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State of Art of Nanotechnology

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Abstract—The emerging fields of nanoscience and nanoengineering are leading to unprecedented understanding and control over the fundamental building blocks of all physical matter. This is likely to change the way almost everything — from vaccines to computers to automobile tires to objects not yet imagined —is designed and made. Use it as a prefix for any unit like a second or a meter and it means a billionth of that unit. A nanosecond is one billionth of a second. And a nanometer is one billionth of a meter—about the length of a few atoms lined up shoulder to shoulder. A world of things is built up from the tiny scale of nanometers. The thousands of cellular proteins and enzymes that constitute eg., The human bodies are a few nanometers thick. Enzymes typically are constructions of thousands of atoms in precise molecular structures that span some tens of nanometers. That kind of natural nanotechnology is about ten times smaller than some of the smallest synthetic nanotechnology that has been prepared until now. The individual components of an Intel Pentium III microprocessor span about 200 nanometers. This is the reason that computing is so powerful and easy these days. Nanotechnology makes microelectronics to be mere hints of what will come from engineering that begins on the even smaller scales of nanostructures. Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionizing the ways in which materials and products are created and the range and nature of functionalities that can be accessed. It is already having a significant commercial impact, which will assuredly increase in the future. In this paper, we have reviewed briefly some nano materials related works already published or available in the internet with organized manner.

Keywords—Nanotechnology, Nanoparticle, Nanotube, Nanowire, Nanocomposite, Diamond like nanocomposite

I. INTRODUCTION

In the recent years a new branch of research and development has raised up, generally referred to as “nanoscale science and technology”. The ability of scientist to manipulate the matter virtually atom by atom has been supported by the development of new instruments and approaches that allow the investigation of material properties with a resolution close to the atomic level. Such new tools had allowed the extensive understanding of the unusual physical and chemical properties characterizing the matter at the nanometer scale opening up the way to the employ of nanomaterial in a wide variety of applications involving material science, engineering, physics, chemistry and biology. The term nanotechnology was first introduced by Richard Feynman in 1959 and K.Eric Drexler popularized it in 1986. The term ‘Nano’ is derived from Greek word ‘dwarf’. Here it refers to one billionth of a meter or 10^{-9}meter. Nanotechnology puts the power of creation in human hands

Nanocomposite is also a challenging area of research in the recent era of nanotechnology [1-5]. Nanocomposite materials basically are formed by mixing two or more dissimilar materials at the nanoscale in order to control and develop new and improved structures and properties [6-8]. The properties of nanocomposites depend not only upon the individual components used but also upon the morphology and the interfacial characteristics. Nanocomposite coatings and materials are among the most exciting and fastest-growing areas of research; with new materials being continually developed which often exhibit novel properties that are absent in the constituent materials. Nanocomposite materials and coatings therefore offer enormous potential for new applications including: aerospace, automotive, electronics, biomedical implants, non-linear optics, mechanically reinforced lightweight materials, sensors, nano-wires, batteries, bioceramics, energy conversion and many others [7-10].

Nanostructures normally assembled from some building blocks. These fundamental building blocks are created from atoms of 91 naturally occurring elements. It is inefficient to start with individual atoms due to the slowness and less strength materials. Usually nanostructures are built, starting with larger building blocks or molecules as components. Nanostructures are new semi molecular building blocks to assemble nanostructures.

Two of these nanostructures are Nanotubes & Nanorods that can be made out of silicon, other semiconductors, metals or even insulators [11-15]. These Nanorods are made using clever solution chemistry methods, but they can then self assemble into larger Nanoscale structures.

II. NANO TECHNOLOGY BASIC

The basic idea of nano structure can be recognize with the help following diagram

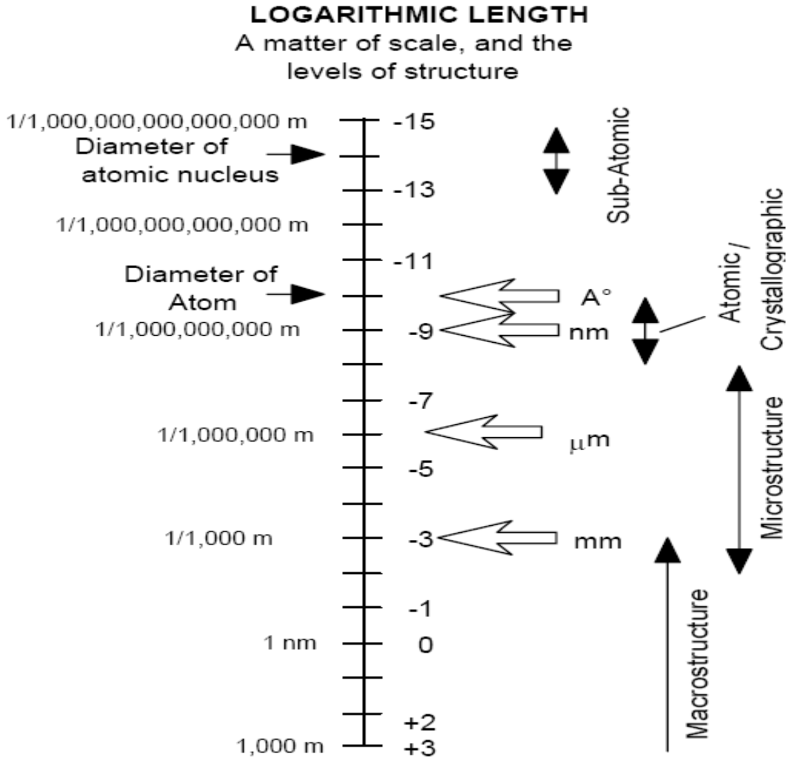

Fig. 1. Macrostructure to nano structure scale

For the whole size issue , the following Fig.2 (a**) Less than nanometre**- individual atoms are up to a few angstroms, or up to a few tenths of a nanometer in diameter; (b) **Nanometer**- Ten shoulder-to-shoulder hydrogen atoms (blue balls) span 1 nm. DNA molecules are about 2.5 nm wide; (c) **Thousands of nanometers**- Biological cells, like these red blood cells, have diameters in the range of thousands of nm; (d) **a million nanometers**- A pinhead sized patch of this thumb (black point) is a million nanometers across; (e) **Billions of nanometers**-a two meter tall person is two billion nanometers tall. Fig.3 shows the evolution of science and technology in past, present and future respectively.

