

Nano Science and Biotechnology

Module-2 (12 Hours)

Nano-Device and Components:

Graphene: structure, synthesis and properties

Graphene is an allotrope of carbon consisting of a single layer of atoms arranged in a two-dimensional honeycomb lattice (see in Fig 1). Each atom in a graphene sheet is connected to its three nearest neighbors by a σ -bond, and contributes one electron to a conduction band that extends over the whole sheet. This is the same type bonding seen in carbon nanotubes and polycyclic aromatic hydrocarbons, and (partially) in fullerenes and glassy carbon. These conduction bands make graphene a semimetal with unusual electronic properties that are best described by theoretical for massless relativistic particles. Charge transport is ballistic over long distances; the material exhibits large quantum oscillations and large and nonlinear diamagnetism. Graphene conducts heat and electricity very efficiently along its plane. The material strongly absorbs light of all visible wavelengths, which account sheet is nearly transparent because of its extreme thinness. The material is also about 100 times stronger than would be the strongest steel of the same thickness.

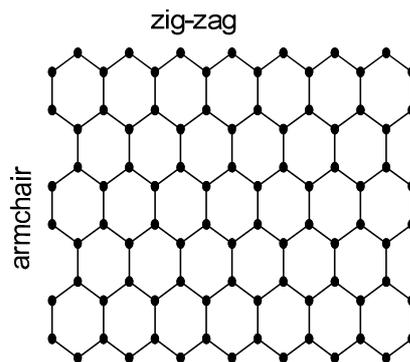


Figure 1. Graphene is an atomic-scale [Hexagonal lattice](#) made of carbon atoms

Structure of Graphene

Three of the four outer-shell electrons of each atom in a graphene sheet occupy three sp^2 hybrid orbitals – a combination of orbitals s , p_x and p_y – that are shared with the three nearest atoms, forming σ -bonds. The length of these bonds is about 0.142 nanometers.

The remaining outer-shell electron occupies a p_z orbital that is oriented perpendicularly to the plane. These orbitals hybridize together to form two half-filled bands of free moving electrons, π and π^* , which are responsible for most of graphene's notable electronic properties. Recent quantitative estimates of aromatic stabilization and limiting size derived from the enthalpies of hydrogenation (ΔH_{hydro}) agree well with the literature reports.

Graphene sheets stack to form graphite with an interplanar spacing of 0.335 nm (3.35 Å).

Graphene sheets in solid form usually show evidence in diffraction for graphite's (002) layering. This is true of some single-walled nanostructures. However, unlayered graphene with only (hk0) rings has been found in the core of premolar graphite anions. TEM studies show

faceting at defects in flat graphene sheets and suggest a role for two-dimensional crystallization from a melt.

Properties of Graphene

1. The carbon-carbon bond length in graphene is 0.142 nm.
2. It is the thinnest (0.34 nm) and the strongest material ever measured.
3. It is very light weight only about 0.77 mg/m²
4. Its density is only about 1.5-2.0 g/m³
5. Its specific surface area is up to 2600 m²/g for a size less than about 6000 atoms.
6. Graphene is thermodynamically unstable in comparison with other fullerene.
7. If size increase larger than 24,000 atoms, it becomes most stable.
8. Occurrence of freestanding atomic planes of graphene is difficult to obtain due to their thermodynamic instability on the Nano scale and thus, they exhibit a tendency to scroll and buckle.
9. Atomic structure of graphene consist of honey-comb lattice.
10. Graphene depicts very high electron mobility at room temperature.
11. The thermal conductivity in graphene ranges from about 4.40 x 10³ to 5.77 x 10³ m⁻¹K⁻¹ near room temperature
12. Graphene produced by graphite oxide film shows high electrical conductivity and super conducting properties.
13. Graphene possess an optical transmission rate of more than 98%, which is higher than that of indium tin oxide films (85%).
14. Graphene has very high mechanical properties, being one of the strongest materials produced.
15. It possess a tensile modulus 1 TPa, Young's modulus of 0.5 TPa.
16. It exhibit hundred times greater breaking strength as compared to steel of the same thickness.
17. Graphene, being the lightest and strongest material and possessing a very thermal and electric conductivity.

Stability

Ab initio calculations show that a graphene sheet is thermodynamically unstable if its size is less than about 20 nm and becomes the most stable fullerene (as within graphite) only for molecules larger than 24,000 atoms.

Properties of Graphene

Electronic

Graphene is a zero-gap semiconductor, because its conduction and valence bands meet at the Dirac points. The Dirac points are six locations in momentum space, on the edge of the Brillouin zone, divided into two non-equivalent sets of three points. The two sets are labeled K and K'. The sets give graphene a valley degeneracy of $g_v = 2$. By contrast, for traditional semiconductors the primary point of interest is generally Γ , where momentum is zero. Four electronic properties separate it from other condensed matter systems.

