high temperature oxidation resistance than the conventional NiCr alloy has been used as the matrix for chromium carbide. The relatively low temperature melting chromium carbides (≈1755$^0$C to 1810$^0$C) invariably melt during laser cladding and consequently lower carbides are precipitated. The study of the presence of various carbides has been a challenge since their major x-ray diffraction (XRD) peaks overlap with each other as well as with that of the matrix Ni phase.

An agglomerated and sintered thermal spray grade Inconel and $Cr_3C_2$ powder was laser cladded onto a 0.27%C steel using a 6 kW diode laser, with the powder being precisely fed into the laser-substrate interaction zone using an off-axis nozzle. In this study, the effect of energy input on the phase constitution of the laser clad layers was studied by varying the continuous wave laser power from 1600W to 2400W, with a 200W increment. Phase identification has been carried out using the electron back diffraction (EBSD) technique.

XRD peaks (Fig.1) of the initial powder and laser clad layers clearly show the overlapping of the major peaks of the carbides and nickel (shown by rectangular boxes in Fig.1) thereby making phase identification ambiguous. However XRD reveals a gradual drop in the presence of chromium carbides with increasing laser power (drop in the intensity of the prominent chromium carbide peaks is indicated by arrows in Fig.1). The drop in chromium carbide content can be directly attributed to the increase in dilution from the substrate with increasing laser power. It is also possible that, since laser cladding is a rapid solidification process, all the chromium carbides dissolved may not have re-precipitated. The initial powder contained two different chromium carbides namely, $Cr_3C_2$ (orthorhombic) and $Cr_7C_3$ (hexagonal) which were identified by EBSD owing to their different crystal structures (Fig.2). The final clad layer contained predominantly $Cr_7C_3$ type of carbide. Chemically assisted EBSD (Fig.3) scans were needed to be performed to show the presence of $Cr_{23}C_6$ in the clad layers since the crystal structure of nickel and $Cr_{23}C_6$ is cubic.

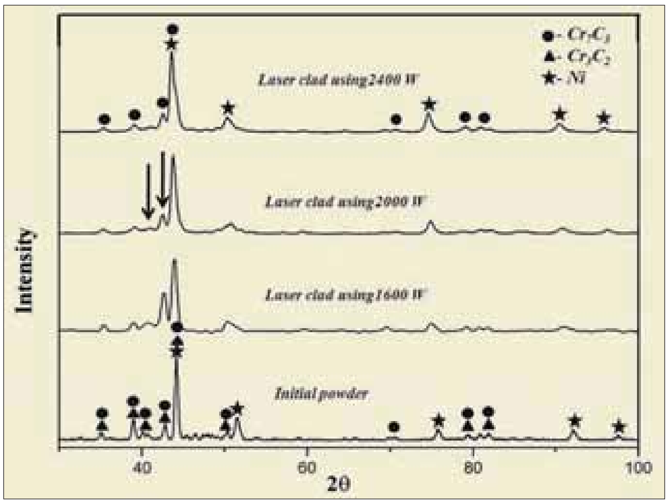

Fig.1 XRD spectra of the feedstock powder and laser clad layers

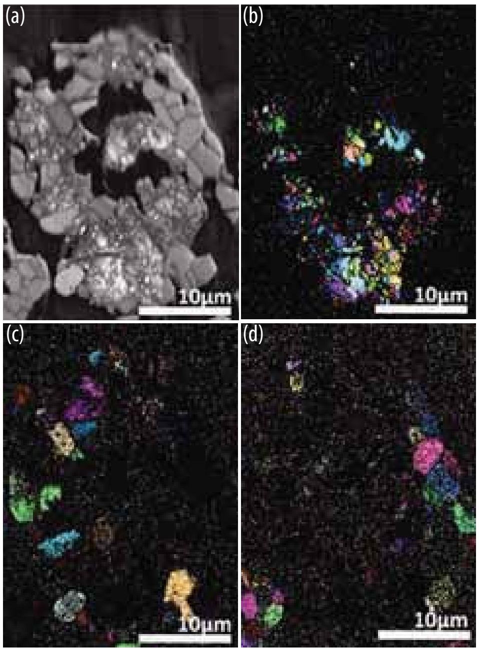

Fig. 2 EBSD images of initial powder particle (a) Image quality map (b) IPF image of Ni (c) IPF image of $Cr_3C_2$ and (d) IPF image of $Cr_7C_3$

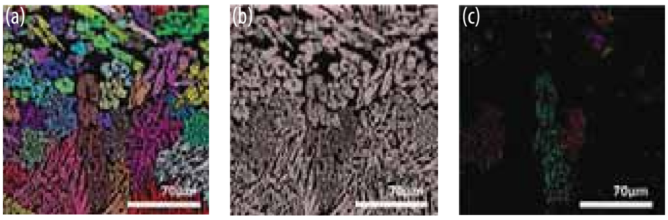

Fig. 3 Laser clad at 1600W (a) IPF image of $Cr_7C_3$
(b) EDS map for Cr (c) IPF image of $Cr_{23}C_6$

***Contributor: Manish Tak***

# TEM Study on High Breakdown Field ZnO Varistor

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Transmission electron microscopy (TEM) study was carried out on Ca-doped Zno varistor material for determining various phases present in the material and to determine calcium segregation at triple junctions. In this report we present results pertaining to calcium mapping using Energy Filtered TEM (EFTEM) technique.

The electrical behavior of the ZnO varistor material is highly dependent on the chemistry and distribution of metal oxide phases at triple junctions and grain boundaries. Doped ZnO powder has been prepared by chemical synthesis and subsequently consolidated using liquid phase sintering. The distribution of Bismuth oxide and spinel phases at grain boundary regions is well understood and is thought to improve the varistor properties. Bismuth oxide encapsulates ZnO grains and acts as an insulator which results in non-linear V-I characteristics, whereas spinel acts as a grain refining agent. Fig. 1, a bright field TEM image, shows an oxide present at the triple junction.

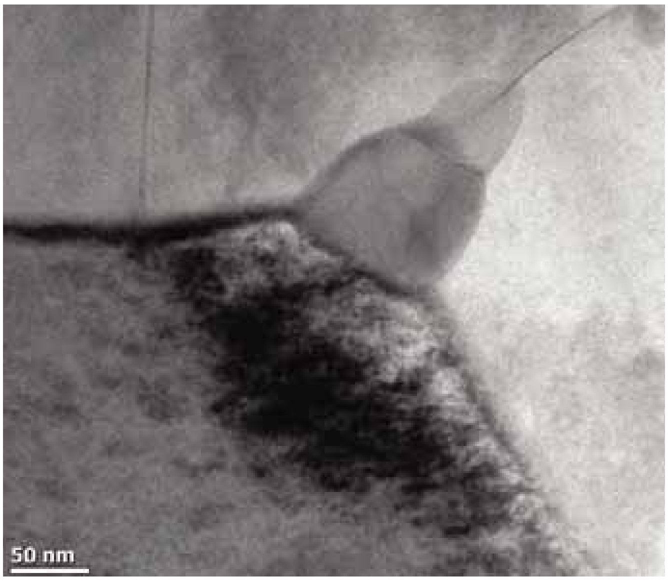

Fig. 1 TEM bright field image showing metal oxide particle at triple junction

It is found that calcium inclusion in the dopant family improves the varistor breakdown field of this kind. It is thought that the added calcium gets into the oxides present at the grain boundary junctions. As the grain boundary regions are very thin and the oxides are of submicron size, TEM analysis was carried out on Ca doped ZnO varistor sample (1 wt% calcium oxide) to find out the calcium distribution in the microstructure in order to understand its effect on varistor behavior.

EDS analysis was carried out at a triple junction but as K edge of calcium overlaps with L edge of antimony, the presence of calcium at triple junctions cannot be clearly established using EDS. Electron energy loss spectroscopy was thus carried out to overcome this limitation. Fig. 2 shows core-loss spectra recorded to capture L-edge of calcium and M-edge of antimony from the same region.

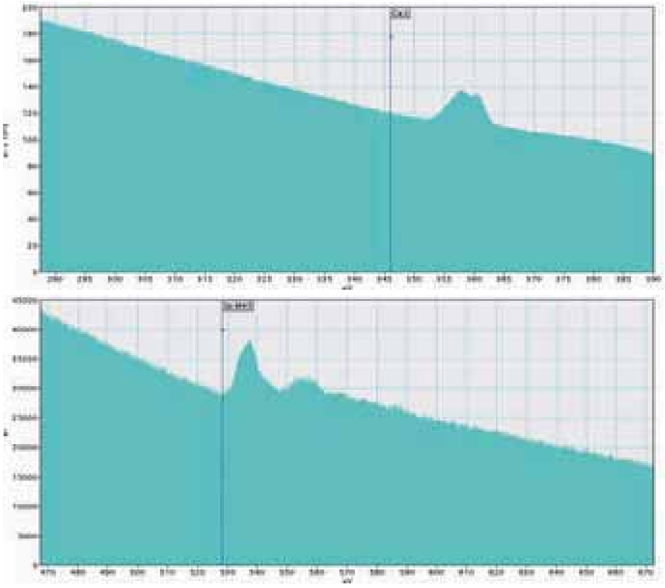

Fig. 2 EEL spectrum depicting Core-loss edges of Ca (top) and Sb (bottom)

From this result, it can be understood that both calcium and antimony are present in the triple junction phase. Elemental mapping was carried out using above edges. Fig. 3 shows an elemental map of antimony generated using the jump-ratio method from the region shown in Fig. 1 and Fig. 4 shows the calcium map from the same region. Thus, EFTEM technique was successfully used to determine calcium segregation at triple junction. It is hoped that such an analysis helps in selecting materials with better performance as varistors.

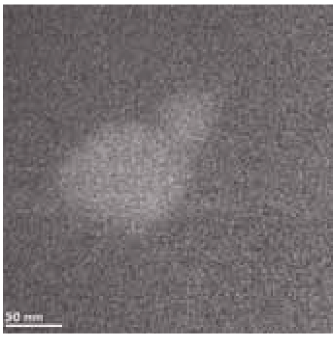

Fig. 3 EFTEM image showing Sb map

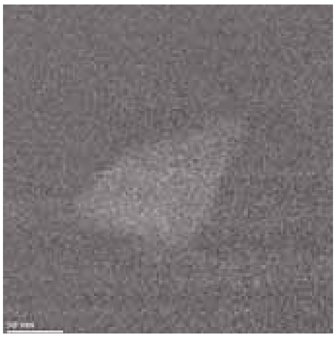

Fig. 4 EFTEM image showing Ca map

***Contributor: Kaliyan Hembram***

# Effect of Plasma Surface Treatment on Corrosion Protection Properties of Hybrid Sol-gel Coatings on Aluminium

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Aluminium with characteristic properties of high strength-to-weight ratio, good formability, good corrosion resistance and recycling capability is a promising material to meet the growing light-weighting demands of the automotive industry. However, the thin passivating oxide layer generated by anodizing deteriorates in aggressive media like Cl-containing electrolytes, resulting in pitting corrosion. In the context of rendering barrier protection, sol-gel derived ceramic coatings possess several advantages like low temperature processing and simple application procedures, with a wide range of relatively simple coating techniques such as dip, spin and spray being available for deposition of coatings. The organic-inorganic hybrid coatings developed by the sol-gel route combine the properties of organic polymeric materials with those of ceramics and have the advantage of obtaining thick, homogeneous and defect-free coatings in a single coating operation. Plasma treatment of substrates prior to coating increases the surface wettability and the adhesion of the coatings to the surface by surface-activation.

Hybrid sol-gel coatings derived from a base catalyzed hydrolysis of tetraethylorthosilicate and methyltriethoxysilane were deposited on untreated and plasma treated Al substrates by a dip coating technique and heated in air at 450°C for 1 hr. A1, A3, A5, A7 coatings on Al were generated with withdrawal speeds 1,3,5 and 7 mm/s respectively thereby yielding varying coating thickness which are given in Table 1. Electrochemical polarization scans were carried out for all the coatings at 27°C (room temperature) in 3.5% NaCl solution after 1 hr exposure time in order to investigate their corrosion resistance behavior by using a Solartron electrochemical interface SI 1287. Figs. 1(a) and (b) show the polarization curves for samples on untreated and plasma treated Al respectively with different coating conditions and Table 1 shows the parameters obtained from Rp fitting of polarization plots.

All the polarization curves for coated samples are similar in nature having a well- developed passive region which shows the protective behavior of coatings compared to that of uncoated substrate. It can be seen that the corrosion current ($I_{corr}$) values derived from the polarization data (Table 1) of the coated samples are lower than that of the bare Al substrate, which confirms that the coatings provide a barrier protection and improve the corrosion resistance of Al. The polarization resistance values are higher for plasma treated and coated samples at all withdrawal speeds when compared to those without plasma treatment.

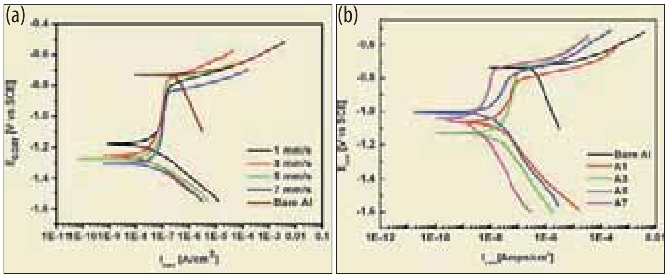

Fig. 1 Polarization plots of bare and coated Al substrates generated using different withdrawal speeds with (a) no prior treatment and (b) plasma treatment after 1hr exposure to 3.5% NaCl

The $I_{corr}$ values decrease with increase in thickness. It is possible that due to surface treatment/activation, the adhesion of coatings to the substrate is substantially improved and a thick coating is deposited in a single step, which provides very good barrier protection. In the case of coatings without plasma treatment, corrosion current increases with thickness, which shows that the coatings have more porosity and defects. The corrosion potentials are shifted towards more positive side, showing that coatings after plasma treatment are nobler than coatings without plasma treatment.

Table 1: Data obtained from Rp fitting of polarization plots shown in Fig. 1 (a) and (b)

| Sample ID | Coating thickness [$\mu$m] | Corrosion potential (-V) vs SCE | Corrosion current [A/cm$^2$] | Polarization resistance [$\Omega$/cm$^2$] |
|---|---|---|---|---|
| Bare Al | - | 0.768 | 4.5E-6 | 5.7E3 |
| A1- pt | 1.35 | 1.065 | 1.3E-8 | 2.1 E6 |
| A3 - pt | 2.49 | 1.135 | 1.1E-8 | 2.5 E6 |
| A5 - pt | 4.02 | 1.005 | 6.6E-9 | 4.0 E6 |
| A7 - pt | 4.85 | 1.048 | 1.6E-9 | 1.7 E7 |
| A1 | 1.30 | 1.181 | 2.8E-6 | 9.2 E5 |
| A3 | 2.56 | 1.249 | 1.9E-8 | 1.4 E6 |
| A5 | 3.82 | 1.271 | 2.9E-8 | 8.9 E5 |
| A7 | 5.34 | 1.300 | 3.4E-8 | 7.7 E5 |

Thus the thicker coatings deposited after plasma treatment are defect-free thereby exhibiting a greater corrosion protection. Apart from an improved adhesion of coatings after plasma treatment, the thick oxide layer, which is formed on the Al surface during plasma treatment, will also improve corrosion resistance of the coatings.

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# Establishment of a Dual Source (Mo & Cr) Small Angle X-ray Scattering (SAXS) Facility at ARCI

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The Small angle x-ray scattering (SAXS) technique is an experimental method allowing the determination of microstructural features such as the size, shape, number density and volume fraction of heterogeneities (pores, precipitates, defects etc.) in a matrix. This tool is widely used in polymer, colloidal, biomaterial and protein research. ARCI is interested in applying this tool to develop precipitate-strengthened steels and other advanced materials. One of the major advantages of SAXS is the ability to determine a statistically significant bulk average particle size from a volume 3 - 4 orders higher than what is observable by TEM at similar resolution.

Most laboratory SAXS systems are usually equipped with Cu targets (radiation) with a wavelength (λ) of 1.54052 Å. With a typical combination of camera lengths upto a maximum of 1 meter, it covers a suitable q-range (where q is the modulus of the momentum transfer vector with $q = (4\pi/\lambda)\sin(2\theta/2)$ and $2\theta$ is the diffraction angle) to probe structures with size ranging from 1 to 100 nm. However, Cu radiation is not suitable to study the structure in Fe based materials (steels) since it results in high fluorescence and high absorption effects. Therefore, other than Cu radiation, Mo would be the right choice for the target as the energy of Mo radiation is 18 keV, which possesses high transmission in metallic samples. As the λ of Mo is 0.72 Å, which is less than half that of Cu radiation, it is difficult to access the low q-region. In order to cover the low q-region, a larger λ is required, therefore Cr would be the right choice as λ of Cr radiation is 2.29 Å. By using a combination of Mo and Cr radiations, it is possible to measure SAXS profiles within a wide q-range from 0.07 to 10 $nm^{-1}$. Based on our research requirements at ARCI, we designed a dual target (Mo & Cr) SAXS system as shown in Fig. 1. The source can be switched over from Mo to Cr targets and vice versa which is accomplished with a high precision motorized stage (Inset in Fig. 1). The maximum camera length of the SAXS system is 2400 mm and it is equipped with a single photon counting and noise free Pilatus 300k area detector. Using additional attachments, grazing incidence SAXS (GISAXS) and temperature (-196 to 350°C) dependent measurements can be performed.

Two-dimensional scattering pattern was obtained from glassy carbon (Fig. 2, inset) with Mo radiation for 30 min at a camera length (CL) of 565 mm. The glassy carbon SAXS profile is used as a standard to convert the sample SAXS intensity to absolute scale. The plots in Fig. 2 show the measured SAXS intensity of the glassy carbon with Cr and Mo radiations with different CLs along with the standard profile of glassy carbon measured with USAXS, Argonne National Laboratory, USA. With the combination of dual (Mo and Cr) targets and various camera lengths, it is now possible to probe structures ranging from from a fraction of a nanometer to 260 nm.

In addition to probing variuos microstructural aspects of nanomaterials, SAXS is also being extensively used to study polymers, colloids, liquid crystals, bio-materials, gels and food materials. This tool is not only limited to applications in the above-mentioned fields, but is also applicable for any system (material) which possesses heterogeneity at nano-length scales.

Fig. 1 Dual source (Cr & Mo) SAXS system installed at ARCI. Inset shows the assembly of dual sources (Cr and Mo) on a moving stage

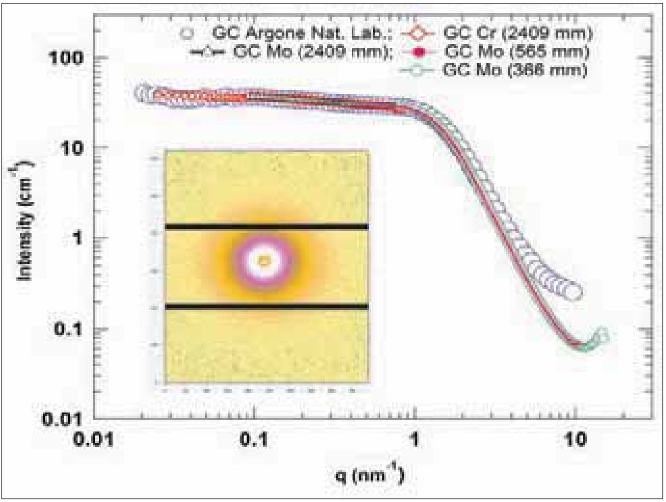

Fig. 2 SAXS profiles (1D) of glassy carbon measured using Cr and Mo radiations with various CLs are plotted along with standard SAXS profile. Inset shows 2D SAXS pattern of GC

# Development of a Framework for Knowledge Management of Nanoscience and Technology in India

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Given the rapid pace at which the field of nanoscience and technology has been growing in recent times, and the concomitant explosive growth in knowledge being generated and information being shared, the nano community as a whole had been increasingly feeling the need for a reliable, comprehensive one-stop nano information centre which can search, categorize, analyze and disseminate the vast nanoscience and technology information, maintain a knowledge database and offer wide ranging nano informatics services, as reliable information plays a key role in taking informed techno commercial decisions. Undertaking all the above activities in an integrated manner encompasses one of the key dimensions of Knowledge Management (KM).

