# MOLECULAR ELECTRONICS AND NANO ELECTRONICS

The last few decades have witnessed a dramatic decrease in feature size accompanied by an enhancement in processing speed. Semiconductor electronics technology has seen a revolutionary change – the transition from macroscopic to nanoscale transistors.

In **1965**, Moore predicted that the number density of compounds that could be fabricated on an integrated circuit at an affordable cost would roughly double **every 18 months**. The simplest formulation of this law is that the number of transistors in an IC doubles every 18 months.

**Molecular electronics** is also known as molecular-scale electronics, moletronics or molectronics. Molecular scale electronics, also called single molecule electronics, is a branch of nanotechnology that uses single molecules, or nanoscale collections of single molecules, as electronic components. Because single molecules constitute the smallest stable structures possible, this miniaturization is the ultimate goal for shrinking electrical circuits.

Molecular electronics is the study and application of molecular building blocks for the fabrication of electronic components. It is an interdisciplinary area that spans physics, chemistry, and materials science. The unifying feature is use of molecular building blocks to fabricate electronic components. Due to the prospect of size reduction in electronics offered by molecular-level control of properties, molecular electronics has generated much excitement. It provides a potential means to extend Moore's Law beyond the foreseen limits of small-scale conventional silicon integrated circuits.

First brought to light in late 1990s, the theory of molecular electronics was presented by Mark Reed. It quickly became popular among electronic device and microchip manufacturers due to its small size, light weight and flexible use. Molecular electronics includes all characteristics of conductors, insulators and semi-conductors. Since this field deals with the smallest scale characteristics and sub-molecules, this field is related to chemistry, physics as well as biology. It deals with laws of electronics. Molecular electronics technology deals with the building structure of electrons and can easily be utilized to create complex fabrications of integrated circuits. It can control the molecular-scale properties of individual atoms of matter according to use.

Molecular electronics uses molecular materials in which the molecules retain the separate identities. As a result, the properties of such materials depend on the molecular arrangement, properties, and interactions. The molecules used have properties that resemble traditional electronic components such as a wire, transistor, or rectifier. This concept of using a molecule as a traditional electronic component was first presented by Aviram and Ratner in 1974, when they proposed a theoretical molecular rectifier composed of donor and acceptor sites which are insulated from one another.

The main elements of molecular electronics are molecular wire, conducting material, molecular-specific transducers of signals similar to the particles, and molecular switches, memories, emitters, detectors, etc. The flux of information between the molecules can be released in many ways. One of the most important is the transfer of individual charges in terms of electrons, holes, or hydrogen ions, or of other shapes similar to the elements, like solitons, soliton waves, or excitons. Molecular switches may be optical, electrical, magnetic, or thermally reversible systems. Storage of information in a molecular system can be realized through a change in the electronic as well as geometric structures of the molecules in reversible thermal reactions, e.g. conformational or configurational changes upon replacement of hydrogen or protons.

Molecular electronics operates in the quantum realm of distances less than 100 nanometers. Miniaturization down to single molecules brings the scale down to a regime where quantum mechanics effects are important. In contrast to the case in conventional electronic components, where electrons can be filled in or drawn out more or less like a continuous flow of electric charge, here the transfer of a single electron alters the system significantly.For example, when an electron has been transferred from a source electrode to a molecule, the molecule gets charged up, which makes it far harder for the next electron to transfer.

## Wires

The sole purpose of molecular wires is to electrically connect different parts of a molecular electrical circuit. As the assembly of these and their connection to a macroscopic circuit is still not mastered, the focus of research in single-molecule electronics is primarily on the functionalized molecules: molecular wires are characterized by containing no functional groups and are hence composed of plain repetitions of a conjugated building block. Among these are the carbon nanotubes that are quite large compared to the other suggestions but have shown very promising electrical properties.

