Nanotechnology and its applications in the field of Physics

Physics

KEYWORDS: Nanoparticles, Nanotechnology, Physics, CNT

Rakesh Kumar

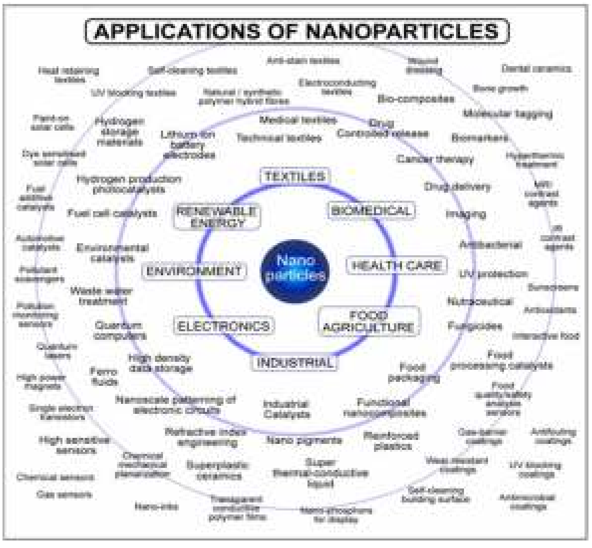
Department of Physics, Kishan Lal Public College, Rewari, Haryana, India 123401

ABSTRACT

Nanotechnology is the most innovative field of 21st century. Extensive research is going on for commercializing nanoproducts throughout the world. Due to their unique properties, nanoparticles have gained considerable importance compared to bulk counterparts. Several research has been conducted in past to use nanotechnology in different fields, here our aim is to summarize existing research and analyze future applications in field of physics by careful analysis of existing nanotechnology techniques.

Introduction

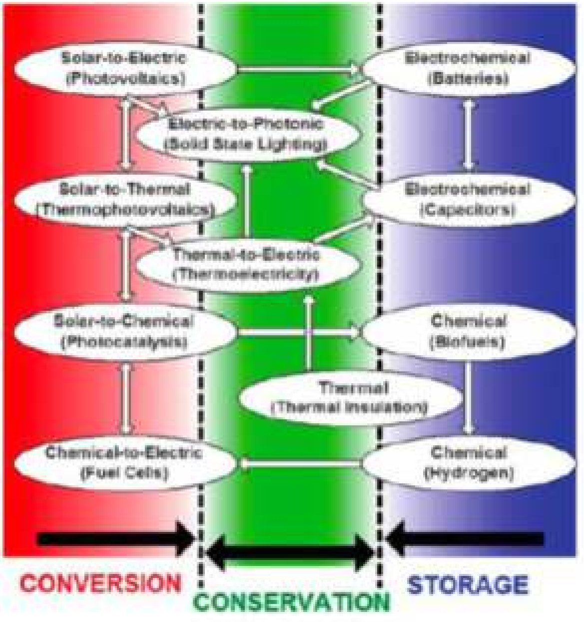
Nanotechnology harnesses the unusual behaviours of materials at a very small scale to achieve amazing scientific and practical results. A nanometer is one-billionth of a meter. A sheet of paper is about 100,000 nanometers thick. Dimensions between approximately 1 and 100 nanometers are known as the nanoscale. Materials behave in different and often useful ways at the nanoscale. Applications of these unusual properties are emerging in aerospace, agriculture, biotechnology, medicine, energy, environmental improvement, information technology, transportation, and impact homeland security and national defence. Quantum size effects (atomic level of matter) result in unique mechanical, electronic, photonic, and magnetic properties of nanoscale materials, Chemical reactivity of nanoscale materials greatly different from more macroscopic form, Vastly increased surface area per unit mass, New chemical formation , e.g., fullerenes, nanotubes of carbon titanium oxide, zinc oxide, other layered compounds.



Use of nanotechnology in renewable Energy:

Renewable energies are considered vital source globally. Photovoltaic cells convert solar energy into electricity. By using thin film PV cells efficiency of power can be increased. Since silicon wafers has layers of silicon, they have less efficiency to produce power. The growing energy demand and the depletion of conventional energy sources along with global warming threat has motivated researchers to design the most efficient photovoltaic (PV) cells.

A PV cell that uses sunlight to generate clean electric power was first designed and fabricated by Bell Laboratories in 1955 [1,6]. To achieve overall PV efficiency of at least 15%, six thin film nanotechnologies methodologies were proposed [2]. Colloidal inorganic nanocrystals provide an excellent opportunity for the development of large area thin-film absorbers for photovoltaic (PVs) [5, 7]. Thin film is more cost-effective solution and uses cheap support on which the active component is applied as a thin coating. As a result much less material is required and costs are decreased. CdTe thin films were made using a layer-by-layer deposition process consisting of spin coating colloidal CdTe Nano crystals followed by a sintering step.



Enhanced light trapping by metal nano-particles. The process of Enhanced light trapping by metal nano-particles is performed by surface plasmonic effect, which increases absorption of light over a broad spectral range by increase of light scattering and electric field strengthening [13,14]. The introduction of the metal nano particles in hetero-junction with thin film solar cell shows increase in the absorption of light, and energy conversion efficiency.