To address the above KM requirement and need, the International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI), which has a strong R&D base for nano materials application development, has set up the Centre for Knowledge Management of Nanoscience &Technology (CKMNT) with partial financial support from the NANOMISSION of the Department of Science & Technology, Govt. of India. The Vision of CKMNT is to harmonize the knowledge produced worldwide in the area of nanoscience & technology and make it available in concised form to all stake holders of the 'nano community to enable them to take nanotechnology to the market place in much faster pace'. In this short communication, a conceptual framework for marketing KM services and its application to take nanotechnology to market place; i.e researchers, industries, policy makers, funding agencies and the civil society is presented, with a few examples.

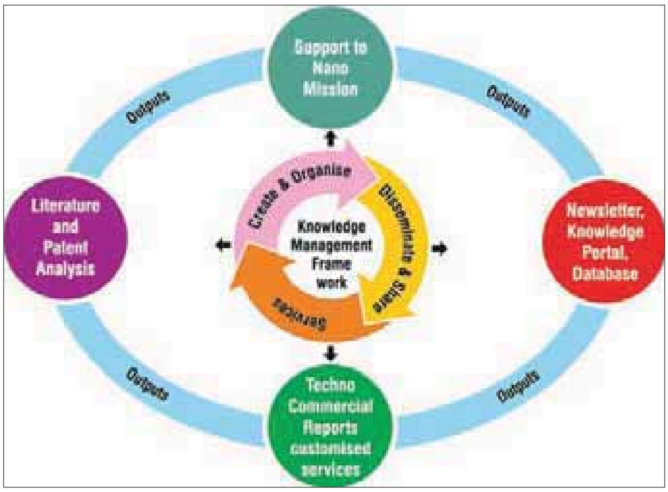


Fig. 1 A framework for taking nanotechnology to the market place

Keeping in view the vision and objectives of the centre and to serve seamlessly all the nanotechnology stake holders, CKMNT has evolved a broad framework for knowledge management of nanoscience and technology. The key dimensions of the framework are shown in Fig. 1. CKMNT team continuously monitors, searches, compiles and analyzes the developments taking place globally in the area of nanoscience & technology using comprehensive state-of-the-art commercial databases/resources available with it and disseminate the information to different stakeholders from their database of more than 7500 potential stake holders for its services. The knowledge created is being used in compiling various value- added techno commercial reports, market research reports, white papers, and databases. Some of the initiatives taken by CKMNT to take nanotechnology to market place in the form of various reports is shown in Fig. 2. Table 1 shows the varied services offered by CKMNT:

Table 1: KM services offered by CKMNT

| | |
|---|---|
| Customised Techno-Commercial Reports | Patents Search and Analysis |
| Market Research Reports | Literature Search and Analysis |
| Techno Economic Feasibility Reports | Identifying Potential Technology Collaborations |

As a result of increasing investments in nanotechnology R&D, a rapidly growing body of scientific publications and patent applications is emerging. To harvest this emerging new knowledge an appropriate KM framework/strategy at the firm level is of paramount importance to sustain the firm's competitiveness. In light of the emerging opportunities in the KM space, CKMNT aims to offer reliable, up to date and comprehensive KM services to researchers, industries, policy makers, VC's and funding agencies for building their portfolios.

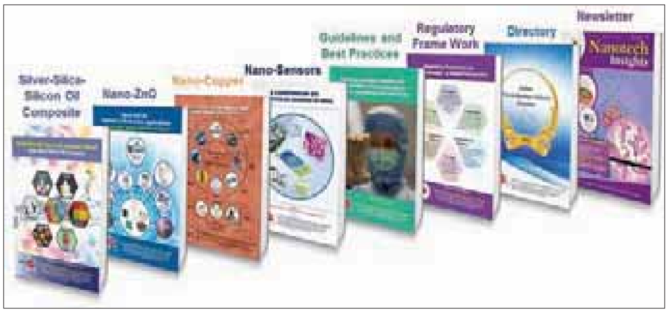
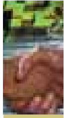


Fig. 2 Techno commercial and other reports

# Technology Acquisition, Transfer and International Cooperation



# Commercialization of Advanced Materials Technologies: Few Important Issues

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To stay ahead of their competitors, scope and scale guided strategic decisions in corporate sector till a few years ago. However, technology has been attaining increasingly important role in this race. Advanced Materials Technologies (AMTs) add value in multiple applications, with relevance to many user segments. In this backdrop, Research and Technology Organizations (RTOs) – which can develop, demonstrate and transfer new materials technologies – can play a critical role. In order for an RTO to accomplish this role effectively, it has to plan and strategize its activities with due consideration to the following aspects:

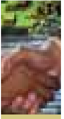
**Application Identification**: It is well-known that advanced materials can impact multiple end-use fields. In such a scenario, know-how development should be focused by identifying an application window before initiating a research and technology development (RTD) programme. This can be achieved through an initial survey of the need and competing technologies, followed by a cost-benefit analysis. Conceiving the targeted applications in advance shall help in assessing possible market size and tentatively predict viability chances. However, such focused development efforts can continue in parallel with the efforts aimed at developing breakthrough Intellectual Properties (IPs). This approach shall ensure a balanced output of commercializable technologies, having immediate use for existing businesses as well as technologies for creation of entirely new businesses.

**Intellectual Property Rights (IPR) Considerations**: IP issues should be kept in view throughout technology value chain. For example: One of the criteria for selection of a technology programme for development should be the availability of blank spaces to be decided based on patents filed and granted in planned area of R & D. IP ownership issues ,while forging different types of alliances, need to be decided on a case-to-case basis.

**Technology Upscaling**: Demonstration of a technology at an appropriate scale immensely helps in identifying and solving all techno-economic issues so as to convince a prospective technology receiver. Laboratory facility can be used to understand the underlying scientific issues associated with a technology. Subsequently, pilot scale facility can be used to prepare prototypes for checking their usability in different contexts. After prototyping in possible user segments, RTO can plan for demonstration through field trials in collaboration with appropriate partners. This can be followed by transfer of technology to interested start-ups/established companies.

**Technology Transfer and Alliance Formation**: Technology Transfer Agreements can be signed by RTOs like ARCI for technologies that have been completely developed and demonstrated without any prior contractual obligations to an industrial organization regarding technology transfer. In other cases, the RTO should identify organizations with complementary assets, technologies and skills to forge alliances. Collaborations not only accelerate the development process but also help in progression of a technology from a laboratory to its preparedness for technology transfer. Conventionally, ARCI has been signing following Agreements to strengthen its own/partners' science and technology value chains (i) Inter-institutional Agreements are signed by ARCI with institutions either from India or from other countries to develop and/or demonstrate a technology. (ii) Sponsorship Agreements have been signed when a government or private organization provides funding and other necessary support to ARCI so that it can carry out a project utilizing its knowledge, skills, infrastructure and experience. And (iii) Service Agreements have been signed by ARCI either to avail services like fabrication from companies or to provide services like characterization or consultancy etc. During past few years, following additional modes have also been adopted by ARCI to forge mutually beneficial alliances with potential collaborators: (i) Co-operative R & D Agreements are being signed by ARCI and industrial organizations to implement collaborative R & D activities by leveraging combined skills, knowledge and infrastructure of partner organizations.(ii) R & D Consortium Agreements at ARCI have included government funded R & D laboratories, academic institutions, and private industrial organization(s) either from a single nation or from different nations for pre-competitive research. Partners work together, by combining their individual core competencies, to potentially benefit an industry sector. (iii) Joint Demonstration Centre (JDC) Agreements are being signed at ARCI to accelerate international technology collaborations with organizations, who have demonstrated a technology in a country other than India. JDC is used to adapt the technology for Indian conditions. (iv) Option Agreement is being signed by ARCI with prospective licensees when these licensees desire to evaluate the commercial potential of a technology and/or claims of patent applications.

***Contributor: G. Padmanabham***



# Portfolio of ARCI Technologies

## Technologies Transferred

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, which are depicted in the following table:

| 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) technology | 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) technology | 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 industry | Transferred on exclusive basis |
| 19. | Ceramic honeycomb molten metal filters | Molten metal filtration | Transferred on exclusive basis |
| 20. | Calcium aluminate cements and furnace sealants | In refractory castables | Transferred on exclusive basis |
| 21-23. | Micro Arc Oxidation (MAO) technology | Hard(1800 VHN) wear resistant coatings on aluminium and titanium alloys | Transferred to 3 companies on region-exclusive basis. |
| 24. | ESC equipment manufacturing technology | Diverse industry segments | Transferred on non-exclusive basis |
| 25. | Nanosilver impregnation of ceramic water filter candles to impart anti-bacterial function | Water purification | Transferred on non-exclusive basis |
| 26 | Nano silver based textile finishes for anti-bacterial applications | Anti-bacterial applications | Transferred on exclusive basis |
| 27. | Fuel cell products | Energy | Ongoing |

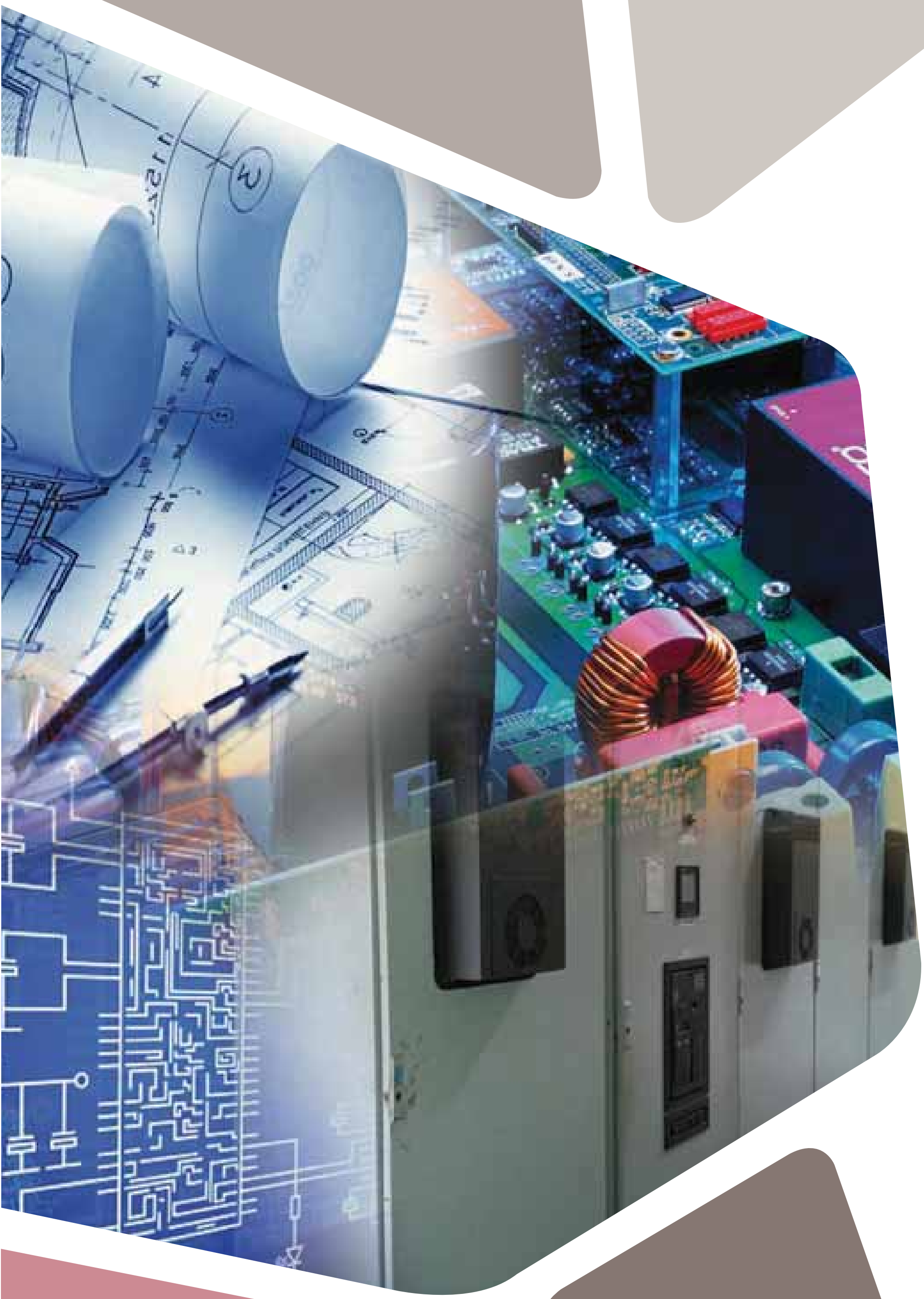
## Technologies Available for Adaptation / Transfer

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

| S. No | Technology and Related Issues | Key Features and Applications | |
|---|---|---|---|
| 3. | **Nano Silver Impregnated Ceramic Candle Filter**<br>(Indian Patent Application Number 2786/DEL/2005 dtd. 19/10/2005)<br>Scale of Validation Achieved: Small scale production (Technology transferred to one company and is available for transfer on non-exclusive basis) | ***Key Features:***<br>- Successfully field tested at various villages in Andhra Pradesh with a Non-Governmental Organization<br>- No electrical power and pressurized water required: Ease in maintenance<br>- Commercially attractive {very low amount of silver used (0.2 wt %), Cost increase : candle (30-50%) and filter assembly (3-5%)}<br>- Replacement needed once in six months | ***Application:***<br>Ceramic candles for drinking water purification |
| 4. | **Nanocrystalline Zinc Oxide (ZnO) based Varistors**<br>(Indian Patent Application Number 1669/DEL/2006 dtd. 20/07/2006)<br>Scale of Validation Achieved: In-house testing completed | ***Key Features:***<br>- 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:***<br>Surge voltage protection in electrical and electronics industry |
| 5. | **Silica Aerogels**<br>(Indian Patent Application Number 2406/DEL/2010 dtd. 08/10/2010)<br>Scale of Validation Achieved: In-house testing completed | ***Key Features:***<br>- Stable from cryo ($-50^0$ C) to $1000^0$ C<br>- Thermal conductivity (0.03 W/mK)<br>- Fire resistant<br>- Chemically inert<br>- Easily cut<br>- Hydrophobic<br>- Thickness range from 5-25 mm can be produced | ***Possible Applications:***<br>- Thermal insulation in automotives<br>- Heating/cold storage<br>- Thermal clothing<br>- Aerospace etc. |
| 6. | **Laser Welding and Laser-MIG Hybrid Welding**<br>Scale of Validation Achieved: Testing on some actual components as per users' requirements done successfully | ***Key Features:***<br>- High power density<br>- Single pass welding of thick sections<br>- Controlled heat input welding with precision (even foils)<br>- No vacuum requirement | ***Possible Applications:***<br>- Can weld a wide variety of materials and thicknesses<br>- Can weld magnetic materials unlike Electron Beam Welding<br>- Tailor welded blanks for automotive applications etc.<br>- Steel plates thick section welds: bolier components, ship building etc. |
| 7. | **Laser Surface Hardening Treatment**<br>Scale of Validation Achieved: Testing on actual components as per users' requirements done successfully | ***Key Features:***<br>- Selective localized area hardening with minimal heat input<br>- No quenchant requirement<br>- No surface damage<br>- Excellent reproducibility with ease of automation<br>- Negligible post process machining requirement<br>- Refined homogenous microstructures<br>- Controlled case depth<br>- Minimal distortion<br>- Chemical cleanliness | ***Possible Applications:***<br>- Suited to wide range of steels, cast irons and profiles<br>- 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)**<br>Scale of Validation Achieved: Testing on actual components done successfully | ***Key Features:***<br>- 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<br>- Fine microstructures<br>- Provides crack-free clad layers without porosity | ***Possible Applications:***<br>- Wear plates for different applications<br>- Component repair and refurbishment |
| 9. | **Laser Drilling**<br>Scale of Validation Achieved: Testing on actual components done successfully | ***Key Features:***<br>- Non-contact drilling method<br>- Holes of large aspect ratio and very small diameter (0.3 mm) can be drilled<br>- Holes can be drilled at shallow angles to the surface<br>- Precise control of heat input | ***Possible Applications:***<br>- A wide variety of materials such as metals, ceramics and composites etc. can be drilled<br>- 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. |

| S. No | Technology and Related Issues | Key Features and Applications | |
|---|---|---|---|
| 10. | **Micro Arc Oxidation**<br>(Indian Patent Number 209817 granted on 06/09/2007; US Patent Number 6893551 granted on: 17/05/2005)<br>Scale of Validation Achieved:Small scale production (Technology transferred to 3 companies and is available for export and for states in India other than Andhra Pradesh, Tamilnadu and Karnataka) | ***Key Features:***<br>- Ability to coat Al, Ti, Mg and Zr metals and their alloys<br>- Ease to coat complex shapes and difficult to access regions<br>- Uniform, dense, hard and thick coatings<br>- Superior coating properties and performance compared to other conventional acid based processes like anodizing and hard anodizing<br>- Excellent tribological properties and corrosion resistance<br>- Eco friendly<br>- 5 to 40 times service life enhancement | ***Possible Applications:***<br>- For a wide array of applications in industries such as textile, automobile etc. |
| 11. | **Detonation Spray Coating (DSC) Technology**<br>Scale of Validation Achieved: Small scale production (Technology transferred to 4 companies and is available for all Indian states except for Delhi, Haryana, Punjab, Uttar Pradesh, Uttaranchal, Bihar, Jammu & Kashmir, and Himachal Pradesh and for export) | ***Key Features:***<br>- Attractively priced compared to imported HVOF units<br>- Extreme versatility<br>- Capable of depositing a wide range of metals, alloys, cermet, ceramic and composite coatings for varied functional properties | ***Possible Applications:***<br>- Coatings for applications such as wear and corrosion resistance etc. for various industries |
| 12. | **Cold Spray Coating Technology**<br>Scale of Validation Achieved: In-house testing done successfully | ***Key Features:***<br>- Ergonomic, Portable PLC based automated control panel<br>- Mobility with onsite job repair and coating capabilities<br>- Thick, dense and pure metallic/ alloy coatings (Ag, Cu, Zn, SS 316 etc.)<br>- Can impart high electrical conductivity and corrosion resistance | ***Possible Applications:***<br>- In all industry sectors where high electrical conductivity and high corrosion resistance properties are required. |
| 13. | **Exfoliated Graphite and its Value Added Products**<br>(Indian Patent Number 187654 granted on 07/06/1995)<br>Scale of Validation Achieved: Commercial Scale (Technology transferred to one company and is available for transfer to all Indian states on non-exclusive basis) | ***Key Features:***<br>- Impermeable to fluids<br>- Leak proof sealing under low turning torque<br>- Easily cut and punched<br>- Can withstand temperature range from -200$^0$ to +500$^0$ C in oxidizing and up to 3000$^0$C in inert atmosphere<br>- Excellent thermal shock resistance<br>- Does not age or creep<br>- Cannot get wetted by molten glass, metal etc., self-lubricating, and resistant to all chemicals | ***Possible Applications:***<br>- Fuel Cells<br>- Automotive<br>- Oil refineries<br>- Petrochemical industries etc. |
| 14. | **Electro Spark Coating (ESC) Equipment Manufacturing Technology**<br>(Indian Patent Application Number 1610/DEL/2005 dtd. 21/06/2005)<br>Scale of Validation Achieved: Small scale production (Technology transferred to one company and is available for transfer to all Indian states on non-exclusive basis) | ***Key Features:***<br>- Simple and cost-effective<br>- Metallurgical bonded coatings with low heat input to the substrate<br>- Any electrically conductive material available in electrode form can be coated on any conductive substrate<br>- Equipment is portable and lends itself easily to automation for ensuring reproducibility<br>- Capable of providing coating thickness in the range of 10 to 130 µm | ***Possible Applications:***<br>- Component refurbishment and to combat severe conditions of wear<br>- Can be used for enhancing life of cutting tools such as end mills, taps and lathe bits |

# Support Groups



# Development of a PC Controlled Detonation Spray Coating System

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

The Detonation spray coating (DSC) technology was developed and transferred by ARCI to four entrepreneurs during the period 2000 to 2005 on the basis of regional exclusivity. In recent times, few other companies have also expressed an interest in acquiring the DSC technology since the period for which the above exclusivity was granted has now elapsed. Although the DSC systems manufactured and provided to the existing technology receivers have operated in a trouble free manner, they use moving components like motors, cams, pistons, circuit breakers for ignition, etc., which are subject to regular wear and tear and, hence, require periodic replacement. In view of the above, a computerized set up without these moving parts has been conceptualized, fabricated and tested.