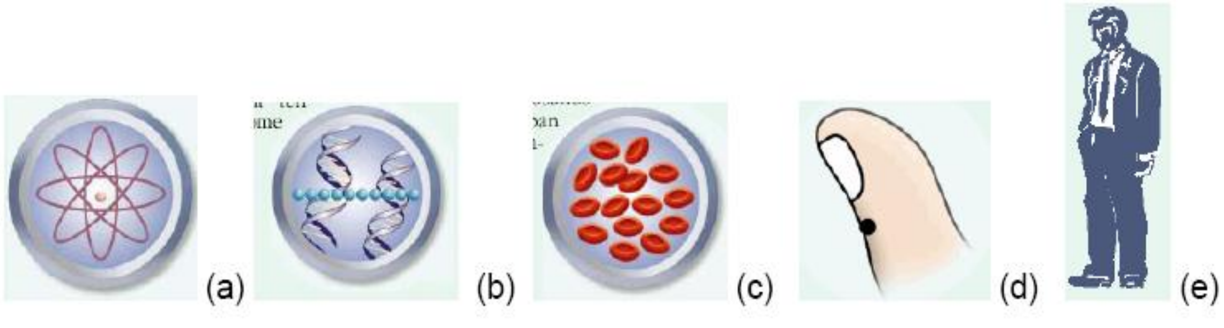

Fig.2. Display nanotechnology whole size issue

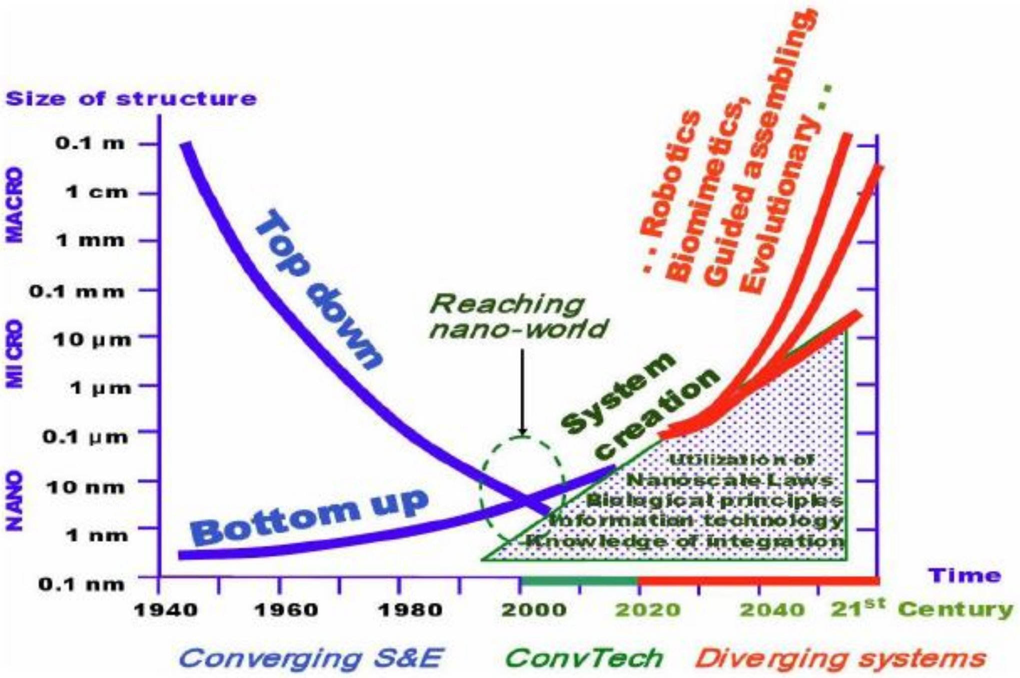

Fig.3. Indicates the evolution of science and technology in past, present and future respectively.

III. NANOTECHNOLOGY APPLICATIONS

III.I Nanotubes and nanowires:

It is a well known thing that Graphite is used as in pencil for written purpose and also as a lubricant. It is basically formed out of sheets of carbon atoms linked together hexagonally like chicken wire. Conceptually, single-wall carbon nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite (called a graphene layer) into a seamless cylinder [16-18]. These materials are considered as promising building blocks in nanoelectronics, spintronics, and nano-electromechanics. Potential applications of carbon nanotubes have strongly relied on their extraordinary ability of property changes upon external factors, such as mechanical alterations or applied external fields. The success in application of carbon nanotubes has significantly depended on predictions from theoretical calculations and modeling.

There is no consensus on some terms describing carbon nanotubes in scientific literature: both "-wall" and "-walled" are being used in combination with "single", "double", "triple" or "multi", and the letter C is often omitted in the abbreviation; for example, multi-walled carbon nanotube (MWNT).

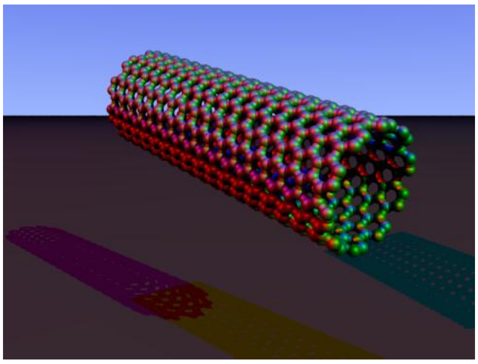

Fig.3(a) Armchair (*n*,*n*)

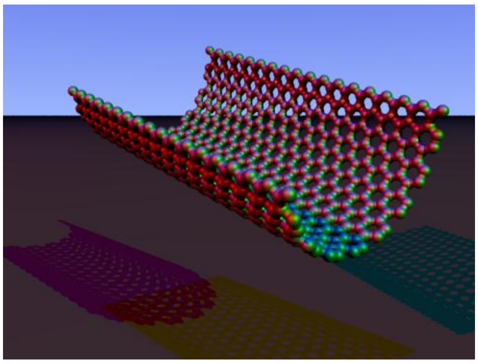

Fig.3(b)The translation vector is bent, while the chiral vector stays straight

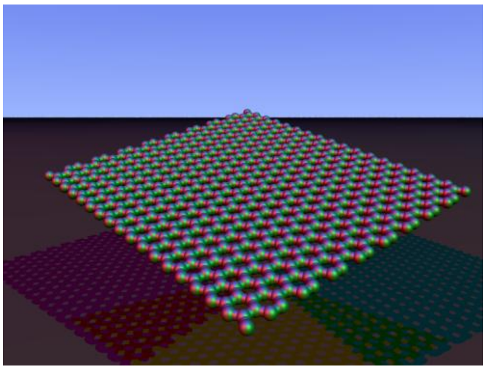

Fig.3(c)Graphene nanoribbon

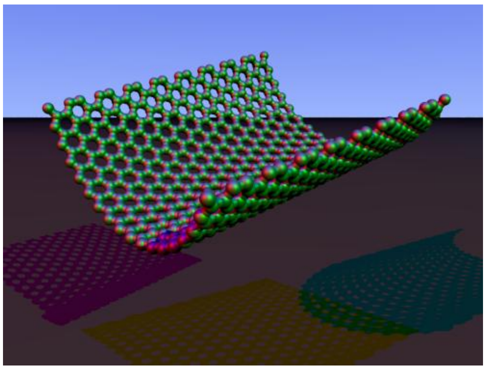

Fig.3(d)The chiral vector is bent, while the translation vector stays straight

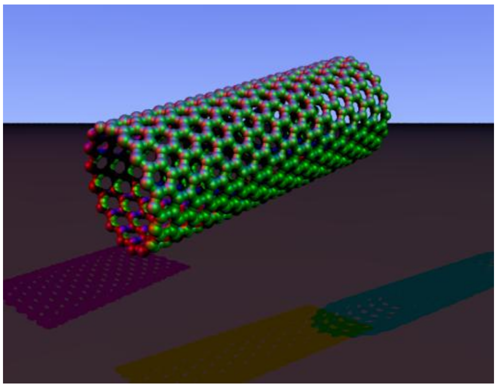

Fig.3(e)Zigzag (*n*,0)

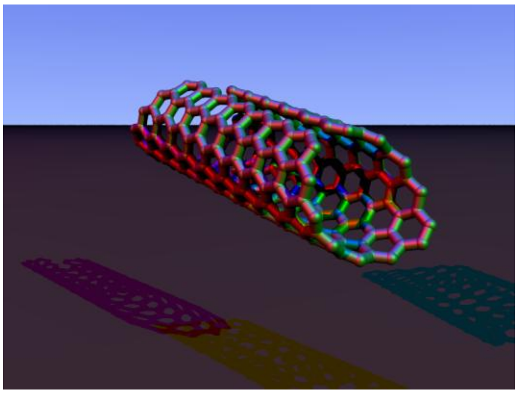

Fig.3(f) Chiral (*n*,*m*)