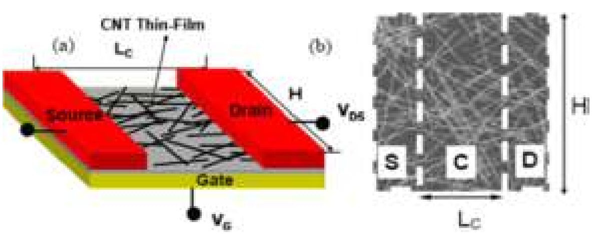
In recent years, crystalline silicon has played a major role in the production of solar cell. Solar energy losses are caused by optical losses because of reflections, carrier losses as a result of poor interface, heat loss, because of wasting the large volume of infra-red light. To enhance energy conversion efficiency, research and development has been motivated for hybrid PV cells utilizing nanotechnologies, especially using quantum dots, nanotubes, and hot carriers. A cost-effective approach is to synthesize a ZnO core-shell nanostructure by combining a low temperature electrochemical process with an atomic layer deposition technique. This indicates the core-shell nanostructure are promising for fabricating advanced solar cells. Efficient solar cells based on inverted CdSe/CdTe hetero junction can be prepared using solution processed nanocrystal thin films followed by a sintering process.

Carbon Nano tubes for thermal and photonics applications
The exceptional electronic, thermal, mechanical and optical characteristics of carbon nanotubes offer significant improvements in diverse applications such as flexible electronics, energy conversion, and thermal management. We review recent research on the fabrication, characterization and modeling of carbon nanotube (CNT) networks or ensembles for three emerging applications:

1. Thin-film transistors for flexible electronics
2. Interface materials for thermal management
3. Transparent electrodes for light emitting diodes

1 CNTs have quasi 1-D structure with unique electrical, optical, mechanical, and thermal properties which make them attractive for wide range of applications [61]. The thermal conductivity of a single wall nanotube is measured as high as 3500 W/mK [62,63], their electron mobility can be up to 10,000 cm2 Vs-1 [64] at room temperature and their Young's moduli are in the range of 1–2 TPa [65]. These remarkable properties of CNTs have motivated for extensive study for their possible use in diverse applications of electronic devices, avionic structures, energy conversion devices, thermal interface materials, interconnects, chemical, biological sensors, solar cells, and hydrogen storage devices [61,66]. Many of these applications require fabrication of thin films or composites using large number of nanotubes in random networks. These structures are relatively inexpensive and compatible with large scale manufacturing [70].

2 CNT Network Based Thin-Film Transistors In CNTN-TFTs, a sub-monolayer to a few layers of 2D ensembles of nanotubes are used as channel region between the source and drain electrodes of the thin-film transistor. Different fabrication techniques have been used to make a thin layer of CNTs which have different degree of control on the density, orientation and length distribution of CNTs [1]. Solution deposition methods such as vacuum-filtration and controlled flocculation are attractive methods for a large area synthesis of CNT-thin-films on wide variety of substrates [52,53]. External electric or magnetic field and mechanical shear is used to align CNTs for fabrication of devices which need aligned arrays of CNTs on substrates to achieve high performance [54]. Chemical vapour deposition techniques can be used to achieve better control of purity, morphology and alignment of CNTs in their thin-films [55].



3 CNTs Arrays as Thermal Interface Materials The combination of high thermal conductivity and high mechanical compliance are difficult to achieve with most materials, such characteristics are desired for high-performance thermal interface materials where the intrinsic resistance of the material should be low and the contact area in the interface should be high. These characteristics can be achieved to varying degrees by tuning the properties of CNT ensembles. Random networks of CNTs have been shown to improve thermal interface resistance. However, as discussed in detail below, several groups have shown that more significant improvements can be achieved by aligning CNTs in arrays, along the direction of heat flow. This approach minimizes the effects of inter tube interface resistance and void space on the effective thermal conductivity of the ensemble. The thermal conductivity of CNT arrays is usually 1–2 orders of magnitude higher than the thermal conductivity of traditional TIMs [75–77], yet these values are still an order of magnitude less than the values for individual tubes [62,63]. The effective thermal conductivity of vertical arrays of CNTs can be improved by increasing the number density of CNTs in the array. Indium tin oxide is the most commonly used material due to its excellent transparency in the visible range and low sheet resistance which can reach levels on the order of 10 X-sq-1.

Application of Nanofluids in Heat Transfer
A wide variety of industrial processes involve the transfer of heat energy. Throughout any industrial facility, heat must be added, removed or moved from one process to another and it has become a major task for industrial necessity. These processes provide a source for energy recovery and process fluid heating/cooling. The enhancement of heating or cooling in an industrial process may create a saving in energy, reduce process time, raise thermal rating and lengthen the working life of equipment. Some processes are affected qualitatively by the action of enhanced heat transfer. The development of high performance thermal systems for heat transfer enhancement has become popular nowadays. There are several methods to improve the heat transfer efficiency. Some methods are

- Utilization of extended surfaces
- Application of vibration to the heat transfer surfaces
- Usage of micro channels.
- Increasing the thermal conductivity of the working fluid. Commonly used heat transfer fluids water, ethylene glycol, and engine oil have relatively low thermal conductivities when compared to the thermal conductivity of solids.

High thermal conductivity of solids can be used to increase the thermal conductivity of a fluid by adding small solid particles to that fluid. The feasibility of the usage of such suspensions of solid particles with sizes on the order of 2 mm or micrometers observed significant drawbacks [21-22]. The particles settle rapidly, forming a layer on the surface and reducing the heat transfer capacity of the fluid. If the circulation rate of the fluid is increased, sedimentation is reduced, but the erosion of the heat transfer devices, pipelines, etc., increases rapidly.

The large size of the particles tends to clog the flow channels, particularly if the cooling channels are narrow. The pressure drop in the fluid increases considerably.