Each detonation cycle consists of three main stage. The first involves purging, in which any remnants of the previous cycle are flushed out. This is followed by filling up of the detonation mixture consisting of Oxygen and Acetylene in defined proportions. Lastly, this mixture is ignited by generating a spark across a spark plug. Initially, a detailed study of the time period for which each gas viz. Nitrogen, Oxygen and Acetylene is let into the mixing chamber was undertaken. Subsequently, fast acting electromagnetic solenoid valves for all gases were fitted in the supply line to feed the gases into a mixing chamber. The mixing chamber had to be completely redesigned to suit the process gas volumes, flow rate and pressures. Synchronously, Nitrogen gas was used as a carrier to push powder particles into the detonation stream.

The above sequence of operations was controlled by a computer programme written in Labview. The software was interfaced with the hardware through driver circuits and a Data Acquisition (DAQ) module. The programme contains a Front Panel, in which the operator can enter process parameters like total no of shots, shot frequency, purge time, fill time, and trigger for ignition and powder feed. A Block diagram of the programme shows the graphical code designed for implementing the sequence of operations for each shot.

The developed programme is very flexible and user friendly. The new system has the additional advantage that more than one powder feeder can be added so that layered or functionally graded coatings can be generated on a substrate.

The integrated assembly has been tested for reliability of operation over thousands of detonation shots. The quality of the coatings has also been compared with those obtained using the original DSC system by scientists at the Centre for Engineered Coatings and found to be satisfactory.

Further work to streamline the whole assembly is currently in progress so that an advanced version of DSC systems can be commercialized.

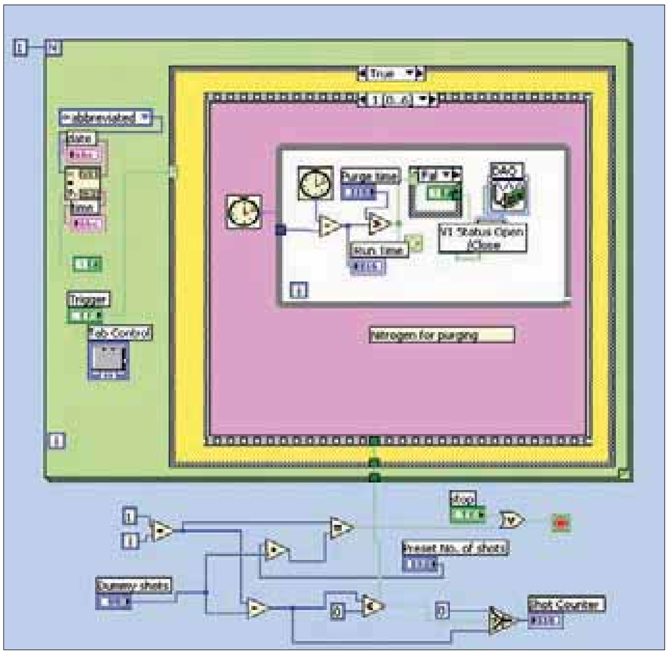
10:25 AM
Thu, Dec, 27, 2012

Shot freq: 3 Hz
Cycle time: 333 ms
Preset No. of shots: 0
Shot Counter: 0

| Nitrogen Purging | O2+C2H2 Filling | Gas Protection | Powder Feed | Spark |
|---|---|---|---|---|
| Purge time | Fill Time | N2 back fill Time | Feed Time | Ignition time |
| 28 | 147 | 28 | 131 | 26 |
| Run Time 2 | Run Time 2 | Run Time | Run Time 2 | Run Time 2 |
| 0 | 0 | 0 | 0 | 0 |

All time indications in ms

Screen shot of front panel



Graphical view of the block diagram

***Contributors: N. Aruna, D. Krishna Sagar, D. Sen and D. Srinivasa Rao***

# Power Analysis of a VRT Controlled 1000 KVA Furnace Load

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

The 1000 KVA vacuum furnace intended for sinter processing of non-oxide ceramics needs 3Φ, 415 V, 50 Hz power supply. The furnace power control uses variable reactance transformer. Supply interruptions in electricity board supply affects the process causing heavy losses. Hence, genset supply is necessary.

Trial run of the furnace was carried out with a normal DG power supply arrangement along with an Automatic Power Factor Control (APFC) panel, but the gensets failed to supply. The available failure indications over current, short circuit current & reverse power could not point to a reasonable cause. This situation prompted attention towards the load and the only way to know load characteristics is by carrying out power analysis.

In some early trials the furnace has run smoothly on the electricity board supply. Hence, power analysis was carried out under this condition. Analysis was repeated with different measuring instruments sourced from reputed agencies in the field and in all the cases the results showed similar trends. Typical data plots are shown in figure.

The analysis shows that the load is non-linear and unbalanced (i.e. up to 40%) with sharp variations. Power factor is very low and follows similar trend as load current.

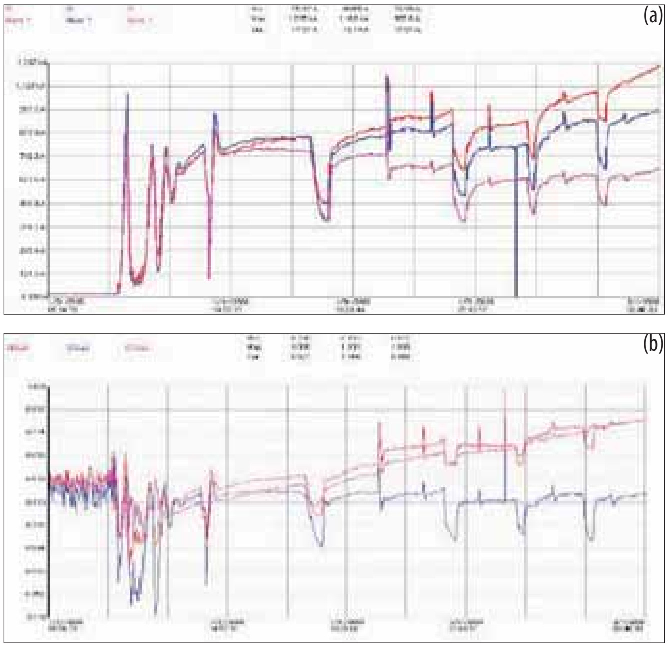


Fig.1 (a) Typical line current plots of 3 phases (b) 3 phases power factors plots

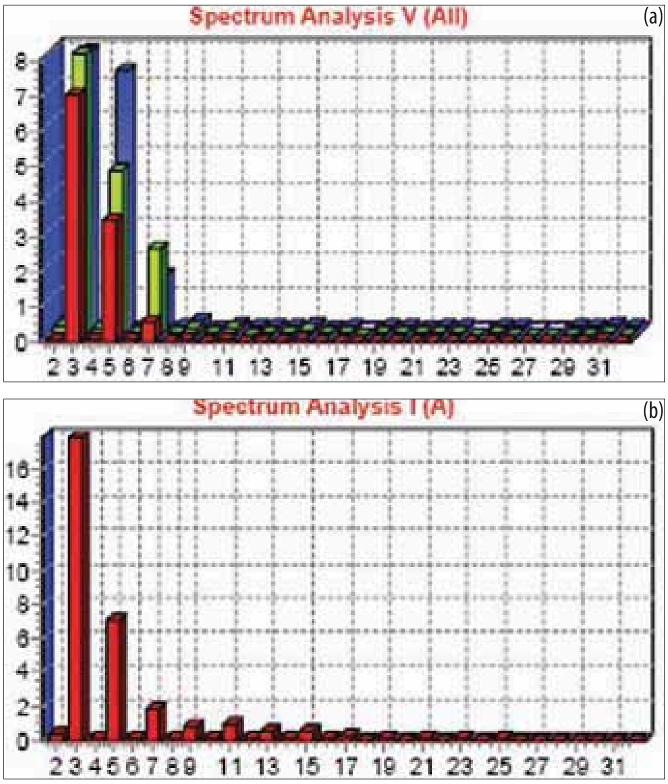


Fig.2 (a) Voltage Harmonics (b) Current Harmonics

Harmonic analysis shows prominent presence of 3rd, 5th, 7th, 9th and 11th harmonics beyond permissible levels (i.e. Current THD 46% & Voltage THD 8%) as per IEEE 519 & IEC 61000.

The kind of rate of change of current and power factor as evident from the Fig.1 (a) & (b) and presence of 3rd harmonic as seen in Fig.2 (a) & (b), could be the reasons for observed fault indications and shutdown of gensets. Accurate terminal voltage regulation of alternator combined with effective speed control of the prime mover can help resolve the adverse effects of this situation. Low power factor, unbalanced load currents and the abrupt variations of these parameters along with high 3rd harmonic current too needs attention because these can also contribute to gensets failure.

The total harmonic distortion issue needs a broader consideration treating the system as a part of the total power system of the campus. So this issue demands a separate study for implementing suitable solutions such as Real Time Power Factor Control (RTPFC), Static Reactive Power Compensator and Active & Passive filters.

***Contributor: V. C. Sajeev***

# Power Supply Solution for 1000 KVA VRT Controlled Furnace Load

***V. C. Sajeev, Electrical and Civil Maintenance*** *sajeev@arci.res.in*

The load in question is a variable reactance transformer controlled furnace. Apparent issue faced while trying to supply this 1000 kVA furnace was unprecedented shut down of the supplying gensets with mostly irrelevant kind of annunciation indications. Load as seen by gensets has been nonlinear, having harmonic distortion, unbalanced and with fast variations of power factor. Detailed study of the situation and consultation with various experts in power engineering area have guided towards a workable solution.

The indicators were to get better engine speed governing and alternator voltage regulation, mitigate harmonic distortion and also to have an effective method for providing variable reactive power compensation that matched the speed of load power factor variation.

Genset engines are Cummins make so they were approached for engine related solution. ABB and CGL provided product information for nullifying load current imbalance and harmonic distortion and KVAR compensation.

Fig.1 Power Command Control (PCC)

The final solution set involved, replacement of the alternator exciter, modification of fuel pump and injector, replacement of sensors and transmitters with new ones, replacement of engine control unit with integrated genset controller (PCC 3100) and real time power factor controller (RTPFC) with 14% reactance in series with capacitor banks. This does not include equipment for mitigation of the effects of total harmonic distortion since it was felt that it has to be treated separately at a later stage.

After installation and integration of this set of components, gensets could supply the furnace without any hitches. Key components of the above set are the PCC 3100 and the RTPFC panel

Cummins PCC 3100 is a microprocessor-based control for gensets. It provides fuel control and engine speed governing, alternator voltage regulation and complete genset control and monitoring. It can also provide automatic and semi-automatic synchronizing and automatic load sharing. The PCC can also monitor the health of the engine, alternator and auxiliary systems through an array of sensors. It can generate warning annunciations of faults and effect an automatic fully programmed shutdown in case of serious faults. Digital voltage regulation is another commendable feature that offers accurate instrumentation and protection and reliable service to non-linear loads.

Fig.2 Real Time Power Factor Control (RTPFC)Panel

Advantages of RTPFC are, no inrush current due to precise auto zero voltage search logic. As there is no inrush current, transformers / gensets are never subjected to heavy currents and hence the life of the transformers / gensets increases. Solid-state devices are used for switching, therefore virtually no limitation on number of switching operations and also there is no chattering and no wear & tear. The point of capacitor switching is controlled and increases the life of the capacitor and switching unit.

***Contributor: V Balaji Rao***

# Composite Structure Construction for Vertical Expansion with Minimal Load

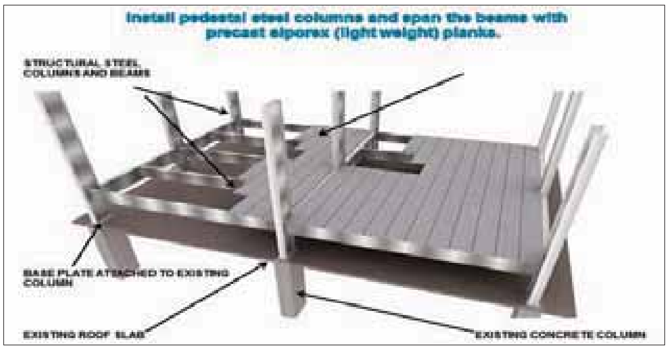
*P. Ramakrishna Reddy, Electrical and Civil Maintenance* *prkreddy@arci.res.in*

One of the buildings at ARCI, viz., Techical Information Centre building is currently a single story building and in order to create more office space, one additional floor is proposed to be added. Study of the drawings available indicated that south side of the building does not have column pedestals above the existing roof for vertical expansion. The reverse structural calculations done based on the existing drawings indicate that the load carrying capacity of the existing slab and beam is approximately 10% below the 763 Kg/ Sq m as per IS 456 as it was designed as a roof slab. Now, the challenge is to accomplish the vertical expansion through minimal weight design. Three options a) strengthening existing slab & beams from below by supporting with new structural steel sections and micro concreting works for strengthening; b) Erect new columns on all sides; and c) Composite structure design were considered. As the option ‘C” can be implemented without disturbance/ modification to existing ground floor, composite column structure design was chosen. Structural steel base plate of 20 mm thickness was centered on the top of existing RCC column and embedded in the existing concrete with the help of non-shrink grout and six numbers (12 mm diameter and 160mm long) anchor fasteners. Structural steel columns were designed with optimum radius of gyration i.e. 58.7sq.cm (ISMB 300) and were erected in-line, level and plumb and welded to the base plate.

Structural steel columns were installed over existing RCC Columns and structural steel beams to spanned the floor with pre-cast siporex planks. Density of siporex planks is 1000kg/cum which is very less compared to RCC slab density of 2400kg / cum. Siporex planks were designed to take the desired live and dead loads i.e 350 kg/sqm as per IS 875 for office type buildings.

Once the structural steel columns are erected on the existing ground floor columns the complete wall and roof structural steel members with welded connections were installed to make complete frame.

Once the complete steel framing is fully aligned the entire structure including the steel columns, beams and roof slab are to be encased with reinforcement and concreting to make the structure ready for masonry and finished works.



Composite structures construction system for vertical expansion of TIC building

View of structural steel columns

Base plate

Composite column junction point

***Contributors: V Balaji Rao***

# Facilitating Access to Scientific and Technical Information

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

The Technical Information Centre (TIC) is an invaluable source of information for Scientists, Research Scholars and the student community of ARCI. It plays a vital role in the acquisition, organization and dissemination of knowledge in the thrust areas of ARCI. The TIC has a specialized collection in most core areas of ARCI such as engineered coatings, ceramics, nanotechnology and laser processing of materials and this is constanttly augmented. TIC has online access to over 3000 e-journals from several international publishers. Its on-line public access catalogue (OPAC) can be accessed on the Local Area Network (LAN) of ARCI.

It is extremely difficult as well as impractical for all libraries to subscribe to every resource that is published in a given discipline due to limited financial resources. Joining hands with similar libraries to share information resources, within the group, and utilizing existing financial as well as human resources, is a cost-effective way to overcome such a challenge. Realizing the importance of having a consortium to provide better services and access to a larger number of e-resources, TIC has joined the recently launched National Knowledge Resource Consortium (NKRC) to satisfy the ever-growing scientific information requirements of ARCI. NKRC is a joint venture of both CSIR and DST libraries to provide an array of e-resources to participating institutions. At present, TIC is getting access to e-journals of many reputed S&T publishers like ASTM, Elsevier Science, IEEE, IOP, Maney, Nature, Oxford, Taylor & Francis and Wiley-Blackwell through NKRC. TIC periodically conducts training programmes on the e-resources of ARCI. Separately acquired access to patent databases Derwent Innovations Index and Thomson Innovation has also helped our scientific community to keep abreast with the latest developments in their respective research areas as far as intellectual property rights are concerned. ARCI's scientists have extensively utilized the above e-resources. Considering the growing number of publications and patents from ARCI, the need and utility of the above resources is clearly apparent.

DST has recently formed a committee on "Standardization of Library Procedures and Best Practices" to look into the procedures and practices followed by libraries of different DST laboratories and to suggest guidelines to streamline the procedures so as to achieve uniformity in all the libraries of Autonomous Institutes and Professional Bodies under DST. The committee has consulted all the Heads of the libraries of DST-funded Institutes and has conducted an elaborate survey touching upon all the issues and procedures associated with research libraries. The committee is hopeful of submitting its guidelines to DST by end of this year. The recommendations of the Committee will also be adopted at ARCI to ensure that the access to scientific and technical information for ARCI's staff is further augmented.

Table1: e-Resources Accessible through NKRC

| No. | e-Resource |
|---|---|
| 1. | American Institute of Physics (AIP) |
| 2. | American Physical Society (APS) |
| 3. | Annual Reviews |
| 4. | ASTM Standards and Engineering Digital Library |
| 5. | Emerald Journals |
| 6. | IEEE/IET Electronic Library (IEL) |
| 7. | Institute of Physics (IOP) Publishing |
| 8. | Maney Materials Science & Engineering Subject Collection |
| 9. | Nature Publishing Group (NPG) |
| 10. | Oxford University Press (OUP) |
| 11. | SAGE Engineering & Materials Science Collection |
| 12. | ScienceDirect (Materials Science Subject Collection) |
| 13. | SciFinder |
| 14. | Taylor & Francis Online |
| 15. | Thomson Innovation |
| 16. | Web of Science & Derwent Innovations Index (DII) |
| 17. | Wiley Online Library |
| 18. | World Scientific |

Training on SciFinder at ARCI

# Events, Data and Statistics

# Major Events

## Jayanthi Celebrations

ARCI celebrated Dr. B. R. Ambedkar Jayanthi and Dr. Babu Jagjivan Ram Jayanthi on April 14, 2012.

## Technology Day

ARCI celebrated the National Technology Day on May 11, 2012. Prof. Mohan Krishnamoorthy, CEO, IIT Bombay-Monash Research Academy, delivered a lecture on "An Innovation Framework for India that Includes a Vibrant Academia-Industry Network" on this occasion.

## Anti-Terrorism Day

ARCI observed Anti-Terrorism Day on May 21, 2012. On this occasion, Shri R. Vijay Kumar, Chief Finance and Accounts Officer administered the pledge, in bilingual form, in the presence of ARCI 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 in presence of their team. On this occasion, Shri R. Vijay Kumar delivered a lecture on "Role of Technology in Combating Terrorism".

Dr. G. Padmanabham and Shri R. Vijay Kumar with ARCI staff after administering the pledge on Anti-Terrorism Day

## Annual Medical Check-up and Health Talk

The Annual Medical Check-up for ARCI employees was organized during August 07-08, 2012. Employees were categorized as 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. In order to create awareness regarding various health issues among its employees, ARCI organized a lecture related to health management. On November 22, 2012, Dr. T. Vamshidar Reddy, MD, DM, Medical Gastroenterology, Yashoda Hospital, Malakpet, Hyderabad delivered a lecture on 'Medical Management of Gastroenterology'.

## Independence Day

ARCI celebrated Independence Day on August 15, 2012. Dr. G. Padmanabham, Associate Director hoisted the National Flag and addressed the gathering on the occasion.