## Transistors

Single-molecule transistors are fundamentally different from the ones known from bulk electronics. The gate in a conventional (field-effect) transistor determines the conductance between the source and drain electrode by controlling the density of charge carriers between them, whereas the gate in a single-molecule transistor controls the possibility of a single electron to jump on and off the molecule by modifying the energy of the molecular orbitals. One of the effects of this difference is that the single-molecule transistor is almost binary: it is either *on* or *off*. This opposes its bulk counterparts, which have quadratic responses to gate voltage.

It is the quantization of charge into electrons that is responsible for the markedly different behavior compared to bulk electronics. Because of the size of a single molecule, the charging due to a single electron is significant and provides means to turn a transistor *on* or *off* . For this to work, the electronic orbitals on the transistor molecule cannot be too well integrated with the orbitals on the electrodes. If they are, an electron cannot be said to be located on the molecule or the electrodes and the molecule will function as a wire.

## Nanoelectronics

Nanoelectronics covers a diverse set of devices and materials, with the common characteristic that they are so small that physical effects alter the materials'properties on a nanoscale – inter-atomic interactions and quantum mechanical properties play a significant role in the workings of these devices. At the nanoscale, new phenomena take precedence over those that hold sway in the macro-world. Quantum effects such as tunneling and atomistic disorder dominate the characteristics of these nanoscale devices

The first transistors built in 1947 were over 1 centimeter in size; the smallest working transistor today is 7 nanometers long – over 1.4 million times smaller (1 cm equals 10 million nanometers). The result of these efforts is billion-transistor processors where, once industry embraces 7nm manufacturing techniques, 20 billion transistor-based circuits are integrated into a single chip.

## Nanoelectronic Devices

Besides miniaturization of conventional FETs, the ability to synthesize electronic materials on the nanoscale with required precision has also resulted in the development of novel electronics devices with quantum mechanical behaviour. These include molecular diodes, single electron devices and tunnelling devices.

The physical dimension of quantum device is such that there is confinement of electrons in at least one of the axes. They can thus be classified into one of the three following categories:

**Quantum dots (QDs)** These are dot – like island of semiconductros with electrons confinement along all three directions. This results in zero classical degrees of freedom as electronic states are quantised in all three dimensins.

**Resonant tunnelling devices** These are 2D quantum devices and consist of a long and narrow semiconductor island, with electron confinement only in two directions. The wire/tube is too long in at least one direction to display quantum properties along the axis. These devices have one or two classical degrees of freedom.

Depending on the applied bias between the source and drain, a tunnelling current can be effected in a resonant tunnelling diode (RTD).

**Resonant tunnelling transistors(RTT)** In contrast to RTDs, RTT work on a three – terminal configuration, with the gate voltage deciding the current flowing through the device. In contrast t conventional MOSFETs, which can perform only as two – state switches, RTTs and RTDs can display multiple on – and – off states associated with multiple discrete quantum levels inside the potential well on a very small or very narrow island. Hence, it would be possible to achieve the same logic using fewer devices in the circuit. This can help decrease the problems caused by heat dissipation associated with increasing component density. Hence, solid state quantum effect nano – electronic devices are likely to provide solutions to at least a few constraints posed on miniaturization of microelecronic components. It is expected that the limit for Moore's law, which is based on the minimum feature size of conventional MOSFET (70 nm), can be scaled down using solid – state quantum devices (25 nm)

**Single electron transistors (SET):** These devices are based on a metallic island structure with three degrees of freedom. These can be contrasted to QDs, with zero degrees of freedom. Although the physical size of the QD and SET can be similar (100 nm), QDs are quantised since they are synthesized of semiconductros, while 100 nm is too large to observe quantisation in metallic island in SETs, SET devices possess a three – terminals configuration. Very small variations in the on – and – off switching function of set; hence they are termed single electron transistros.

## Spintronics

Besides transistors, nanoelectronic devices play a role in data storage (memory). Here, *spintronics*– the study and exploitation in solid-state devices of electron spin and its associated magnetic moment, along with electric charge – is already an established technology.Spintronics also plays a role in new technologies that exploit quantum behavior for computing

# NANOROBOTS

Nanorobotics (nanobot, nanomachine, nanomite) are an emerging technology field creating machines whose components are at the scale of a nanometer. Nanorobotics refers to the nanotechnology engineering discipline of designing and building nanorobots with devices ranging in size from 0.1 to 10 micrometers.