Finally, conductivity enhancement based on particle concentration is achieved (i.e., the greater the particle volume fraction is, the greater the enhancement—and greater the problems, as indicated above). Thus, the route of suspending particles in liquid was a well known but rejected option for heat transfer applications. [23-30]

However, the emergence of modern materials technology provided the opportunity to produce nanometer-sized particles which are quite different from the parent material in mechanical, thermal, electrical, and optical properties, the situation changed with nanoscale metallic particle and carbon nanotube suspensions

Nanofluid is a new kind of heat transfer medium, containing nanoparticles (1–100 nm) which are uniformly and stably distributed in a base fluid. These distributed nanoparticles, generally a metal or metal oxide greatly enhance the thermal conductivity of the nanofluid, increases conduction and convection coefficients, allowing for more heat transfer

Nanofluids have been considered for applications such as advanced heat transfer fluids for almost two decades. Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids having properly dispersed nanoparticles possess the following advantages:

- High specific surface area and therefore more heat transfer surface between particles and fluids.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.

- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications. Application of Nanofluids in Heat Transfer.
- Abnormal enhancement of thermal conductivity.
- Stability Nanofluids are reported to be stable over months using a stabilizing agent.
- Small concentration and Newtonian behaviour.
- Particles size dependence The enhancement of conductivity depends not only on particle concentration but also on particle size.

Heat transfer applications The increases in effective thermal conductivity are important in improving the heat transfer behaviour of fluids. A number of other variables also play key roles. For example, the heat transfer coefficient for forced convection in tubes depends on many physical quantities related to the fluid or the geometry of the system through which the fluid is flowing. These quantities include intrinsic properties of the fluid such as its thermal conductivity, specific heat, density, and viscosity, along with extrinsic system parameters such as tube diameter and length and average fluid velocity. Researchers have shown that nanofluids have not only better heat conductivity but also greater convective heat transfer capability than that of base fluids. The following section provides the wide usage and effective utilization of nanofluids in heat exchangers as heat transfer fluids.

Quantom dots

Optical research Colloidal semiconductor nanocrystals or quantum dots (QDs) are one of the most relevant developments in the fast-growing world of nanotechnology. Their photoluminescent properties have been exploited in environmental monitoring, pharmaceutical and clinical analysis and food quality control.

Despite the enormous variety of applications that have been developed, the automation of QDs-based analytical methodologies by resorting to automation tools such as continuous flow analysis and related techniques, which would allow to take advantage of particular features of the nanocrystals such as the versatile surface chemistry and ligand binding ability, the aptitude to generate reactive species, the possibility of encapsulation in different materials while retaining native luminescence providing the means for the implementation of renewable chemosensors or even the utilisation of more drastic and even stability impairing reaction conditions.

Optical properties With a size typically between 1 and 10 nm quantum dots show optical, electronic and mechanical properties quite different from those exhibited by bulk materials [36].

In bulk semiconductors the large number of atoms leads to the formation of almost a continuum of energy levels. The valence band, comprising the lower energy levels, is filled with electrons and separated from the unoccupied conductance band, corresponding to the higher energy levels, by a fixed energy gap.

In quantum dots, due to their small size, the energy levels are discrete and the energy gap between the valence and conductance band depends on the nanocrystal size.

The absorption of a photon, leading to the excitation of an electron from the valence band to the conductance band, is related with the band gap energy. Its dependence on nanocrystal size can be understood through the three dimensions confinement of the exciton, i.e. the excited electron-hole pair whose recombination is responsible for the fluorescence emission

Similarly to the particle-in-a-box model a stronger confinement leads to a larger separation of the energy levels and therefore the band-gap of semiconductor QDs increases as size decreases resulting in the emission of light at shorter wavelengths (blue shift) Oppositely, the bandgap decreases as more atoms are added to the nanocrystal with the lower limit of the band-gap corresponding to the bulk material. Moreover, increasing the nanoparticles size leads not only to an increase in the emission wavelength (red shift) but also to a decrease in the molar extinction coefficient [36]. Since QDs emission is size-dependent they can be tailored in a way by adjusting the synthesis conditions to assure fluorescence emission matching virtually any wavelength of visible region.

Apart from the band-gap tunability, QDs exhibit other relevant photoluminescent properties, namely an intense and highly stable against photo bleaching fluorescence, potentially high quantum yield, broad absorption and narrow, symmetric emission spectra and long excited-state decay lifetimes. Moreover, the broad absorption bandwidth, due to the presence of multiple electronic states at higher energy levels, allows simultaneous excitation of multicolour QDs by using a single light source.

Fluorescence In recent years QDs have emerged as remarkable fluorescent materials in numerous applications with noteworthy advantages regarding comparable organic molecular probes. The ability to absorb light at a broad bandwidth and to emit at a narrow spectrum, being the emission intensity dependent on the quantum yield, which in turn is conditioned by the type of surface interactions that the QDs established with the target analyte, has been exploited to implement assorted fluorescent analytical methodologies.

Fullerenes

Fullerenes are molecules composed entirely of carbon and were discovered in 1985 at Rice University. Fullerenes are essential components for the future of nano-electromechanical systems. In many cases, the necessity of building organic compounds leads to the exploration of nanostructures like Fullerenes. These molecules bring to the word engineering flexibility and promising applications in electrical, military and medical fields.

The high electron affinity and superior ability to transport charge make Fullerenes the best acceptor component currently available. First, they have an energetically deep-lying LUMO, which endows the molecule with a very high electron affinity relative to the numerous potential organic donors. The LUMO of C60 allows the molecule to be reversibly reduced with up to six electrons, thus illustrating its ability to stabilize negative charge.[44] Importantly, a number of conjugated polymer–fullerene blends are known to exhibit ultrafast photo induced charge transfer, with a back transfer that is orders of magnitude slower. The state of the art in the field of organic photovoltaic is currently the Bulk Hetero-junction (BHJ) solar cells based on Fullerene derivate phenyl- C61_butyric acid methyl ester (PCBM), with reproducible efficiencies approaching 5 % [45]. Conventional silicon solar cells exceed 20% efficiency.