Dr. G. Padmanabham hoisting the National Flag on the occasion of Independence Day

## 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 2012-13, ARCI issued more than 3000 letters etc. in bilingual form and surpassed the target set by the Dept. of Official Language (D.O.L), Ministry of Home Affairs, Govt. of India. This Achievement was appreciated by DST during a review. 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 also convenes OLIC meetings on a quarterly basis to review the progress in the implementation of Official Language (O.L.) in ARCI. The minutes of this review is sent to DST and D.O.L for their review.

ARCI celebrated Hindi Week during September 17 to 21, 2012. Various programmes and competitions like Quiz, Elocution, Noting and Drafting in Hindi were conducted, and the winners were given prizes. On this occasion, ARCI organized a lecture on 'Progress and Effect of Official Language Implementation' delivered by Shri Narahar Dev, DGM (Retd.), Bharat Dynamics Limited, Hyderabad.

ARCI in collaboration with seven organizations under the Ministry of Defence jointly organized an "All India Official Language Scientific and Technical Seminar" held at DLRL, Hyderabad on February 07 and 08, 2013. Dr. P. K. Jain,

Participants during the Hindi week celebrations

Dr. R. Subasri, Shri. Manish Tak, and Shri Arun Seetharaman delivered lectures on different technical subjects and Shri N.K. Bhakta, delivered a lecture on "Hindi Software- Problems and Solutions" in Hindi. Dr. P. K. Jain and Shri R. Prabhakara Rao also chaired a session during the seminar.

## Vigilance Awareness Week

ARCI observed Vigilance Awareness Week from October 29, 2012 to November 03, 2012. 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. •Important quotes from the Citizens Guide to Fight Corruption issued by Central Vigilance Commission were placed at conspicuous places for the guidance/awareness of all employees. During the week, ARCI also organized a lecture titled 'Transparency in Public Procurement', which was delivered by Shri B. Prasada Rao, Director General, Anti-Corruption Bureau (ACB), Govt. of Andhra Pradesh, Hyderabad. An exhibition displaying posters on different aspects of vigilance awareness was also organized.

Shri B. Prasada Rao, Director General, Anti-Corruption Bureau, Govt. of Andhra Pradesh, Hyderabad giving a talk on the occasion of Vigilance Awareness Week

## Annual Day

ARCI celebrated its 16th Annual Day on December 21, 2012. On this occasion, Dr. G. Sundararajan, Director delivered a speech detailing various achievements during the year. Associate Directors, Dr. S.V. Joshi and Dr. G. Padmanabham also addressed the gathering. As a part of these celebrations, various cultural events with participations from employees and their families were organized, and prizes were distributed to the participants.

Dr. G. Sundararajan addressing the gathering on Annual Day

A play, organised as part of the cultural events on Annual Day, in progress

## Republic Day

ARCI celebrated Republic Day on January 26, 2013. Dr. G. Sundararajan, Director hoisted the National Flag and addressed the gathering on the occasion.

Dr. G. Sundararajan hoisted the National Flag on the occasion of Republic Day

## National Safety Day

ARCI observed National Safety Day on March 04, 2013. Shri. S. Jagan Mohan Reddy, Security and Fire Officer arranged a demo on the usage of portable fire extinguishers kept handy at all major locations in ARCI. He explained in detail the function of various fire extinguishers in case of emergencies.

## Women Welfare

ARCI celebrated International Women's Day on March 08, 2013. As a part of this occasion, Mrs. Lalitha Raghuram, MOHAN Foundation was invited as Chief Guest to deliver a lecture Organ Donation "Life...Pass it On". Ms. Rajeshwari Chouhan, Karate Instructor, delivered a lecture on "The Various Techniques of Self-defence". Various Posters were also displayed enlightening the status of present day women, stress, harassment and declining girl child rate. It was also decided by the Women employees of ARCI to felicitate the senior most woman employee of ARCI, due for retirement that year, on the occasion of International Women's Day. Dr.K. Radha, Scientist 'E' was felicitated on this occasion.

Mrs. Lalitha Raghuram delivering a talk on Women's Day

Ms. Rajeshwari Chouhan, Karate Instructor, during her visit to ARCI to deliver a talk on self-defence techniques

Dr. (Mrs.) K. Radha was felicitated on the occasion of International Women's Day

## National Science Day

National Science Day (NSD) was celebrated on March 11, 2013 at ARCI. Dr. S. V. Joshi, Associate Director welcomed the audience comprising of Scientists, Officers, Research Fellows, Project and Trainee Students and briefed about the importance of National Science Day Celebrations. The focal theme selected for the occasion was "Genetically Modified Crops and Food Security". Dr. (Mrs.) R. Kalpana Sastry, Head Research Systems Management Division, National Academy of Agricultural Research Management, Hyderabad delivered an interesting lecture on the above theme on this occasion.

## Conferences/Workshops/Symposia/Schools Organized by ARCI

### 5-day School on Surface Engineering Technologies: Research and Applications (SETRA)

As a part of ongoing effort to constantly update the knowledge base of mid-level professionals, practicing engineers, researchers and academicians in the country and also to provide an update about the state-of-the-art surface engineering technologies, a five day school on "Surface Engineering: Technologies, Research and Applications" was organized by ARCI on behalf of Prof. T.R.Anantharaman Education and Research Foundation (TRAERF) during 27-31 August 2012. Around 60 participants from industry, research organizations and academic institutions were selected for the workshop. Eminent speakers were invited to deliver lectures on various topics of surface engineering. A visit was also scheduled so that the participants get a chance to discuss with scientists working on diverse technologies.


Participants of 5-day school on Surface Engineering Technologies: Research and Applications

### Indo-Belarus Bilateral Cooperation Workshop On Material Sciences & Metallurgy

A one day workshop in the area of Material Sciences & Metallurgy was jointly organized by the Bilateral Cooperation Committees of India and Belarus on November 15, 2012 at ARCI, Hyderabad. Dr. G. Sundararajan, Director-ARCI, representing Department of Science and Technology (DST), Govt. of India, inaugurated the workshop and Dr. O. L. Smorygo, Senior Scientist-Belarus Institute of Powder Metallurgy, representing the State Committee for Science and Technology, Govt. of Belarus, gave his remarks on the importance of Bilateral Cooperation. During the workshop, lectures on various topics such as water purification using aeration and ozonization technologies, layered composite materials manufactured by the impulse loading methods for the use in the electronics production and electrolytic metal productions, equipment and technologies of formation of functional coatings for various applications, prospective composites based on high-porosity cellular materials, manufacture of composite powders by SHS methods for the thermal-spray deposition of wear and heat-resistant coatings were delivered by scientists from both the countries. Experts also discussed on possible collaboration in the above mentioned areas for joint research, application development and commercialization of technology both in India and Belarus.

### Advance Workshop on Evaluation of Hydrogen Producing Technologies for Industry Relevant Application

An advance level workshop on “Evaluation of Hydrogen Producing Technologies for Industry Relevant Application” was organized at ARCI, Hyderabad during February 8-9, 2013. Experts from Academia and Industry, with commendable research experience and achievements in the field of hydrogen production technologies, were invited for the workshop. Experts from various fields of non-renewable and renewable hydrogen generation discussed the present status and future prospects of hydrogen generation technologies at commercial as well as research level. The workshop also focussed on the steps necessary to produce practical and industrially viable hydrogen, as it is a green and cheap fuel for next generation.


Panel discussion on non-renewable hydrogen production technologies

### 5th Indo-German Frontiers of Engineering Symposium

The 5th Indo-German Frontiers of Engineering Symposium (INDOGFOE) was organised during March 14–17, 2013 by ARCI Co-Chaired by Dr G. Padmanabham, ARCI, Hyderabad and Prof Jörg Schulze, Institute of Semiconductor Engineering, University of Stuttgart. The INDOGFOE symposia are a series of interdisciplinary, bi-national conferences, co-organised by the Department of Science and Technology (DST), India and the Alexander von Humboldt Foundation, Germany and is held alternately in India and Germany. The activity brings together outstanding, early-career German and Indian engineers from industry, universities and other research institutions to introduce their areas of engineering research and technical work, thereby facilitating interdisciplinary transfer of knowledge and methodology that could eventually lead to development of co-operative networks of young engineers from both the countries. The 2013 symposium was a highly inter-disciplinary one including four sessions on Clean Water: Engineering for Natural Disaster and Hazard Management; Power Electronics; and Organic-inorganic Hybrid Materials and Nanocomposites. The symposium was inaugurated by Dr. G. Sundararajan, Director ARCI. About 30 German scientists/engineers and 30 Indian Scientists/engineers participated in the event. 16 lead lectures and 50 posters were presented around which intense interactions took place and several collaborations seeded.


Dr G. Padmanabham and Prof Jörg Schulze with delegates of the 5th Indo-German Frontiers of Engineering Symposium

# 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. The ARCI 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 |
| Synthesis of cathode material for lithium ion batteries | IIT- Hyderabad | A. Bhaskar | 01.08.2010 | Ongoing |
| Stable and highly efficient CZTS thin film photovoltaics | IIT - Madras | Deepak Kumar | 01.08.2012 | Ongoing |

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

| | |
|---|---|
| Post Doctoral Fellows | 02 |
| Research Scholars | 01 |
| Senior ARCI Fellows (SAF) | 22 |
| Junior ARCI Fellows (JAF) | 17 |
| Post Graduate Trainees | 04 |
| Graduate Trainees | 17 |
| M. Tech./B. Tech. Project Students | 50 |

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

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

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

| Topic | Name of the Student | Status |
|---|---|---|
| Development of nanostructured 8YSZ electrolytes with enhanced ionic conductivity for SOFC applications | K. Rajeswari | Completed |
| Joining of aluminium and steel by thermal joining techniques | Y. Krishna Priya | Ongoing |
| Evaluation of structure property correlation in nanostructured copper and copper 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 |
| Structure property correlation in cathodic arc deposited coatings | P. Sai V Pramod Kumar | Ongoing |
| Structure property correlation in ODS 18 Cr steels | M. Nagini | Ongoing |
| To stabilize cadmium chalcogenide based phto anode for phto electro chemical hydrogen production using solar light | Alka Pareek | Ongoing |
| A comparative evaluation of extrusion and pressure slip casting processing parameters on thermo mechanical properties of low thermal expanding ceramics | R. Papitha | Ongoing |

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

| Topic | Name of the Student | Status |
|---|---|---|
| Synthesis and characteristics of ferrite photocatalysts | D. Rekha | Ongoing |

- 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 is extended up to April 30, 2015. Following student is registered at Anna University Chennai for her Ph.D. studies:

| Topic | Name of the Student | Status |
|---|---|---|
| Graphene as catalyst support for Polymer Electrolyte Membrane Fuel Cell (PEMFC) electrodes | P. Karthika | Ongoing |

- Following are the students registered at IIT-H for their Ph.D studies

| Topic | Name of the Student | Status |
|---|---|---|
| Electrochemical synthesis and characterization of CIS and CIGS materials for solar cell applications | Mandati Sreekanth | Ongoing |

| Topic | Name of the Student | Status |
|---|---|---|
| Electrospinning of organic and inorganic nanofibers for health and energy applications | K. H. Anulekha | Ongoing |
| Spherical indentation behaviour of porous copper and cold sprayed cracked copper coatings | Bolla Reddy | Ongoing |

- Indian Institute of Technology–Bombay (IIT-B) has recognized ARCI as an external centre for carrying out Ph.D. research and has signed a Memorandum of Understanding with ARCI in this regard.
- Indian Institute of Technology–Kharagpur (IIT-Kgpr.) has recognized ARCI as an external centre for carrying out Ph.D. research and has signed a Memorandum of Understanding with ARCI in this regard.
- National Institute of Technology–Warangal (NIT-W) has recognized ARCI as an external centre for carrying out Ph.D. research and has signed a Memorandum of Understanding with ARCI in this regard.
- 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. Prabhu Delhi Babu | Scientist (Contract) | May 1, 2012 |
| Dr. Srinivasan Anandan | Senior Scientist (Contract) | June 4, 2012 |
| Dr. M.B. Sahana | Scientist (Contract) | July 2, 2012 |

## 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 2012-13:

| Name of the Promotees | Effective Date | Promotion for the Post | |
|---|---|---|---|
| | | From | To |
| E. Anbu Rasu | October 1, 2011 | Technical Assistant "B" | Technical Officer "A" |
| S. Sankar Ganesh | October 1, 2011 | Technical Assistant "B" | Technical Officer "A" |
| K. Satyanarayana Reddy | April 12, 2012 | Driver "C" | Technician "C" (LDCE) |
| Lingaiah Mothe | April 12, 2012 | Lab. Assistant "B" | Technician "A" (LDCE) |
| L. Venkatesh | August 27, 2012 | Technical Assistant "B" | Scientist "B" |
| K. V. Phani Prabhakar | October 1, 2012 | Scientist "D" | Scientist "E" |
| G. Siva Kumar | October 1, 2012 | Scientist "D" | Scientist "E" |
| Shakti Prakash Mishra | October 1, 2012 | Scientist "D" | Scientist "E" |
| Kaliyan Hembram | October 1, 2012 | Scientist "C" | Scientist "D" |
| Dr. K. Murugan | October 1, 2012 | Scientist "C" | Scientist "D" |
| Dulal Chandra Jana | October 1, 2012 | Scientist "C" | Scientist "D" |
| K. Rama Chandra Somaraju | October 1, 2012 | Technical Officer "C" | Technical Officer "D" |
| P. Rama Krishna Reddy | October 1, 2012 | Technical Officer "B" | Technical Officer "C" |
| M. Srinivas | October 1, 2012 | Technical Officer "A" | Technical Officer "B" |
| P. Nagendra Rao | October 1, 2012 | PS to Director | Officer "C" |
| N. Srinivas | October 1, 2012 | Officer "B" | Officer "C" |
| N. Aparna Rao | October 1, 2012 | Officer "A" | Officer "B" |
| K. Naresh Kumar | October 1, 2012 | Technical Assistant "B" | Technical Officer "A" |
| M. ILaiyaraja | October 1, 2012 | Technical Assistant "B" | Technical Officer "A" |
| A. Janga Reddy | October 1, 2012 | Technician "B" | Technician "C" |
| A. Praveen Kumar | October 1, 2012 | Technician "B" | Technician "C" |
| A. Ramesh | October 1, 2012 | Technician "B" | Technician "C" |
| K. Venkata Ramana | October 1, 2012 | Technician "B" | Technician "C" |
| Ch. Venkateswara Rao | October 1, 2012 | Technician "B" | Technician "C" |
| J. Venkateswara Rao | October 1, 2012 | Technician "B" | Technician "C" |

## Superannuation

| Employee Name | Designation Held | Date of Resignation |
|---|---|---|
| T. Panduranga Rao | Officer "C" | June 29, 2012 |

## Resignations

| Employee Name | Designation Held | Date of Resignation |
|---|---|---|
| R. Varadarajan | Officer "C" | August 13, 2012 |
| Dr. Dinesh Rangappa | Senior Scientist (Contract) | June 14, 2012 |
| Dr. Rajappa Tadepalli | Senior Scientist (Contract) | March 1, 2013 |

## Visit by Students and Others to ARCI

01. 60 B.E. (Mechanical Engineering) students from MVSR Engineering College-Hyderabad visited ARCI on April 4, 2012.
02. 20 M.E. (Industrial Metallurgy) students from PSG College of Technology-Coimbatore visited ARCI on April 19, 2012.
03. 16 Engineers from various Govt. Organizations who participated in ESCI's "Welding Technology and NDT Techniques Programme" visited ARCI on April 25, 2012.
04. 25 M.Sc. (Physics) students from National Institute of Technology-Warangal visited ARCI on May 8, 2012.
05. 20 Scientists from various DRDO Laboratories who participated in ASCI's "General Management Programme" visited ARCI on June 27, 2012.
06. 30 Scientists/Engineers of ISRO who participated in ASCI's "Management Development Programme" visited ARCI on June 28, 2012.
07. 31 Faculty and Student members of SAE India, Southern Section visited ARCI on July 13, 2012.
08. 24 Scientists from various National Laboratories who participated in ASCI's "General Management Programme" visited ARCI on September 5, 2012.
09. 50 M.Tech. (Nanotechnology) and M.Sc. (Nanoscience & Technology) students from JNTU-Hyderabad visited ARCI on September 12, 2012.
10. 20 Scientists from various National Laboratories who participated in ASCI's "Advanced Training Programme" visited ARCI on October 5, 2012.
11. 40 B.Sc. (Physics) students from D.B.F. Dayanand College of Arts & Science College-Solapur visited ARCI on January 8, 2013.
12. 32 Scientists from DRDO Laboratories who participated in DMRL's CEP course on "Advanced Ceramics and Composites for Defence and Space Applications" visited ARCI on January 9, 2013.
13. 20 M.Tech. (Production Engineering) students from PDA College of Engineering-Gulbarga visited ARCI on January 10, 2013.
14. 60 B.Sc. (Physics/Electronics) students from Govt. City College-Hyderabad visited ARCI on January 17, 2013.
15. 90 B.Tech. (Civil Engineering) students and faculty from Somaiya Vidyavihar-Mumbai visited new construction sites in ARCI on February 6, 2013.
16. 32 M.Tech. (Nanotechnology) students from JNTU-Kakinada visited ARCI on March 15, 2013.
17. 40 M.Tech. (Nanotechnology) students from Vellore Institute of Technology visited ARCI on March 18, 2013.
18. 26 M.Sc. (Physics) students from Kakatiya University-Warangal visited ARCI on March 22, 2013.
19. 30 Scientists/Engineers of ISRO who participated in ASCI's "Management Development Programme" visited ARCI on March 25, 2013.

Dr. Shrikant V Joshi, Associate Director with Summer Training students

## Summer Training Programme for Students

As in the previous year, this year too students from IITs, NITs, Banaras Hindu University and various other universities from all over the country were short-listed for availing Summer Training Programme at ARCI. 40 students were selected for the summer training programme, which was held during May 15 to June 29, 2012. The selected students initially underwent a week long orientation course so as to get familiarity with the activities being carried out at ARCI. Each student was guided by a scientist to carry out a mini project. The students were issued certificates on 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 16.77%, S.T is 3.72%, OBC is 24.84% and that of persons with disabilities is 1.86% as on March 31, 2013.