Nanomachines are largely in the research and development phase. Some nanometers have been tested. Ex: A sensor having a switch approximately 1.5nm across, able to count specific molecules in a chemical sample.

Nanotechnology robots are essentially NEMS (Nano Electro mechanical Systems) and all the important issues like design, sensing, actuation, control, communications, power and interfacing across spatial scales and between organic and inorganic materials.

Due to their size, comparable to biological cells, nanorobots have potential applications in the fields such as environmental monitoring and medicine.

**Nanorobots in Medicine:**

Nanorobots is a self propelled nanomotors, biodegradable nanodevice made of nano materials which carry medicine to the target sites. They deliver drugs to diseased cells. For instance, nanorobots can be programmed to transport molecular medicine and cause on-site attack on tumors.

Ex: 1. Gold nanoparticles loaded PEDOT/Zinc based artificial micromotors are tested in mouse models. They showed excellent acid-driver, self propulsive properties with high cargo-loading capacities.

2. Cell like nonorobots that clear bacteria and toxins from blood. These nanoboats are built by coating gold nanowires with a hybrid of platelet and RBC membrane this hybrid cell membrane coating allows the nanorobots to perform the tasks of platelets and RBC at once. Platelets removes the bacteria and RBCs absorb and neutralize the toxins produced by these bacteria.

3. Unimolecular submersible nano machines that are activated by UV light, DNA organ based nanorobots, light induced actuating nanotransducers, magnetic multilink nanoswimmers are few technological developments that are anticipating the application of nanorobots in drug delivery.

There are no nanorobots yet. To build a true nanorobot – a completely self contained electronic, electric or mechanical device to do such activities as manufacturing at the nanoscale – many breakthrough advances will need to be achieved.

## BIOLOGICAL APPLICATIONS OF NANOMATERIALS

Living organisms are built of cells that are typically 10 μm across. However, the cell parts are much smaller and are in the sub-micron size domain. Even smaller are the proteins with a typical size of just 5 nm, which is comparable with the dimensions of smallest manmade nanoparticles. This simple size comparison gives an idea of using nanoparticles as very small probes that would allow us to spy at the cellular machinery without introducing too much interference. Understanding of biological processes on the nanoscale level is a strong driving force behind the application of nanotechnology in Biology.

Nanotechnology offers potential developments in pharmaceuticals, medical imaging and diagnosis, cancer treatment, implantable materials, tissue regeneration, and multifunctional platforms combining several of these modes of action.

### Diagnosis

One primary goal in nanobiotechnology is the design of new methodologies to diagnose a number of diseases at an early stage with cheaper material and more sophisticated equipment than is possible today. The utilization of metal and semiconductor nanoparticles in biomedical applications has been demonstrated.

- Nanobodies have the potential to be a new generation of antibody-based therapeutics and to be used in diagnostics for diseases such as cancer.

- 25-nm gold nanoparticles when conjugated with anti-epidermal growth factor receptor monoclonal antibodies can be efficiently used as *in vivo* targeting agents for imaging cancer markers, specifically epidermal growth factor receptors
- An interesting tool being developed today to be utilized in tumor diagnosis is RNA nanoparticles.
- Functionalized nanoparticle aggregating fluorescence imaging techniques, known as quantum dots, have the potential for real-time and non-invasive visualization of biological events *in vivo*.

## Gene Therapy

Gene therapy is a recently introduced method for the treatment or prevention of genetic disorders by correcting defective genes responsible for disease development based on the delivery of repaired genes or the replacement of incorrect ones.

Mammalian cells typically have a diameter of a few microns and their organelles are within the nanometer range. The use of nanodevices has the advantage of entering the cells more easily when compared to larger devices and they can, therefore, interact better with the cells.