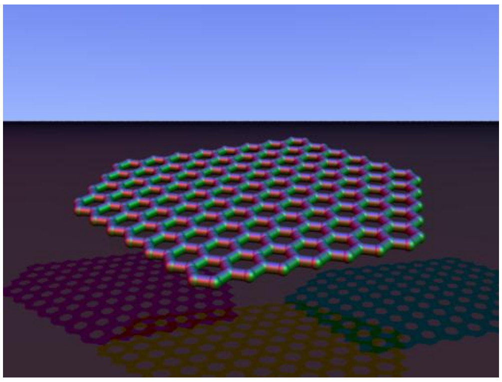

Fig.3(g) *n* and *m* can be counted at the

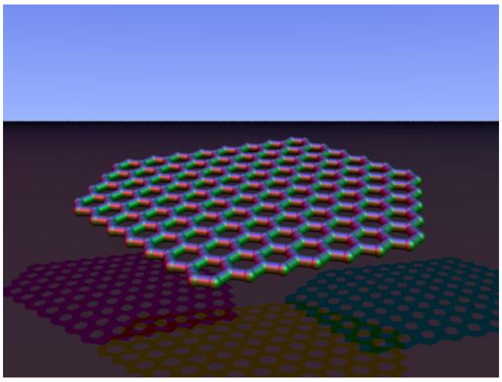

Fig.3(h) Graphene nanoribbon end of the tub

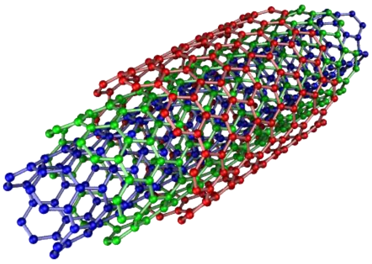

Fig.4. Multiwall carbon nanotube

A multiwall carbon nanotube (MWCNT) can similarly be considered to be a coaxial assembly of cylinders of SWCNTs, like a Russian doll, one within another; the separation between tubes is about equal to that between the layers in natural graphite [19]. Hence, nanotubes are one-dimensional objects with a well-defined direction along the nanotube axis that is analogous to the in-plane directions of graphite." In many earlier theoretical calculations, carbon nanotubes were considered to be with perfect structure, where ideal graphite plane was rolled up into a cylindrical tube. Depending on the particular way of graphene rolling, nanotubes can be metallic or semiconducting. The rolling direction is characterized by a chiral index (*n*, *m*)[20]. Achiral zigzag (*n*,0) and armchair (*n*,*n*) nanotubes are distinguished from the rest (chiral nanotubes). Armchair tubes are always metallic, while zigzag tubes can be semiconducting or metallic (Reich et al., 2004). It has been revealed that these nanostructures have interesting mechanical and electronic properties strongly depended on chirality[21], which immediately drew interest to their application in micro-electro-mechanics, spintronics, and nanoelectronics. However, experimental measurements have shown that the nanotube structure is not perfect (Fan et al., 2005; Hashimoto et al., 2004; Suenaga et al., 2007). External factors, such as mechanical deformations, mechanical defects, or applied external fields can induce various changes in nanotube properties In addition, researchers have realized that these external factors can be used in new methods to control and/or tune carbon nanotube properties for practical applications.

Most single-walled nanotubes (SWNT) have a diameter of close to 1 nanometer, with a tube length that can be many millions of times longer. The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder. The way the graphene sheet is wrapped is represented by a pair of indices (*n*,*m*) . The integers *n* and *m* denote the number of unit vectors along two directions in the honeycomb crystal lattice of graphene. If $m = 0$, the nanotubes are called zigzag nanotubes, and if $n = m$, the nanotubes are called armchair nanotubes. Otherwise, they are called chiral. The diameter of an ideal nanotube can be calculated from its (n,m) indices as follows

$$d = \frac{a}{\pi}\sqrt{(n^2 + nm + m^2)}.$$

Where $a = 0.246$ nm.

Experimentally found different types of nano tube by C.N.R Row group [22] are shown in Fig.5

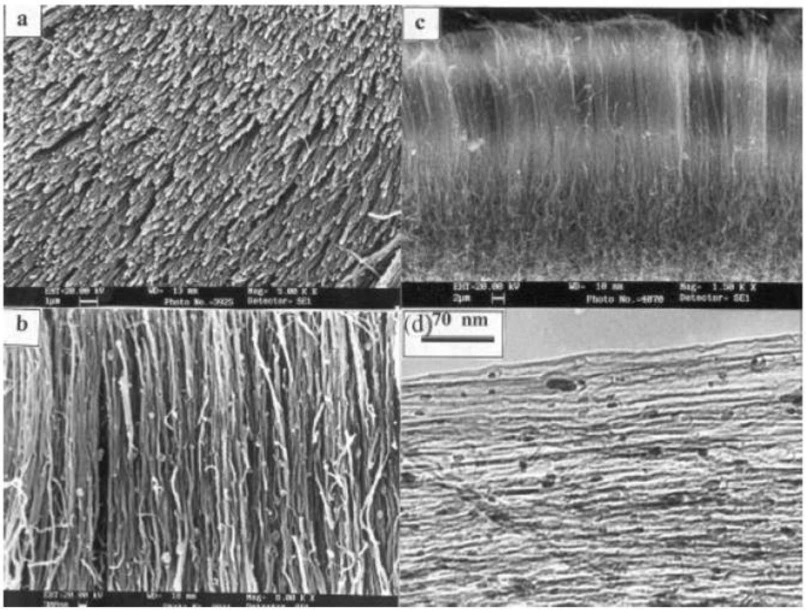

Fig.5 SEM picture of aligned nanotubes obtained by the pyrolysis of ferrocene at 1373K and 1000sccm Ar: And (b) show views of the aligned nanotubes along and perpendicular to the axis of the nanotubes;(c) shows the SEM picture of aligned–nanotube bundled obtained under a flow of C_2H_2(5sccm) and Ar(1000sccem) and (d) shows the TEM image of densely packed aligned nanotubes obtained in presence of a highely proportion of C_2H_2(85sccm) in the reaction mixrure[22].

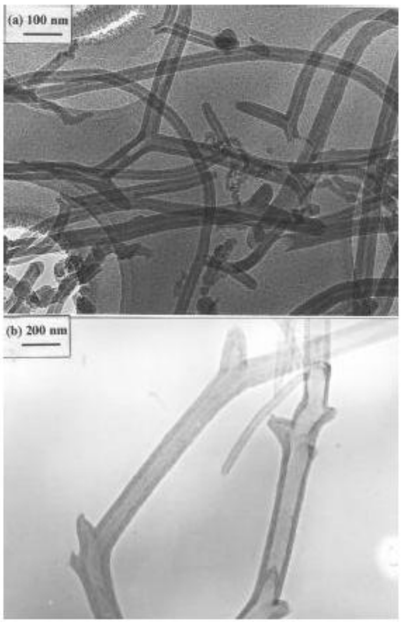

Fig.6 TEM image of Y-junction nanotubes obtained by the pyrolysis of cobaltocene–thiophene mixtures under flow of (a) H2 (100 sccm) and Ar (150 sccm and (b) by the pyrolysis of thiophene over the Ni/SiO2 catalyst under flow of H2 (50 sccm) and Ar (200 sccm) [22].

III.II Nanowire :

A nanowire is an extremely thin wire with a diameter on the order of a few nanometer s (nm) or less, where 1 nm = 10 $^{-9}$ meters [. At these scales, quantum mechanical effects are important — which coined the term "quantum wires". Many different types of nanowires exist, including metallic (e.g., Ni, Pt, Au), semiconducting (e.g., Si, InP, GaN, etc.), and insulating (e.g., SiO_2, TiO_2). Molecular nanowires are composed of repeating molecular units either organic (e.g. DNA) or inorganic (e.g. $Mo_6S_{9-x}I_x$). SEM micrograph of nanowire formed under different technology are shown in Fig.7 and Fig.8 respectively.