## Indian and Foreign Visitors for Technical Discussion

1. Dr. S.G. Shankar, President & Chief Executive Officer (CEO), Advanced Materials Corporation, USA visited on April 09, 2012
2. Mr. V. Karthikeyan, Technical Manager, Pricol Technologies Ltd, Coimbatore visited on May 03, 2012.
3. Prof. Baldev Raj, Former Director, Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam visited on May 04, 2012.
4. Dr. Rajganesh Pala, Assistant Professor, Indian Institute of Technology (IIT) Kanpur, Kanpur visited on May 22, 2012.
5. Dr. R. K. Tayal, Advisor, Department of Science and Technology (DST), New Delhi visited on June 01, 2012.
6. Dr. Anantha Subramaniam, Associate Professor, IIT Kanpur, Kanpur visited on June 14, 2012.
7. Mr. S.V. Kulkarni and Mr. V.V.Dubal, Technical Managers, Thermax, Pune visited on June 15, 2012.
8. Dr. Vijay Mhetar, Vice President of Technology North America-General Cable Technology Centre, USA, Dr. James Freestone, Senior Vice President Global Technology-General Cable Technology Centre, USA and Mr. R. Satish, General Cable Technology Centre, USA visited on June 19, 2012.
9. Dr. J. A. Kamalakar, Director, Laboratory of Electro Optic Systems (LEOS), Indian Space Research Organization (ISRO), Bangalore and team visited on July 03, 2012.
10. Prof. S.Basu, IIT Delhi, New Delhi visited on July 05, 2012.
11. Dr. Vijay Kumar Saraswat, Scientific Advisor to Defense Minister and Director General, Defense Research and Development Organization (DRDO), New Delhi visited on July 07, 2012.
12. Dr. M. Satyaprasad, Section Head-Advanced Engineering, Ashok Leyland, Chennai and Dr.G.V.N.Prasad, Senior Manager, Ashok Leyland, Chennai visited on July 11, 2012.
13. Dr. Frank Riedel, Fraunhofer Institute for Machine Building and Forming, Germany visited on July 12, 2012
14. Prof. D. Sathiyamoorthy, Outstanding Scientist, Head-Powder Metallurgy Division and Professor of Homi Bhabha National Institute, Bhabha Atomic Research Centre (BARC), Mumbai visited on July 13, 2012.
15. Mr. Yury Langer, Project Manager, Harris Environmental Systems, USA visited during July 14-17, 2012.
16. Rev. Dr. Francis P Xavier SJ, Director, Dr. Jose Swaminathan, Principal, Loyola ICAM College of Engineering & Technology (LICET) , Chennai visited on July 17, 2012.
17. Dr. Hideki Abe, Principal Researcher, National Institute for Materials Science (NIMS), Tsukuba, Japan visited on July 17, 2012.
18. Dr. M. Atmanand, Director, National Institute of Ocean Technology (NIOT), Chennai visited on July 18, 2012.
19. Prof. P. M. Beulah Devamalar, Director (Academics & Development), Prathyusha Institute of Technology and Management, Tiruvallur visited on August 09, 2012.
20. Mr. M. R. Linghanathan, General Manager, Process Engineering Group, Titanium Tantalum Products Ltd., Chennai visited on August 09, 2012.
21. Dr. Mathew Abraham, Senior General Manager, Mahindra & Mahindra, Chennai visited on August 14, 2012.
22. Mr. Shivam Tiwari, Director, Eastern Electrolysers, New Delhi visited on August 16, 2012.
23. Mr. S. Prakash, Managing Director, P&P Metalloys Pvt. Ltd., Peramangalam, Trichy visited on August 27, 2012.
24. Mr. S. Gowri Sankar, Additional General Manager and Team Leader, Bharat Heavy Electricals Ltd (BHEL) R&D Gateway, Chennai visited on August 31, 2012.
25. Mr. Abhishek Jethva, Business Development Engineer, Aerovironment, USA visited on September 13, 2012.
26. Dr. S. Bandopadhyay, Senior Advisor, Ministry of New

and Renewable Energy (MNRE), New Delhi visited on September 24, 2012.

27. Dr. Senad Dizdar, R&D Engineer, Hoganas, Sweden visited on September 24-25, 2012.

28. Mr. Masaki Takahashi and Mr. Kazumoto Oohara, Engineers of Toda Kogyo Corp., Japan visited on September 25, 2012.

29. Dr. Stephen P. Gaydos, Technical Fellow, Boeing, USA visited on October 17, 2012.

30. Dr. Gary Schubert, Technology Leader, GE, USA visited on October 30, 2012.

31. Dr. Meron Pini, Director-Entegris, Israel visited on November 08, 2012

32. Dr. B. C. Chakraborty, Associate Director, National Metallurgical and Research Laboratory (NMRL), Ambernath visited on November 08, 2012.

33. Dr. A.V.K. Reddy, Chairman, Hydergy India Pvt. Ltd., Chennai visited on November 09, 2012.

34. Dr. J. Narayana Dass, Chief Controller Research & Development, DRDO, New Delhi visited on November 15,2012.

35. Dr. Andreyev Mikhail, Deputy Director, Powder Metallurgy Institute, Belarus, Dr. Letsko Andrej, Head of Research Laboratory of Synthesis Process of Powder Composite, Powder Metallurgy Institute, Belarus and Dr. Smoryogo Oleg, Head of Research Laboratory of High Porous Materials, Powder Metallurgy Institute, Belarus visited during November 15-16, 2012.

36. Dr. Yarisa V. Sudhik, National Academy of Sciences Belarus (NASB), Belarus during November 15-16, 2012.

37. Prof. Narendra B. Dahotre, University of North Texas, USA visited on December 11, 2012.

38. Mr. S. Mani, President Active Pharmaceutical Ingredients (API), Orchid Chemicals and Pharmaceuticals Ltd., Chennai., Mr. S. Sugavanam, Sr. General Manager (Engineering), Orchid Chemicals and Pharmaceuticals Ltd., Chennai and Mr. Sunil Deva Josh, General Manager, Orchid Chemicals and Pharmaceuticals Ltd., Chennai visited on January 03, 2013.

39. Ms. S. Barathy, Sr. Manager (R&D), GAIL (India) Ltd., New Delhi visited on January 04, 2013.

40. Dr. Kota Harinarayana, DRDO Chair at Aeronautical Development Agency, Bangalore visited on January 07, 2013.

41. Mr. K. Mannstom Singh, Manager (Technical Services) and Mr. M. Balaji, Senior Engineer, Tamilnadu Petroproducts Ltd., Chennai visited on January 10, 2013.

42. Mr. Syed Mubasher Ali, Director, D-EAPAT Private Ltd, Chennai visited on January 16, 2013.

43. Mr. R.C. Nautiyal, General Manager, Bharat Electronics Ltd (BEL), Machilipatnam and Mr. Rajasekhar, Assistant General Manager, BEL visited on January 28, 2013.

44. Prof. P. Mahesh and Prof. S. Chakraborty, IIT Madras, Chennai visited on February 25, 2013.

45. Mr. Sylvain Bentivegna, Managing Director, MPA Industrie, France visited during March 06-08, 2013.

46. Prof. Jorg Schulze, University of Stuttgart, Germany visited on March 13, 2013.

47. Dr. Pehlken Alexandra, Project Leader, Centre for Environment and Sustainability Carl von Ossietzky University (COAST), Germany visited on March 13, 2013.

48. Dr. Micheala Wilhelm, Senior Scientist, University of Bremen, Germany visited on March 13, 2013.

49. Dr. Katja Hartmann, Programme Director, Frontiers of Research, Alexander Von Humbolt Foundation, Berlin, Germany visited on March 18, 2013.

50. A 30 member team from ISRO, Bangalore visited on March 25, 2013.

## Seminars by Indian and Foreign Visitors

1. Dr. Paresh Nasikkar, Research Engineer, Sun Edison- Solar Services India Ltd, Bangalore delivered a lecture on "The Development of Copper Indium Diselenide ($CuInSe_2$)-based Absorber Thin Films for use in Photovoltaic Solar Cells" on April 18, 2012.

2. Dr. D.V. Kiran, Post Doc, Department of Mechanical Engineering, IIT Bombay, Mumbai delivered a lecture on "An Experimental and Numerical Investigation on Two Wire Tandem Submerged Arc Welding Process" on April 19, 2012.

3. Dr. M.M. Shaijumon, Assistant Professor, Institute of Science Education Research, Thiruvananthapuram, delivered a lecture on "3-D Lithium Batteries" on April 20, 2012.

4. Prof. Mohan Krishnamoorthy, CEO, IIT Bombay-Monash Research Academy, delivered a lecture on "An Innovation Framework for India that Includes a Vibrant Academia-Industry Network" on May 11, 2012.

5. Dr. P. Uday Bhaskar, Assistant Professor, Madanapalle Institute of Technology and Science, Andhra Pradesh

delivered a lecture on "Studies on $Cu_2ZnSnSe_4$ and $Cu_2ZnGeSe_4$ Thin Films for Solar Cell Absorber Layer" on May 28, 2012.

6. Mr. Ralf Lehmann, Area Sales Manager, Inspection Technologies-GE Measurement & Control, Germany delivered a lecture on "X-Ray Tomography" on May 29, 2012.

7. Prof. M.A. Vijayalakshmi, Director, Centre for Bio Separation Technology (CBST) Vellore Institute of Technology (VIT), Vellore delivered a lecture on "PEO-based Dendrimers for Targeted Delivery of Drugs" on June 22, 2012.

8. Dr. Pulickel M. Ajayan, Benjamin M and Mary Greewood Anderson Professor of Engineering, Rice University, USA delivered a lecture on "Nano-Engineered Materials (Opportunities and Challenges for Applications)" on June 29, 2012.

9. Dr. A.K. Mishra, Research Scientist, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany delivered a lecture on "Tuning of Physical Properties in Nanomaterials by Electrochemical and Ferroelectric Gating" on July 07, 2012.

10. Mr. K. R. A. Nair, Executive Director, Development Lucas-TVS, Chennai delivered a lecture on "Magnets for Automotive Motor Applications" on July 09, 2012.

11. Dr. Vijay Ramani, Associate Professor, Illinois Institute of Technology, Chicago, USA delivered a lecture on "Non Carbon Supports for PEFCs" on July 19, 2012.

12. Dr. Christopher A. Schuh, Massachusetts Institute of Technology, USA delivered a lecture on "Harder, Cheaper, Greener: Design of Stable Nanocrystalline Alloys for Coating Applications" on August 20, 2012.

13. Dr. Ram Vijaygopal, Scientist, Argonne National Laboratory (ANL), USA delivered a lecture on "Vehicle System Analysis for HEV/EV-Modeling and Simulation" on September 17, 2012.

14. Mr. Jacques Francoise, CEO, CSM Instruments, Switzerland delivered a lecture on "Surface Characterization Instruments" on September 26, 2012.

15. Prof. Bhaskaran Muraleedharan, IIT Bombay, Mumbai delivered a lecture on "Quest for High Performance Thermoelectrics: Lessons from Nanostructures" on September 28, 2012.

16. Mr. Charles Halasz, General Manager, A&D Technology Inc, USA delivered a lecture on "Automotive Test Systems" on October 01, 2012.

17. Prof. Keith Scott, New Castle upon Tyne, United Kingdom (UK) delivered a lecture on "Materials for Electrocatalyst Ultra Low Loading for Fuel Cell Applications" on October 08, 2012.

18. Prof. A. Kucernek, Imperial College, London, UK delivered a lecture on "Electrocatalyst Ultra Low Loading for Fuel Cell Application" on October 10, 2012.

19. Prof. Sumio Iijima, Meijo University, Japan delivered lecture on "Synthesis and Characterization of Carbon Nanomaterials" on October 16, 2012.

20. Mr. Gaetan Damblanc, Project Test Engineer, CD-Adapco, UK delivered a lecture on "Design, Simulation and Analysis Software for Lithium Ion Batteries" on November 08, 2012.

21. Prof. Raj N. Singh, Oklahoma State University, USA delivered a lecture on "Processing and Properties of Diamond Thin Films for Electronics" on December 03, 2012.

22. Mr. Gareth Joseph, Business Director, NDC Infrared Engineering, UK delivered a lecture on " On-Line Battery Electrode Thickness Measurement for Coating Line" on December 06, 2012.

23. Mr. Roderik Hoeppener, President, Haiku Tech Inc, USA delivered a lecture "Coating Techniques" on December 12, 2012.

24. Prof. R. Mahendiran, National University of Singapore, Singapore delivered a lecture on "Magnetocaloric Effect in Mn-Oxides" on December 21, 2012.

25. Dr. Venkat Viswanathan, Research Scientist, Stanford University, USA delivered a lecture on "Surface Electro Catalysis and Charge Transport Issues in Non-Aqueous Li-Air Batteries from First-Principles" on January 02, 2013.

26. Dr. Amartya Mukhopadhyay, Assistant Professor, IIT Bombay, Mumbai delivered a lecture on "Stress Development due to Surface Processes and High Rate Capabilities of Graphitic Carbon Thin Film Electrodes for LIB" on February 02, 2013.

27. Dr. Lalgudi V. Ramanathan, Materials Science and Technology Center Instituto de Pesquisas Energéticas e Nucleares, Brazil delivered lectures on "An Introduction to the Materials Science and Technology Center at the Instituto de Pesquisas Energéticas e Nucleares IPEN, Brazil" and "Coatings to Control High Temperature Oxidation of Metals" on February 07, 2013.

28. Dr. Sneha Manjaree Samal, Post Doc, Inha University, Korea delivered a lecture on "Design of Glass Composite with Various Filler Distribution System for Electronic Devices" on February 25, 2013.

29. Dr. K. K. Sharma, Scientist-F (Retired), Defense Metallurgical Research Laboratory (DMRL), Hyderabad

delivered a lecture on "Safety Related Issues and Hazards" on March 04, 2013.

30. Dr. Krishna C. Etika, Sr. Technology Development Process Engineer, Die Embedding Technology Development, Intel Corporation, USA delivered a lecture on "Tunable Dispersion State of Carbon Nanoparticles" on March 07, 2013.

## Visits Abroad

1. Dr. K. Suresh and Dr. V. Krishna visited the Indian Beam Line Facility at Photon Factory, KEK, Japan during April 14-21, 2012 for carrying out GIXRD and high temperature stress analysis on different coatings.

2. Dr. Sanjay Dhage and Dr. Easwaramoorthy Ramasamy visited France and Germany during April 22-May07, 2012 for training and pre-dispatch inspection of equipments required for fabrication of CIGS thin films for solar cells.

3. Dr. G. Sundararajan visited France during May 07-16, 2012 to (i) attend the Industrial Research Committee and Scientific Council Meeting of IFCPAR and (ii) to visit other industries in France.

4. Dr. R. Gopalan visited USA during May 17-26, 2012 to i) visit Prof. Gregory B. Thompson's Lab at University of Alabama and ii) participate in the '53rd International Field Emission Symposium (IFES2012)' held at Tuscaloosa where he presented a paper on "3 Dimensional Atom Probe Analysis of Sm0Co17 Type Magnets".

5. Dr. G. Padmanabham visited USA during May21-June10, 2012 to (i) visit Fraunhofer Institute for Coating and Laser Applications and Trumpf Laser Applications Centre for technical discussions and (ii) participate in the '9th International Conference on Trends in Welding Research' at Chicago.

6. Dr. S.V. Joshi visited USA during May 30- June 12, 2012 to (i) participate in the 'Spring 2012 Thermal Spray Consortium Meeting' at New York and (ii) visit University of Wisconssin, Ionbond Chicago Coating Centre, Pratt & Whitney and GE Global Research Centre.

7. Dr. T. Mohan and Dr. Raju Prakash visited USA, Canada and Italy during May 27-June 13, 2012 for pre-dispatch inspection and training on various equipment related to the project on development of Lithium Ion batteries for electric vehicle applications.

8. Dr. P. Suresh Babu, was awarded the 'Indo-US Research Fellowship' by the Indo-US Science and Technology Forum (IUSSTF) for a period of 1 year and was therefore deputed to Florida International University, Miami, USA during May 31, 2012- May 30, 2013.

9. Dr. G. Sundararajan visited Belgium during May 31-June 01, 2012 to participate in India-EU Partnership for Research and Innovation Conference' and delivered an invited lecture on "Energy: Challenges and Areas of Cooperation".

10. Mr. B. Viswanath Sasank visited Hong Kong during May 31-June 05, 2012 to participate in the International Conference on Chemical and Process Engineering (ICCPE 2012) and presented a paper on "Design and Development of a Closed Two Loop Thermal Management Configuration for Polymer Electrolyte Membrane Fuel Cell (PEMFC)".

11. Dr. G. Padmanabham visited Germany during June 14-17, 2012 to participate in Indo-German Frontiers of Engineering (INDOGFOE) Symposium.

12. Dr. K. Murugan visited The Netherlands during June 23-July 01, 2012 to participate in the '8th Coatings Science International Conference' and presented a paper on "Synthesis, Characterization and Demonstration of Self Cleaning $TiO_2$ Coatings on Glass and Glazed Ceramic Tiles".

13. Mr. D. Srinivasa Rao visited Moscow, Russia during June 25-28, 2012 for technical discussion with Indo-Russian Science & Technology Centre at Moscow.

14. Dr. K.S. Dhathathreyan visited UK during June 26-July 01, 2012 to participate in the 'DST-Engineering and Physical Sciences Research Council (EPSRC), UK Interaction Meeting on Smart Energy Grids and Energy Storage' and delivered a lecture on "Energy Storage Research in India".

15. Mr. Kaliyan Hembram and Dr. Krishna Valleti visited China during July 04-17, 2012 for participating in the 'Asia Nanotech Camp 2012'. Mr. Hembram made a poster presentation on "Combustion Synthesis of Doped Zinc Oxide Nanopowders for Varistor Applications" and an oral presentation on "Nanotechnology in Energy". Dr. Valleti made a poster presentation on "Nanocomposite Nitride Thin Films for High Temperature Tribological and Green Energy Applications" and an oral presentation on "Nanocomposites for Energy Sector" at the event.

16. Dr. S.V. Joshi visited Singulus Technologies AG, Germany during July 15-19, 2012 for technical discussion and demonstration of the sputtering equipment.

17. Dr. Sanjay Dhage visited Singulus Technologies AG, Germany during July 15-23, 2012 for pre-dispatch inspection and demonstration of the sputtering equipment.

18. Dr. S.V. Joshi visited Singapore during August 01-05, 2012, as a part of the Indian delegation visiting Singapore for participating in the India-Singapore Science and Technology Committee meeting.

19. Dr. G. Sundararajan visited to South Korea during August 13-18, 2013 to i) participate in the '10th International Nanotech Symposium and Nano-Convergence Expo (Nano Korea 2012)' at Seoul and to deliver an invited lecture on "Nano Technology Programmes with Societal Impact : ARCI's Experience" (ii) visit to Korean Institute of Materials Science (KIMS), Korea Institute of Industrial Technology (KITECH), Korea Institute of Science & Technology (KIST) and delivered lecture on "Materials & Process Development Activities @ ARCI - An Overview" at these Institutes.

20. Dr. R. Gopalan visited Seoul, South Korea during August 16-18, 2012 to participate in the '10th International Nanotech Symposium and Nano-Convergence Expo (Nano Korea 2012)' and presented a paper on "Nanostructured Functional Materials for Sustainable Energy Application".

21. Dr. T. Rajappa visited JK Lasers, UK during August 20-25, 2012 for pre-dispatch inspection and training on Laser welding equipment for sealing lithium ion battery casing.

22. Dr. I. Ganesh was awarded the 'Indo-US Research Fellowship' by the Indo-US Science and Technology Forum (IUSSTF) for a period of 1 year and therefore has been deputed to Emory University, Atlanta, USA during August 19, 2012-August 18, 2013.

23. Dr. G. Padmanabham and Mr. S. M. Shariff visited Hoganas AB (publ), Sweden during August 26-September 01, 2012 for technical discussion on the sponsored project on 'Development of Laser Clad Coatings (using powders supplied by Hoganas) and evaluation of tribological properties of Laser Clad and PTA Coatings'.

24. Dr. G. Sundararajan visited Russia during September 02-08, 2012 for technical discussion with Indo-Russian Science & Technology Centre, Moscow and also to lead the delegation under the Indo-Russian S&T Programme.

25. Dr. S. V. Joshi, Mr. D. Srinivasa Rao and Mr. S. P. Mishra visited Russia during September 02-12, 2012 for technical discussion with Indo-Russian Science & Technology Centre, Moscow.

26. Dr. Easwaramoorthi Ramasamy visited Oriel Instruments, USA during September 15-21,2012 for pre-shipment inspection and training on the Solar cell tester.

27. Mr. Manish Tak visited California, USA during September 22-29, 2012 to participate in the '31st International Congress on Applications of Lasers & Electro-Optics (ICALEO 2012)' and presented a paper on "A Novel Method of Pulsed Laser-Cladding for Effective Control of Melting of WC Particulates in NiCr-WC Composite Coatings".

28. Dr. G. Sundararajan visited USA during October 04-16, 2012 to (i) participate in the 'Materials Science and Technology 2012 Conference' held at Pittsburgh and delivered invited lectures on "Comparison of Structure and Properties of 9 & 18Cr-$Y_2O_3$ Dispersion Strengthened Steels" and "Structure and Properties of Detonation Sprayed Conventional & Nanostructure WC-12Co Coatings" and (ii) to visit Florida International University, University of North Texas and Rice University for technical discussions.

29. Dr. Sanjay Dhage visited LPKF SolarQuipment GmbH, Germany during October 10-14, 2012 for pre-dispatch inspection & training on Scribing system for CIGS thin film solar cell.