The use of nanoparticles, has some advantages in gene delivery: the structure of the nanoparticles protects the nucleic acids from degradation by nucleases and the environment; it also minimizes side effects by directing the nucleic acid to the specific location of action; they facilitate cell entry of nucleic acids and normally nanoparticles sustain gene delivery for longer periods when compared to other vehicles.

## Drug Delivery

Controlled delivery systems are used to improve the therapeutic efficacy and safety of drugs by delivering them to the site of action at a rate dictated by the need of the physiological environment, which in turn would reduce both toxicity and side effects.

Electrospun nanofibers may serve as a promising delivery vehicle as a result of their 3D nano-sized features. By this technique it is possible to incorporate biological molecules by using an emulsion or directly in a polymer solution. Nano particles can principally be fabricated by lipids and polymers. They are also being investigated as a tool for the delivery of drugs through the blood-brain barrier.

## Tissue Engineering

The growing trend of increasing life expectancy of the population as well as the serious limitations in the use of allografts, autologous grafts, or xenografts has led scientists around the world to invest more in the search for alternatives.Therefore, research in this area aims to apply the principles of cell transplantation and engineering to construct biological substitutes. These, in turn, are used in an attempt to restore and maintain normal function of organs and tissues previously diseased or injured. Thus, the focus of tissue engineering (TE) is to repair or reconstruct lost or damaged tissue through the use of growth factors, cell therapy, injectable biopolymers, and biomaterials, which serve as support for the development of the cells. Cells interact with the environment around them through thousands of interactions on a nanometric scale.

- The regeneration of skin is an important field for TE. The substitutes fabricated for use in TE normally act as supplementary dermal templates and improve wound healing.
- For bone injuries the design of scaffolds bone TE is based on the physical properties of bone tissue, such as mechanical strength, pore size, porosity, hardness, and overall 3D architecture Currently, the most widely used synthetic bioactive bone substitute is calcium phosphate-based materials
- One in five people will develop heart failure in their life time. Such a high risk is fueledby the intrinsic inability of the heart to regenerate itself after injury.Tissues are engineered that are

capable of establishing normal heart contractile function and prevent pathological remodeling.

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## Food Safety

Some applications for these areas are natural biopolymer-based nanocomposite films used for food packaging for safe storage, nanowire immunosensors array for the detection of microbial pathogens, quick detection of food-borne pathogens using bioconjugated nanomaterials, biosensor, nanocantilevers and carbon nanotubes, and nanoscale titanium dioxide particles as a blocking agent of UV light in plastic packaging.

## Environment

Nanomagets for removal of soil contaminants and nanosensors for new pesticides and insecticides are in use. Besides, the sensors we are talking about can even help in monitoring of environment and could provide data on the amount of undesirable elements present in the atmosphere.

### Elimination of pollutants

Due to their enhanced chemical activity, nanomaterials can be used as catalysts to react with such noxious and toxic gases as carbon monoxide and nitrogen oxide in automobile catalytic converters and power generation equipment to prevent environmental pollution arising from buring gasoline and coal.

### Veterinary Applications

Veterinary medicine will enter a phase of new and incredible transformation. The major contributor to those changes is our recent ability to measure, manipulate and organize matter at the nanoscale level. Our understanding of the principles that rule the nanoscale world will have a great impact on veterinary research leading to new discoveries never before imagined.

## GOLD NANO PARTICLES AS CATALYSTS

Chemical reactions are significantly enhanced by catalysts. Due to the large surface area-to-volume ratio, nanomaterials can be more efficient catalysts. Nanocatalysts can lead to cost savings and can also have higher selectivity than conventional catalysts; this can reduce waste and hence the environmental impact.

A catalyst is a substance that changes the rate of reaction without itself being consumed in the reaction. The catalyst usually reacts with the reactants to form a stable complex:

Reactants + Catalyst → Complex

The complex rearranges to yield the products and regenerates the catalyst:

Complex → Products + Catalyst

Since the catalyst is regenerated at the end of the reaction, so there is no net consumption of catalyst. In general, high conversion can be achieved if the catalyst species is not sintered during the reaction, and selectivity is achieved from the specific crystal structure of the catalytically active metal or metal oxide precursor. Hence, controlling the catalyst species at a molecular level is possible if the catalysts are fabricated at the nanoscale. Particles of nano-size have definite crystal structure, and hence the application of nanostructured materials as catalysts can drastically change the conversion and selectivity in the chemical processes.

