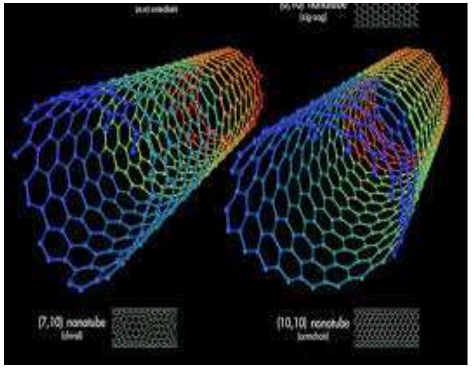
Wide Band Gap Semiconductors and their Applications

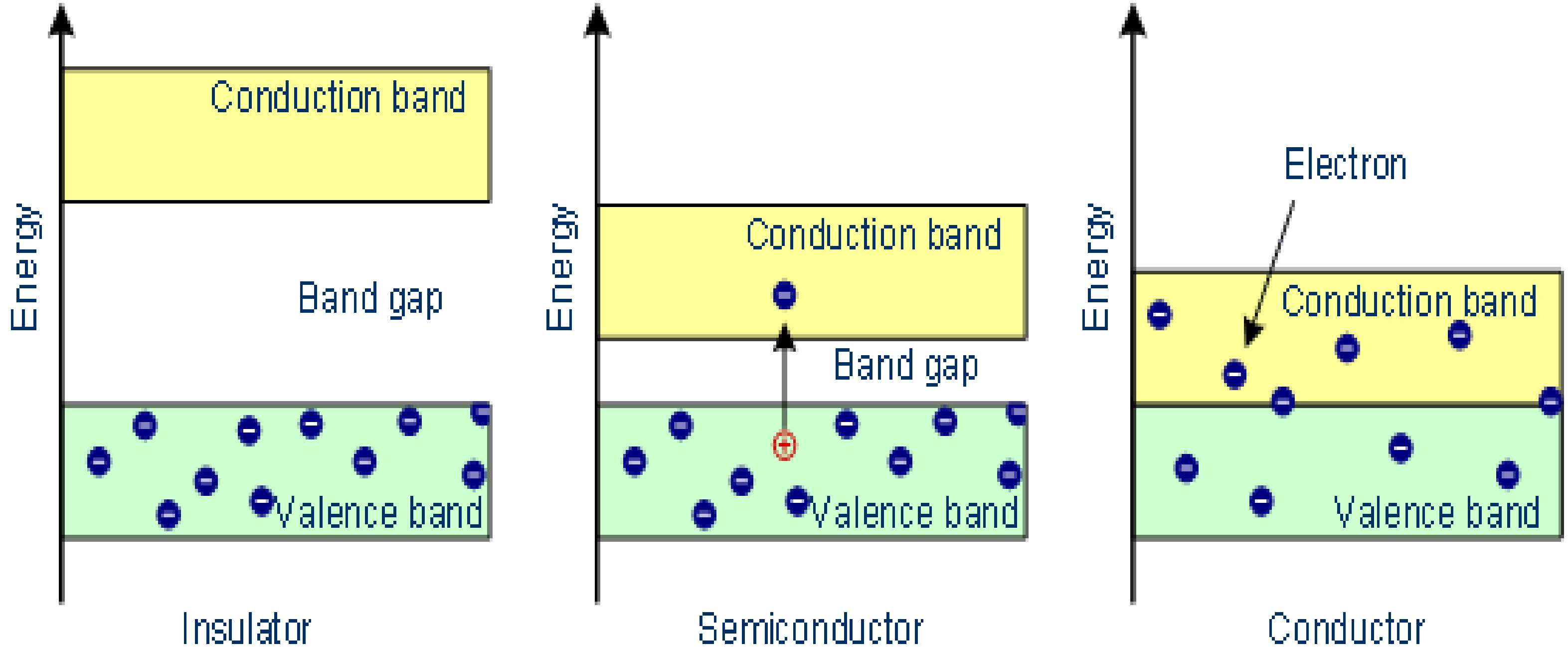
Mrs.R.Arulmozhi,
Assistant Professor of Physics,
Arulmigu Palaniandavar Arts College for Women,
Palani.