30. Dr. D. Siva Prahasam and Dr. D. Prabhu visited Laboratoria Electrofisico Walker LDJ Scientific Le, Italy during October 21-28, 2012 for pre-dispatch inspection and training on B-H loop recorder for hard & soft magnetic properties, Mini Pulsed Magnetize and Coercimeter.

31. Dr.K.S. Dhathathreyan, visited National Taiwan University, Taiwan during November 10-16, 2012 to participate in '2012 International Conference on Renewable Energy Policy'.

32. Dr. G. Sundararajan visited Tsukuba, Japan during November 23-28, 2012 to i) attend the '4th Project Review Meeting of the ASEAN-India Thermal Spray Project' and (ii) participate in the '5th Asian Thermal Spray Conference (ATSC)' and delivered an invited lecture on "Cold Spray Coatings : The Importance of Intersplat Debonding/ Cracking".

33. Dr. S.V. Joshi visited Tsukuba, Japan during November 23-28, 2012 to (i) attend the '4th Project Review Meeting of the ASEAN-India Thermal Spray Project' and (ii) to present a paper on "Hybrid plasma Sprayed Thermal Barrier Coatings using Powder and Solution Precursor Feedstock" at the '5th Asian Thermal Spray Conference (ATSC)'.

34. Dr. Ravi N. Bathe visited USA and Canada during January 19-February 03, 2013 for (i) pre-dispatch inspection and training on the Ti: Sapphire Regenerative Amplifier (Spitfire Ace) laser system at Spectra-Physics (Newport Corporation), USA and (ii) carrying out preliminary experiments on laser surface texturing using femtosecond and nanosecond lasers at NRC, Canada.

35. Mr. K.V. Phani Prabhakar and Mr. S.M. Shariff visited Fraunhofer Institute of Machine Tools and Forming Technology (IWU), Germany and Fraunhofer Institute for Materials and Beam Technology (IWS), Germany during February 10-24, 2013 for joint experimental work pertaining to the 'Multijoin' project.

36. Dr. R. Vijay visited USA during March 01-10, 2013 to participate in 'TMS 2013 Annual Meeting and Exhibition' and presented a paper on "Structure and Properties of Oxide Dispersion Strengthened 18Cr Steels".

37. Dr. R. Gopalan visited NIMS, Japan during March 15-25, 2013 as a part of Indo-Japan Cooperative Science Programme (IJCSP).

38. Dr. G. Sundararajan visited Japan during March 16-19, 2012 to (i) visit National Institute for Materials Science, Tsukuba to explore possible collaboration between Indian institutions and NIMS and (ii) participate in the 'DST-JSPS Science Council Meeting' held at Tokyo.

## Invited Lectures and Presentations by ARCI Personnel in India

1. Dr. K. S. Dhathathreyan delivered an invited lecture on "Role of Hydrogen and Fuel Cell Technologies for a Sustainable Energy Future" at the 'International Workshop and Conference on Renewable Energy and Climate Change-Exploring Opportunities for Sustainable Development (IWCRECC-2012)' held at Madurai during April 05-07, 2012.

2. Dr. K. S. Dhathathreyan delivered an invited lecture on "System Integration - PEM FCs" at the '3rd EICOON School on Science & Technology of Renewable and Clean Energy Sources (EICOON-2012)' held at Kolkata during April 30-May 01, 2012.

3. Mr. M. Sreekanth (Dr. B.V. Sarada) made a poster presentation on "Preparation of CuInSe$_2$ (CIS) Thin Films by Pulsed Electrodeposition for Solar Cell Applications" at the '3rd EICOON School on Renewable and Clean Energy Sources (EICOON-2012)' held at Kolkata during April 30-May01, 2012.

4. Dr. S. V. Joshi delivered an invited lecture on "ARCI's Solar Energy Initiatives: Straddling Research and Technology Demonstration" at the '3rd EICOON Workshop on Nanomaterials in Solar Energy Applications' held at Kolkata on May 03, 2012.

5. Dr. K. S. Dhathathreyan delivered invited lectures on "Building Proton Exchange Membrane Fuel Cells" and "Fuel Cell for Automobile Applications: Stack Design, Issues in System Development and System Integration" at the 'DST Sponsored Two Day National Workshop on Exigent Apprehensions in Scaling Up and Stacking Fuel Cells' held at PSG College of Technology, Coimbatore during June 22-23, 2012.

6. Dr. R. Vijay delivered an invited lecture on "Machine Condition Monitoring and Failure Diagnostics – An Overview" at the 'National Workshop on Machine Condition Monitoring and Failure Diagnostics' held at Sidhartha Engineering College, Vijayawada during June 25-26, 2012.

7. Mr. V. Sai Pramod (Dr. Ravi Chandra) presented a paper on "Influence of High Temperature Exposure Microstructure and Phase Constitution of TAlCrN Coatings" at the 'Satellite Workshop on Electron Microscope' held at Bangalore during July 05-06, 2012.

8. Dr. R. Gopalan delivered an invited lecture on "High Performance Magnets for Energy Related Applications" at 'Continuing Education Programme (CEP)' held at DMRL, Hyderabad during July 16-19, 2012.

9. Dr. K. Suresh presented a paper on "Small Angle X-Ray Scattering (SAXS) and Synchrotron XRD Study of Bulk 9Cr-ODS Ferritic Steel" at the '12th International Conference on Surface X-Ray and Neutron Scattering' held at Kolkata during July 25-28, 2012.

10. Dr. K. S. Dhathathreyan delivered an invited lecture on "Recent Developments in Fuel Cells" at the 'Reaction 2012 Workshop' held at Chennai during July 26-28, 2012.

11. Dr. K. S. Dhathathreyan delivered an invited lecture on "Recent Advances in Materials for Polymer Electrolyte Membrane Fuel Cell" at the 'Indo-UK Workshop on Advanced Materials Engineering & Technology' held at Anna University, Chennai during July 27-28, 2012.

12. Dr. K. S. Dhathathreyan delivered an invited lecture on "Fuel Cells for Electric Vehicle (EV) - Stack Design, Issues in System Development and System Integration" at the 'Workshop on Automotive Power Sources and EMS for EV and HEV' held at VIT, Vellore during August 02-04, 2012.

13. Dr. G. Sundararajan delivered an invited lecture on "Influence on the Milling Time on the Microstructure and Mechanical Behaviour of 9Cr-2W-Y$_2$O$_3$-Ti ODS Steels" at the '16th International Conference on Strength of Materials (ICSMA 16)' held at Bangalore during August 19-24, 2012.

14. Mr. Dibyendu Chakravarty presented a paper on "Densification Mechanisms for Spark Plasma Sintering in Alumina and Alumina Based Systems" at the '16th International Conference on Strength of Materials (ICSMA 16)' held at Bangalore during August 19-24, 2012.

15. Dr. P. K. Jain delivered an invited lecture on "Carbon Nanotubes based Composites and its Applications" at the 'National Workshop on Nanomaterials' held at Narsarraopet Engineering College, Guntur on August 25, 2012.

16. Dr S. V. Joshi delivered an invited lecture on 'Thermally Sprayed Coatings: An Overview" at the five-day school on 'Surface Engineering-Technologies, Research and Application (SETRA)', organized by ARCI in association with T.R.Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

17. Mr. D. Srinivasa Rao delivered an invited lecture on "Detonation Spray Coatings: Properties & Applications" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

18. Dr R. Subasri delivered an invited lecture on "Sol-Gel Coatings: Processing and Applications" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

19. Dr. G. Ravi Chandra delivered an invited lecture on "Characterizing the Coated World" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

20. Dr. B.V. Sarada delivered an invited lecture on "Conventional and Pulsed Electrodeposition Techniques" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

21. Dr L. Ramakrishna delivered an invited lecture on "Micro Arc Oxidation Coatings: Properties & Applications" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

22. Mr. G. Sivakumar delivered an invited lecture on "Solution Precursor Plasma Spray Coatings" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

23. Dr. S. Kumar delivered an invited lecture on "Cold Gas Dynamic Spraying" at the five-day school on 'SETRA', organized by ARCI in association with T. R. Anantharaman Educational and Research Foundation at ARCI, Hyderabad during August 27-31, 2012.

24. Dr. G. Sundararajan delivered an invited lecture on "An Overview of Surface Engineering Activities at ARCI" at the '3rd Asian Symposium on Materials and Processing 2012 (ASMP-2012)' held at IIT Madras, Chennai during August 30-31, 2012.

25. Mr. T. Gururaj presented a paper on "Effect of Heat Treatment on Microstructure and Properties of Laser Cladded H13 Tool Steel Layer on H13 Tool Steel" at the 'ASMP-2012' held at IIT Madras, Chennai during August 30-31, 2012.

26. Mr. Sanjay Bhardwaj delivered invited lectures on "Technology-based Ventures" and "New Product Development and Intellectual Property (IP) Strategies" at the 'Entrepreneurship Development Programme' organized by Osmania University, Hyderabad at Hyderabad on August 31, 2012.

27. Dr. K. S. Dhathathreyan delivered an invited lecture on "Wind Energy Integration and Hydrogen" at the '9th International Training Course on Wind Turbine Technology and Applications' held at Centre for Wind Energy Technology (C-WET), Chennai during September 05-27, 2012.

28. Dr. K. S. Dhathathreyan delivered an invited lecture on "Hydrogen Research at Centre for Fuel Cell Technology, ARCI", at the '17th National Convention of Electrochemists (NCE-17)' held at B.S. Abdur Rahman University , Chennai during September 14-15, 2012.

29. Mr. S. Seetharaman (Dr.K.S.Dhathathreyan) presented a paper on "Synergistic Effect of Stabilizer in Alkaline Water Electrolysis" at the 'NCE-17' held at B.S. Abdur Rahman University, Chennai during September 14-15, 2012.

30. Ms. N. Sasikala presented a paper on "Carbon Bifunctional Electrocatalysts for Oxygen/Air Electrodes" at the 'NCE-17' held at B.S. Abdur Rahman University, Chennai during September 14-15, 2012.

31. Dr. Tata N. Rao delivered an invited lecture on "Low Cost Nanosilver-Based Ceramic Candle Filters for Drinking Water Disinfection" at the '1st - International Conference on Emerging Technologies for Clean Water' held at IIT Madras, Chennai during September 14-16, 2012.

32. Mr. H. Purushotham delivered an invited lecture on "Nanocopper: Applications and Markets", at the 'National Seminar on Strengthening Vedic-Modern Science Interface: Opportunities and Strategies' held at Sri Maharshi Research Institute for Vedic Technology (SRIVT), Hyderabad on September 17, 2012.

33. Dr. G. Ravi Chandra delivered an invited lecture on "Introduction to Electron Backscatter Diffraction" at 'CEP in Materials Characterization' held at DMRL, Hyderabad on September 26, 2012.

34. Mr. Vivek Patel delivered an invited lecture on “Polymer Nanocomposites for the Global Automotive Industry” at the ‘Automotive and Transportation Technology Online Trade Show’ organized by Global Spec (HIS Inc) on September 26, 2012.

35. Dr. G. Padmanabham delivered an invited lecture on “Innovative Manufacturing Technologies for Sustainability in Automotive Construction” at the ‘Valedictory of National Student Convention on Automotive Technologies’, Organized by the SAE India Southern Section at Mahatma Gandhi Institute of Technology (MGIT), Hyderabad on October 06, 2012.

36. Mr. Vivek Patel presented a paper on “Rubber-based Nanocomposites: Market and Growth Opportunities” at the ‘Seminar on Recent Advances in Rubber Technology’, organized by Indian Rubber Manufacturers Research Association at Hyderabad on October 12, 2012.

37. Dr. R. Vijay delivered an invited lecture on “Development of Oxide Dispersion Strengthened F/M Steel” at the ‘7th National Frontiers of Engineering (7NatFoE) Symposium’ held at IIT Guwahati, Guwahati during October 12-14, 2012.

38. Dr. K. S. Dhathathreyan presented a paper on “Design, Development and Operational Experience of Non-Humidified PEMFC Systems Built With Light Weight Bipolar Plates” at ‘PETROTECH-2012’ held at New Delhi during October 14-17, 2012.

39. Dr. G. Sundararajan delivered an invited lecture on “Nanocomposites at ARCI” at the ‘International Conference on Advanced Nanomaterials (ANM2012)” held at IIT Madras, Chennai during October 17-19, 2012.

40. Dr. K. S. Dhathathreyan delivered an invited lecture on “Nanostructured Electro Catalysts: A Journey in the Advance of Catalysts for Low Temperature Fuel Cells” at ‘ANM2012’ held at IIT Madras, Chennai during October 17-19, 2012.

41. Dr. N. Rajalakshmi delivered an invited lecture on “Nanocarbons for Hydrogen Storage” at ‘ANM 2012’ held at IIT Madras, Chennai during October 17-19, 2012.

42. Ms. M. Maidhily presented a paper on “ TiO2 Nanotube (NT-TiO$_2$) Array based Durable Electro Catalyst Support for PEMFC” at ‘ANM 2012’ held at IIT Madras, Chennai during October 17-19, 2012.

43. Dr. K. Ramya delivered an invited lecture on “PEMFC Technology Development at Advanced Research Centre-International” at the ‘Indo-US Interactive on Hybrid Power Systems and Energy Meet’ held at NMRL, Ambernath during October 18–19, 2012.

44. Dr. Roy Johnson delivered an invited lecture on “Transparent Polycrystalline Ceramics: Unique Materials for Engineering Applications” at the ‘National Conference on New Materials and Processes for Improving Quality of Infrastructure (NEMPIQI2012)’ held at University of Hyderabad, Hyderabad during October 19-21, 2012.

45. Dr. K. S. Dhathathreyan delivered an invited lecture on “Fuel Cells - Powering the World” at the ‘CSIR Renewable Energy PhD Programme ACSIR’ held at Chennai on October 26, 2012.

46. Mrs. S. Nirmala presented a paper on “Automation of Arc Discharge Setup for Production of Carbon Nanotubes” at the ‘National Symposium on Instrumentation (NSI-37)’ held at Central Scientific Instruments Organization(CSIO)-Council of Scientific and Industrial Research (CSIR), Chandigarh during October 30 - November 01, 2012.

47. Ms. V. Uma made a poster presentation on “Design Automation for Sol-Gel Dip Coating Equipment” at ‘NSI-37’ held at CSIO-CSIR, Chandigarh during October 30 - November 01, 2012.

48. Dr. G. Padmanabham delivered a Plenary Lecture on “Hardfacing and Reclamation by Innovative Laser Processing” at the ‘International Welding Symposium 2k12 (IWS 2k12)’ held at Bombay Convention & Exhibition Centre (BCEC), Mumbai during October 30 - November 01, 2012.

49. Mr. K. V. P. Prabhakar presented a paper on “Effect of Heat Input in Laser Welding of Dual Phase Steel (DP 780)”, at ‘IWS 2k12’ held at BCEC, Mumbai during October 30 - November 01, 2012.

50. Mr. D. Narsimha Chary presented a paper on “Effect of Shielding on Autogeneous Laser Welding of Aluminium Alloy 6061 T6”, at ‘IWS 2k12’ held at BCEC, Mumbai, during October 30 - November 01, 2012.

51. Ms. Y. Krishna Priya (Dr. G. Padmanabham), presented a paper on “Effect of Si Content on Macro and Microstructural Features of Cold Metal Transfer Brazed Aluminium Steel Joints”, at the ‘IWS 2k12’ held at BCEC, Mumbai, during October 30 - November 01, 2012.

52. Dr. K.S. Dhathathreyan delivered an invited lecture on “Carbon in Hydrogen Technologies” at the ‘National Conference on Carbon Materials 2012 (CCM12)’ held at BARC, Mumbai during November 01-03, 2012.

53. Mr. S. Seetharaman (Dr. K.S. Dhathathreyan) presented a paper on “Electrochemically Reduced Grapheme Oxide/Sulphonated Polyether Ether Ketone Composite Membrane for Electrochemical Applications” at ‘CCM12’ held at BARC, Mumbai during November 01-03, 2012.

54. Mr. B. Padya presented a paper on “Highly Ordered Nitrogen Doped Carbon Nanotube Novel Structures of Aligned Carpet for Enhanced Field Emission Properties” at ‘CCM12’ held at BARC, Mumbai during November 01-03, 2012.

55. Mr. M. Kota (Dr. P.K. Jain) presented a paper on “Role of Buffer Gas Pressure on the Synthesis of Carbon Nanotubes by Arc Discharge Method” at ‘CCM12’ held at BARC, Mumbai during November 01-03, 2012.

56. Mr. G.V. Ramana( Dr. P.K. Jain) presented a paper on “Thermal Properties of Multi-Walled Carbon Nanotubes-Graphite Nanosheets/ Epoxy Nanocomposites”, at ‘CCM12’ held at BARC, Mumbai during November 01-03, 2012.

57. Mr. M. Srikanth (Dr. P.K. Jain) presented a paper on “Electrochemical Properties of Flexible Conductive Paper using Carbon Nanotubes for Energy Storage Applications”, at ‘CCM12’ held at BARC, Mumbai during November 01-03, 2012.

58. Dr. R. Subasri delivered an invited lecture on “Sol-Gel Functional Coatings for Solar Thermal Applications” at the ‘International Conference on Advances Materials and Processing: Challenges and Opportunities (AMPCO 2012)’ held at IIT Roorkee, Roorkee during November 02-04, 2012.

59. Dr. Y. Srinivasa Rao presented a paper on “Honeycomb based Solid Oxide Fuel Cell (SOFC)-An Innovative Method for Fuel Cell Application” at the ‘5th AP Science Congress-2012’ held at Acharya Nagarjuna University, Guntur during November 11-16, 2012.

60. Dr. G. Ravi Chandra delivered invited lectures on “Physics and Materials Characterization” and “Mechanical Properties of Materials at the Sub-Micron Scale” at the ‘Refresher Course in Physics’ held at Academic Staff College, Osmania University, Hyderabad during November 15-19, 2012.

61. Dr. Rajappa Tadepalli presented a paper on “Laser Welding Studies on Casing Materials for Lithium Ion Battery Application” at the IIM-NMD-ATM 2012, held at Jamshedpur during November 16-19, 2012.

62. Dr. G. Sundararajan delivered an invited lecture on “Energy: Challenges and Role for Nanotechnology” at the ‘3rd MRSI Trilateral Workshop’ held at IIT Bombay, Mumbai on November 19, 2012.

63. Dr. G. Ravi Chandra delivered an invited lecture on “EBSD Studies on Coatings” at the ‘National Conference on Advances in Materials Science and Technologies’ held at Kakatiya University, Warangal during November 19-21, 2012.

64. Dr. G. Padmanabham delivered an invited lecture on “Laser based Joining Technologies” at the ‘Workshop on Welding Research Trends’ organized by IIT Madras and Indian Institute of Welding at IIT Madras, Chennai, during November 23-24, 2012.

65. Dr. Tata N. Rao delivered an invited lecture on “Commercial Prospects for Nanomaterials” at the ‘First International Workshop on Green Nanotechnology-2012’ held at Belgaum, Karnataka during November 26-27, 2012.

66. Dr. Easwaramoorthi Ramasamy delivered an invited lecture on “Nanostructure Solar Cells for Green Energy” at the ‘First International Workshop on Green Nanotechnology - 2012’ held at Belgaum, Karnataka during November 26-27, 2012.

67. Dr. K. S. Dhathathreyan delivered an invited lecture on “Status of PEMFC Development at ARCI” at the ‘1st Meeting of Sub-Committee for Fuel Cell Development’ held at MNRE, New Delhi on November 29, 2012.

68. Dr. N. Rajalakshmi delivered an invited lecture on “Nanomaterials for Fuel Cells and Supercapacitors” at the ‘Indo-German Workshop on Advanced Materials for Future Energy Requirements - (WAMFER2012)’ held at New Delhi during November 29- December 01, 2012.