The cost of production of organic light-converting devices compared to the corresponding inorganic analogues is lower by more than two orders of magnitude. And second, an important merit of organic solar cells is their flexibility. They can be rolled up, cut, and spread over any surface. Particularly, such plastic can be used for covering both the inner and outer walls of buildings; cells of any colour and texture can be manufactured. For example, a cell phone can be painted with this material, thus walking in a sunny day will be enough to charge the device's battery. American military departments actively support projects associated with organic solar cells because these materials demonstrate high capabilities to be used in new armaments and attendant systems [46].

Hydrogen Gas Storage Due to its unique molecular structure, fullerene is the only form of carbon, which potentially can be chemically hydrogenated and de-hydrogenated reversibly [47]. When fullerenes are hydrogenated, the C=C double bonds become CC single bonds and C-H bonds. The bond strength of single C3 C bonds is 83 kcal/mole, and theoretical calculations show that the bond strength of the hydrogenated C-H bond is 68 kcal/mole[47], This means that for fullerene hydrides, the H-C bond is appreciably weaker that C-C bonds. Therefore, when heat is applied to fullerene hydrides, the H-C bonds will break before the C-C bonds, and the fullerene structure should be preserved. The considerably lower heat of formation for C60H36 indicates that C60H36 as a molecule is thermally more stable than C60. Therefore, hydrogenation of C60 is thermodynamically favoured and can be accomplished under the right chemical conditions. The colour of the hydrogenated fullerene changes from black to brown, then to red, orange, and light yellow with increasing hydrogen content. Fullerenes with up to 6.1% hydrogen content has been developed experimentally [47]. A potential application of fullerene hydrides is in hydrogen gas storage devices for electric vehicles that would employ a fuel cell. Currently available hydrogen storage technologies like compressed gas or storage as metal hydrides are potentially hazardous and/or have low hydrogen storage densities.

Strengthening/Hardening of Metals Fullerenes offer unique opportunities to harden metals and alloys without seriously compromising their ambient temperature ductility. This is due to the unique characteristics of fullerenes, namely their small size and high reactivity, which enable the dispersion strengthening of metallic matrices with carbide particles that result from interactions between fullerenes and metals. In a comparison of the hardness of a popular aerospace inter-metallic compound Ti- 24.5AI-17Nb, with and without fullerene additives, a 30% hardness enhancement was measured for the material with fullerene additives [48].

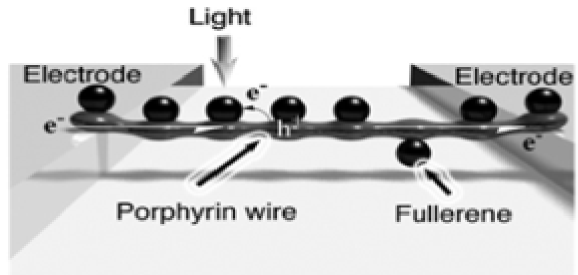
Fullerene as Precursor to Diamond Fullerenes have proven to be an excellent precursor to diamond. This can be attributed in part to the curved structure of fullerenes, which possess a partial sp' (diamond) bonding configuration, as opposed to graphite, which is planar. Argonne National Laboratories and MER Corporation have investigated fullerenes as the source of carbon to CVD deposit. MER has demonstrated excellent diamond coatings using fullerenes as the only source of carbon to deposit diamond at five times the growth rate of methane carbon sources, resulting in a projected 70% cost savings [47]. With low cost fullerenes it can be expected that conversion to diamond will be a very important commercial application.

Optical Application of Fullerene Optical limiting refers to a decrease in transmittance of a material with increased incident light intensity. The phenomenon of optical limiting has a significant potential for applications in eye and sensor protection from intense sources of light. Based on the optical limiting properties of fullerenes, one can make an optical limiter, which allows all light below an activation threshold to pass and maintains the transmitted light at a constant level below the damage threshold for the eye or the sensor [47].

Fullerenes Based Sensors Fullerene-based interdigitated capacitors (IDCs) recently have been developed to explore sensor applications. This novel solid-state sensor design is based on the electron accepting properties of fullerene films and the changes that occur when planar molecules interact with the film surface. Fullerene chemistry provides a high degree of selectivity and the IDC design provides high sensitivity. The solid-state chemical sensor's small size, simplicity, reproducibility and low cost make them attractive candidates for fullerene applications development. Studies of IDC configurations with fullerene films have been able to sense water in isopropanol with a resolution of 40 ppm [47]. These results demonstrate the feasibility of using fullerenes as selective dielectric films for IC chemical sensors.

Fullerenes as Molecular Wires Recent experiments have documented electron transport through single molecules. Under certain experimental conditions molecular conduction through a

single molecule rather than through an ensemble of molecules is guarantee. This phenomenon is possible due the high electron affinity of Fullerenes. If a molecular computer is ever to be built, then it will need molecular wires in order to connect to its various components. Figure shows a computer created scenario of a possible use of Fullerenes in the manufacture of molecular conductors. When a source of UV light is applied to the system in figure, the Fullerene molecules get excited and electrons move from the Porphyrin wire towards the Fullerenes. These electrons leave holes in the Porphyrin, through which electrical current can flow from one electrode to other [49].



