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An era of high-tech materials

Dear Reader,

A very happy scientific new year 2016!

The design of innovative materials is one of measure for driving industry to place the sustainable basis of new technology in order to enhance the wealth and well-being of society. The last half century has realized a vital development in the area of high-tech materials ranging from various elements and composites, emerged through synthetic chemistry and often drawing motivation from the nature. The idea of an intelligent material imagines added values in terms of functionality built into the materials structure desirable to response the defined conditions. The previous two decades has emerged to understand the extraordinary behavior and properties of engineered nanostructured materials.

Nanotechnology was first conceptualised by science fiction writers like Robert Heinlen and Eric Frank Russel in the 1940s, but it was Richard Feynman's (1918-1988) visionary talk "There's plenty of room at the bottom" in 1959 that is often credited with launching Nanotechnology. While much of the early focus was on nanofabrication and nanoelectronics, the application of science and technology at the nano-scale also promises to revolutionise medicine in the 21st Century, enabling us to understand many diseases leading to new insights in diagnostics and therapy and contributing to the development of new generations of medicinal products exploiting functional materials, nano-biomaterials and medical nano-devices. Healthcare is one of the largest and most rapidly expanding needs in society today and smart nanomaterials will have application in a diverse arena including drug screening technologies, biocompatible materials and orthopaedic implants, lab-on-a-strip and nanobiosensors, drug delivery, degenerative disease diagnosis and treatment, self-assembled bio-structures, advanced medical imaging and regenerative medicine. On a wider front, intelligent nanomaterials are contributing to new coatings, fabrics, memory and logic chips, contrast media, optical components, superconducting electrical components etc. Some commentators have rather overstated the market size for nanomaterials by referring to the price of finished products such as cars and phones, rather than the intermediate products more properly attributed to the materials themselves. Nevertheless, even conservative estimates place the current market size for the materials alone at around US$25b. Current products have been dominated by simple nanostructures with beneficial properties such as the antimicrobial properties of silver nanoparticles. However, we are now witnessing the emergence of active nanostructures in the form of electronics, sensors, drug release technologies and adaptive structures. The future promises molecular nanosystems with hierarchical functions and evolutionary systems that will power the next generation of industrial developments.

In general, nanomaterials are made up of components with at least one dimension ranging from 1 to 100 nm. In the nanometer dimensions, amazing physical and chemical properties can be observed, which have formed the basis for a growing nanotechnology industries. The systematic understanding and commercial exploitation of nanomaterials appeared in the early 1990's, as indicated by a burgeoning number of patents. These new varieties of low dimensional materials have much larger surface to volume (S/V) ratios as compared to their bulk counterparts. With decrease in the size of nanoparticles, the S/V ratio increases abruptly. It is well known that surface atoms in any material are loosely bound as compared to the interior atoms, hence with increase in surface area the surface free energy increases. Nanomaterials therefore play very prominent role in physical, chemical, biomedical, engineering and technological applications due to their high surface energies. Also the electronic configuration of atoms within the materials is imperative since this principally determines the type of bonding and thus electrical, optical, luminescent, mechanical and magnetic properties.

The graphene and related 2D super-thin materials are the most focused domain of materials research in the present decade mainly fundamental phenomenon related to physics, chemistry, biology, applied sciences and engineering. As the first atomic-thick two-dimensional crystalline material, graphene has continuously created a wonder land in nanomaterials and nanotechnology. A number of methods have been developed for preparation and functionalization of single-layered graphene nanosheets, which are essential building blocks for the bottom-up architecture of various graphene based materials. They possess unique physicochemical properties such as large surface areas, good conductivity and mechanical strength, high thermal stability and desirable flexibility. Altogether they create a new type of super-thin phenomenon and are highly attractive for a wide range of applications. The electronic behaviour in graphene such as Dirac fermions obtained due to the interaction with the ions of the lattice has led to the discovery of novel miracles like Klein tunneling in carbon based solid state systems and the so-called half-integer quantum Hall effect due to a special type of Berry phase.

Noble metallic nanoparticles/nanostructures exhibit interesting feature of localised surface plasmon resonant (LSPR); absorption can be tuned from ultraviolet region to infrared region of electromagnetic spectrum and this field has been developed to deliver potential applications in photonics, optoelectronics, optical-data storage, solar cells, filters, sensors not to mention the considerable scope in medical engineering, such as DNA labeling, tumor and cancer therapy etc.

Study of the propagation of electromagnetic waves through metallic nanostructures with different shapes has become a major field due to fascinating applications in antennas and also left handed materials. Semiconductor nanostructures on the other hand are very promising candidates for applications in luminescent devices such as light emitting diodes, flat screen displays, lasers etc. and especially in electronic devices, due to their extraordinary feature of band gaps ranging from UV-visible to infrared regions.

Silicon has reigned supreme amongst materials responsible for miniaturization of the world of electronics in the last century. However, recent progresses in the design of materials synthesised from other semiconducting families, such as III-V or II-VI, are showing even more promise for versatile applications and may provide a new generation of materials. For example, nano-micro structures of zinc oxide/sulphide, tin oxide, cadmium sulphide and titanium oxide display interesting electrical, optical and mechanical properties. They can be used in a wide variety of applications ranging through from sensors, LEDs, flat panel displays, energy storage/ harvesting and batteries.

Similarly, advances in synthesizing nano-micro structures from insulators like silica and polymers, have found interesting applications in biomedical engineering such as drug delivery and implants. Conducting polymers have opened an entirely new field of organic field-effect transistors, organic light-emitting diodes, light weight electronics etc. The current challenges in material engineering demand the fabrication of multicomponent composite materials having multifunctional properties. Inter-mixing of two or several nanostructural components into a composite form will give rise complementary properties which will enable these materials to exhibit the capability of self-repair under any external damage or perturbation. These kinds of materials which exhibit the ability of self-repairing under external cause clearly fall into the category of 'intelligent nanomaterials'.

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With kindest regards,

Ashutosh Tiwari, PhD, DSc
Editor-in-Chief, Advanced Materials Letters

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