However, if the in-plane direction is no longer infinite, but confined, its electronic structure would change. They are referred to as graphene nanoribbons. If it is “zig-zag” the bandgap would still be zero. If it is “armchair”, the bandgap would be non-zero.

Graphene’s hexagonal lattice can be regarded as two interleaving triangular lattices. This perspective was successfully used to calculate the band structure for a single graphite layer using a tight-binding approximation.

Optical

Graphene’s unique optical properties produce an unexpectedly high opacity for an atomic monolayer in vacuum, absorbing $\pi a \approx 2.3\%$ of light, from visible to infrared. Here, a is the “universal low-energy electronic structure of monolayer graphene that features electron and hole conical bands meeting each other at the Dirac point. Based on the Slonczewski-Weiss-McClure band model of graphite, the interatomic distance, hopping value and frequency cancel when optical conductance is calculated using Fresnel equations in the thin-film limit.

Structure of carbon nanotube, Classification and physical properties of CNT

CARBON NANOTUBES

Carbon is a unique element. It can exist in several different allotropic forms at room temperature, namely graphite, diamond, amorphous carbon, carbon clusters (like C_{60} , C_{70} , etc.) and carbon nanotubes. Diamond and graphite are the two well-known forms of crystalline carbon. Diamond has four-coordinate sp^3 carbon atoms that form an extended three-dimensional network, whose motif is the chair conformation of cyclohexane. Graphite has three-coordinate sp^2 carbons that form planar sheets, whose motif is the flat six-membered benzene ring. The new carbon allotropes, the fullerenes, are closed-cage carbon molecules with three-coordinate carbon atoms tiling the spherical or nearly-spherical surfaces, the best known example being C_{60} , with a truncated icosahedral structure formed by [twelve pentagonal rings and twenty hexagonal rings](#). Sumio Iijima observed, in 1991, that nanotubules of graphite were deposited on the negative electrode during the direct current arcing of graphite for the preparation of fullerenes. These nanotubes are concentric graphitic cylinders closed at either end due to the presence of five-membered rings. Nanotubes can be multi-walled with a central tubule of nanometric diameter surrounded by graphitic layers separated by 0.34 \AA . Unlike the multi-walled nanotubes (MWNTs), in single-walled nanotubes (SWNTs), there is only the tubule and no graphitic layers. Since carbon nanotubes are derived from fullerenes, they are referred to as tubular fullerenes or bucky tubes.

Carbon Nanotubes have a very broad range of electronic, thermal, and structural properties that change depending on the different kinds of nanotube (defined by its diameter, length, and chirality, or twist). To make things more interesting, besides having a single cylindrical wall (SWNTs), Nanotubes can have multiple walls (MWNTs)--cylinders inside the other cylinders.

Carbon atoms can be chemically bonded to each other either in the sp^2 (graphite, carbon clusters, CNT) or sp^3 (diamond) hybridized state. In diamond-like carbon (DLC) films, there is a random network of the two hybridized states. In fullerenes (C_{60} , or ‘bucky ball’) the carbon atoms are sp^2 hybridized, but in contrast to graphite, they are not arranged on a plane. The geometry of C_{60} strains the bonds of the sp^2 hybridized carbon atoms, creating new properties for C_{60} . Graphite is a semi-metal, whereas C_{60} is a semiconductor. Rick Smalley and co-

workers discovered fullerenes in 1985. C_{60} was the first fullerene prepared. It is a football-shaped (icosahedral) molecule with 60 carbon atoms bonded together in pentagons and hexagons. Fullerenes get their name from Buckminster Fuller, an architect who built a dome that has the same structure as that of the C_{60} molecule. This is possibly the first time that an architect's name was associated with a scientific discovery.

Types of CNTs

The two main types of CNT are the single and multi-walled, but there are some other rare types such as fullerite, torus, and nanoknot.

Single-walled carbon nanotubes (SWCNTs)

A single-walled 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 (long wrapped graphene sheets). As stated before, CNTs generally have a length to diameter ratio of about 1000 and more so they can be considered as nearly one-dimensional structure. Most SWCNTs have a diameter of close to 1 nm. More detailed, a SWCNT consists of two separate regions with different physical and chemical properties. The first is the sidewall of the tube and the second is the end cap of the tube (Iijima and Ichihashi, 1993).

SWCNTs are a very important variety of a CNT because they exhibit important electric properties that are not shared by the MWCNT variants. The most basic building block of these systems is the electric wire, and SWCNTs can be excellent conductors.