Molecular Wire System

Applications of Diamond Nanopillars in Mesoscopic Physics and Nano-NMR The Nitrogen-vacancy (NV) center in diamond is a spin 1 system that can be optically initialized and readout at room temperature. NV centers have been recognized as sensitive magnetic field probes for scanning magnetometry, as well as nano-NMR, with many possible applications in physics and biology [81]. The measurement time of a typical pump-probe experiment can be inconveniently long, often on the order of days, due to the averaging needed to achieve sufficient signal-to-noise. The sensitivity of NV magnetometry can be significantly improved with probes that have much higher photon collection efficiency and stability. In particular, diamond nanopillars [82,83] are simple and robust structures that can be used as scanning probes [84], but also for an increase in measurement bandwidth for nano-NMR. Depending on the exact application, the pillar's aspect ratios can be adjusted to ensure an optimal signal-to-noise ratio. For example, a tapered tip enables a closer sample approach and thus higher scanning resolution, while an expanded pillar base enhances transmission into the bulk material. Here, we will discuss the fabrication and characterization of these diamond nanopillars and demonstrate their application in scanning mangetometry and nuclear spin sensing.

Nanomaterials in paints, varnishes and lacquers
Modern surface finishing products such as paints and varnishes are easier to use, last longer and offer effective substitutes for problematic biocides. The time is ripe to exploit these advantages, without losing sight of the possible risks. Nanoparticles added to paints render them corrosion resistant and scratch-proof, and can even make them self-cleaning.

One company which is already exploiting the advantages offered by nanotechnology is Buehler AG in Uzwil, Switzerland. Their Oxylink™ product is a water-based, multi-component metal-oxide nanodispersion. According to the firm's representative, Detlef Burghard, Oxylink™ can significantly improve the service characteristics of water-based coatings in several ways including. It makes them more resistant to caking and offers better humidity tolerance, while at the same time accelerating the drying rate and increasing the dirt repelling properties of the coatings.

Nanomaterials are also having a positive impact on coatings for building façades. They slow down the rate of degradation due to UV exposure and are being studied as possible alternatives to problematic biocides.

Use of Nanotechnology in Reduction of Friction and Wear Nanotechnology enhances the revolutionary technological changes and the research emphasis which are directly related to improvement of nanopolymer composites as lubricants. The polymeric materials have to exhibit good abrasion and wear resistance by mechanical strength, lightness, ease of processing, versatility and low cost, together with acceptable thermal and environmental resistances which are suitable for tribological applications. The viscoelasticity of polymeric materials demerit this target and make the analysis of the tribological features and the processes involved in such phenomena quite complicated [87- 89]. Hence by accumulating miniature inorganic particles in the polymer matrices the mechanical properties can be effectively enhanced. The development of composite materials is derived from a combination of properties possess a high stiffness, toughness and wear resistance which are essentially valid for tough operational conditions as slide bearings. Apart from this the reinforcing effect depends on composite materials which are strongly affected by the microstructure represented by the filler size, shape, homogeneity of distribution/dispersion of the particles within the polymer, and filler/matrix interface extension, plays a crucial role which cannot be achieved by either components alone since composite material is derived from a combination of properties. The improvement of nanocomposites showing high tribological features requires a deep investigation on their microto- nanostructure, aiming to find synergistic mechanisms and reinforcement effects exerted by the nanofillers.

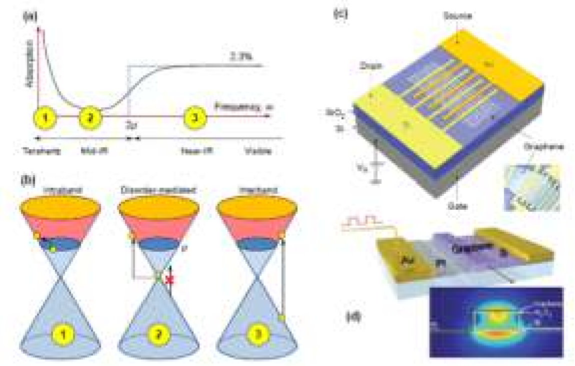
NANOTECHNOLOGY IN LUBRICATION The significant parameters in lubricants is the concentration of nanoparticles, since both wear scar diameter and friction coefficient were found to be dependent on the concentration of additives. Heat is produced as a result of friction, such that lubricants are required to have higher temperature degradation points. Addition of inorganic nanoparticles significantly improves their lifetime and performance, although nanomaterials tend to manifest a sharp decrease in their melting point at around or below 50 nm. To improve the friction and wear behaviour for a range of systems, low concentration of less than 2wt% was found to be optimal where the addition of nanoparticles of more than 1% was not achieved in any studies on different fractions of nanoparticles in various circumstances and more damage can be found in High concentrations easily.

NANOTUBES REINFORCED COMPOSITES The high mechanical strength of carbon nanotubes (CNTs) plays a major role in strengthening the composite by considering nanoscale fibers to enhance the performance of polymer composite materials. The most important application of CNTs is to be polymer nanocomposites [90]. In polymer nanocomposites (PNCs) the reinforcements of filler is in the order of few nanometres in contrast to conventional system which is of microns. The high structural performance can be obtained from Single walled nanotubes (SWNTs) and multi walled nanotubes (MWNTs), the former contains single graphite sheet which is wrapped into a cylindrical tube and the lateral consist an array of nanotubes which are made in nested like rings. Polymers such as epoxy, thermo plastics, gels and polymethylmethacrylate (PMMA) are extensively used as matrix. The axial electrical conductivity offers the potential fabricating conducting polymers. The mechanical properties of a composite are improved by load transfer across CNT matrix interface which is acquired by good interfacial bonding.