Insulators:- The materials whose electrical conductivity is either very very small or nil. They do not conduct charges.
Ex: Glass, Rubber, Wood etc.

Semiconductors: The materials whose electrical conductivity lies in between insulators and conductors. They can conduct charges but not so easily as in case of conductivity.
EX: Germanium.Silicon etc.

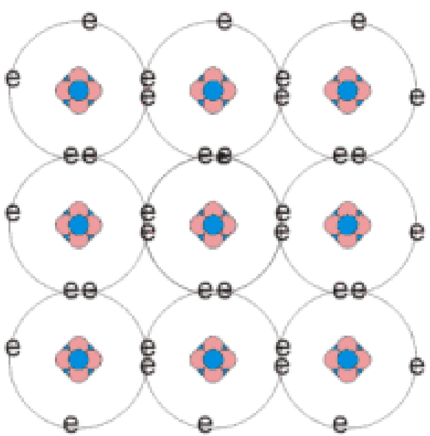
Conductors:- The materials whose electrical conductivity is very high. They conduct charges very easily .
Ex: Copper, Silver. Aluminum, Tungsten etc.



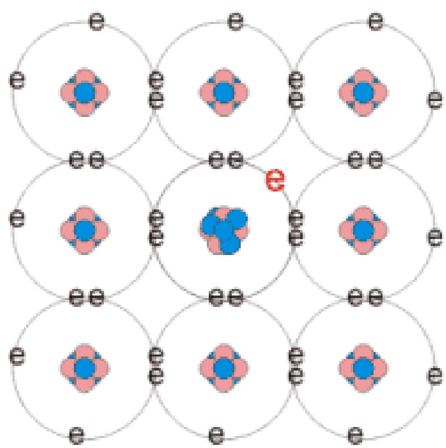
Semiconductors

- It is a substance whose conductivity is less than a conductor but more than an insulator. Resistivity is less than an insulator but more than a conductor.
- At low temperature, the valence band is completely full and conduction band is completely empty.
- The energy gap between valence and conduction band is small (Si- 1.1 ev)