SWCNTs are still very expensive to produce, and the development of more affordable synthesis techniques is vital to the future of carbon nanotechnology. If cheaper means of synthesis cannot be discovered, it would make it financially impossible to apply this technology to commercial scale applications

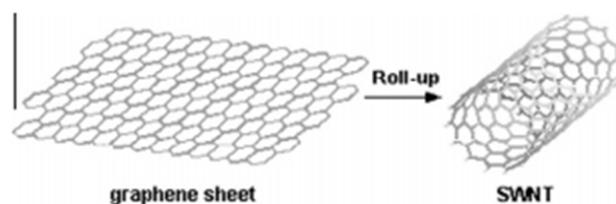
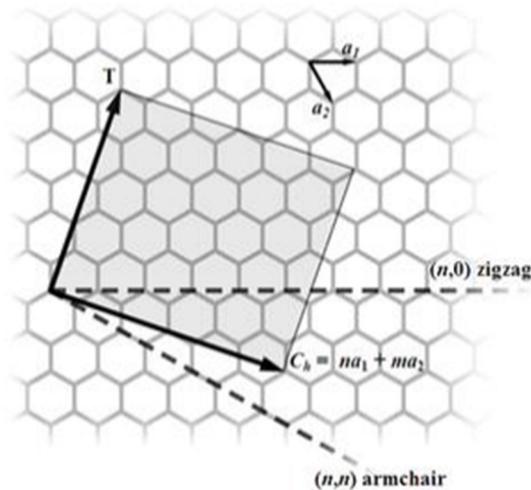


Figure 2. Rolling of a single layer of graphite sheet into SWCNT.

Single-walled carbon nanotubes can be formed in three different designs: [Armchair](#), [Chiral](#), and [Zig-zag](#). The design depends on the way the graphene is wrapped into a cylinder. For example, imagine rolling a sheet of paper from its corner, which can be considered one design, and a different design can be formed by rolling the paper from its edge. A single-walled nanotube's structure is represented by a pair of indices (n, m) called the chiral vector. The chiral vector is defined in the image below.



The structural design has a direct effect on the nanotube's electrical properties. When $n - m$ is a multiple of 3, then the nanotube is described as "metallic" (highly conducting), otherwise the nanotube is a semiconductor. The Armchair design is always metallic while other designs can make the nanotube a semiconductor.

Multi-walled carbon nanotubes (MWCNTs)

Multi-walled carbon nanotubes (MWCNTs) can be considered as a collection of concentric SWCNTs (consist of multiple layers of graphite rolled in on themselves to form a tube shape) with different diameters. The length and diameter of these structures differ a lot from those of SWCNTs and, of course, their properties are also very different (Iijima and Ichihashi, 1993). The interlayer distance in MWCNTs is close to the distance between graphene layers in graphite, approximately 3.3 Å. The special case of MWCNTs (double-walled carbon nanotubes DWCNTs) must be emphasised here because they combine very similar morphology and properties as compared to SWCNT. DWCNT synthesis on the gram scale was first proposed in 2003 (Flahaut et al., 2003) by the chemical vapour deposition (CVD) technique, from the selective reduction of oxides solid solutions in methane and hydrogen (Figure. 3).

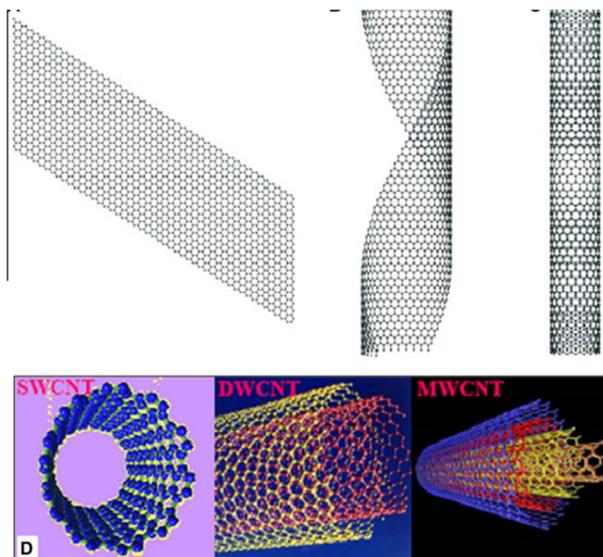


Figure 3. Schematic diagrams showing different types of CNTs and other carbon structures: (A) Flat sheet of Graphite, (B) Partially rolled sheet of graphite, (C) SWCNT, (D) Structures of the three CNT types; SWCNT, DWCNT, and MWCNT, respectively.

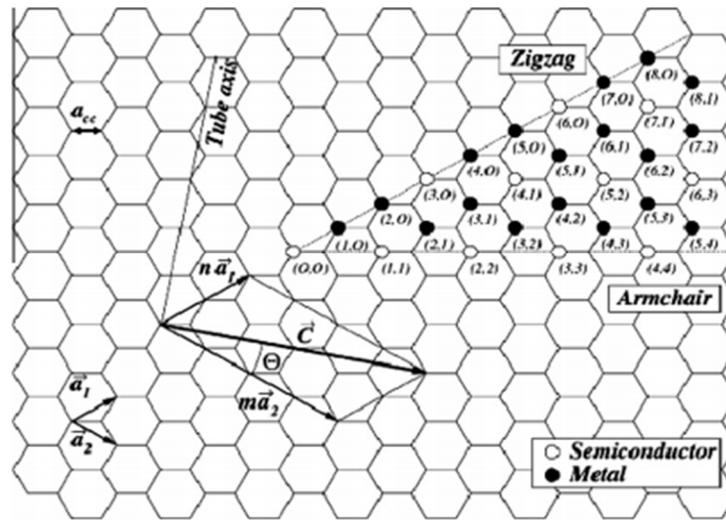


Figure 4. The 2D graphene sheet diagram showing a vector structure classification used to define CNT structure (Dresselhaus et al., 1996).