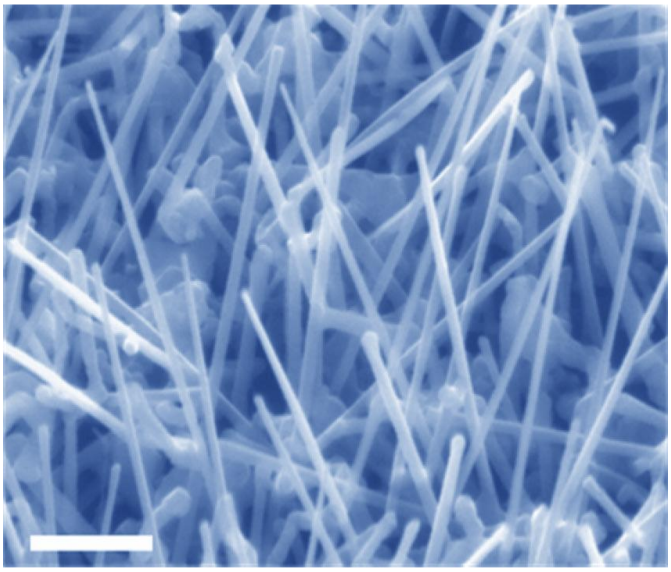

Fig.7. SEM picture of nano wire (link:http://nanotechnologytoday.blogspot.in/2008_05_01_archive.html)

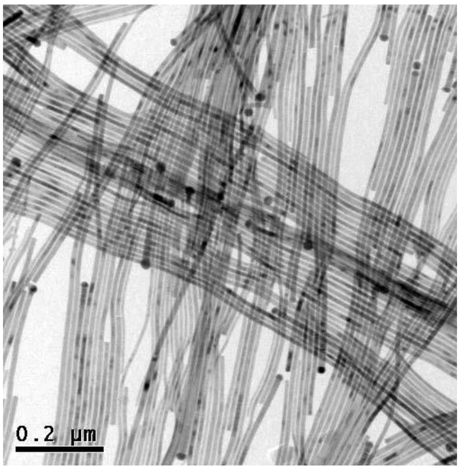

Fig.8. CdTe nanowires grown by the SLS mechanism (Jianwei Sun, Washington University).[23]

The nanowires could be used, in the near future, to link tiny components into extremely small circuits. Using nanotechnology, such components could be created out of chemical Two processes in nanotechnology by which nanowires can be manufactured are suspension and deposition compounds

The advantages of nanoparticle-catalyzed nanowire growth include its general applicability to a wide variety of materials, the diameter control afforded, the uniformity of the wires(lack of significant diameter fluctuations) and their oriented, near-single crystallinity. The surface passivation, solubility and length of the wires may also be systematically varied. Small-diameter “quantum” wires are ideal specimens for fundamental studies of two-dimensional (2D) quantum-confinement phenomena and for property comparisons to 3D-confined quantum dots, 1D-confined quantum wells and anisotropically 3D-confined quantum rods. Potential applications of semiconductor nanowires in nanophotonics and lasing, nanoelectronics, solar-energy conversion and chemical detection are under active development. Exciting progress and advances in the semiconductor-nanowire field, enabled by the emergence of nanoparticle-catalyzed growth, are anticipated in the immediate future.

The ability to create high-efficiency solar cells is a key strategy to meeting growing world energy needs. Nanotechnology is currently enabling the production of high-efficiency organic photovoltaics (OPVs) to help meet this challenge. Organic photovoltaics are nanostructured thin films composed of layers of semi-conducting organic materials that absorb photons from the solar spectrum. These devices will revolutionize solar energy harvesting, because they can be manufactured via solution-based methods, such as ink-jet or screen printing, enabling rapid mass-production and driving down cost.

III.III Nanocomposite:

The possibilities of producing materials like nanocomposite with tailored physical & electronic properties at low cost could result in the wide range of applications ranging from drug delivery to corrosion prevention to electronic/automotive parts to industrial equipment and several others. A nanocomposite is a matrix to which nanoparticles have been added to improve a particular property of the material [6-8, 24-28]. It is as a multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (nm), or structures having nano-scale repeat distances between the different phases that make up the material. Typically, the structure is a matrix-filler combination where the fillers like particles, fibers, or fragments surrounds and binds together as discrete units in the matrix. The term nano-composite encompasses a wide range of materials right from three dimensional metal matrix composites, two dimensional lamellar composites and nano-wires of single dimension to zero-dimensional core-shells all representing many variations of nano-mixed & layered materials. Various composite materials like fiberglass and reinforced plastics are in wide use for copious applications now-a day. Moreover, there is a continuous increase in demand for novel composites with desirable properties for many other different applications.

In the broadest sense this definition can include porous media, colloids, gels and copolymers, but is more usually taken to mean the solid combination of a bulk matrix and nano-dimensional phase(s) differing in properties due to dissimilarities in structure and chemistry. The mechanical, electrical, thermal, optical, electrochemical, catalytic properties of the nanocomposite will differ markedly from that of the component materials. Size limits for these effects have been proposed, <5 nm for catalytic activity, <20 nm for making a hard magnetic material soft, <50 nm for refractive index changes, and <100 nm for achieving superparamagnetism, mechanical strengthening or restricting matrix dislocation movement. The properties of nanocomposites have caused researchers and companies to consider using this material in several fields.

The physical, chemical and biological properties of nano materials differ from the properties of individual atoms and molecules or bulk matter. By creating nano particles, it is possible to control the fundamental properties of materials, such as their melting temperature, magnetic properties [29], charge capacity and even their color without changing the materials’ chemical compositions.

Nano-particles and nano-layers have very high surface-to-volume and aspect ratios and this makes them ideal for use in polymeric materials. Such structures combine the best properties of each component to possess enhanced mechanical & superconducting properties for advanced applications. The properties of nano-composite materials depend not only on the properties of their individual parents but also on their morphology and interfacial characteristics. Some nanocomposite materials could be 1000 times tougher than the bulk component. The general class of nanocomposite organic/inorganic materials is a fast growing area of research.

The inorganic components can be three-dimensional framework systems such as zeolites, two-dimensional layered materials such as clays, metal oxides, metal phosphates, chalcogenides, and even one-dimensional and zero-dimensional materials such as $(Mo_3Se_3$-)n chains and clusters. Fig.9 shows the TEM micrographs nanocomposite formed by zeolite doped nanomagnetite. Thus, nanocomposites promise new applications in many fields such as mechanically reinforced lightweight components, non-linear optics, battery cathodes, nano-wires, sensors and other systems. Inorganic layered materials exist in many varieties. They possess well defined, ordered intralamellar space potentially accessible by foreign species. This ability enables them to act as matrices for polymers yielding hybrid nano-composites.

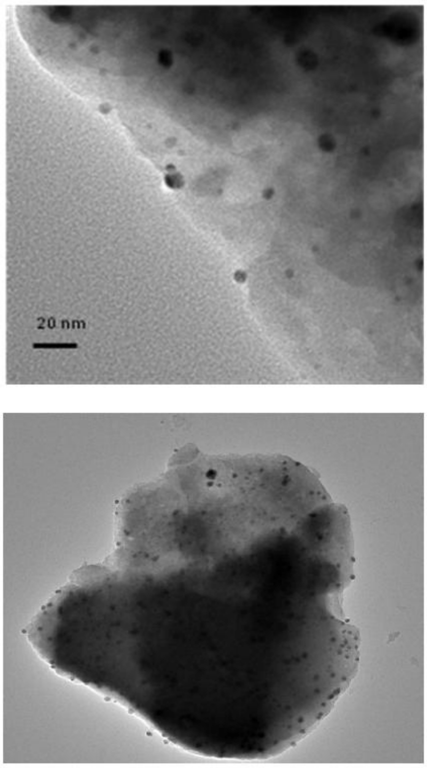

Fig.9.TEM micrographs nanocomposite formed by zeolite doped nanomagnetite [30]

Lamellar nanocomposites represent an extreme case of a composite in which interface interactions between the two phases are maximized. By engineering the polymer-host interactions, nanocomposites could be produced with the broad range of properties. Lamellar nano-composites can be divided into two distinct classes viz. intercalated and exfoliated. In the former, the polymer chains are alternately present with the inorganic layers in a fixed compositional ratio and have a well-defined number of polymer layers in the intralamellar space as shown in Fig.10.