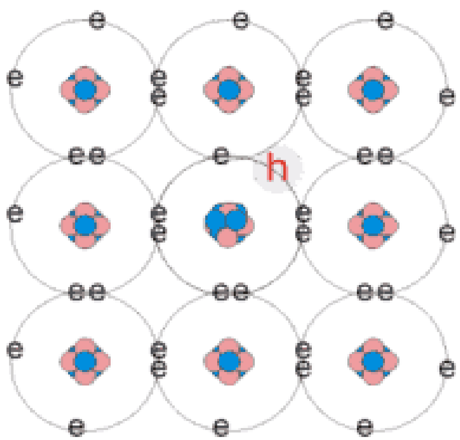
Intrinsic

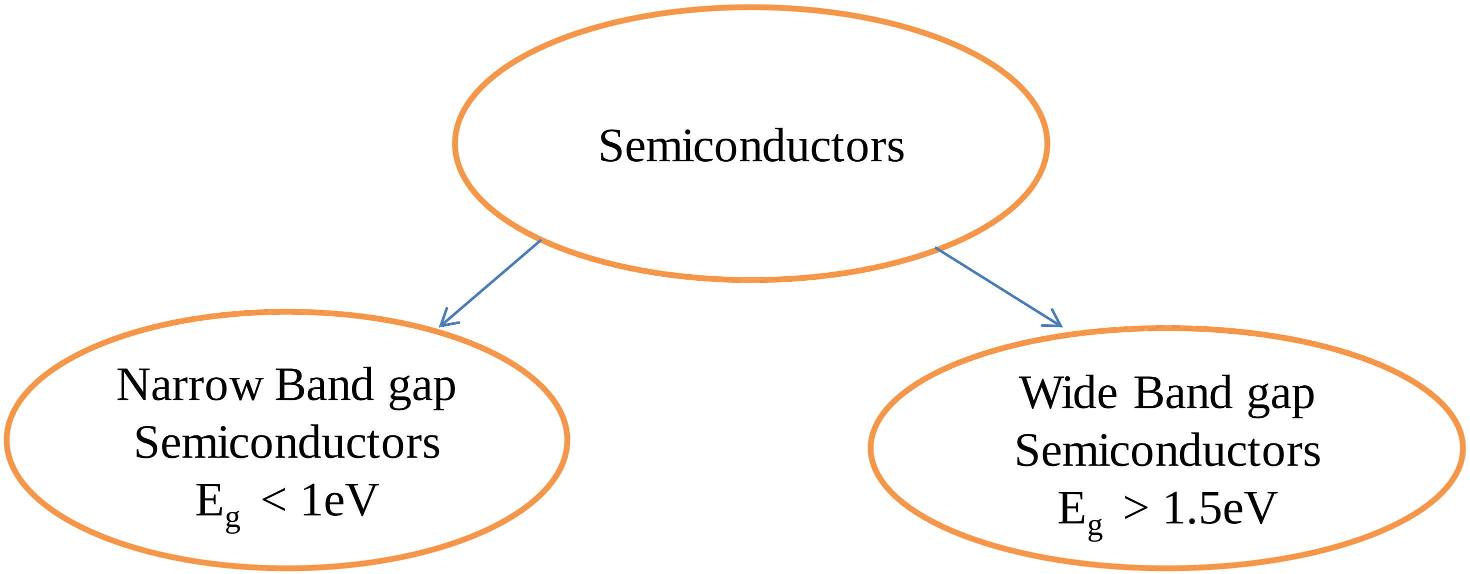


n-type



p-type





Semiconductors
Narrow Band gap
Semiconductors
E_g < 1eV
Wide Band gap
Semiconductors
E_g > 1.5eV

WIDE BAND GAP SEMICONDUCTORS

- The wide bandgap (WBG) semiconductor materials have energy bandgaps roughly 2-3 times that of silicon.
- The higher energy gap gives devices the ability to operate at higher temperatures and for some applications, allows devices to switch larger voltages.
- The wide band gap also brings the electronic transition energy into the range of energy of visible light.
- Hence light-emitting devices such as light-emitting diodes (LEDs) and semiconductor lasers can be made to emit in the visible spectrum or even produce ultraviolet emission.

Material	Chemical Symbol	Bandgap Energy (eV)
Germanium	Ge	0.7
Silicon	Si	1.1
Gallium Arsenide	GaAs	1.4
Silicon Carbide	SiC	3.3
Gallium Nitride	GaN	3.4
Diamond	C	5.5

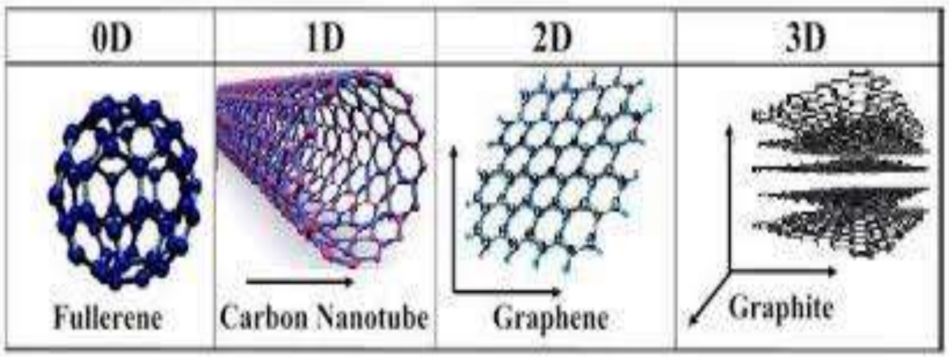
- Wide bandgap semiconductors are the group of materials called the III nitrides.
- Ex: GaN, AlN and InN and ternary compounds are GaInN, AlGaN and InAlN.
- Gallium nitride (GaN) and silicon carbide (SiC) are the ideal choice when looking for next generation of efficient power converter switches.
- Quantum Confinement is the spatial confinement of electron-hole pairs (excitons) in one or more dimensions within a material.
- The quantum confinement effect is observed when the size of the particle is too small to be comparable to the wavelength of the electron.