The reactivity of nanoparticles depends on its size, shap, composition and surface atomic arrangement . Each nanocluster with a specific number of atoms has its own intrinsic chemical and physical properties and the size dependent quantum effects can become dominant. Nanoparticles have an appreciable fraction of their atoms at the surface. Their activity depends on the surface area.

Gold nanoparticles with clean surface have demonstrated to be extremely active in the oxidation of carbon monoxide if deposite on partly reactive oxides, such as $Fe_2O_3$, NiO, $MnO_2$ and alumina. Gold nanoparticles also exhibit extraordinary high activity for partial oxidation of hydrocarbons, hydrogenation of unsaturated hydrocarbons and reduction of nitrogen oxides.

The excellent catalytic property of gold nanoparticles is a combination of size effect and the unusual properties of individual gold atom. The unusual property of gold atoms attributable to the so called relativistic effect that stabilizes the $6_{S2}$ electron pairs. As the atomic number increases so does the mass of nucleus. The speed of innermost $1_{S2}$ electrons has to increase to maintain their position and for gold they attain 60% of the speed of light. A relativistic effect on their mass results in the $1_S$ orbital contraction. Than all the outer s orbitals have to contract in sympathy but p and d electrons are much less affected. This relativistic effect explains why gold differs so much from its neighbours.

# BANDGAP ENGINEERED QUANTUM DEVICES

Band-gap engineering is the process of controlling or altering the band gap of a material. This is typically done to semiconductors by controlling the composition of alloys or constructing layered materials with alternating compositions. A band gap is the range in a solid where no electron state can exist. Controlling the band gap allows for the creation of desirable electrical properties.

Altering the band gap of semiconducting materials such that a desirable optical or electronic transport property is achieved. This is done via doping, compound semiconductors such as binary (Si:Ge) ternary InxGa1−xAsInxGa1−xAs or quaternary epitaxial alloys, ramping compositional modulation, (spike) delta doping,selective etching, self-assembly and a number of other possible techniques.
In practice, it involves the creation of

- potential barriers,
- quantum wells,
- quantum dots-in-a-well,
- triangular wells or accumulation layers,
- excitonic absorption/recombination layers for detectors,
- layers that alternate a high optical gain with high reflectance in an active region of a laser,
- layers that act as a diffraction grating or quantum cascade under bias, etc.

The scope is to either achieve a **desired wavelength**, or a **desired detection** capability, or **desired conductance** region. The band shape a final device can take is only limited by imagination and financial resources.

**Few methods**

**Strain-induced band-gap engineering**

Semiconducting materials are able to be altered with strain-inducing from tunable sizes and shapes due to quantum confinement effects. A larger tunable bandgap range is possible due to the high elastic limit of semiconducting nanostructures. Strain is the ratio of extension to original length, and can be used on the nanoscale. Several studies have been conducted on the effect of strain on different physical properties. Sb-doped ZnO nanowires experience variation in resistance when exposed to strain. Strain can also induce change of transport properties and band-gap variation. By correlating these two effects under experimentation the variation of transport properties as a function of band-gap can be generated.

## Energy band-gap engineering of graphene nanoribbons

When lithographically generated graphene ribbons are laterally confined in charge it creates an energy gap near the charge neutrality point. The narrower the ribbons result in larger energy gap openings based on temperature dependent conductance. A narrow ribbon is considered a quasi one dimensional system in which an energy band gap opening is expected.

## Few devices

### Interband Light-Emitting Diodes and Lasers

Quantum Wires have found widespread use in light-emitting diode (LED) and laser diode applications for a number of years now.

1. The ability to control the quantum confinement energy provides an extra degree of freedom to engineer the emission wavelength.

