Commercial Prospects for Nanomaterials in India

G. Sundararajan AND Tata Narasinga Rao

Abstract | The area of nanoscience and technology is growing rapidly around the world and nanomaterials based products, especially in the consumer sector, are coming into market very rapidly. India is competing, with great difficulty, with other developed countries to make its position strong in this field. In other respect, several challenges have to be overcome in terms of production of nanomaterials at commercial scale, their processing, applications and commercialization. The present article describes the present state of nanomaterials based technology development, commercialization and future prospects for this technology in our country.

1. Introduction

Nanotechnology, defined as the application of nanoscience in technological devices/processes/products, is fast emerging as an important enabling technology capable of impacting almost all the sectors of industries and consumer products. Therefore, not surprisingly, all governments and industries the world over are investing heavily in the development of nanotechnology based processes, products and systems. Nanotechnology represents a very broad area and is composed of three main fields, i.e. nanomaterials, nanotools and nanodevices. Of these, both research and commercialization have occurred to a significant level only in the area of nanomaterials. In India also much of the research and technology development work has taken place in the arena of nanomaterials. Thus, this paper will concentrate on highlighting the status of nanomaterials research and commercialization in India.

Nanomaterials represent a class of materials characterized by a feature size of less than 100 nm. In the case of nanoparticles, the feature size is the particle diameter while in carbon nanotubes, it is the nanotube diameter. At the other extreme, in the case of bulk materials, either the grain size in homogeneous materials or the reinforcing particle size and spacing in the case of composites represent the feature size. Thin films having thickness less than 100 nm or multi-layer coatings with the thickness of each layer less than 100 nm also qualify as nanomaterials. Therefore, it is important to note that while nano devices will certainly have to be made from nanomaterials, nanomaterial itself impacts areas beyond nanotechnology. For example, the recently developed nanosteel by a Japanese company [1] is a nanomaterial which will impact the automobile and infrastructure industry by providing high strength, high toughness steel sheets with superior formability and corrosion resistance.

It is also important to understand that merely bringing the feature size to below 100 nm is not enough; more importantly, such a decrease in feature size should result in significant enhancement of strength, toughness or electrical, electronic, optical and magnetic properties.

2. International Status

The last decade has witnessed an explosive growth in the area of nanomaterials research and commercialization primarily because of the availability of new methods of synthesis of

International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Balapur Post, Hyderabad-500005, India
gsundar@arci.res.in

Figure 1: Categories of nanomaterials-based products as listed by the Project on Emerging Nanotechnologies (PEN).

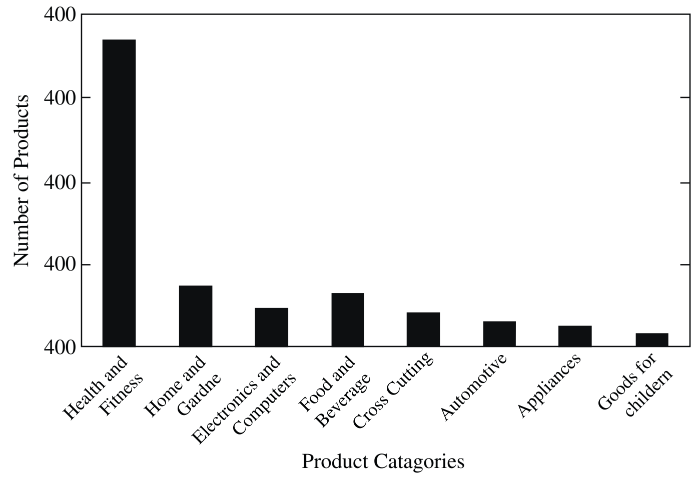
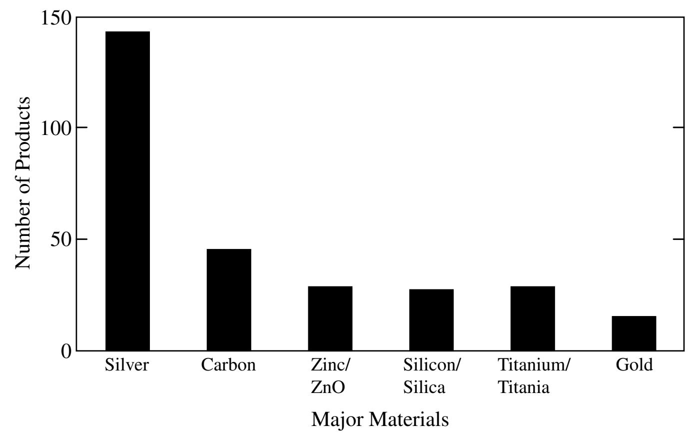