Low-dimensional materials

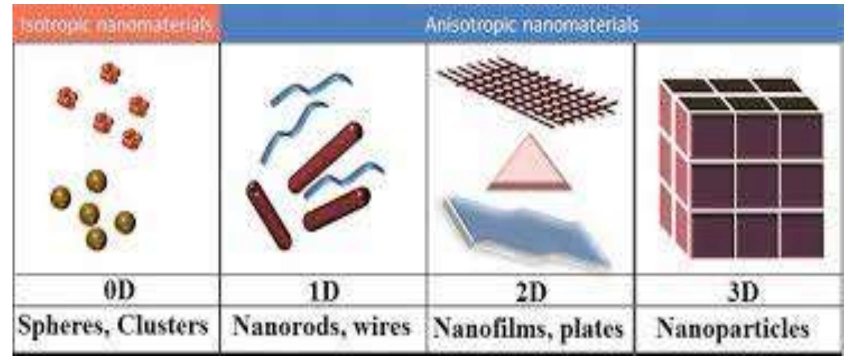
- Low-dimensional materials (nanomaterials) have a size of at least 1–100 nm.
- Ability to acquire the electronic quantum confinement.
- Have a great potential in electronic/optoelectronic applications due to their unique structure and characteristics.

Low-dimensional structures

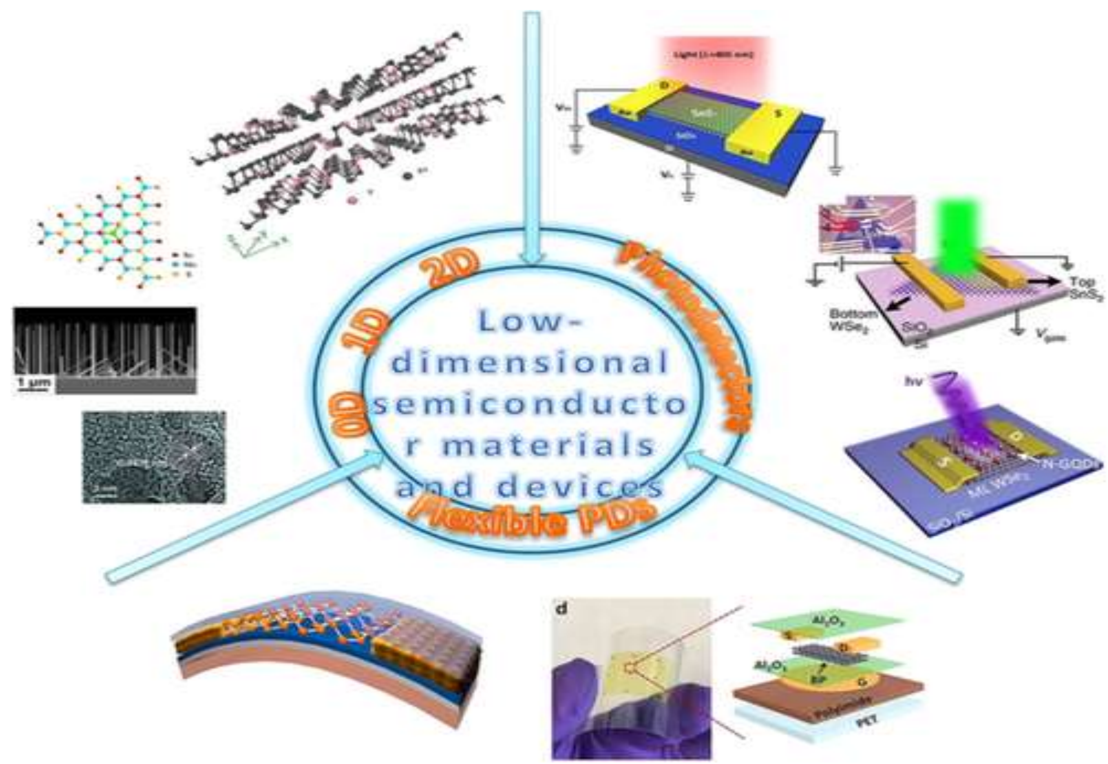
- Two-dimensional (2D) structure or quantum well: Quantization of the particle motion occurs in one direction. (e.g) graphene, hexagonal boron nitride (hBN), black phosphorus etc.,
- One-dimensional (1D) structure or quantum wire: Quantization occurs in two directions. (e.g) nanotubes, nanorods, and nanowires.
- Zero-dimensional (0D) structure or quantum dot : Quantization occurs in all three directions. (e.g) nanoparticles.