2. The change of the density of states and the enhancement of the electron–hole overlap leads to superior performance.

3. The ability to grow strained layers of high optical quality greatly increases the variety of material combinations that can be employed, thus providing much greater flexibility in the design of the active regions.

A major application of QWs is in vertical-cavity surface-emitting lasers (VCSELs). These lasers emit from the top of the semiconductor surface, and have several advantages over the more conventional edge emitters. Arrays are readily fabricated, which facilitates their manufacture. No facets are required, which avoids complicated processing procedures. The beam is circular which enhances the coupling efficiency into optical fibers, while their small size leads to very low threshold currents. For these reasons the development of VCSELs has been very rapid, and many local area fiber networks operating around 850nm currently employ VCSEL devices.This would not have been possible without the high gain coefficients that are inherent to the QWstructures.

**Quantum Cascade Lasers**

When the electron density in the upper level is large enough, population inversion can occur, giving rapid stimulated emission and subsequent laser operation. This is the operating concept of the QC laser Present research on QC lasers focuses on practical systems for chemical sensing and medical imaging, and also on extending their performance at both the short (< 5_m) and long (> 50_m) wavelength ends. At short wavelengths, new material systems based on antimonides offer much promise , while at the long wavelengths, there is much interest in developing sources for THz imaging .

**Detectors**

Photodetectors for the visible and near-infrared spectral regions are generally made from bulk silicon or III–V alloys such as GaInAs. Since these devices work very well, the main applications for QW photodetectors are in the infrared spectral region and for especially demanding applications such as APDs and solar cells.

## NANOMECHANICS

Nanomechanics is a branch of nanoscience studying fundamental mechanical (elastic, thermal and kinetic) properties of physical systems at the nanometer scale. Often, nanomechanics are viewed as a branch of nanotechnology, i.e., an applied area with a focus on the mechanical properties of engineered nanostructures and nanosystems. Few nanosystems are nanoparticles, nanopowders, nanowires, nanorods, nanoribbons, nanotubes, including carbon nanotubes (CNT) nanoshells, nanocomposite materials, nanomotors, nanoelectromechanical systems (NEMS), and nanofluidics.

As a fundamental science, nanomechanics is based on some empirical principles (basic observations), namely general mechanics principles and specific principles arising from the smallness of physical sizes of the object of study.

Due to smallness of the studied object, nanomechanics also accounts for:

- Discreteness of the object, whose size is comparable with the interatomic distances
- Plurality, but finiteness, of degrees of freedom in the object
- Importance of thermal fluctuations
- Importance of entropic effects
- Importance of quantum effects

Quantum effects also determine novel electrical, optical and chemical properties of nanostructures, and therefore they find even greater attention in adjacent areas of nanoscience and nanotechnology, such as nanoelectronics, advanced energy systems, and nanobiotechnology.

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## Nanomaterials in automobiles

### In aircrafts

Lighter and stronger materials will be of immense use to aircraft manufacturers, leading to increased performance. Space craft will also benefit, where weight is a major factor. Nano materials thereby help to reduce size of equipment used.

Nanotechnology is lowering the mass of capacitors that will increasingly be used to give power to assistive electrical motors for lunching hang gliders off flatland to thermal chasing altitudes. Much like aerospace, lighter and stronger materials will be useful for creating vehicles that are both faster and safer. Combustion engines will also benefit from parts that are more hard wearing and more heat resistant.

### In cars

Incorporation of small amount of nanoparticles in car bumpers can make them stronger than steel. Polymer nanocomposites are being used for body panels as these can be made light weight and nanocomposites can improve the engine efficiency also. Specially designed nanoparticles are presently used as fuel additives to lower consumption in commercial vehicles and reduce toxic emissions.

Cars are notable for increasing their high technology content; using smart nanosensors for prevention of possible problems from a tyre blow out to break failure, even to avoid collision. Investigations are underway in how nanomaterials may lead to reduction in toxic wastes and by products of substituting new nanomaterials for hazardous reactans and solvent of better still, by using nanotechniques to eliminate their need altogether. Using nanotech applications, refineries producing materials such as steel and aluminium will be able to remove any impurities in the materials they create.