Structure of CNTs

Carbon nanotubes are sheets of graphite that have been rolled into a tube. A graphene sheet can be rolled more than one way, producing different types of CNTs, (graphene is an individual graphite layer, Fig. 2).

CNTs are considered as nearly one-dimensional structures (1D Bucky tube shape) according to their high length to diameter ratio. Most important structures are SWCNTs and MWCNTs. A SWCNT is considered as a cylinder with only one wrapped graphene sheet while MWCNTs are similar to a collection of concentric SWCNTs. The length and diameter of these structures differ a lot from those of SWCNTs and, of course, their properties are also very different. **The bonding in CNTs is sp^2 and consist of honeycomb lattices and are seamless structure**, with each atom joined to three neighbors, as in graphite. The tubes can therefore be considered as rolled up graphene sheets.

The type of CNT depends on how the graphene sheet is oriented on rolling. This can be specified by a vector (called chiral vector), which defines how the graphene sheet is rolled up. Fig. 4 showing how a hexagonal sheet of graphite is rolled to form a CNT in a vector structure classification. The vector is determined by two integers (n, m). Two atoms in a planar graphene sheet are chosen and one is used as origin. The chiral vector C is pointed from the first atom toward the second one and is defined by the relation:

$$C = na_1 + ma_2$$

Where: n and m are integers. a_1 and a_2 are the unit cell vectors of the two-dimensional lattice formed by the graphene sheets. The direction of the CNT axis is perpendicular to this chiral vector. For example; to produce a CNT with the indices (6, 3), say, the sheet is rolled up so

that the atom labelled (0, 0) is superimposed on the one labelled (6, 3). The length of the chiral vector C is the circumference of the CNT and is given by the corresponding relationship:

$$c = |C| = a\sqrt{(n^2 + nm + m^2)}$$

Where the value a is the length of the unit cell vector a_1 or a_2 . This length a is related to the carbon-carbon bond length a_{cc} by the relation:

$$a = |a_1| = |a_2| = a_{cc}\sqrt{3}$$

For graphite, the carbon-carbon bond length is $a_{cc} = 0.1421$ nm. The same value is often used for CNTs. But due to the curvature of the tube a slightly larger value such as $a_{cc} = 0.144$ nm should be a better approximation.

The relation thus gives using the circumferential length c , the diameter of the CNT:

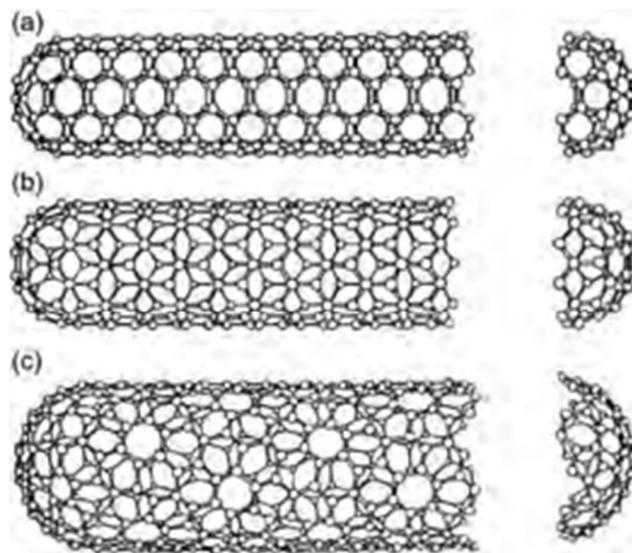
$$d = c/\pi$$

The angle between the chiral vector and zig-zag nanotube axis is the chiral angle θ . With the integers n and m already introduced before, this angle can be defined by:

$$\theta = \tan^{-1}(m\sqrt{3})/(m + 2n)$$

The pair of integers (n, m) which is related to the chiral vector only describe carbon nanotubes. Three types of CNTs are revealed with these values:

- $m = 0$ for all zig-zag tubes and ($\theta = 30^\circ$);
- $n = m$ for all armchair tubes and ($\theta = 0^\circ$);
- Otherwise, when $n \neq m$ they are called chiral tube and ($0^\circ < \theta < 30^\circ$).



Models of (a) armchair, (b) zigzag, and (c) chiral nanotubes

The value of (n, m) determines the chirality of CNT and affects the optical, mechanical and electronic properties. CNTs with $|n - m| = 3i$ are metallic like as in (10, 10) tube, and those with $|n - m| = 3i \pm 1$ are semiconducting like as in (10, 0) tube, (i is an integer).