Graphene Plasmonics for Terahertz to Mid-Infrared Applications In recent years, we have seen a rapid progress in the field of graphene plasmonics, motivated by graphene's unique electrical and optical properties, tunabilty, long-lived collective excitation. The application space of graphene plasmonics lies in the technologically significant, but relatively unexploited terahertz to mid-infrared regime. We discuss emerging and potential applications, such as modulators, polarizers, mid-infrared photodetectors, mid-infrared vibrational spectroscopy, among many others. Plasmonics[91] is an

important subfield of photonics that deals with the excitation, manipulation, and utilization of surface plasmon polaritons (SPP, hereafter also called simply plasmons), the quantum of elementary excitation involving the collective electron oscillation.[92] Over the last decade or so, research has focused mainly on noble metals plasmonics, with silver and gold being the predominant materials of choice. Today, metal plasmonics constitute the foundational pillars for applications as diverse as nanophotonics for integrated photonic systems, metamaterials with unusual electromagnetic phenomena,[6{9] biosensing with nanostructures,[100, 101] photovoltaic devices,[102] single photon transistors for quantum computing[103, 104] and surface-enhanced Raman spectroscopy for single molecule detection.[105, 106] These breakthroughs were realised in the visible to near-infrared frequencies. In the ongoing search for new and better plasmonic materials,[107] graphene has emerged to be a very promising candidate for terahertz to mid-infrared applications, the frequency range where its plasmonic resonance resides. Today, the terahertz to midinfrared spectrum, is finding a wide variety of applications in information and communication, medical sciences, homeland security, military, chemical and biological sensing, spectroscopy, among many others.

Graphene as a tunable optical material: Accompanying the relativistic-like linear energy dispersion in graphene, with electrons travelling at a Fermi velocity only 300 times smaller than the speed of light, are its unique electronic and optical properties.[108, 109] Intrinsic graphene has a universal optical conductivity of e2=4~, where e is the electronic charge and ~ is the reduced Planck constant, hence an absorption of 2:3%. Unlike metals, which have abundance of free charges, graphene is a semi-metal. Free carriers can be induced through chemical doping or electrical gating with great ease due to its two-dimensional nature. The two-dimensionality and its semimetallic nature of graphene therefore allows for electrical tunability not possible with conventional metals.



Mid-infrared vibrational spectroscopy: Vibrational spectra provide fingerprints of molecular structures and as such they are used extensively in science and technology. The two techniques commonly used to obtain vibrational spectra are infrared absorption spectroscopy and Raman scattering. Nanoscience and technology demands spectroscopy on smaller and smaller samples and even single molecules and there is increasing need for better detectivity of vibrational spectra. Plasmonic effects have served as a powerful means to enhance optical fields and are utilized in various surface enhanced optical phenomena such as Raman scattering and second harmonic generation. To fully exploit the possibilies, a number of advances are required. First, more fundamental science work is needed to fully understand the behavior of plasmons in both monolayer and multiple layer graphenes, in particular the damping processes. The detailed behavior of these plasmons is largely determined by the quality of the graphene itself. Large scale grown high quality graphene is highly desirable in many of the applications we discussed. Advances in the high quality graphene growth and in the passivation chemistry of edges would reduce scattering and increase the Q-factors of the corresponding plasmonic devices. Development of controllable and stable chemical doping for graphene is highly desirable. While use of localized plasmons in patterned graphene provides a very convenient way of optically accessing these excitations, edge-scattering increases their damping rates. For this reason alternative ways of exciting plasmons in extended graphene such as the use patterned substrates, e.g. gratings, should be pursued. At the same time, we should be reminded that graphene is only a particular example of 2D van der Waals layered materials. In the larger picture, we have other 2D materials such as boron nitride,[110] transition metal dichalcogenides, metallic oxides and many others. These materials include metals, semimetals, semiconductors, topological insulators, common insulators, including hybrid heterostructures, and comes with interesting electrical and optical properties.

Graphene in Fuel cells Catalysts are used with fuels such as hydrogen or methanol to produce hydrogen ions. Platinum, which is very expensive, is the catalyst typically used in this process. Companies are using nanoparticles of platinum to reduce the amount of platinum needed, or using nanoparticles of other materials to replace platinum entirely and thereby lower costs. Fuel cells contain membranes that allow but do not allow other atoms or ions, such as oxygen, to pass through. Companies are using nanotechnology to create more efficient membranes; this will allow them to build lighter weight and longer lasting fuel cells.

Small fuel cells are being developed that can be used to replace batteries in handheld devices such as PDAs or laptop computers. Most companies working on this type of fuel cell are using methanol as a fuel and are calling them DMFC's, which stands for direct methanol fuel cell. DMFC's are designed to last longer than conventional batteries. In addition, rather than plugging your device into an electrical outlet and waiting for the battery to recharge, with a DMFC you simply insert a new cartridge of methanol into the device and you're ready to go. Fuel cells that can replace batteries in electric cars are also under development. Hydrogen is the fuel most researchers propose for use in fuel cell powered cars. In addition to the improvements to catalysts and membranes discussed above, it is necessary to develop a lightweight and safe hydrogen fuel tank to hold the fuel and build a network of refueling stations. To build these tanks, researchers are trying to develop lightweight nanomaterials that will absorb the hydrogen and only release it when needed. The Department of Energy is estimating that widespread usage of hydrogen powered cars will not occur until approximately 2020.