69. Mr. K. Samba Sivudu presented a paper on “Synthesis of Graphene: An Analysis of Worldwide Patents” at the ‘3rd National Conference on Intellectual Property Rights’ held at Hyderabad on November 30, 2012.

70. Dr. S. V. Joshi delivered an invited lecture on “Surface Engineering: Growing Relevance to Design & Manufacturing” at the ‘Asian Academic Seminar on Manufacturing, Design and Innovation’ held at IIT-Bombay on December 03, 2012.

71. Dr. Tata N. Rao delivered an invited lecture on “Application of Nanomaterials” at the ‘National Conference on Nanomaterials (NCN-2012)’ held at Karunya University, Coimbatore during December 03-04, 2012.

72. Dr. K. S. Dhathathreyan delivered an invited lecture on “Production of PEMFC Systems – Challenges” at the ‘Asian Academic Seminar: Manufacturing, Design and Innovation’ held at IIT Bombay, Mumbai during December 03-07, 2012.

73. Dr. Tata N. Rao made a poster presentation on 'Thematic Unit of Excellence on Nanomaterials-Based Technologies for Automotive Applications' at the '5th Bangalore Nano Conference' held at Bangalore during December 05-07, 2012.

74. Mr. H. Purushotham presented a paper on "Nanotechnology Knowledge Management Services to Startups and SMEs" at the '5th Bangalore Nano Conference' held at Bangalore during December 05-07, 2012.

75. Mr. B. Bolla Reddy (Dr. G. Sundararajan/Dr. P. Suresh Babu) presented a paper on "The Indentation Behaviour of Cold Sprayed Copper Coatings with Spherical Indentor" at the '3rd Asian Conference on Mechanics of Functional Materials and Structures' held at New Delhi during December 05-08, 2012.

76. Dr. G. Ravi Chandra delivered an invited lecture on "Microstructural Study of 18-Cr ODS Steels" at the 'Conference-cum-Workshop on Electron Microscopy' held at Banaras Hindu University (BHU), Varanasi on December 08, 2012.

77. Ms. K.H. Anulekha (Dr. Tata N. Rao) presented a paper on "Fabrication and Surface Functionalization Studies on Electrospun Polystyrene Sub-Micron Fibers" at the 'Chemference 2012' held at Mumbai during December 10-11, 2012.

78. Dr. G. Padmanabham delivered an invited lecture on "Laser Welding and Brazing" at the 'Course on Welding Technologies and NDT' held at Engineering Staff College of India, Hyderabad on December 12, 2012.

79. Mr. P. Barick presented a paper on "Microstructure, Mechanical Properties and Weibull Modulus of Reaction Bonded Boron Carbide", at the 'International Conference on Ceramics (ICC-12)' held at Bikaner, Rajasthan during December 12-13, 2012.

80. Mr. B. Viswanath Sasank presented a paper on "Thermal Management System Development for a 5kW PEMFC Stack for Vehicular Applications" at the 'Hydrogen Energy and Advanced Materials (HEAM) Young Scientist Award 2012 Conference' held at Trivandrum during December 14-15, 2012.

81. Ms. M. Maidhily presented a paper on "Role of Precursor Concentration, Platinum Loading and Size of Pt in Carbon Supported Catalysts and its Performance on PEM Fuel Cell" at the 'HEAM Young Scientist Award 2012 Conference' held at Trivandrum during December 14-15, 2012.

82. Dr. N. Rajalakshmi delivered an invited lecture on "Photovoltaics/ Photo Electrochemistry for Fuel Cells" at the 'Workshop on Photoelectrochemistry' organized by National Centre for Catalysis Research (NCCR) and IIT Madras at Chennai on December 18, 2012.

83. Dr. G. Sundararajan delivered the Keynote Lecture on "Powder Metallurgy Related Activities at ARCI" at the 'Powder Metallurgy Short Course (PMSC 2012)' held at MGIT, Hyderabad during December 19-22, 2012.

84. Mr. Dibyendu Chakravarty delivered an invited lecture on "Spark Plasma Sintering of Ceramics and Metallic Materials for various Structural and Functional Applications" at the 'Powder Metallurgy Short Course PMSC-12' held at MGIT, Hyderabad during December 19-22, 2012.

85. Mr. M. Sreekanth (Dr.B.V.Sarada) presented a paper on "Improved Photoelectrochemical Performance of CIGS Thin Films Deposited by Pulsed Electrodeposition" at the 'International Conference on Solar Energy Photovoltaic (ICSEP) held at Bhubaneswar during December 19-21, 2012.

86. Dr. K. S. Dhathathreyan delivered an invited lecture on "Design and Development of Fuel Cell Stacks" at the 'Technology Appreciation Programme on Fuel Cells' held at IIT Madras, Chennai on December 21, 2012.

87. Dr. R. Gopalan delivered an invited lecture on "Functional Materials for Sustainable Energy Applications" at the '100th Indian Science Congress 2013' held at Kolkata during January 03-07, 2013.

88. Mr. Sanjay Bhardwaj delivered invited lectures on "Managing Intellectual Property Rights and Technology in New Ventures" and "Managing Technology Value Chain: Case Studies" at the 'Entrepreneurship Development Programme' held at Osmania University, Hyderabad on January 04, 2013.

89. Dr. Roy Johnson delivered an invited lecture on "Processing and Properties of Advanced Transparent Ceramic Materials" at the 'CEP Course' held at DMRL, Hyderabad during January 07-11, 2013.

90. Dr. S. V. Joshi delivered an invited talk on "Technology Commercialization : ARCI's Perspective" at a one week programme on 'Managing Technology Value Chains' held at Administrative Staff College of India, Hyderabad on January 08, 2013.

91. Dr. B. P. Saha delivered an invited lecture on "Advanced Ceramics for Defense and Space Applications" at the 'CEP Course' held at DMRL, Hyderabad during January 07-11, 2013.

92. Mr. S.M. Shariff presented a paper on “Application of Laser Coating Technologies for Life Enhancement of Components used in Thermal Power Plants” at the ‘National Workshop on Coal Energy for Sustainable Development’ organized by National Thermal Power Corporation (NTPC) Energy Technology Research Alliance (NETRA) & CSIR-Central Institute of Mining and Fuel Research (CIMFR) at New Delhi during January 10-11, 2013.

93. Ms. Alka Pareek (Dr.P.H. Borse) presented a paper on “Photoelectrochemical Characterization of Metal-Semiconductor Nanoparticle Modified Nano-structured Cds Photoelectrodes” at the ‘5th ISEAC Triennial Conference on Advances and Recent Trends in Electrochemistry’ held at Hyderabad during January 16-20, 2013.

94. Mr. M. Sreekanth (Dr. B.V. Sarada) presented a paper on “Pulse Electrodeposition and Characterization of CIGS Thin-Films for Solar Cell Applications” at the ‘5th ISEAC Triennial Conference on Advances and Recent Trends in Electrochemistry’ held at Hyderabad during January 16-20, 2013.

95. Mrs. D. Rekha (Dr.P.H. Borse) presented a paper on “Photoelectrochemical Characterization of $Fe_2O_3$ and $ZnFe_2O_3$ and Composite Photoelectrodes for Hydrogen generation Application” at the ‘5th ISEAC Triennial Conference on Advances and Recent Trends in Electrochemistry’ held at Hyderabad during January 16-20, 2013.

96. Dr. M. Buchi Suresh presented a paper on “Development of Dense Electrolyte Coating on Anode Based Honeycomb Substrates for SOFC Application” at the ‘76th Annual Session of Indian Ceramic Society and International Conference on Emergence of New Era in Glass and Ceramics’ held at Ahmedabad during January 18-19, 2013.

97. Ms. R. Papitha (Dr. R. Johnson) presented a paper on “Effect of Low Temperature Thermal Cycling on Thermo Mechanical Behavior of $Al_2TiO_5$ Ceramics” at the ‘76th Annual Session of Indian Ceramic Society and International Conference on Emergence of New Era in Glass and Ceramics’ held at Ahmedabad during January 18- 19, 2013.

98. Dr. K. Rajeshwari (Dr. R. Johnson) made a poster presentation on “Effect of Hot Isostatic Presssing on Visible Transparency and Ionic Conductivity of Pressure-Less Sintered 8Y Zirconia Specimens” at the ‘76th Annual Session of Indian Ceramic Society and International Conference on Emergence of New Era in Glass and Ceramics’ held at Ahmedabad during January 18-19, 2013.

99. Dr. K. S. Dhathathreyan delivered an invited lecture on “Architecture of Proton Exchange Membrane Fuel Cells” at the ‘CSIR Sponsored National Workshop on Opportunities and Challenges for Fuel Cells in India’ held at Coimbatore Institute of Engineering and Technology, Coimbatore on January 21, 2013.

100. Dr. G. Sundararajan delivered an invited lecture on “Technology Diffusion, Transfer and Commercialisation” at the ‘NIAS Programme for Senior Executives’ held at National Institute of Advanced Studies (NIAS), Bangalore on January 22, 2013.

101. Dr. S. V. Joshi delivered an invited talk on “Surface Engineering: A Powerful Tool to Address Diverse Industrial Applications” at the ‘Induction Training Programme for Management Trainees” held at MIDHANI on February 06, 2013.

102. Dr. P.K. Jain presented a paper on “Oil Absorption from Exfoliated Graphite” at the Raj Bhasa Conference on Importance of Defense R&D in the Progress of the Nation’ held at Hyderabad during February 07-08, 2013.

103. Dr. R. Subasri presented a paper on “Hybrid Sol-gel Coatings for Defence Applications” at the ‘Raj Bhasa Conference on Importance of Defense R&D in the Progress of the Nation’ held at Hyderabad during February 07-08, 2013.

104. Mr. S. Arun presented a paper on “Non Disclosure Agreements and Important Issues” at the ‘Raj Bhasa Conference on Importance of Defense R&D in the Progress of the Nation’ held at Hyderabad during February 07-08, 2013.

105. Mr. Narendra K. Bhakta presented a paper on “Implementation of Official Language Policy and Role of Hindi Software and its Problems” at the ‘Raj Bhasha Conference on Importance of Defense R&D in the Progress of the Nation’ held at Hyderabad during February 07-08, 2013.

106. Dr. S. V. Joshi delivered an invited talk on “Engineering Surfaces Using Powders, Suspensions and Solution Precursors” at the ‘International Conference and Exhibition on Powder Metallurgy for Automotive and Engineering Industries-Precision and Additive Manufacturing (PM-13)’ held at Pune during February 07-09, 2013.

107. Dr. Malobika Karanjai presented a paper on “Corrosion Aspects of Cerametallic Friction Materials” at the

'PM-13 International Conference and Exhibition on Powder Metallurgy for Automotive and Engineering Industries Precision and Additive Manufacturing' held at Pune during February 07-09, 2013.

108. Dr. P.H. Borse delivered an invited lecture on "Solar $H_2$ Generation from Photoelectrochemical and Photochemical Methods" at the 'National Workshop on Evaluation of Producing Technologies for Industry Relevant Applications' held at ARCI, Hyderabad during February 08-09, 2013.

109. Dr. K. Ramya delivered an invited lecture on "PEMFC Technology", at the 'National Seminar on Strategies for Harnessing Fuel Cell Energy for Innovative Applications', held at VIT, Vellore during February 08 -09, 2013.

110. Dr. S. Sakthivel delivered an invited lecture on "Role of Nanotechnology in the field of Environment and Energy" at the 'National Seminar on Role of Nanotechnology in Environmental Protection" held at Jawaharlal Nehru Technological University (JNTU), Ananthapur during February 11-12, 2013.

111. Dr. Tata N. Rao delivered an invited lecture on "Nanotechnology Innovations" at 'Nano India 2013- A National Conference', organized by National Institute for Interdisciplinary Science and Technology (NIIST) at Thiruvananthapuram, Kerala during February 19-20, 2013.

112. Mr. K.R.C. Soma Raju made a poster presentation on "Nano Structured Sol-Gel Coatings for High Temperature Wear and Tarnish Resistant Applications" at 'Nano India 2013 - A National Conference', organized by NIIST at Thiruvananthapuram, Kerala during February 19-20, 2013.

113. Dr. V. Krishna delivered a lecture on "Nanocomposite CrAlSiN Hard Protective Coatings for High Temperature Applications" at the 'International Workshop on Mechanical Behaviour of Systems at Small Length Scales-4' held at Orange County, Coorg during February 24-28, 2013.

114. Dr. K.S. Dhathathreyan delivered an invited lecture on "Clean Transporation – the Fuel Cell Option" at the 'Workshop on Clean and Sustainable Transportation' held at IIT Madras, Chennai on February 25, 2013.

115. Dr. N. Rajalakshmi delivered an invited lecture on "Nanomaterials for Energy Devices" at the 'Seminar Series Nanorevalation 2012' held at National Centre for Nanoscience and Nanotechnology, University of Madras, Chennai on February 26, 2013.

116. Mrs. D. Rekha (Dr. P.H. Borse) presented a paper on "Microwave Synthesis of Solar Active Nanocrystalline $ZnF_2O_4$ Photocatalysts" at the 'National Seminar on Advanced Materials' held at Osmania University, Hyderabad during February 27-28, 2013.

117. Dr. G. Ravi Chandra delivered an invited lecture on "Microstructural Study of Oxide Dispersed Strengthened 18-Cr ODS Steels" at the 'National Seminar on Advanced Materials and their Applications' held at Osmania University, Hyderabad on February 28, 2013.

118. Dr. K. S. Dhathathreyan delivered an invited lecture on "Mitigating the Effects of Climate Change through Solar Energy" at the 'National Convention on Challenges , Innovations & Opportunities in Solar Energy to Enact the Kyoto Protocol (SEEK-2013)' held at Sathyabama University , Chennai during February28-March 01, 2013.

119. Dr. K. S. Dhathathreyan delivered an invited lecture on "Application of Hydrogen in Automobiles" at the 'National Workshop on Contemporary Approaches in Hydrogen Fuel-An Eco-Friendly Future Fuel', held at Sri Muthukumaran Institute of Technology, Chennai during March 01-02, 2013.

120. Dr. K. Ramya presented a paper on "Polymer Electrolyte Membranes in Sensor Applications" at the 'International Conference on Advancements in Polymeric Materials, Innovation in Materials and Product Developments' organized by Central Institute of Plastics Engineering (CIPET), Lucknow at Lucknow during March 01-03,2013.

121. Dr. N. Rajalakshmi delivered an invited lecture on "Green Energy Initiative – Transport Perspective" at the 'Conference on Automotive R & D Trends 2015, Theme : Cost Effective Green Mobility' held at Chennai on March 08, 2013.

122. Mr. H. Purushotham presented a paper on "Nanotechnology Applications in Cement Industry: Worldwide Patent Analysis" at the 'International Conference on Advanced Nanocomposites for Construction Materials (ICNC 2013)' held at Kottayam, Kerala during March 12-14, 2013.

123. Dr. G. Sundararajan delivered an invited lecture on "Advanced Ceramics Programmes at ARCI" at the 'National Level Students Technical Symposium-ConCerT 13' held at Anna University, Chennai on March 13, 2013.

124. Dr. R. Subasri delivered an invited lecture on "Organic – Inorganic Hybrid Nanocomposite Coatings by

Sol-Gel Process" at the '5th Indo-German Frontiers of Engineering Symposium (INDOGFOE 2013)', organized by ARCI at Pragati Resorts, Hyderabad during March 14-17, 2013.

125. Dr. Ravi N. Bathe made a poster presentation on "Laser Processing Applications for Automotive and Energy Sector" at 'INDOGFOE 2013' organized by ARCI at Pragati Resorts, Hyderabad during March 14-17, 2013.

126. Dr. N. Rajalakshmi delivered an invited lecture on "Functional Materials for Energy Devices" at a 'One Day Workshop on Functionalised Materials' held at Vel Tech University, Chennai on March 15, 2013.

127. Dr. K. S. Dhathathreyan delivered an invited lecture on "Hydrogen – An Ideal Energy Vector" at the 'International Conference on Recent Advances in Textile and Electrochemical Sciences (RATES-2013)' held at Alagappa University , Karaikudi during March 21-23, 2013.

128. Dr. G. Sundararajan delivered an invited lecture on "Alternative Energy Programmes at ARCI" at the 'Indo-UK Joint Seminar on Functional Energy Materials Manufacturing & Structures(FAEMMS-2013)' held at University of Hyderabad, Hyderabad during March 25-26, 2013.

129. Dr. K. S. Dhathathreyan delivered an invited lecture on "Advances in Materials for PEMFC" at 'FAEMMS-2013' held at University of Hyderabad, Hyderabad during March 25-26, 2013.

130. Dr. R. Gopalan delivered an invited lecture on "Functional Materials for Automotive Energy Applications" at 'FAEMMS-2013' held at University of Hyderabad, Hyderabad during March 25-26, 2013.

131. Dr. Raju Prakash presented a paper on "Development of Large Lithium Ion Batteries for Electrical Vehicle Applications" at 'FAEMMS-2013' held at University of Hyderabad, Hyderabad during March 25-26, 2013.

132. Dr. G. Sundararajan delivered an invited lecture on "Technology Transfer & Commercialisation" at a 'One Day Workshop on Strategies for Linking R&D Efforts in the Laboratories to Technology and Business Development' held at NIIST, Thiruvananthapuram on March 26, 2013.

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

1. Mr. S. Arun attended the 'Global Investors Meet 2012' held at the Bangalore International Exhibition Centre, Bangalore during June 06-08, 2012.

2. Mr. Manish Tak, Mr. G. Siva Kumar and Mr. R. Senthil Kumar attended the 'Aerospace Standards Workshop' held at Hyderabad on June 07, 2012.

3. Mr. H. Purushotham attended the 'Workshop on Structural Equation Modeling Basics and Applications' held at ICFAI Business School (IBS), Hyderabad during June 28-29, 2012.

4. Mrs. S. Nirmala attended the 'IEEE PES Industrial Trip to Solar Semiconductor' held at Hyderabad on July 21, 2012.

5. Mr. T.K. Gireesh Kumar attended the training programme on 'E-Resources and User Needs' held at Hyderabad on August 11, 2012.

6. Mr. D. S. Reddy attended the 'Theme Meeting on Recent Trends on Analytical Chemistry (TRAC-2012)' held at Chennai during August 30-31,2012.

7. Mr. A. Ramesh, Mr. A. Satyanarayana, Mr. B. Venkanna, Mr. K. Satyanarayana Reddy, Mr. G. Venkata Rao, Mr. G. Venkata Reddy, Mr. J. Venkateshwara Rao, Mr. M. Satyanand, Mr. A. Jagan, Mr. G. Anjan Babu, Mr. Ch. Jangaiah, Mr. P. K. Mukhopadyay, Mr. Sheik Ahmed, and Mr. B. Hemanth Kumar attended a one day training programme on 'Safe Operation/Safety and Normal Maintenance of Forklift' conducted by Voltas at ARCI, Hyderabad on September 11, 2012.

8. Dr. R. Gopalan attended the workshop on 'Hybrid and Electric Vehicles-II Opportunities, Challenges and Technology' held at New Delhi during September 13-14, 2012.

9. Mr. K.V.P. Prabhakar, Dr. Ravi N. Bathe, Dr. Neha Hebalkar, Dr. B.V. Sarada, Dr. Srinivasan Anandan, Mr. T. Gururaj, Dr. Krishna Valleti, Dr. S. Kumar, Ms. J. Revathi, and Mr. K.R.C. Somaraju attended a 'Workshop on Metallurgy for Non-Metallurgists (MNM-2012)' organized by Indian Institute of Metals, Hyderabad Chapter at Nuclear Fuel Complex (NFC), Hyderabad on September 28, 2012.

10. Dr. Y. R. Mahajan attended the 'Workshop on Nanotechnology for Defence Applications' organized by DRDO at New Delhi on October 01, 2012.

11. Mr. L. Venkatesh attended a two day course on 'Materials Selection and Testing of Materials' at IIT Madras, Chennai during October 05-06, 2012.