The armchair and zig-zag tubes structures have a high degree of symmetry. These terms refer to the arrangement of hexagons around the circumference. While the chiral tube structure, which in practice is the most common, meaning that it can exist in two mirror-related forms.

The terminating cap of CNT is formed from pentagons and hexagons. The smallest cap that fits on to the cylinder of the carbon tube seems to be the well-known C_{60} hemisphere.

The smallest experimental value of CNT diameter of 0.7 nm is in good agreement with this cap.

Specific surface area gives good information of CNT characteristics and properties. Using some geometrical calculations, the theoretical external specific surface area for CNTs have been determined. For one side of graphene sheet, the value obtained is $1315 \text{ m}^2\text{g}^{-1}$ but using different multi-walled geometries and nanotubes bundles the value decreases to $50 \text{ m}^2\text{g}^{-1}$.

The easiest way to visualize how CNTs are built up is to start with graphite, the most stable form of crystalline carbon. Graphite consists of layers of carbon atoms. Within the layers, the atoms are arranged at the corners of hexagons, which fill the whole plane (in the idealized case without defects). The carbon atoms are strongly (covalently) bound to each other (carbon-carbon distance 0.14 nm). The layers themselves are rather weakly bound to each other (weak long-range van der Waals-type interaction, interlayer distance of 0.34 nm). The weak interlayer coupling gives graphite the property of a seemingly very soft material, the property that allows using graphite in a pen to write with.

The nature of the bonding of a CNT is described by applied quantum chemistry, specifically, orbital hybridization. The chemical bonding of CNTs is composed entirely of sp^2 bonds, similar to those of graphite. This bonding structure, which is stronger than the sp^3 bonds found in diamond, provides the molecules with their unique strength. CNTs naturally align themselves into ropes held together by van der Waals forces. Under high pressure, CNTs can merge together, trading some sp^2 bonds for sp^3 bonds, giving great possibility for producing strong, unlimited length wires through high pressure CNT linking.

Synthesis of CNTs

Chemical Vapour Deposition (CVD)

The chemical vapour deposition (CVD) method uses a carbon source in the gas phase and a plasma or a resistively heated coil, to transfer the energy to the gaseous carbon molecule. Commonly used carbon sources are methane, carbon monoxide and acetylene. The energy source cracks the molecule into atomic carbon. The carbon then diffuses towards the substrate, which is heated and coated with a catalyst (usually a first row transition metal such as Ni, Fe or Co) and binds to it. Carbon nanotubes are formed in this procedure if the proper parameters are maintained. Good alignment as well as positional control on a nanometric scale are achieved by using CVD. Control over the diameter, as well as the growth rate of the nanotubes is also achieved. Use of an appropriate metal catalyst permits preferential growth of single-walled rather than multi-walled nanotubes.

CVD synthesis of nanotubes is essentially a two-step process, consisting of a catalyst preparation step followed by synthesis of the nanotube. The catalyst is generally prepared by sputtering a transition metal onto a substrate, followed by etching by chemicals such as ammonia, or thermal annealing, to induce the nucleation of catalyst particles. Thermal annealing results in metal cluster formation on the substrate, from which the nanotubes grow. The temperature for the synthesis of nanotubes by CVD is generally in the 650–900 °C range. Typical nanotube yields from CVD are around 30%. Various CVD processes have been used for carbon nanotubes synthesis, including plasma-enhanced CVD, thermal chemical CVD, alcohol catalytic CVD, aerogel-supported CVD and laser assisted CVD.

Plasma-enhanced Chemical Vapour Deposition

The plasma-enhanced CVD method involves a glow discharge in a chamber or a reaction furnace through a high-frequency voltage applied to both the electrodes. Figure 1.4 shows a schematic diagram of a typical plasma CVD apparatus with a parallel plate electrode structure. A substrate is placed on the grounded electrode. To form a uniform film, the reaction gas is supplied from the opposite plate. Catalytic metals such as Fe, Ni and Co are deposited on a Si, SiO₂, or glass substrate using thermal CVD or sputtering. After the nanoscopic fine metal particles are formed, the carbon nanotubes grow on the metal particles on the substrate by the glow discharge generated from a high frequency power source. A carbon-containing gas, such as C₂H₂, CH₄, C₂H₄, C₂H₆ or CO is supplied to the chamber during discharge. The catalyst has a strong effect on the nanotube diameter, growth rate, wall thickness, morphology and microstructure. Nickel seems to be the most suitable catalyst for the growth of aligned MWNTs by this technique. The diameter of the MWNTs is around 15 nm. The highest yield of carbon nanotubes achieved by Chen et al. was about 50%, at a relatively low temperature (533 °C).

Photonic Crystal

A photonic crystal is a periodic optical nanostructure that affects the motion of photons in much the same way that ionic lattices affect electrons in solids. Photonic crystals occur in nature in the form of structural coloration and animal reflectors and in different forms promise to be useful in range of application.