Figure 2: Categories of nanoproducts based on material applications as listed by the project on emerging Nanotechnologies (PEN).



nanomaterials as well as tools for characterization and manipulation of materials at nanoscale. In countries like USA, Germany, UK, Japan, Singapore, Taiwan, Korea and China, the area of nanomaterials have reached the stage of commercialization. New nanomaterials based consumer products are coming into the market at the rate of three to four per week, according to a survey [2] concerned with the inventory of nanomaterials based consumer products being conducted by the Project on Emerging Nanotechnologies (PEN). The number of consumer products using nanomaterials has increased from 212 to 609 since PEN launched the world's first on-line inventory of manufacture identified nanoproducts in March 2006 as illustrated in Fig. 1. Of the 609 nanoproducts in the market, more than 60% correspond to health and fitness items (i.e., cosmetics, sunscreens etc.) while only 6% of the products represent engineering products for the auto industry (e.g. paints, nanocomposites etc.). In terms of consumption of nanomaterials for manufacture of the above nanoproducts, nanosilver is the most used material with 143 products using this material as observed from Fig. 2. Nanosilver is followed by Carbon (Carbon nanotubes, fullerenes and carbon itself), nano Zinc (Zinc Oxide and Zinc) and nano Titanium (e.g. Titania). At present, as depicted in Table 1, large and medium companies are concentrating on nanomaterial synthesis on large scale while the smaller companies (majority of them being hi-tech start-ups) are looking at specific application and product development. Many of these smaller companies are looking towards bigger companies buying their technologies (and companies) once it is proven.

3. Indian Scenario

3.1. *Governmental Support*

Compared to developed countries, India has initiated a focused effort on nanotechnology only in 2001, i.e., 5–7 years after countries like USA, EU, Japan, Korea and Taiwan started their own programmes. In October 2001, India launched a major programme in nanotechnology when Department of Science and Technology (DST) launched the Nano Science and Technology Initiative (NSTI) and operated it for 5 years during the period 2001–02 to 2006–07. During this phase, the emphasis was on creating Centers of Excellence in various aspects of nanotechnology in the various universities and R&D laboratories in India. Bulk of the funding was utilized to procure specialized equipment required for nanoscience like AFM, SEM, TEM, Nanoindentor etc. In all, about 100 projects were funded under NSTI.

Enthused by the overwhelming response to the NSTI programme, DST has now initiated the Nano Mission programme with a funding of Rs. 1, 000 crores over the period 2007–08 to 2001–12 [3]. However, unlike NSTI, Nano Mission has created three full-fledged institutes of Nanoscience and Nanotechnology in Bangalore, Kolkata and Mohali respectively. Further, the Nano Mission will not only support high quality research in nanoscience (as NSTI did earlier) but also fund projects focusing on application and product development with the active participation of Indian industries. It should also be pointed out that other governmental agencies like CSIR, DBT, DRDO, DAE and ISRO are also undertaking major projects in the area of nanoscience and nanotechnology.

As a result of the NSTI programme of DST, the number of technical papers constituting original research contributions to the nanotechnology area has continuously increased year after year as illustrated in Fig. 3. The cumulative number of publications in the area of nanotechnology over the last decade (1998–2007) has crossed a figure of 7, 000. The research area covered in these publications includes a wide range of topics such as carbon nanotubes, inorganic nanotubes, inorganic and organic composites, nanophase alloys, optical materials, semiconductor materials, nanomagnets, nanocatalysts, photocatalysts, nanophosphors, fuel cell electrodes, coatings, sensors, quantum dots, solar cell and photonic materials, nanostructured and nanolayered coatings, aerogels, nanofunctional textiles, nanopolymer composites and nanoembedded systems. A wide range of synthesis routes have been explored for nanomaterial synthesis including sol-gel, salvo-thermal, chemical precipitation, chemical combustion, hydrothermal, spray pyrolysis, flame synthesis, microwave plasma synthesis, electrical wire explosion, chemical vapour synthesis, arc discharge, electrochemical and biological methods. Thus, it is obvious that bulk of the research work being carried out in India is in the area of nanomaterials.