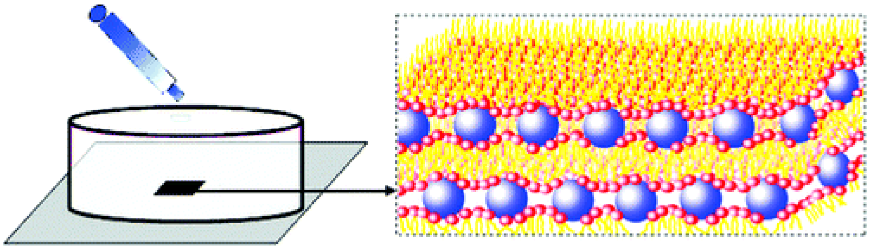

Fig.10. Self-Assembly of Highly Oriented Lamellar Nanoparticle-Phospholipid Nanocomposites on Solid Surfaces [31]

In exfoliated nano-composites, the number of polymer chains between the layers is almost continuously variable and the layers stand >100 Å apart. The intercalated nano-composites are useful for electronic and charge transport properties. On the other hand, exfoliated nano-composites possess superior mechanical properties as shown in Fig.11.

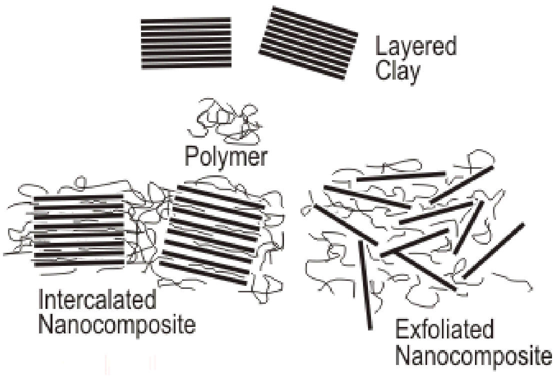

Fig.11. Formation of intercalated and exfoliated nanocomposites from layered silicates and polymers [32]

For example, the electronics industry utilizes materials that have high dielectric constants and that are also flexible, easy to process, and strong. Finding single component materials possessing all these properties is difficult. The most commonly used ceramic materials with high dielectric constant are found to be brittle and are processed at high temperatures, while polymer materials, which are very easy to process, have low dielectric constants. Composite materials having micron-scale ferroelectric ceramic particles as the filler in liquid crystal polymer, fluoropolymer, or thermoplastic polymer matrices do not possess ideal processing characteristics and are difficult to form into the thin uniform films used for many microelectronics applications. Here comes the necessity of utilizing nanocomposite materials having a wide range of materials mixed at the nanometer scale.

Fluoropolymer coatings are blends of high performance resins and fluoropolymer lubricants. These coatings are a superior dry film lubricant that produce a smooth, hard, slick coating and provide excellent corrosion and chemical resistance. Other benefits of fluoropolymer coatings include reduced friction, resistance to galling, non stick, non wetting, electrical resistance and abrasion resistance. Fluoropolymer coatings are applied to fasteners and various OEM components to provide a longer life before replacement.

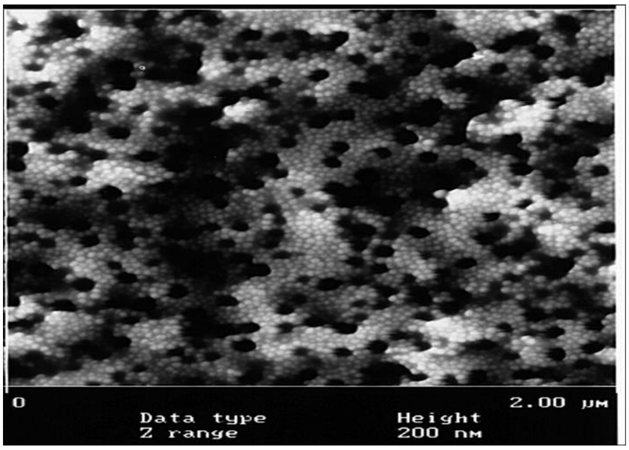

Fig.12. Nano-Composite based on Silica Sol

Recently, exquisite control over colloidal nanocrystal assembly has been developed, including highly ordered superlattices(Fig.13), binary nanocrystal assemblies, and oriented nanorod assemblies. Herein we show that such nanocrystal assemblies can be converted into inorganic nanocomposites by the post assembly replacement of organic ligands with inorganic chalcogenidometallate clusters (ChaMs). The nanocrystals and ChaMs are synthesized and processed independently, so this approach affords complete compositional modularity. Critically, the morphology of the original nanocrystal assemblies, including oriented nanorod assemblies, is maintained in the resulting nanocomposites.(Modular Inorganic Nanocomposites by Conversion of Nanocrystal Superlattices (Ravisubhash Tangirala, Jessy L. Baker, A. Paul Alivisatos, and Delia J. Milliron)

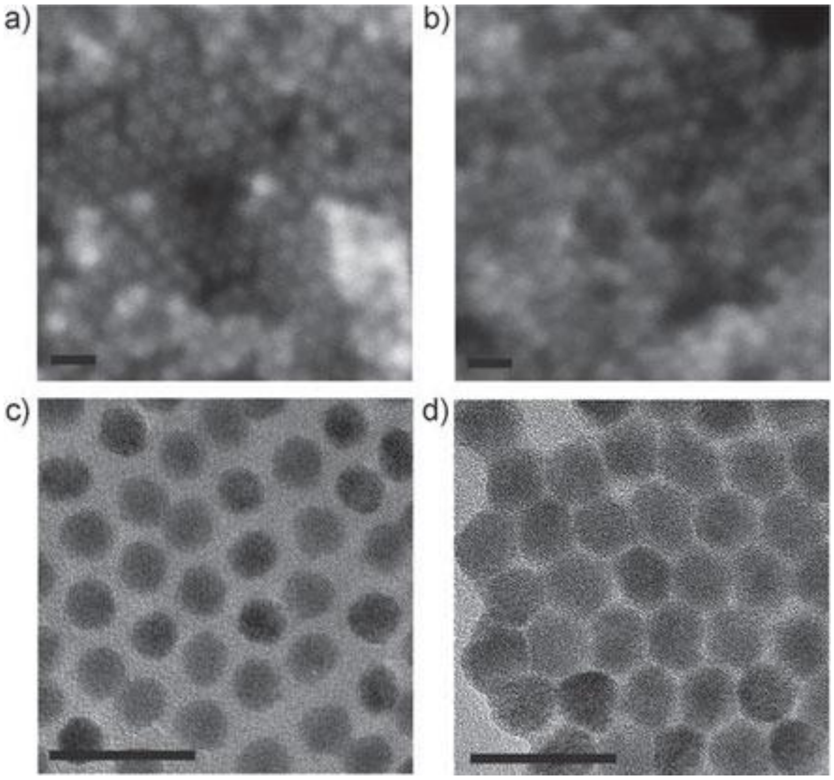

Fig.13. Formation of a PbSe-Sb2Se3 nanocomposite from a PbSe nanocrystal superlattice. a,b) SEM images of a PbSe nanocrystal film: a) the original superlattice, and b) after ligand exchange with an Sb-Se ChaM; c,d) TEM images of c) a PbSe nanocrystal superlattice, and d) PbSe-Sb2Se3 nanocomposite film. Scale bars: 20 nm.

The diamond fibres are made by coating thin (100 mm diameter) tungsten wires with a uniform coating of polycrystalline diamond using hot filament chemical vapour deposition. The diamond-coated wires are extremely stiff and rigid, and can be embedded into a matrix material (such as a metal or plastic) to make a stiff but lightweight composite material with anisotropic properties. Such materials may have applications in the aerospace industry. Fig.14 shows SEM picture of Diamond fibre composites. Carbon fibre composite layer development work have already reported by the researcher of University of Bristol as mentioned in Fig.15.