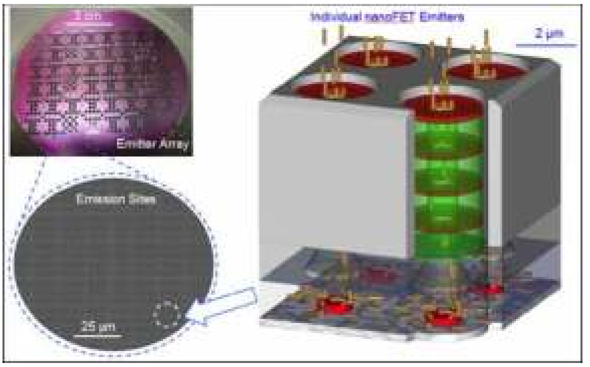
RECENT DEVELOPMENTS IN NANOTECHNOLOGY IN VARIOUS INDUSTRIES

Nanotechnology in space Nanotechnology will play an important role in future space missions. Nanosensors, dramatically improved high-performance materials, or highly efficient propulsion systems are but a few examples.

Propulsion systems Most of today's rocket engines rely on chemical propulsion. All current spacecraft use some form of chemical rocket for launch and most use them for attitude control as well (the control of the angular position and rotation of the spacecraft, either relative to the object that it is orbiting, or relative to the celestial sphere). Real rocket scientists though are actively researching new forms of space propulsion systems.

One heavily researched area is electric propulsion (EP) that includes field emission electric propulsion (FEEP), colloid thrusters and other versions of field emission thrusters (FETs). EP systems significantly reduce the required propellant mass compared to conventional chemical rockets, allowing to increase the payload capacity or decrease the launch mass. EP has been successfully demonstrated as primary propulsion systems for NASA's Deep Space 1, Japan's HAYABUSA, and ESA's SMART-1 missions.

A nanotechnology EP concept proposes to utilize electrostatically charged and accelerated nanoparticles as propellant. Millions of micron-sized nanoparticle thrusters would fit on one square centimeter, allowing the fabrication of highly scalable thruster arrays.

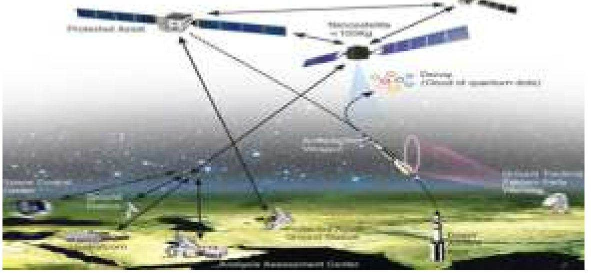


nanoFET characteristic size scales (Image: University of Michigan Department of Aerospace Engineering)

Pretty far out are proposals that the manipulation of Casimir forces could lead to a propulsion system for interstellar spaceships. The basic idea is that if one could exploit the fact that vacuum is an energy reservoir, thanks to zero-point energy, future space travelers would have access to a limitless energy source. The only thing they need, of course, is some kind of propulsion system that harvests the required energy from the vacuum. That this is not totally crazy was demonstrated in a 1984 paper. Serious research efforts are being made in various laboratories to harness the Casimir and related effects for vacuum energy conversion.

Radiation shielding Radiation shielding is an area where nanotechnology could make a major contribution to human space flight. NASA says that the risks of exposure to space radiation are the most significant factor limiting humans' ability to participate in long-duration space missions. A lot of research therefore focuses on developing countermeasures to protect astronauts from those risks. To meet the needs for radiation protection as well as other requirements such as low weight and structural stability, spacecraft designers are looking for materials that help them develop multifunctional spacecraft hulls. Advanced nanomaterials such as the newly developed, isotopically enriched boron nanotubes could pave the path to future spacecraft with nanosensor-integrated hulls that provide effective radiation shielding as well as energy storage.

Anti-satellite weapon countermeasure In January 2007, China successfully tested an Anti-satellite (ASAT) missile system by destroying their own defunct LEO satellite, which generated huge amounts of space debris. This ASAT test raised worldwide concerns about the vulnerability of satellites and other space assets and possibility of triggering an arms race in space. In order to meet emerging challenges posed by such ASAT missile systems, military strategists and researchers are developing novel technologies to protect their space assets. In view of this, Raytheon Company has developed a counter measure system using quantum dots to protect space assets such as satellites from missile attacks. They have developed a decoy consisting of quantum dots of different sizes and shapes that are engineered to emit radiation having a radiation profile similar to that of the asset.



Schematic of a countermeasure system: Anti-satellite weapon seeks the decoy cloud of quantum dots instead of the target satellite

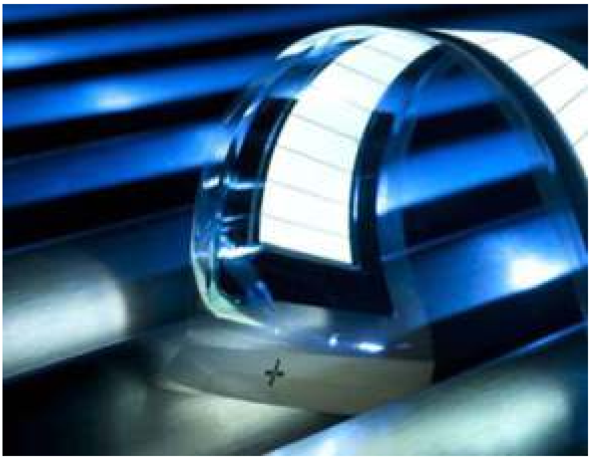
Space elevator Tie a rock to the end of a piece of ribbon, then spin it over your head. It will be pulled taut as the rock circles about. Now, imagine a ribbon 62,000 miles long, anchored near the equator with a weight on the other end. The centrifugal force of the earth's rotation will make it behave the same way. You'll end up with not only the world's biggest nunchuck, but also a kind of elevator to outer space.
A space elevator based on carbon nanotube cables is one of those ideas from 1950s-style futurism that are so whacky they might just work.