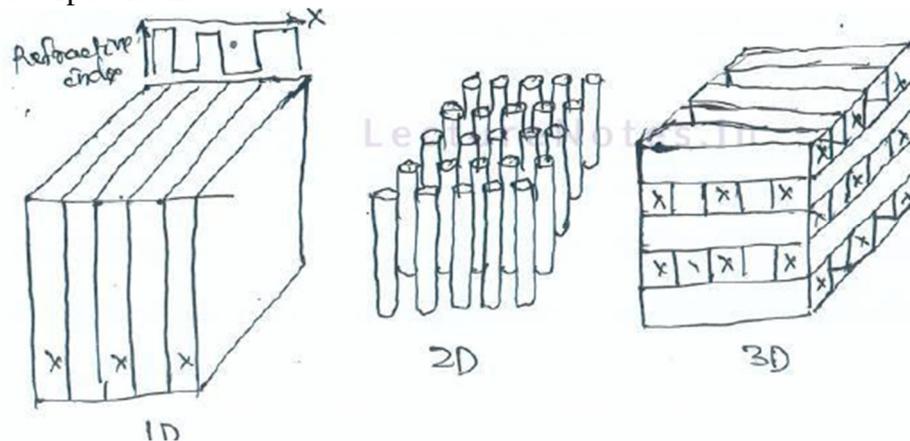
Photonic crystals are composed of periodic dielectric, metallo-dielectric or even superconductor microstructures or nanostructures that affect electromagnetic wave propagation. Photonic crystals contain regularly repeating regions of high and low dielectric constant. Photons (behaving as waves) either propagate through this structure or not, depending on their wavelength. Wavelengths that propagate are called modes and groups of allowed modes form bands. Disallowed bands of wavelengths are called photonic band gap. This gives rise to distinct optical phenomena, such as inhibition of spontaneous emission, high deflection Omni-directional mirrors, and low-loss wave guiding. Inductively, the band gap of photonic crystals can be understood to arise from the destructive interference of multiple reflections of light propagating in the crystal at the interfaces of the high and low-dielectric constant regions, akin to the band gaps of electron solids. The periodicity of the photonic crystal structure must be around half the wavelength of the electromagnetic waves to be diffracted.

(a) One-dimensional photonic crystal:

In a one-dimensional photonic crystal, layers of different dielectric constant may be adhered together to form a band gap in a single direction. One-dimensional photonic crystal can be either isotropic or anisotropic optical switch.

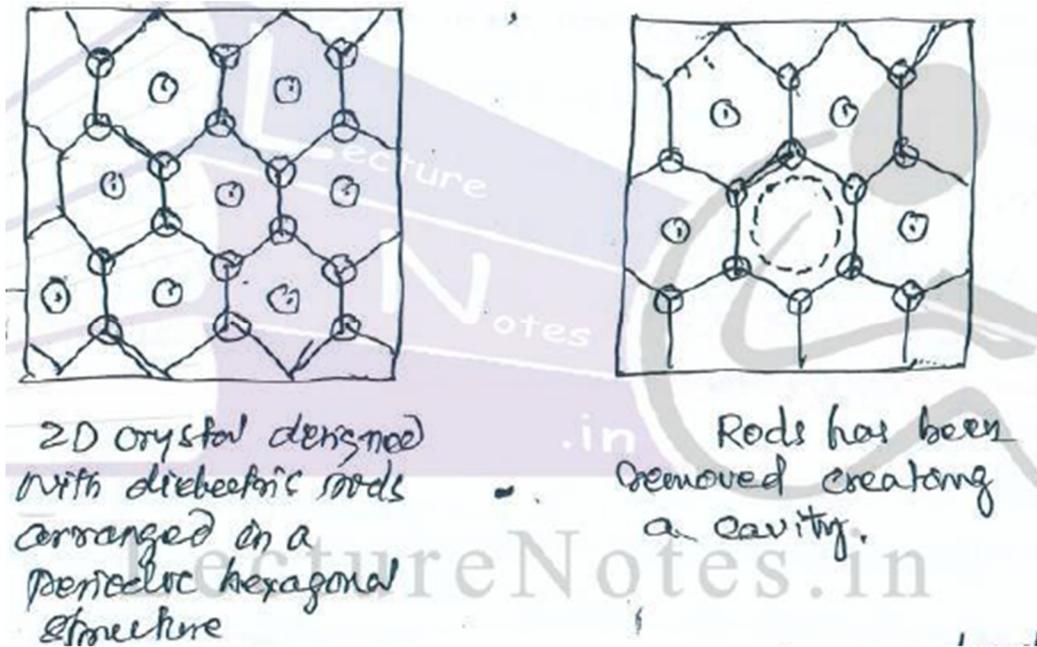
One-dimensional photonic crystal can form as an infinite number of parallel alternating layers filled with a Meta material and vacuum. This produces identical photonic band gap (PBG) structures for TE and TM modes.