3.2. *Industrial Support to Nanomaterials R&D*

Unlike in USA, Europe and Japan, the Indian industries have started looking at nanotechnology as a solution for their problems only recently. Among the bigger companies, Reliance Industries, Tata Chemicals, Mahindra and Mahindra, Ashok Leyland, Asian Paints, Crompton Greaves have initiated programmes in the area of nanomaterials on their own or in collaboration with academic/R&D institutions. In addition, industry associations like Confederation of Indian Industry (CII), Federation of Indian Chambers of Commerce and Industry (FICCI), Society for Indian Automobile Manufacturers (SIAM), Automotive Component Manufacturers Association (ACMA) have realized the importance of nanomaterials and nanotechnology and have started arranging get-togethers among the industry representatives and experts in nanomaterials/nanotechnology to evaluate the possibilities with respect to nanomaterials in the industry. Lastly, R&D centers of multi-national companies like GE R&D at Bangalore, GM Science Centre at Bangalore, DuPont R&D at Hyderabad have already initiated a number of programmes in the area of nanomaterials. However, compared to developed countries, the R&D expenditure incurred by Indian companies in the area of nanomaterials/nanotechnology are still minuscule. Further, the R&D expenditure of Indian industries are substantially lower than the R&D support provided by the Government of India unlike in countries like USA, Japan, Korea, Taiwan and Europe wherein the industrial investment in nanotechnology R&D are at least 2 to 3 times that of their respective governments.

3.3. *Nanomaterials: Application Development*

As India is already behind the developed countries in both nano research and application development by 5–10 years, it is important that India chooses the application areas for nanomaterials wherein either the Indian market is very large in the world context

Figure 3: Technical papers (year wise) in the field of nanotechnology contributed from the scientists from Indian institutions. The data for 2008 was updated up to 15th October.

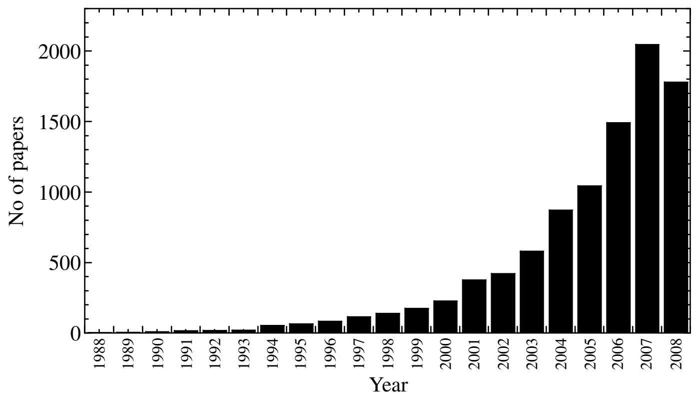


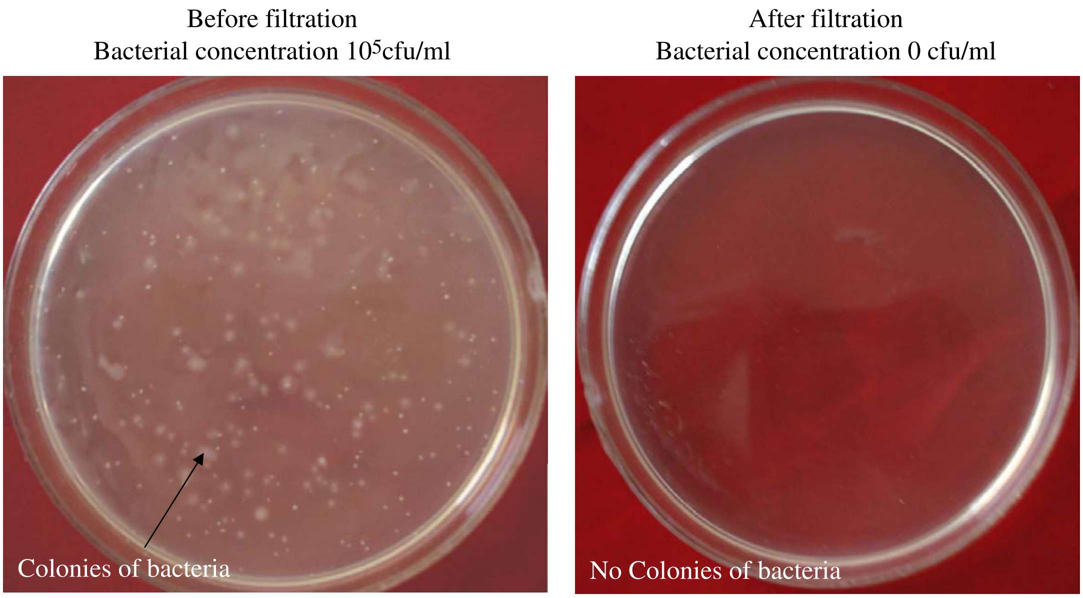
Table 1: Major global manufacturers of Engineered nanomaterials.