## Controlling pollution

Currently, automobile engines waste considerable amounts of gasoline, thereby contribute to environmental pollution by not completely combusting the gas.

A conventional spark plug is not designed to burn the gasoline completely and efficiently. This problem is compounded by defective, or worn-out, spark plug electrodes. Since nanomaterials are stronger, harder, and much more wear-resistant and erosion-resistant, they are presently being envisioned to be used as spark plugs. These electrodes render the spark plugs longer-lasting and combust fuel far more efficiently and completely.

## CNT EMITTERS

Carbon nanotubes (CNTs) have unique emission characteristics which are caused by their high aspect ratio and good electrical conductivity. In combination with high thermal, mechanical and chemical stability, these properties of CNTs determine a possibility of development of a new type of vacuum electronic devices involved CNT-based electron field emission cathodes.

Given their high electrical conductivity, and the incredible sharpness of their tip (the smaller the tips' radius of curvature, the more concentrated the electric field, the higher field emission), carbon nanotubes are considered the most promising material for field emitters and a practical example are CNTs as electron emitters for field emission displays (FED).

Electrical characteristics of single walled nanotubes (SWNT) depend considerably on their chirality and diameter. The nanotubes having “armchair” structure possess metallic electrical properties; the rest ones have semiconductor characteristics. Therefore, only one third of nanotubes are good conductors of electricity. The forbidden band gap of semiconductor SWNTs is rather narrow (less 1 eV) and inversely proportional to their diameter, so that their conductivity at a temperature of 300–1000 K is quite high to provide the electron emission under the action of the electrical field.

Application of various one-dimensional nanostructure materials as field emission sources has attracted extensive scientific efforts. Elongated structures are suitable for achieving high field-emission-current density at a low electric field because of their high aspect ratio. Area of its application includes a wide range of field-emission-based devices such as flat-panel displays, electron microscopes, vacuum microwave amplifiers, X-ray tube sources, cathoderay lamps, nanolithography systems, gas detectors, mass spectrometers etc.

## Applications

### Field emission displays

Flat-panel displays with CNT-based cathodes are proposed as alternative to other displays with film emitters. Field emission display (FED) technology makes possible a new class of large area, high resolution, low cost flat panel displays. However, FED manufacturing requires CNT to be grown in precise sizes and densities. Height, diameter and tip sharpness affect voltage, while density affects current.

The first diode-type display consisting of 32 X 32 matrix-addressable pixels was manufactured by Wang et al. in 1998. At present, flat-panel displays based on CNT field-emission cathodes are developed in hundreds of laboratories, and engineering samples have been already manufactured. Researchers have turned to carbon nanotubes to create a new class of large area, high resolution, low cost flat panel displays. The 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 colored 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.

# PHOTONIC CRYSTALS

Photonic crystals are defined as materials in which the refractive index varies periodically, whose lattice constant is half the wavelength of the light used. They are in one way similar to semiconductors and have selectable band gap light or photons instead of electrons.

Photonic crystals – also known as photonic band gap material – are similar to semiconductors, only that the electrons are replaced by photons (i.e. light). By creating periodic structures out of materials with contrast in their dielectric constants, it becomes possible to guide the flow of light through the photonic crystals in a way similar to how electrons are directed through doped regions of semiconductors.

The photonic band gap (that forbids propagation of a certain frequency range of light) gives rise to distinct optical phenomena and enables one to control light with amazing facility and produce effects that are impossible with conventional optics. Because photonic crystals reflect light of different wavelengths selectively depending on their bandgaps, we can construct the spectrum using the reflection intensity profile from the constituent photonic crystals.

Photonic crystals can be fabricated for one, two, or three dimensions. One-dimensional photonic crystals can be made of layers deposited or stuck together. Two-dimensional ones can be made by photolithography, or by drilling holes in a suitable substrate. Fabrication methods for three-dimensional ones include drilling under different angles, stacking multiple 2-D layers on top of each other, direct laser writing, or, for example, instigating self-assembly of spheres in a matrix and dissolving the spheres.