The 1D photonic crystal is better known as Bragg reflector or mirror, a periodic structure composed of alternate layer of two different material one with high refractive index η , and another with lower refractive index η_1 and thickness $d = \lambda/4\eta_1$, where λ is the wavelength of light for which the reflector is designed. The Bragg reflection of an electron wave at the Brillouin zone boundary is the cause of energy band gap in solid. The Bragg's condition is given by $k = \pm n\pi/a$, which is characteristic of the wave propagation in crystals. If the path difference $2d\sin\theta$ of the reflected waves from the adjoining planes is half the wavelength, they will interfere destructively and cannot propagate in the lattice, which is the result of the periodicity of the lattice and the wave nature of the electron in solids. This is also true in the case of the interaction of photons with the photonic crystal, which is a periodic structure and the photon possesses dual nature as corpuscle and wave.



(b) Two dimensional photonic crystal:

In 2D photonic crystal designed with dielectric rods arranged in a periodic triangular/hexagonal structure, separated by air space as shown in fig. which has shaded circles representing the upper end of the rods that lie perpendicular to the plane of the paper.



If one rod is removed, it introduces a level in the forbidden photonic band gap, creating a resonant cavity in the structure (dashed circle), which behaves as the wave guide for light. The resonant cavity can also be created by changing the radius of the rod, introducing a level in the photonic band gap (stop gap for light).

The photonic crystal fiber can be made by taking cylindrical rods of glass in hexagonal lattice and then heating and stretching them, the triangle like air gaps between the glass rods becomes the holes that confine the modes.

(c) Three dimensional photonic crystals

Wooder structure: rods are repeatedly etched with beam lithography, filled in, and covered with a layer of new material. As the process repeats, the channels etched in each layer are perpendicular to the layer below, and parallel to and out of phase with the channels two layers below. The process repeats until the structure is of the desired height.

- ❖ Inverse colloidal crystal: sphere (such as polystyrene or silicon dioxide) can be allowed to deposit into a cubic close packed lattice suspended in a solvent. Then a hardener is introduced that makes a transparent solid out of the volume occupied by the solvent. The sphere are then dissolved with an acid such a HCl. The colloids can be either spherical or non spherical.
- ❖ Circular polarization uses 3D laser nanotechnology to exploit circular polarization to built a microscopic prison that contains in excess of 750,000 polymer Nano rods, light focused on this beam splitter penetrates or is reflected depending on polarization.

Quantum well (Density of state in two dimensional:

In two-dimensional materials such as a quantum well, electron motion is confined along one direction (say, z) and they are free to move along rest two directions (x, y). thus electron energy

is quantized in one dimension. Total energy of this material is the sum of the energy along the quantized direction and the energy along the other two (i.e., free) direction.

It can be expressed as,

$$E = \frac{\hbar^2 k_z^2}{2m} + \frac{\hbar^2 k^2}{2m} = E_n + E_{x,y}$$

Where, $k^2 = k_x^2 + k_y^2$ and $k_z = 2\pi/L_z$ and $n = 1, 2, 3, \dots$

E = energy, k = magnitude of wave vector.

Density of states in one dimension (Quantum wire)

In a one dimensional material such as a quantum wire, particle motion is confined along two directions say (y, z) and free along one direction (x).

Thus there is only one degree of freedom, particle energy is quantized for motion along y and z directions. Total energy of system can be written as the sum of the energy along the quantized direction (y, z) and the energy along the free direction (x).

$$\therefore E = \frac{\hbar^2 k_y^2}{2m} + \frac{\hbar^2 k_z^2}{2m} + \frac{\hbar^2 k_x^2}{2m} = E_y + E_z + E_x$$

$$\text{Where } k = k_x = \frac{2\pi}{L_x}$$

Density of states on zero dimension system (Quantum Dot)

In the extreme case of confinement along all the three directions, particles is not free to move at all. Its motion is confined along all the three directions x, y, z . The resultant material or nanostructure is called a "quantum dot" or "nano particle". The energy of the particle is quantized along all the three directions x, y, z . Therefore total energy of the system is quantized and is given by

$$E = \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m} + \frac{\hbar^2 k_z^2}{2m} = E_x + E_y + E_z$$

where $l, n, p = 1, 2, 3, \dots$ are integers.
Also $k_x = \frac{l\pi}{L_x}$, $k_y = \frac{n\pi}{L_y}$, $k_z = \frac{p\pi}{L_z}$.

Nanofluidics

A multidisciplinary field comprising physics, chemistry, engineering and biotechnology that studies the behaviour of fluid at volumes thousands of times smaller than a common droplet. Fluid confined in these structures exhibit physical behaviors not observed in larger structures, such as those of micrometer dimensions and above, because the characteristic physical scaling lengths of the fluid (e.g. Debye length, hydrodynamic radius) very closely coincide with the dimensions of the nanostructure itself.

At molecular scaling length, new physical constraints are placed on the behaviour of the fluid. For example, these physical constraints induce regions of the fluid to exhibit new properties not observed in bulk, e.g. Vastly increased viscosity near the pore wall, they may affect

changes in thermodynamic properties and may also alter the chemical reactivity of species at the fluid-solid interface.