Name	Type	Country	Products
Bayer	Big Chemical	Germany	Bulk production of Baytube carbon nanotubes
BASF	Big Chemical	Germany	Bulk production of various nanomaterials (uses include food additives and sunscreen)
Degussa	Big Chemical	Germany	Bulk production of a range of ultrafine and nanomaterials
ICI/Uniquema	Big Chemical	UK	Bulk production of nanomaterials (including nano titanium dioxide for sunscreens)
Mitsubshi Chemical	Big Chemical	Japan	Bulk production of carbon nanotubes
Advanced Nanomaterials	Nano Specialist	Australia	Bulk production of a range of nanomaterials (uses include sunscreens, catalysts. cosmetics and coatings)
Nanophase	Nano Specialist	USA	Bulk production of a range of nanomaterials
Hyperion Catalysis	Nano Specialist	USA	Nanotubes for incorporation into plastics
Carbon Nanotechnologies Inc	Nano Specialist	USA	Bulk production of carbon nanotubes
Umicore	Specialty Chemical	Belgium	Bulk production of nanomaterials (including nano titanium dioxide for sunscreens)
Elementis	Specialty Chemical	UK	Bulk production of nanomaterials (including nanoparticles ZnO sunscreens)
Nanogist	Nano Specialist	Sounth Korea	Bulk production of nanomaterials (anti microbial silver nanoparticles)
Qinetiq Nanomaterials	Nano Specialist	UK	Bulk production of a range of nanomaterials

or which are unique/specific to India. Examples of the former include two and three wheelers, autocomponent and textiles markets while the health, drinking water are examples of the latter.

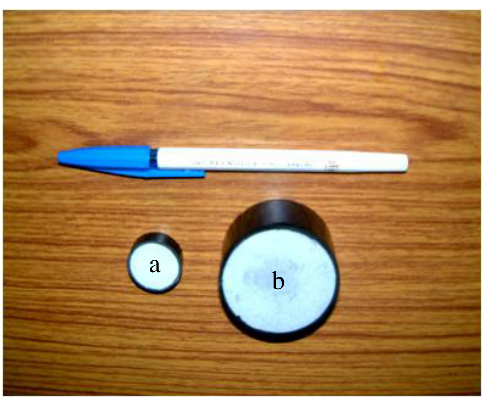
The application-oriented research in India in the last few years has focused primarily on energy, environment and health related areas. For example, the invention of flow induced electrical response in carbon nanotubes has direct relevance in biological and biomedical applications [4]. Indian Institute of Science has transferred the exclusive rights of this technology to an American start-up to commercialize the gas-flow sensors. Nanocrystalline gold triangles developed by a group at National Chemical Laboratory (NCL) has been shown to be useful for cancer treatment by hyperthermia, where the irradiation of the cancer cells is carried out by infra-red radiation [5]. These materials have also found their use in insulin delivery for advanced diabetics. NCL has already applied for an American patent for this breakthrough. The achievements of a research group at University of Delhi on drug delivery are highly commendable. This group has developed 11 patentable technologies for improved drug delivery systems using nanoparticles. One of the important achievements of this research is the development of a reverse micelles based process for the synthesis of hydrogel nanoparticles for

Figure 4: Antibacterial performance of nanosilver-coated ceramic candle filters for drinking water developed at ARCI, Hyderabad.



encapsulating water-soluble drugs. This technology has been sold to Dabur research foundation in India. They are also co-developing nano-polymer and liposome based drug delivery systems. A research group at Banaras Hindu University, has developed a novel method to produce a membrane out of carbon nanotubes for treating contaminated drinking water [6]. Eureka Forbes, in collaboration with IIT Madras, has come out with a nanosilver-based water filter for the removal of dissolved pesticides in drinking water [7].