Protecting satellites from energy weapons A recent research paper published at the Center for Strategy and Technology, at the Air Force's Air War College, discusses how nanotechnology can be used to improve the design of satellites to mitigate the threats posed by ground-based directed energy weapons and high-powered microwaves. The paper states that several nations, including the U.S., Russia and China, already have either built or are developing the technology to construct ground-based directed energy weapons.

Space instrumentation According to a team of NASA engineers now developing a blacker-than pitch nanomaterial that will help scientists gather hard-to-obtain scientific measurements or observe currently unseen astronomical objects, like Earth-sized planets in orbit around other stars. The nanomaterial being developed by a team of 10 technologists at the NASA Goddard Space Flight Center in Greenbelt, Md., is a thin coating of multi-walled carbon nanotubes. While carbon nanotubes would find use in the Space Elevator thanks to their extraordinary strength, in this application, NASA is interested in using the technology to help suppress errant light that has a funny way of ricocheting off instrument components and contaminating measurements.

Nanotechnology in Displays
Display technologies can be grouped into three broad technology areas; Organic LEDs, electronic paper and other devices intended to show still images, and Field Emission Displays.

OLEDs and OLETs OLEDs – organic light-emitting diodes – are full of promise for a range of practical applications. OLED technology is based on the phenomenon that certain organic materials emit light when fed by an electric current and it is already used in small electronic device displays in mobile phones, MP3 players, digital cameras, and also some TV screens. With more efficient and cheaper OLED technologies it will possible to make ultra flat, very bright and power-saving OLED televisions, windows that could be used as light source at night, and large-scale organic solar cells. In contrast to regular LEDs, the emissive electroluminescent layer of an OLED consists of a thin-film of organic compounds. What makes OLEDs so attractive is that they do not require a backlight to function and therefore require less power to operate; also, since they are thinner than comparable LEDs, they can be printed onto almost any substrate.



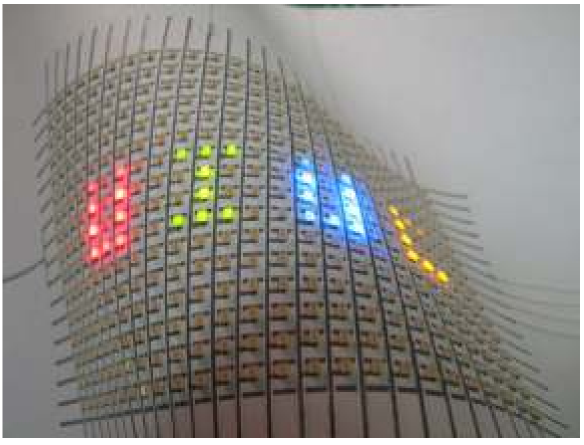
Transparent organic light-emitting diode on foil (Courtesy of TNO/Holst)

Areas where nanomaterials and nanofabrication techniques are used in OLED manufacturing are transparent electrodes (where for instance carbon nanotubes thin-films are gaining popularity) and nanoparticles-based coatings for packing the OLEDs to protect them from environmental damages (e.g. water). Nanoparticle-based deposition methods that might also overcome OLED fabrication problems where issues such as material damage, yield, and thickness uniformity haven't been completely solved yet. And recently, researchers have even developed brand new concept of OLEDs with a few nanometer of graphene as transparent conductor. This paved the way for inexpensive mass production of OLEDs on large-area lowcost flexible plastic substrate, which could be rolled up like wallpaper and virtually applied to anywhere.

Nonetheless, exciton quenching and photon loss processes still limit OLED efficiency and brightness. Organic light-emitting transistors (OLETs) are alternative, planar light sources combining, in the same architecture, the switching mechanism of a thin-film transistor and an electroluminescent device. Thus, OLETs could open a new era in organic optoelectronics and serve as test beds to address general fundamental optoelectronic and photonic issues.

"OLET is a new light-emission concept, providing planar light sources that can be easily integrated in substrates of different nature – silicon, glass, plastic, paper, etc. – using standard microelectronic techniques.

Electronic paper Unlike a conventional flat panel display, which uses a power-consuming backlight to illuminate its pixels, electronic paper reflects light like ordinary paper and is capable of holding text and images indefinitely without drawing electricity, while allowing the image to be changed later. Because they can be produced on thin, flexible substrates an due to their paper-like appearance, electrophoretic displays are considered prime examples of the electronic paper category



Optical image of a flexible paper display containing a LED array (25 × 16) on a Xerox paper.

Electrophoretic displays already are in commercial use, for instance in the Kindle or in the Sony Reader, but so far the displays are mostly black and white. There are still cost and quality issues with color displays. Nanotechnology researchers have shown that organic ink nanoparticles could provide an improved electronic ink fabrication technology resulting in e-paper with high brightness, good contrast ratio, and lower manufacturing cost

Field Emission Displays Researchers have turned to carbon nanotubes to create a new class of large area, high resolution, low cost flat panel displays. Some believe field emission display (FED) technology, utilizing carbon nanotubes (CNT) as electron emitter, will be the biggest threat to LCD's dominance in the panel display arena and that FED is the technology of choice for ultra-high definition, wide-screen televisions.

FEDs, in a sense, are a hybrid of CRT televisions and LCD televisions. They capitalise on the well-established cathode-anode-phosphor technology built into full-sized CRTs using this in combination with the dot matrix cellular construction of LCDs. The electron emitters, arranged in a grid, are individually controlled by "cold" cathodes (unlike in normal CRTs, field emission does not rely on heating the cathode to boil off electrons) to generate coloured light.

Field emission display technology makes possible the thin panel of today's liquid crystal displays (LCD), offers a wider field-of-view, provides the high image quality of today's cathode ray tube (CRT) displays, and requires less power than today's CRT displays.

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