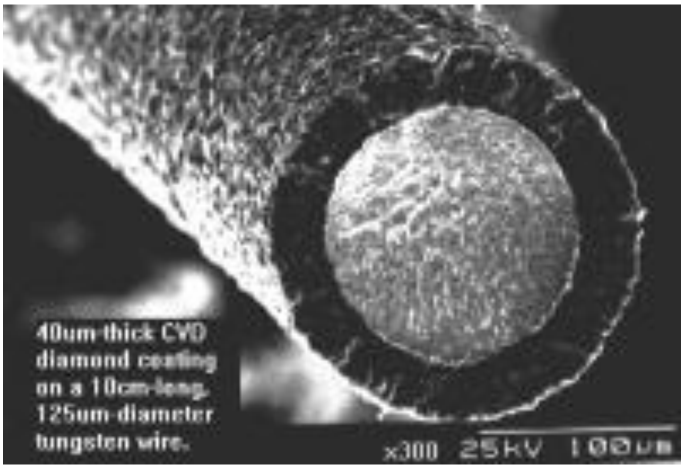

Fig.14. Diamond fibre composites (Reported by Dr Paul May and Prof Mike Ashfold, University of Bristol, http://www.bristol.ac.uk/composites/research/multifunctional-and-novel-microstructures/#tab9)

Fig.15. Carbon fibre composite (Internet Report By Nanocomposites for coatings - Dr H-X Peng, University of Bristol, http://www.bristol.ac.uk/composites/research/multifunctional-and-novel-microstructures/#tab5)

An electrospinning technique has been used to produce polymer, ceramic and nanocomposite nanofibres for wound addressing, tissue engineering and dental composites applications. The electrospun nanofibres have typical diameters of 100-500 nm. Natural biopolymers, such as alginate, chitosan, gelatin and collagen nanofibres, have been investigated. Novel nanocomposites, such as Ag nanoparticles doped alginate nanofibres and alginate/chitosan core-shell nanofibres, have also been investigated for antimicrobials and tissue engineering scaffolds. Zirconia and silica nanofibre/epoxy composites are currently under investigation for dental fillings and aesthetic orthodontic archwires.

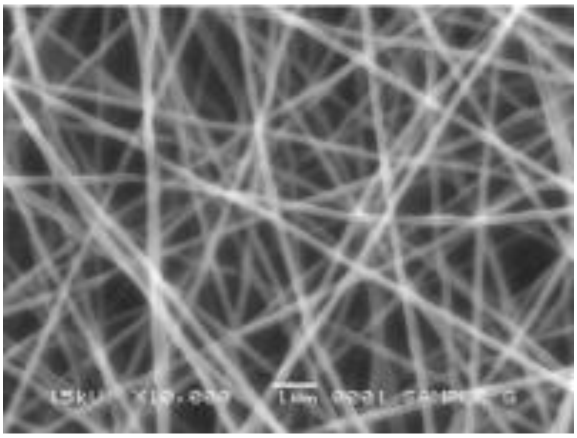

Fig.15. Nanofibres and nanocomposites - Prof. H-X Peng, Dr Sameer Rahatekar, Prof. Fabrizio Scarpa, Dr Bo Su, Dr Jeroen van Duijneveldt, Prof. Geoff Allen, University of Bristol, http://www.bristol.ac.uk/composites/research/multifunctional-and-novel-microstructures/#tab5)

In mechanical terms, nanocomposites differ from conventional composite materials due to the exceptionally high surface to volume ratio of the reinforcing phase and/or its exceptionally high aspect ratio. The reinforcing material can be made up of particles (e.g. minerals), sheets (e.g. exfoliated clay stacks) or fibres (e.g. carbon nanotubes or electrospun fibres). The area of the interface between the matrix and reinforcement phase(s) is typically an order of magnitude greater than for conventional composite materials. The matrix material properties are significantly affected in the vicinity of the reinforcement. It has been noted that with polymer nanocomposites, properties related to local chemistry, degree of thermoset cure, polymer chain mobility, polymer chain conformation, degree of polymer chain ordering or crystallinity can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix.

The Nanocomposites has revealed clearly the property advantages that nanomaterial additives can provide in comparison to both their conventional filler counterparts and base polymer. Properties which have been shown to undergo substantial improvement. The Nanocomposites 2000 conference has revealed clearly the property advantages that nanomaterial additives can provide in comparison to both their conventional filler counterparts and base polymer. Properties which have been shown to undergo substantial improvements include:

- Mechanical properties e.g. strength, modulus and dimensional stability
- Decreased permeability to gases, water and hydrocarbons
- Thermal stability and heat distortion temperature
- Flame retardancy and reduced smoke emissions
- Chemical resistance
- Surface appearance
- Electrical conductivity

- Optical clarity in comparison to conventionally filled polymers

To date one of the few disadvantages associated with nanoparticle incorporation has concerned toughness and impact performance. Some of the data presented has suggested that nanoclay modification of polymers such as polyamides, could reduce impact performance. Clearly this is an issue which would require consideration for applications where impact loading events are likely. In addition, further research will be necessary to, for example, develop a better understanding of formulation/structure/property relationships, better routes to platelet exfoliation and dispersion etc.

In addition it is important to recognize that nanoparticulate/fibrous loading confers significant property improvements with very low loading levels, traditional microparticle additives requiring much higher loading levels to achieve similar performance. This in turn can result in significant weight reductions (of obvious importance for various military and aerospace applications) for similar performance, greater strength for similar structural dimensions and, for barrier applications, increased barrier performance for similar material thickness.

Areas of Application

Such mechanical property improvements have resulted in major interest in nanocomposite materials in numerous automotive and general/industrial applications. These include potential for utilisation as mirror housings on various vehicle types, door handles, engine covers and intake manifolds and timing belt covers. More general applications currently being considered include usage as impellers and blades for vacuum cleaners, power tool housings, mower hoods and covers for portable electronic equipment such as mobile phones, pagers etc.

Gas Barriers

The gaseous barrier property improvement that can result from incorporation of relatively small quantities of nanoclay materials is shown to be substantial. Data provided from various sources indicates oxygen transmission rates for polyamide-organoclay composites which are usually less than half that of the unmodified polymer. In particular, aspect ratio is shown to have a major effect, with high ratios (and hence tendencies towards filler incorporation at the nano-level) quite dramatically enhancing gaseous barrier properties. Such excellent barrier characteristics have resulted in considerable interest in nanoclay composites in food packaging applications, both flexible and rigid. Specific examples include packaging for processed meats, cheese, confectionery, cereals and boil-in-the-bag foods, also extrusion-coating applications in association with paperboard for fruit juice and dairy products, together with co-extrusion processes for the manufacture of beer and carbonated drinks bottles. The use of nanocomposite formulations would be expected to enhance considerably the shelf life of many types of food.

Oxygen Barriers

Honeywell have also been active in developing a combined active/passive oxygen barrier system for polyamide-6 materials. Passive barrier characteristics are provided by nanoclay particles incorporated via melt processing techniques whilst the active contribution comes from an oxygen scavenging ingredient (undisclosed). Oxygen transmission results reveal substantial benefits provided by nanoclay incorporation in comparison to the base polymer (rates approximately 15-20% of the bulk polymer value, with further benefits provided by the combined active/passive system). Akkapeddi suggests that the increased tortuosity provided by the nanoclay particles essentially slows transmission of oxygen through the composite and drives molecules to the active scavenging species resulting in near zero oxygen transmission for a considerable period of time.