Figure 5: Nanocrystalline ZnO-based varistors (a) developed by ARCI are compared with a commercial conventional varistor (b) exhibiting similar performance.



Among the Indian research laboratories, ARCI is one of the fast growing research centers with a unique mandate to develop and demonstrate technology and transfer the same to industries. ARCI has set up the Centre for Nanomaterials with a view to develop nanomaterial synthesis and application technologies which are scalable and economical in comparison to existing technologies. The Centre for Nanomaterials at ARCI has the synthesis facilities to produce a wide range of metallic, ceramic and cermet nanopowders in large quantities, processing facilities for agglomeration, compaction and sintering of nanopowders to produce bulk nanostructured components, unique coating facilities to produce nanostructured and nanolayered coatings and films and also CNT based nanocomposites. In addition, the nanopowders have been used as such for a variety of applications.

ARCI has already developed a number of applications over the last few years. One of them is the low cost nanosilver-coated ceramic candle for disinfection of drinking water. The Centre has filed an Indian patent [8] for the above process and has subsequently installed 100 nanosilver candle based water filter systems for field testing at various village health centers in Andhra Pradesh in collaboration with Byrraju Foundation. During the field testing, these filters have demonstrated a consistent performance in removing the bacteria from the water as illustrated in Fig. 4.

Another technology that ARCI has developed is the lightening arresters based on ZnO

Figure 6: I-V characteristics of nanocrystalline ZnO-based varistor (a) compared with that of a commercial one (b).

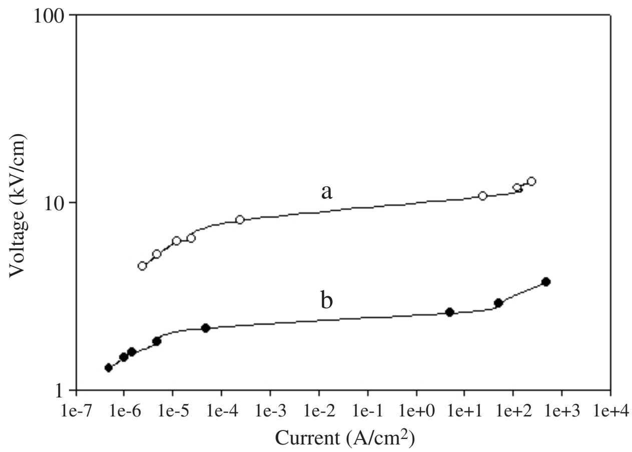


Figure 7: Commercial nanosilver-coated ceramic candle filters for drinking water. (technology developed and transfered by ARCI)

microcrystalline powders [9]. The lightening arrestor (varistor) is commercially made using nanocrystalline powders of ZnO blended with several other oxides which are necessary to get the varistor action. As the breakdown voltage (at which the varistor becomes conductor) depends on the grain boundary area, this can be tuned by decreasing the grain size in the sintered compact of varistor. While main challenge being the synthesis of nanocrystalline ZnO along with the additive oxides in one step with a scalable method, the other challenge is to process the nanopowders into sintered compacts with high reproducibility. This is because the powder metallurgy of nanopowders is difficult due to high surface to volume ratios. ARCI has demonstrated a single step synthesis of nanocrystalline varistor powders and processing of these materials into sintered compacts by conventional powder metallurgy route (Fig. 5). A five fold increase in the breakdown voltage has been demonstrated by this technology (Fig. 6).

3.4. *Nanomaterials: Commercialisation*

The migration of the technology developed at the laboratory to the market place is more challenging than the development of the technology itself. Apart from the scalability and cost-effectiveness of the process/technology to enable large-scale production, it is important to ensure that sufficient market (new or replacement) is available for the product produced using the process/technology. Even if sufficient market is waiting to be tapped, marketing skill largely determines the actual market size for the product.