12. Dr. Y. Srinivasa Rao attended the 'National Conference on New Materials and Processes for Improving Quality of Infrastructure (NEMPIQI2012)' held at University of Hyderabad, Hyderabad during October 10-20, 2012.

13. Dr. R. Subasri, Mr. Nitin Wasekar, Mrs. A. Jyothirmayi, and Mr. Naveen M. Chavan attended the 'National Workshop on Evaluation and Prevention of Corrosion and Failures' held at University of Hyderabad, Hyderabad during November 29-30, 2012.

14. Dr. P. H. Borse attended the 'International Conference on Advances in Biological Hydrogen Production and Applications' held at JNTU, Hyderabad on December 03, 2012.

15. Mr. Vivek Patel and Ms. Abhilasha Verma attended the '5th Bangalore Nano Conference' held at Bangalore during December 05-07, 2012.

16. Mr. S.P. Mishra, Mr. S. Arun, and Mr. Aan Singh attended the 'Pride of India Exhibition' organized as a part of the '100th Indian Science Congress' held at Kolkata during January 03-07, 2013.

17. Mrs. Priya A. Mathews and Dr. Deepika Bhatt attended the 'Pride of India Exhibition' and 'Women's Science Congress' organized as a part of '100th Indian Science Congress' held at Kolkata during January 03-07, 2013.

18. Dr. B. P. Saha attended a 'Workshop on Advanced Manufacturing Technology (AMT-2013)' held at DRDL, Hyderabad on January 04, 2013.

19. Mr. N. Ravi, Dr. Ravi Bathe, Mr. K.V.P. Prabhakar, and Mrs. A. Jyothirmayee attended 'AMT-2013' held at DRDL, Hyderabad on January 04, 2013.

20. Dr. P. K. Jain, Dr. R. Subasri, Dr. K. Radha, Mr. Sanjay Bharadwaj, Mr. R. Prabhakar Rao, Mr. Nitin P. Wasekar, Mr. Kaliyan Hembram, Mr. Arun Seetaraman, Mr. Manish Tak, Mrs. Papiya Biswas, Mr. R. Vijay Chander, Mr. N. Srinivas, Mr. K Srinivasa Rao, Mr. A Srinivas, Mr. Anirban Bhattacharjee, Mr. A. R. Srinivas, Mr. K. Naresh Kumar, Mrs. N. Aruna, Mr. R. Anbu Rasu, Mr. P. Dharma Rao, Mr. G. Venkata Rao, Mr. Narendra Kumar Bhakta, Mr. J. Bansilal, Mr. Ch. Jangaiah and Dr. S. Devidas attended the "8th All India Joint Scientific and Technical Official Language Seminar" held at Defence Electronics Research Laboratory (DLRL) on February 7-8, 2013.

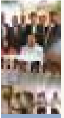
21. Mrs. S. Nirmala, Mr. Ch. Sambasiva Rao, and Mrs. N. Aruna attended the 'Embedded Control and Monitoring Conference' held at Hyderabad on February 22, 2013.

22. Dr. R. Subasri attended the 'Indo-UK Joint Seminar on Functional Energy Materials Manufacturing & Structures (FAEMMS-2013)' held at University of Hyderabad, Hyderabad during March 25-26, 2013.

# Patents' Portfolio

## Indian Patents Granted

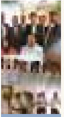
| Title of Patent | Patent Application Number | Date of Filing | Patent Number | Date of Grant |
|---|---|---|---|---|
| A Solar Drier | 487/ MAS/1994 | 08/06/1994 | 184674 | 23/09/2000 |
| A Process for Preparation of Reaction Bonded Silicon Carbide Components | 1886/ MAS/1996 | 28/10/1996 | 195429 | 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) |



## 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 |
| 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 |

| Title of Patent | Patent Application No. | Date of Filing |
|---|---|---|
| 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 |
| 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 |



## International Patents Granted

| Title of Patent | Country | Patent Number | Date of Grant | Year 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 | 2001 | 209817 |
| A Process for the Preparation of Nano Silver and Nano Silver-Coated Ceramic Powders | South Africa | 2006/8591 | 30/04/2008 | 2006 | 2786/ DEL/2005 |
|  | Sri Lanka | 14258 | 02/11/2011 | 2006 |  |
| A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process | South Africa | 2009/06786 | 26/05/2010 | 2009 | 1829/ DEL/2008 |
| 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 | 2006 | 1610/ DEL/2005 |

## International Patents Filed

| Title of Patent | Country | Patent Application No. | Year & Date of Filing | Indian Patent Details |
|---|---|---|---|---|
| A Process for the Preparation of Nano Silver and Nano Silver-Coated Ceramic Powders | Indonesia | P-00200600616 | 2006 | 2786/ DEL/2005 |
|  | Bangladesh | 233/2006 | 2006 |  |
| A process for continuous coating deposition and an apparatus for carrying out the process | Germany | DE102009044256A1 | 2009 | 1829/ DEL/2008 |
|  | United Kingdom | GB0917306.3 | 2009 |  |
|  | USA | US20090579002 | 2009 |  |
|  | France | FR0957102 | 2009 |  |
|  | Japan | JP20090237921 | 2009 |  |
|  | Brazil | BR2009PI04232A2 | 2009 |  |
| Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity | Other countries -under consideration | PCT/IN2011/000474 | 19/07/2011 | 1835/ DEL/2010 |
|  | United Kingdom | 1303768.4 |  |  |
|  | 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 | 2012 | 2965/ DEL/2011 |
|  | USA | 13/484613 | 31/05/2012 |  |
|  | Japan | 2012-093888 | 2012 |  |
|  | United Kingdom | 1206843 | 18/04/2012 |  |
|  | Germany | Not Available (NA) | 2012 |  |
|  | France | NA | 2012 |  |
|  | Brazil | NA | 2012 |  |
|  | Canada | NA | 2012 |  |

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| 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 |

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110. P. Karthika, N. Rajalakshmi and K. S. Dhathathreyan, "Phosphorus Doped Exfoliated Graphene for Supercapacitor Electrodes", Journal of Nanoscience and Nanotechnology (In Press).
111. G.V. Ramana, B. Padya, V.V. S.S. Srikanth and P.K. Jain, "Electrically Conductive Small-Diameter Carbon Nanotubes/Polyaniline Nanofibers Composite Thin Films", Bulletin of Materials Science Journal (In Press).
112. 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 (In Press).
113. S. Sudhakara Sarma and T.N. Rao, "A Novel Method for Measurement of Porosity in Nanofiber Mat using Pycnometer in Filtration", Journal of Engineered Fibers and Fabrics (In Press).
114. 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", Special Issue of Progress in Organic Coatings (In Press).
115. P. Barick, D.C. Jana and B.P. Saha "Load Dependent Indentation Behaviour of β-SiAlON and α-Silicon Carbide", Journal of Advanced Ceramics (In Press).
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## Publications in Conference Proceedings

1. T. Gururaj, J.D. Majumdar, Manish Tak, G. Padamanabham and I. Manna, "Effect of Heat Treatment on Microstructure and Properties of Laser Cladded H13 tool steel Layer on H13 Tool Steel", Proceedings of the 3rd Asian Symposium on Materials & Processing ASMP 2012, Reference No: MPFCM 10, 2012.
2. Manish Tak, S.M. Shariff, Vikram Sake and G. Padmanabham, "A Novel Method of Pulsed Laser-Cladding for Effective Control of Melting of WC Particulates in NiCr-WC Composite Coatings", Proceedings of 31st International Congress on Applications of Lasers & Electro-Optics (ICALEO 2012), USA p 515-523, 2012.
3. S.P. Pemmasani, K. Valleti, M. Ramakrishna, K.V. Rajulapati, R.C. Gundakaram and S.V. Joshi, "Structure-Property Correlations In Cathodic Arc Deposited TiAlN Coatings", 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 967-970, 2012.
4. P.H. Borse, "Photocatalytic and Photoelectro-Chemical Investigations of Fe/ Sn/ Nb Containing Oxides for Energy Application: Comparative Study", Journal of Physics Conference Series (Proceedings of International Conference on Recent Trends In Physics (ICRTP 2012), Indore), Vol. 365, Article Number: 012006, 2012.
5. H.A. Colorado, S.R. Dhage, J.M. Yang, and H.T. Hahn, "Intense Pulsed Light Sintering Technique for Nanomaterials", TMS 2012 141st Annual Meeting and Exhibition, Supplemental Proceedings: Materials Processing and Interfaces, Vol. 1, p 577-584, 2012.
6. Y. Krishna Priya, K.V.P. Prabhakar, K. Bhanusankara Rao and G. Padmanabham, "Effect of Si Content on Macro and Microstructural Features of Cold Metal Transfer Brazed Aluminium Steel Joint", Proceedings of International Welding Symposium 2k12 (IWS 2k12), Mumbai, Vol.1, p 133-139., 2012.
7. K.V.P. Prabhakar and G. Padmanabham, "Effect of Heat Input in Laser Welding of Dual Phase Steel (DP 780)", Proceedings of International Welding Symposium 2k12 (IWS 2k12), Mumbai, Vol.1, p 149-161, 2012.
8. D. Narsimha Chary, R. N. Bathe, A. Basu and G. Padmanabham, "Effect of Shielding on Autogenous Laser Welding of Aluminium Alloy 6061-T6" Proceedings of International Welding Symposium 2k12 (IWS 2k12), Mumbai, Vol.1, p193-202, 2012.
9. 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 & 28D) for Indirect Ophthalmoscopy", Proceedings of the International Conference on

Advancements in Polymeric Materials (APM 2013), CIPET, Lucknow, p177-178, 2013.

10. 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.
11. 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.
12. D. Rekha, 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", ISEAC proceedings, Fifth ISEAC Triennial International Conference on Advances and Recent Trends in Electrochemistry (ELAC-2013), p 368-371, 2013.
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14. 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.
15. 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.
16. 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.
17. 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.
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19. 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.

## Books/Chapters in Books by ARCI Personnel

1. I. Ganesh, P.S.C. Sekhar, G. Padmanabham and G. Sundararajan, "Preparation and Characterization of Li-Doped ZnO Nano-Sized Powders for Photocatalytic Applications" a Chapter in the book on Materials Science Forum Viz. 'Photocatalytic Materials and Surfaces for Environmental Cleanup-II" Trans Tech Publications-Switzerland, (ed.) R. Tayade, p 90-116, 2013.
2. D. Rekha and P.H. Borse, "Photocatalytic and Photoelectro-Chemical Study of Ferrites for Water Splitting Applications: A Comparative Study", a Chapter in the book on Materials Science Forum Viz. 'Photocatalytic Materials and Surfaces for Environmental Cleanup-II" Trans Tech Publications-Switzerland, (ed.) R. Tayade , p 334-348, 2013.
3. G. Padmanabham and B. Shanmugarajan, "Laser based Joining of Metallic and Non-Metallic Materials", a Chapter in the book on 'Laser Assisted Fabrication of Materials", Springer Series in Materials Science, 161, p 159-220, 2013.
4. T.K. Gireesh Kumar, "Wikis: Tool for Altering Tacit Knowledge Explicit", a chapter in the book on 'Challenges of Library and Information Science in Digital Era', (eds.)KSR Vithal et.al, p 340-348, 2013.
5. I. Ganesh, "Conversion of Carbon Dioxide into Several Potential Chemical Commodities Following Different Pathways- A Review", a Chapter in the book on Materials Science Forum Viz. 'Photocatalytic Materials and Surfaces for Environmental Cleanup-III' Trans Tech Publications-Switzerland, (ed). R. Tayade, p 01-82, 2013.
6. D. Rekha, H.Y. Kim and P.H. Borse, "Investigation of Solar Photoelectrochemical Hydrogen Generation Ability of Ferrites for Energy Production", a Chapter in the book on Materials Science Forum Viz. 'Photocatalytic Materials and Surfaces for Environmental Cleanup-III' Trans Tech Publications-Switzerland, (ed). R. Tayade, p 97-115-, 2013.
7. I. Ganesh, D. Rekha, 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 the book on Materials Science Forum Viz. 'Photocatalytic Materials and Surfaces for Environmental Cleanup-III' Trans Tech Publications-Switzerland, (ed). R. Tayade, p 266-283, 2013.
8. Vivek Patel and Y.R. Mahajan, "Polymer Nanocomposites Emerging Growth Driver for the Global Automotive Industry" a Chapter in the book on 'Technology Advancement in Polymer Nano-composites of layered Silicates Processing, Performance and Applications', Springer Verlag 2012 (In Press).
9. Dr. R. Subasri, "Properties of Nanocomposite Hard Coatings on Polycarbonate" a Chapter in book on "Polymer Nanocomposite Coatings (ed.), Vikas Mittal, CRC Press (Taylor & Francis Group), USA (In Press).

## Awards and Honours

1. Mr. M. Sreekanth (Dr.B.V. Sarada) received the 'Best Poster Award' for the poster presentation on "Preparation of $CuInSe_2$ (CIS) Thin Films by Pulsed Electrodeposition for Solar Cell Applications" at the '3rd EICOON School on Renewable and Clean Energy Sources 2012' held at Kolkata during April 30-May 01, 2012.

2. Mr. B. Viswanath Sasank received the 'Excellent Paper Award' for presenting the paper on "Design and Development of a Closed Two Loop Thermal Management Configuration for PEM Fuel Cell" at the 'International Conference on Environment and Industrial Innovation 2012' held in Hong Kong during June 02-03, 2012.

Mr. B. Viswanath Sasank receiving the 'Excellent Paper Award'

3. Dr. G. Padmanabham delivered the 'Dr. S.P. Luthra Memorial Lecture' on "Industrial Laser based Manufacturing Technologies for Sustainability and Safety in Mobility" at the '28th National Convention of Mechanical Engineers NCME 2012' organized by the Institution of Engineers (India), Coimbatore at Coimbatore during September 03-05, 2012.

4. Dr. K. S. Dhathathreyan received the 'Best Paper Award' for presenting a paper on "Design, Development and Operational Experience of Non-humidified PEMFC Systems Built With Light Weight Bipolar Plates" at 'PETROTECH-2012' held at New Delhi during October 14-17, 2012.

5. Dr. G. Padmanabham was conferred the 'Honorary Fellow of the Indian Welding Society' during the 'International Welding Symposium-2012 (IWS2k12)' held at Mumbai during October 30-November 01, 2012.

6. Mr. M. Srikanth (Dr. P. K. Jain) received the 'Best Poster Award' for the poster presentation on "Electrochemical Properties of Flexible Conductive Paper using Carbon Nanotubes for Energy Storage Application" at the 'National Conference in Carbon Materials 2012' held at BARC, Mumbai during November 01-03, 2012.

7. Dr. S. V. Joshi was inducted as a 'Fellow' of the Indian National Academy of Engineering (INAE), during the "INAE Annual Convention" held at Roorkee on December 06, 2012. On this occasion he delivered a talk on "Solution Precursor Plasma Spraying: Opening New Vistas in Surface Engineering".

8. Ms. K. H. Anulekha (Dr. Tata N. Rao) received the 'Best Oral Presentation Award' for presenting a paper on "Fabrication and Surface Functionalization Studies on Electrospun Polystyrene Sub-Micron Fibers" at 'Chemference 2012' held at Mumbai during December 10-11, 2012.

Ms. K. H. Anulekha receiving the 'Best Oral Presentation Award'

9. Mr. T. K. Gireesh Kumar was awarded the 'LIS Links Scholar Award 2010' by the Library and Information Science Links (LIS Links) at Guwahati, Assam on December 31, 2012.

10. Dr. K. Rajeshwari (Dr. Roy Johnson) received the 'Second Best Poster Award' for the poster presentation on "Effect of Hot Isostatic Pressing on Visible Transparency and Ionic Conductivity of Pressure Less Sintered 8Y Zirconia Specimens" at the 'National Conference on Green Manufacturing and technologies in Glass and Ceramics (GTGC-ICS)' held at Ahmedabad during January 18-19, 2013.

11. Ms. R. Papitha (Dr. Roy Johnson) received the 'Second Best Oral Presentation' for presenting a paper on "Effect of Low Temperature Annealing on Thermomechanical Properties of $Al_2TiO_5$ Ceramics" at the 'National Conference on Green Manufacturing and technologies in Glass and Ceramics (GTGC-ICS)' held at Ahmedabad during January 18-19, 2013.

12. Dr. G. Padmanabham was conferred the 'MRSI Medal' by the Materials Research Society of India at the 'Annual General Meeting 2013' of the Materials Research Society of India held at IGCAR, Kalpakkam during February 11-13, 2013. On this occasion he delivered the MRSI medal lecture on "Some Microstructural Effects in Laser Materials Processing".

# PERSONNEL

## (as on March 31, 2013)

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Dr. G Sundararajan

### ASSOCIATE DIRECTORS

Dr. Shrikant V Joshi
Dr. G Padmanabham
Dr. K S Dhathathreyan

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M Satyanand, Technician 'B'
B Hemanth Kumar, Technician 'B'
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A Jagan, Technician 'B'
Suri Babu Pandit, Technician 'B'
G Anjan Babu, Technician 'B'
I Prabhu, Technician 'A'
D Manikya Prabhu, Technician 'A'
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S Narsing Rao, Technician 'A'
Ch. Jangaiah, Technician 'A'
Lingaiah Mothe, Technician 'A'

### CHIEF FINANCE & ACCOUNTS OFFICER

R Vijay Kumar

### ADMIN. & PERSONNEL OFFICER

R Prabhakara Rao

### SECURITY & FIRE OFFICER

S Jagan Mohan Reddy

### STORES & PURCHASE OFFICER

N Srinivas

### OFFICERS

T Panduranga Rao, Officer 'C' (till 29/06/2012)
P Nagendra Rao, Officer 'C'
Anirban Bhattacharjee, Officer 'B'
G M Raj Kumar, Officer 'B'
A Srinivas, Officer 'B'
Ms. N Aparna Rao, Officer 'B'
Y Krishna Sarma, Officer 'A'
G Ramesh Reddy, Officer 'A'
P Venugopal, Officer 'A'
B Uday Kumar, Officer 'A'
Venkata Ramana Pothuri, Officer 'A'
Ms. P Kamal Vaishali, Officer 'A'

### ASSISTANTS

Ms. K Shakunthala, Assistant 'B'
P Dharma Rao, Assistant 'B'
G Gopal Rao, Assistant 'B'
T Venu, Assistant 'B'
B Laxman, Assistant 'B'
Ms. Rajalakshmi Nair, Assistant 'B'
Ravi Singh, Assistant 'B'
Ms. K Madhura Vani, Assistant 'A'
Narendra Kumar Bhakta, Assistant 'A'
J Bansilal, Jr. Assistant

### DRIVERS

Md Sadiq, Driver 'C'
P Ashok, Driver 'B'
T Satyanarayana, Driver 'B'
M A Fazal Hussain, Driver 'B'

### LAB ASSISTANTS

Aan Singh, Lab Assistant 'C'
Roop Singh, Lab Assistant 'C'
Gaje Singh, Lab Assistant 'C'
Hussain Ali Khan, Lab Assistant 'C'

### CONSULTANTS

Dr. Y R Mahajan
Dr. A M Sriramamurthy
Arun Joshi
Dr. A Venugopal Reddy
A Sivakumar
G Ramachandra Rao
Dr. T G K Murthy
Dr. S Devi Das
Dr. R Madhusudhan Sagar
Dr. V Chandrasekharan
Suresh Prasad Sarma

### OFFICERS ON DEPUTATION/ LIEN TO OTHER ORGANIZATIONS

R Varadarajan, Officer 'C' (on lien) (till 13/08/2012)

### CONTRACT SCIENTISTS

Dr. N Rajalakshmi
Dr. K Ramya
Dr. T Mohan
Dr. K Suresh
Dr. Dinesh Rangappa (till 14/06/2012)
Dr. Raju Prakash
Dr. Rajappa Tadepalli (till 01/03/2013)
Dr. Srinivasan Anandan (from 04/06/2012)
Dr. Prabhu Delhi Babu (from 01/05/2012)
Dr. M. B. Sahana (from 02/07/2012)