Films

The presence of filler incorporation at nano-levels has also been shown to have significant effects on the transparency and haze characteristics of films. In comparison to conventionally filled polymers, nanoclay incorporation has been shown to significantly enhance transparency and reduce haze. With polyamide based composites, this effect has been shown to be due to modifications in the crystallisation behaviour brought about by the nanoclay particles; spherilitic domain dimensions being considerably smaller. Similarly, nano-modified polymers have been shown, when employed to coat polymeric transparency materials, to enhance both toughness and hardness of these materials without interfering with light transmission characteristics. An ability to resist high velocity impact combined with substantially improved abrasion resistance was demonstrated by Haghighat of Triton Systems.

Environmental Protection

Water laden atmospheres have long been regarded as one of the most damaging environments which polymeric materials can encounter. Thus an ability to minimise the extent to which water is absorbed can be a major advantage. Data provided by Beall from Missouri Baptist College indicates the significant extent to which nanoclay incorporation can reduce the extent of water absorption in a polymer. Similar effects have been observed by van Es of DSM with polyamide based nanocomposites. In addition, van Es noted a significant effect of nanoclay aspect ratio on water diffusion characteristics in a polyimide nanocomposite. Specifically, increasing aspect ratio was found to diminish substantially the amount of water absorbed, thus indicating the beneficial effects likely from nanoparticle incorporation in comparison to conventional microparticle loading. Hydrophobic enhancement would clearly promote both improved nanocomposite properties and diminish the extent to which water would be transmitted through to an underlying substrate. Thus applications in which contact with water or moist environments is likely could clearly benefit from materials incorporating nanoclay particles.

Flammability Reduction

The ability of nanoclay incorporation to reduce the flammability of polymeric materials was a major theme of the paper presented by Gilman of the National Institute of Standards and Technology in the US. In his work Gilman demonstrated the extent to which flammability behaviour could be restricted in polymers such as polypropylene with as little as 2% nanoclay loading. In particular heat release rates, as obtained from cone calorimetry experiments, were found to diminish substantially by nanoclay incorporation. Although conventional microparticle filler incorporation, together with the use of flame retardant and intumescent agents would also minimise flammability behaviour, this is usually accompanied by reductions in various other important properties. With the nanoclay approach, this is usually achieved whilst maintaining or enhancing other properties and characteristics.

IV. DIAMOND LIKE NANOCOMPOSITE

In the early 1990s, diamond-like nanocomposite (DLN) films, a new group of thin-film coating materials with unique and versatile properties, were developed by Russian scientists in collaboration with Advanced Refractory Technologies, Inc. (ART), a supplier of advanced materials and technologies, and universities and laboratories in the United States.

By 1995, many potential applications for DLN films had been identified, and ART sought financial assistance to further explore these possibilities. After obtaining limited funding through private investors, ART applied to the Advanced Technology Program (ATP) and was awarded cost-shared funding in 1995. This project was a high-risk endeavor because the entire field of diamond-like film coatings was new at the time, and DLN technology was in an early stage of development. However, the domestic market potential for DLN coatings was estimated to exceed $100 million annually. By the end of the ATP-funded project in 1997, ART had developed DLN technology and then successfully marketed it in 2000. That same year, the division of the company that produced diamond-like coatings was purchased by Bekaert Corporation (which later became Bekaert Advanced Coating Technologies). As of 2003, the company sells a number of products that utilize DLN technology. DLN films are the most adaptable of thin films. They can be combined with a wide range of metals and ceramics. They also adhere to many substrates, are very hard, resist corrosion, remain stable at high temperatures, and can be produced with a broad range of electrical conductivities.

At the time, there were many thin films that were similar to DLN, including diamond and diamond-like carbon (DLC). Although these competitors had many useful characteristics, they also had drawbacks. Diamond films were crystalline and very hard, and they conducted heat well. However, they did not adhere to many substrates, they did not easily accept other elements into the film coating, and they were expensive. DLC had characteristics ranging from amorphous (formless) to highly crystalline. It was used in applications such as Ray-Ban sunglasses. However, these films were also inflexible and exhibited relatively poor adhesive and electro-optical properties.

IV.I DLN material description:

Diamond–like nanocomposites (DLN) represent a family of thin coating engineered at the atomic scale with several unique advantages over alternative coatings [33-35]. DLN coatings are amorphous in nature and the film comprises of two interpenetrating network structures: one is “diamond-like” (a-C:H) network in the form of sp^3 diamond like bonds and the other is “glass like” (a-Si:O) network in an adjustable proportion . The “diamond-like” network forms the matrix whereas the “glass like” network forms the reinforcements of a typical nanocomposite structure and, therefore, the name Diamond-like Nanocomposite (DLN). The presence of a-Si:O network as a reinforcement matrix distinguishes the DLN film from conventional DLC film. DLN film can be doped with metals providing the capability to tailor the electrical resistivity over 16 orders (10^{14} – 10^{-2} Ωcm) of magnitude. Undoped DLN films are highly dielectric with high dielectric breakdown (~ 2.2×10^6 V/cm). The ability to tailor and customize the DLN coatings for specific electrical properties in conjunction with good wear resistance makes DLN attractive for a development of capacitor. The mechanical properties like coefficient of friction, wear factor, hardness, etc. are also remarkably good. The dielectric constant and conductivity of DLN can be increased substantially by doping the films with metals like tungsten at the expense of reduced breakdown field. Moreover, by doping the DLN structure with metals and ceramics, the electrical, mechanical and optical properties can be varied over a wide range and has a board range of applications eg. for protection of magnetic discs and media, sliding parts in motors, space applications, optical components etc.

The material possesses a number of unique bulk and surface properties like hardness with flexibility, good thermal stability, greater corrosion and wear resistance etc. Moreover, the interpenetrating networks are mutually stabilized by chemical bonding that lead to low residual stresses. Therefore, the film may be deposited on a variety of conducting and nonconducting substrates without the need for any interlayer. This makes them particularly useful for nonconducting ceramics and polymers. The film hardness reported in the literature is although lower than the DLC film, the film showed an extremely low value of frictional coefficients ranging from 0.04 to 0.05 depending on the growth condition. It is found that the lower hardness of the film leads to a better wear resistance. The low residual stresses, and better adherence to any type of substrates, high wear resistance combined with low frictional coefficient in comparison to DLC make the DLN film a potent material for a variety of tribological applications.

IV.II Research activity using DLN:

DLN thin films are deposited on glass (pyrex) /silicon substrate by PECVD technique using siloxane or silazane based gas precursor with argon as a source gas. Inductively coupled plasma (IPC) chemical vapour deposition (CVD) technique is also another technique for deposition DLN film. We have already started some work related to Diamond like nanocomposite coating and its applications. In our Nanotechnology Centre,TIG has a modern facility for coating diamond like nanocomposite (DLN) films using vacuum based plasma assisted chemical vapour deposition (PACVD) technique[36]. The highly expensive equipment is unique in the country. Salient features of deposition in our PECVD DLN system are:

1. Films have been deposited with good adhesion on many types of substrate, including polymers, glass, ceramics & metals (including aluminum & stainless steel) without the need for interlayer.
2. Large area deposition (~ 3000 cm^2) has been achieved and further scales up concepts are under evaluation.
3. The synthesis procedure excludes or minimizes cluster formation in the source, in the primary plasma, in the deposition region and during film growth.
4. The growth rate of DLN film typically varies from 1.0 to 3.0 µm/hr and depends on a number of factors.
5. Substrate diameter up to 500mm can be used in the existing system. [Although in principle there is no size limitation in the processing of even layer area

The photographic picture of the DLN coating unit in our research and development centre is shown in Fig.16.

Fig.16. Existing DLN coating set up in '**DLN nanotech laboratory'** at Meghnad Saha Institute of Technology (Techno India Group), Kolkata, West Bengal

During synthesis of DLN film usually involves co-deposition of clusterless beams of C-cotaining and Si-containng radicals and ions and /or atoms of transition metals. The synthesis procedures attempt to exclude or minimize cluster formation in the sources, in the primary plasma, in the deposition region, and during film growth. The schematic of DLN atomic structure is shown in Fig.17.