The ARCI technology for nanosilver based candle filter has been transferred to SBP Aquatech Pvt. Ltd., a Hyderabad company, which will have an initial capacity to product 500 candles a day [10]. The product, already in the market (Fig. 7), is now undergoing initial marketing trials. Like the Hyderabad company marketing nanosilver candle filters, there are a few more companies operating in the area of nanomaterials and all of them are operating at small scales. For example, United Nanotechnology Products, Kolkata has set up a pilot scale production facility for nanocrystalline Lithium iron phosphate required for making the electrode for Li-ion batteries [11]. However, the above product is largely meant for export. Similarly, Monad Nanotech Ltd. and Innovation Unifed Technologies, both from Mumbai, are selling carbon nanotubes and carbon nanofibres, but in small quantities.

Nano Cutting Edge Technology Pvt. Ltd., Mumbai is undertaking contract research to make metal nanogels and palladium nanoparticles. Valbionanotech, Bangalore develops bionanochips and DNA based drugs. CARD, Bangalore has developed nanoblaster to blast cancer cells in the human brain. Bharat Biotech, Hyderabad has developed nanoparticle-loaded drugs (Estrosarb) for drug delivery. Cranes Software, Bangalore is working om MEMS. SSB Technologies, Mumbai is making nanoproducts under the name of Nanocid. Panacea Biotech, New Delhi and Lifecare Innovations, Gurgaon are developing nanotech-based drug delivery systems. Arrow is selling unstainable textiles. Yashnanotech, Bangalore is launching sensitive substrates for Raman Spectroscopy, AFM tips and metal sponges. Auto Fibre Craft, Jamshedpur is producing nanosilver and nanogold in both powder and suspension forms. Bee Chems in Kanpur is making nanosilica and nanoalumina binders for various applications. Nanobio Chemicals, Belgaum is developing high quality metal and oxide nanoparticles, peptides and other biochemicals. Nano Factor Materials Technologies Pvt. Ltd., Bangalore manufactures carbon nanotubes through a patented technology.

3.5. *Safety, Health and Environmental (SHE) Issues*

It is increasingly becoming apparent that nanotechnology, though touted as the future solution for almost all our technological requirements, has to be assessed carefully and now with regard to safety, health and environmental (SHE) issues so that we do not repeat the mistakes made in the past with regard to asbestos, chloroflurocarbons etc [12]. The nanotechnology community should evaluate the SHE issues with an open mind, on the basis of scientific data, and voluntarily embark on regulatory measures and create specific standards for nanotechnology products. In extreme cases, wherein the health, safety or environmental concerns are sufficiently high, the concerned product/technology should be abandoned or temporarily suspended till specific evaluation studies are carried out to resolve the issue.

4. Conclusions

The above review clearly indicates that the awareness about nanomaterials and nanotechnology and its benefits to society has continuously increased among the Indian scientific and industrial community over the last decade. The intensity of scientific research in the area has also increased considerably over the years, though in terms of number of quality publications in technical journals, we still lag behind countries like Korea, China and Taiwan leave alone the leading countries like USA, Japan and Europe. However, in the areas of application development and commercialization of nanomaterials based technologies, India is far behind even compared to countries like Singapore. Both the government and industry needs to ramp up their efforts in this area dramatically and immediately; otherwise we may miss the "nanobus" as we did with the "semiconductor bus".

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Dr. G. Sundararajan obtained his B.Tech (Metallurgy) from IIT, Madras in 1976 and M.S and Ph.D from Ohio State University, Columbus, Ohio, U.S.A in 1979 and 1981 respectively. He returned to India in September 1982 and joined Defence Metallurgical Research Laboratory (DMRL) as a scientist. He was at DMRL till 1997 and then was appointed as Director of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) from September 1997.

Dr. Tata Narasinga Rao was born in Andhra Pradesh in India in 1963. He received his Ph. D. in the field of Photoelectrochemistry in 1994 from Banaras Hindu University, Varanasi. After working as Research Associate for a year at IIT, Madras, he moved to The University of Tokyo as a JSPS Postdoctoral Fellow in 1996 and became an Assistant Professor of the Department of Applied Chemistry at the University of Tokyo in 2001. He Joined International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) in 2003 as a Senior Scientist and became Team Leader of Centre for Nanomaterials at ARCI. He is also guest faculty at IIT, Hyderabad.