Photonic crystals can, in principle, find uses wherever light must be manipulated. Existing applications include thin-film optics with coatings for lenses. Two-dimensional photonic-crystal fibers are used in nonlinear devices and to guide exotic wavelengths. Three-dimensional crystals may one day be used in optical computers. Three-dimensional photonic crystals could lead to more efficient photovoltaic cells as a source of power for electronics, thus cutting down the need for an electrical input for power.

**Applications**

Photonic crystals are attractive optical materials for controlling and manipulating light flow. One dimensional photonic crystals are already in widespread use, in the form of thin-film optics, with applications from low and high reflection coatings on lenses and mirrors to colour changing paints and inks. Higher-dimensional photonic crystals are of great interest for both fundamental and applied research.

Applications for photonic crystal fibers include spectroscopy, metrology, biomedicine, imaging, telecommunication, industrial machining and military technology. Various photonic crystals conforming to various photonic lattices are manufactured depending on the required properties of the propagated light.

# PLASMON WAVEGUIDES

Plasmonic waveguides use surface Plasmon to confine light near a metal to surface. The light confinement ability of plasmonic waveguids is not limited by diffraction and as a result they can confine light to very small volumes.

Due to their non radioactive nature, there is strong interest in the development of optical techniques for biomedical diagonistics, pathogen detection, gene identification gun mapping and DNA sequences.

**Plasmons** there are quasiparticles obtained by quantization of plasma oscillations, similar to photons, which form by quantization of light and found waves. Plasmons can couple with a photon to create another quasi particles called **plasma polariton**. **Surface plasmons(SP)** are plasmons that are confined to surfaces and interact strongly with light resulting in a polariton. SPs are responsible for the colour of nanomaterials. An SP is a natural oscillation of the $e^-$ gas inside a given nanosphere

When light is shined on their surfaces, conduction electrons are excited causing excitation of surface plasmons. This can lead to electromagnetic enhancement for ultrasensitive detection such as surface-enhanced Raman scattering (SERS) and surface-enhanced fluorescence (SEF).

It has been shown earlier in the 1970s that the Raman signal is enhanced when molecules were adsorbed onto specific substrates, and this effect is known as **surface enhanced Raman scattering (SERS) spectroscopy**. The localized fields due to surface plasmon resonance and chemical effects were found to cause SERS enhancement. Silver-coated active nanospheres are used for sensitive detection of a variety of compounds of environmental and medical interest. SERS has also been used for gene probing, wherein selective detection of HIV DNA and the cancer gene was demonstrated.

## Plasmonic field enhancement

Plasmonic field enhancement is key to numerous applications ranging from surface enhance spectroscopy, sensing, nonlinear optics, light-activated cancer treatments and the enhancement of light absorption in photovoltaics and photocatalysis. For instance, researchers have developed a tuneable nano antenna that paves the way for new kinds of plasmonic-based optomechanical systems, whereby plasmonic field enhancement can actuate mechanical motion.

## Nanoplasmonics in photovoltaics

Nanoplasmonic techniques that rely on nanostructured metal surfaces could harvest more of the sun's energy compared to conventional silicon-based photovoltaic cells. The use of plasmonic black metals – nanostructured metals are designed to have low reflectivity and high absorption of visible and infrared light – could someday provide a pathway to more efficient photovoltaics (PV) to improve solar energy harvesting.

## Nanoplasmonic biosensors

With the potential to revolutionize infection diagnostics, researchers have developed nanoplasmonic sensors capable of detecting live viruses. These label-free optofluidic-nanoplasmonic biosensor have been demonstrated to directly detect live viruses from biological media at medically relevant concentrations with little to no sample preparation.

Another example are simple, ultrasensitive nanoplasmonic microRNA sensors that hold promise for the design of new diagnostic strategies and, potentially, for the prognosis and treatment of pancreatic and other cancers.Researchers have demonstrated the label-free cancer marker detection of a single protein using a nanoplasmonic-photonic hybrid microcavity.