0D
1D
2D
3D
Fullerene
Carbon Nanotube
Graphene
Graphite



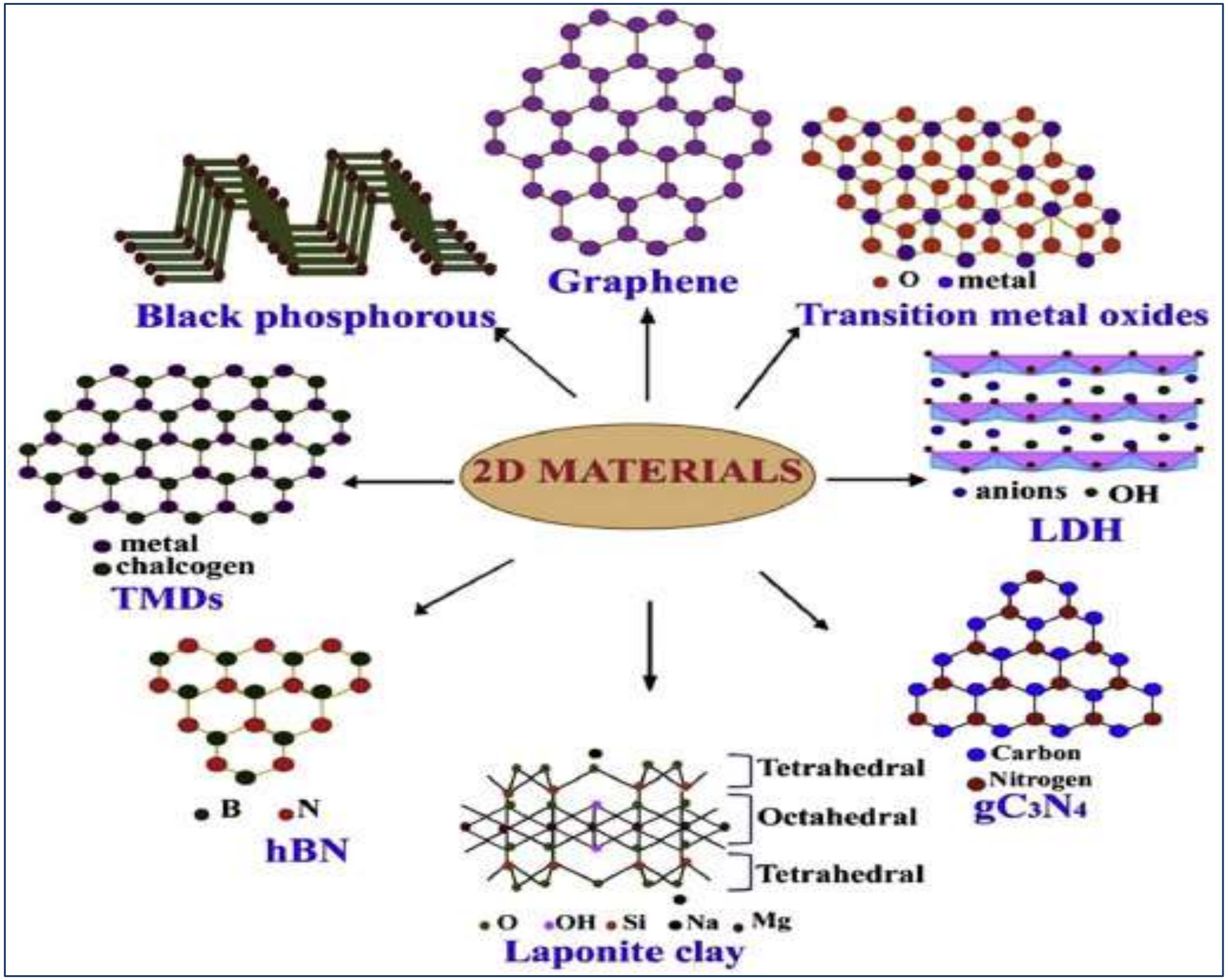
Isotropic nanomaterials
Anisotropic nanomaterials
0D
1D
2D
3D
Spheres, Clusters
Nanorods, wires
Nanofilms, plates
Nanoparticles