Applications:

- * Used for analytical separations and determination of biomolecules, such as proteins and DNA
- * Nanofluidics has potential for integration into microfluidic systems, i.e., micrototal analytical systems or lab-on-a-chip structure.
- * There is a natural analogy between the fluid handling capabilities of nanofluidic structures and the ability of electronic components to control the flow of electrons and holes.

* It has significant impact on biotechnology, medicine and clinical diagnostics with the development of lab-on-a-chip devices and related techniques.

Nano pores →

A nano pore is a pore of nano meter size. It may, for example, be created by a pore-forming protein or a hole in synthetic materials such as silicon or graphene. Nanoscale pores found in purpose-built filters, sensors, or diffraction gratings to make them function better.

Scientists believe nanopores, tiny holes that allow DNA to pass through one strand at a time, will make DNA sequencing more efficient. As

DNA passes through a nanopore, scientists can monitor the shape and electrical properties of each base, or letter, on the strand.

Application:

- * Biological and protein nanopores: Nanopores may be formed by pore-forming proteins typically a hollow core passing through a mushroom-shaped protein molecule.
- * Solid state nanopores: Solid state nanopores are generally made in silicon compound membrane, one of the most common being silicon nitride. Solid state nanopores can be manufactured with several techniques including ion-beam sculpting and electron beams.

* Nanopore measurement in track etched membranes:

Track-etched membranes are typically made in polymer membrane through track-etching procedure, during which the polymer membrane is first irradiated by heavy ion beam to form tracks and then cylindrical pores or asymmetric pores are created along the track after wet etching.

* Ion current rectification: It is an important phenomenon for nanopore. Ion current rectification can also be used as a drug sensor and be employed to investigate charge status in the polymer membrane.

* Nanopore based sequencing: The observation that a passing strand of DNA containing different bases results in different blocking levels has led to the nanopore sequencing hypothesis. Apart from rapid DNA sequencing

other applications include separation of single stranded and double stranded DNA in solution, and the determination of length of polymer.

* Size tunable nanopore: Size-tunable elastomeric nanopores have been fabricated, allowing accurate measurement of nanoparticles as they occlude the flow of ionic current. This measurement methodology can be used to measure a wide range of particle types.

Debye length : \rightarrow

In plasmas and electrolytes, the Debye length (also called Debye radius), named after Dutch physical chemist Peter Debye, is a measure of charge carrier's net electrostatic effect in solution and how far its electrostatic effect persists. In other words, the Debye length is the distance over which significant charge separation can occur.

A Debye sphere is a volume whose radius is the Debye length, in which there is a sphere of influence and outside of which charges are screened.

In space plasmas where the electron density is relatively low, the Debye length may reach macroscopic values, such as in the magnetosphere, solar wind, interstellar medium and intergalactic medium.

Hannes Alfvén pointed out that: "In a low density plasma, localized space charge regions may build up large potential drops over distances of the order of some tens of the Debye lengths. Such regions have been called electric double layers."

Nano Capillaries

A typical application for glass capillaries supplied by Hilgenberg GmbH is found in microbiology, where they are used as "vacuum cleaner", during ~~micro~~ cell manipulation.

Now, a new approach has resulted in a quantum leap regarding the reduction of the tip opening - from diameters in the micron region (10^6m) down to the nanoscale (10^9m). This permits glass capillaries to be produced, whose tip openings are able to capture even single molecules such as proteins or DNA. In combination with ultra-sensitive current amplifiers, this enables proteins or DNA to be detected, which permits a precise definition of length, size, and quantity of molecules that pass through the tip of the glass capillary.

This extreme reduction of the tip opening was made possible by introducing heat energy from an electron microscope into the glass, which consists mainly of silica oxide. In this process the tip opening decreases continuously due to a temperature increase in the glass surface caused by the electron beam, thereby rearranging the atoms.

Nano Mechanics

Nano mechanics is a branch of nano science studying fundamental mechanical (elastic, thermal and kinetic) properties of physical systems at the nanometer scale. Nano mechanics has emerged on the cross road of classical mechanics, solid state physics, statistical mechanics, materials science, and quantum chemistry. As an area of nano science, nano mechanics provides a scientific foundation of nanotechnology.

Often, nano mechanics is viewed as a branch of nanotechnology, i.e. an applied area with focus on the mechanical properties of engineering nanostructure and nanosystems (system with nanoscale components of importance). Examples of the latter include

nanoparticles, nanopowders, nanowires, nanorods, nanoribbons, nanotubes, including carbon nanotubes, nano composite / nano structured material, nano shells, nano membranes, nano coatings, nano fluids, nano motors etc.

Some of well-established field of nanomechanics are: nanomaterials, nanotribology (friction, wear and contact mechanics at the nanoscale), nanoelectromechanical system (NEMS) and nanofluidics.