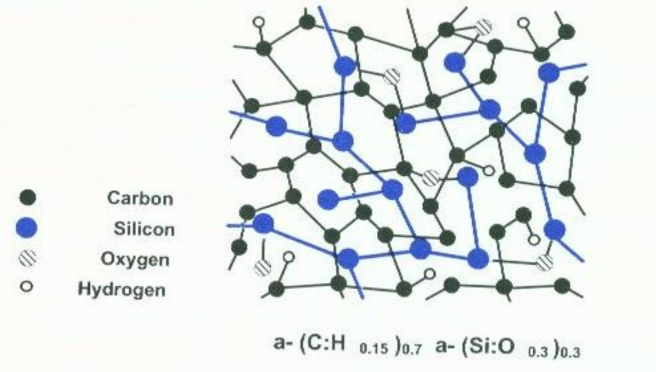

Fig.17. Schematic of DLN atomic structure

The mean free path of each particle species must exceed the distance between its source the growing film surface. Radicals are formed via glow discharge plasma breakdown of the precursor using a quasi closed plasmatron, and high frequency (90-450 kHz, 0.3-5.0 kV) fields are used to transport the radicals to the substrate. Variation of precursor, plasma and field conditions and dopants change the state of the basic matrix. The precursors belong to family of siloxanes or silazane, and the species selected depends on the elemental ratios and bonding states desired in the film. Deposition pressure utilized range from 7.0×10^{-4} torr. The SEM picture of a typical DLN film deposited on glass substrate in our centre is shown in Fig. 18.

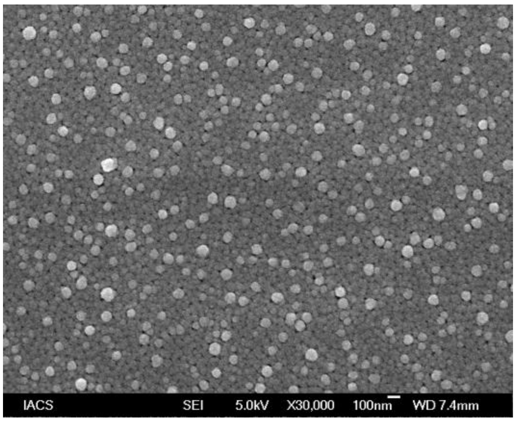

Fig.18. SEM picture of a typical DLN film deposited on glass substrate in our DLN Nanotech Centre.

In our DLN nanotech laboratory, we have already developed the following coating technology using Diamond like nanocomposite (DLN) films:

Fig.19. DLN coating on automobile parts & Copper utensil & still knife

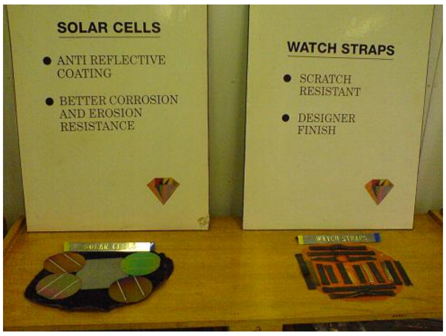

Fig. 20. DLN coating on crystalline silicon Solar cells and watch straps

Fig.21. DLN optical coating on Sun Glass

Fig.22. DLN coating on Razor Blades

Fig.23. Important part of articulating Knee joint

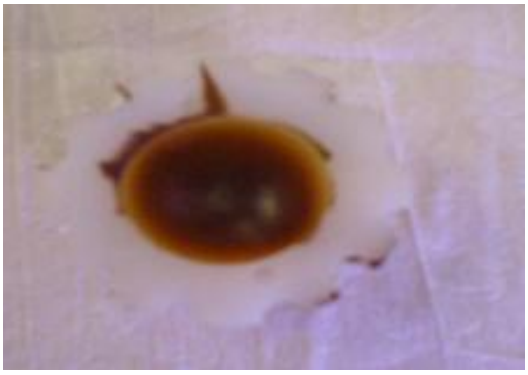

Fig.24. Important part of articulating Hip joint

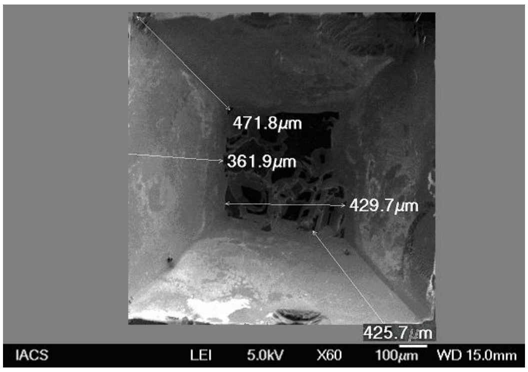

Fig.25. DLN MEMS on Silicon Substrate

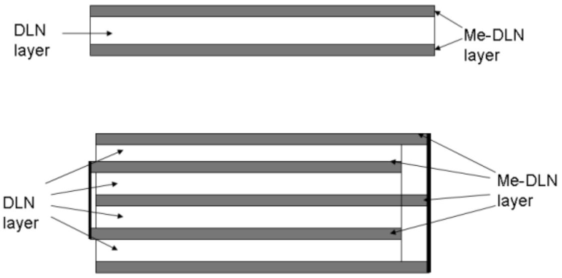

Fig.26. Schematic of DLN based capacitor

Table-1 shows the comparative properties of Diamond, Diamond Like Carbon(DLC) and Diamond Like Nanocomposite (DLN)

Properties	Diamond	DLC	DLN
Resistivity (Ω cm)	>10^{16}	10^{10}-10^{13}	10^{-4}-10^{14}
Hardness (GPa)	90	10-32	10-22
Coefficient of Friction (against Steel)	0.02	0.1-0.2	0.03-0.2
Wear Factor (10^{-7} mm^3/Nm)	0.2-1.2	0.5-1	0.2 – 0.4
Transmission	UV-VIS-IR	VIS-IR	VIS-FAR IR
Modulus of Elasticity (GPa)	1145	100-340	150-200
Residual Stress	Almost nil	8-10GPa	200-300 MPa
Dielectric Constant	5.68	3.5-5.0	3-9
Maximum Operating Temperature (°C)	600(O2 atm.) 1500(N2 atm)	300	600 (O_2 atm) 1200 (O_2 free)

I. Application of DLN:

DLN Films has suitable for a Wide Range of Applications such as:

- Hard, scratch proof and transparent coating on any materials
- Antireflection coating and environmental protection of photovoltaic solar panels and sensors
- As a dielectric material for micro-capacitor
- Development of MEMS device
- Reduced friction in moving parts, such as bearings and seals
- Biocompatible coating on articulation Knee joint, Hip joint and stent
- Improved stability and performance of field-emission devices for flat panel displays
- Improved dielectric materials for X-ray lithography
- Molds for CDs and DVDs in which the coating reduces abrasion and wear in the transfer of data, decreasing the need for machine maintenance
- Coatings on blow-molding components used in manufacturing plastic juice bottles where the coating is used inside the mold to reduce sticking and to retard plastic residue buildup, resulting in increased productivity and reduced maintenance Coatings for components used in semiconductor cluster tools

V. CONCLUSION

Today, many researchers throughout the world are finding new ways to use nanotechnology to improve the world in which we live. They visualize a world in which new materials, designed at the atomic and molecular level, provide realistic, cost-effective methods for harnessing renewable energy sources and keeping our environment clean. The fabrication of nanostructures will yield materials with new and improved properties for use in solar panels, anti-corrosion coatings, tougher and harder cutting tools, photocatalytic air purifiers, longer-lasting medical devices, chemical catalysts, and for the transport industry. In addition, there will be new materials for optical, electronic and energy storage applications and products. It has opened scientific Inquiry to the level of molecules-and a world of new opportunities.

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