Low-dimensional semiconductor materials and devices
0D
1D
2D
Flexible PDs
1 μm
Top SnS$_2$
Bottom WSe$_2$
hv

Two-dimensional (2D) nanomaterials

- They are composed of thin layers that may have a thickness of at least one atomic layer.
- Used in field effect transistors, photodetectors (PDs), and some flexible devices.
- Particularly used in optoelectronics.
- Graphene is the first studied 2D material.
- It has excellent properties such as ultra-high electron mobility, excellent mechanical properties, and excellent light transmission and thermal conductivity.
- It is stronger than steel, light, flexible and transparent.



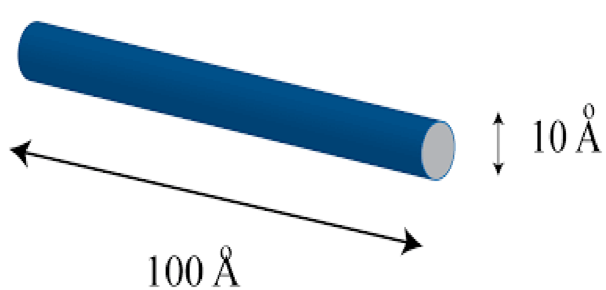
Graphene
Black phosphorous
O
metal
Transition metal oxides
2D MATERIALS
metal
chalcogen
TMDs
anions
OH
LDH
B
N
hBN
Tetrahedral
Octahedral
Tetrahedral
O
OH
Si
Na
Mg
Laponite clay
Carbon
Nitrogen
gC3N4

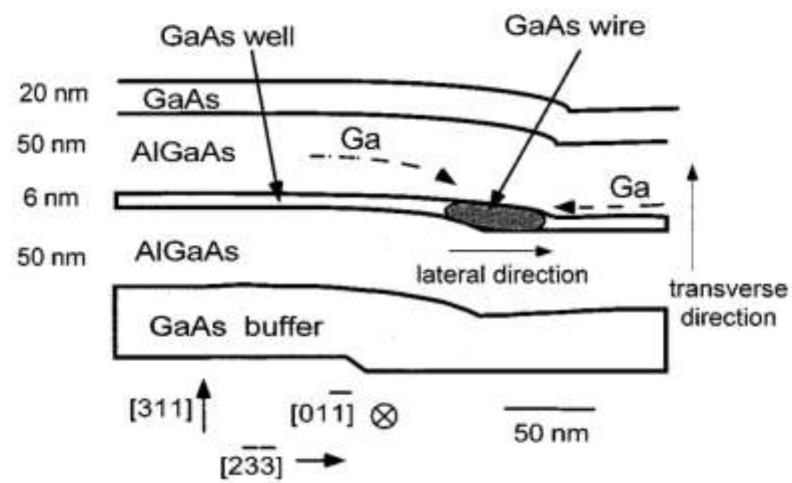
One Dimensional (1D) Nanomaterials

- 1D nanomaterials - nanowires (NWs), nanorods (NRs), nanotubes.
- The structural properties, electrical and optical properties are very different from ordinary materials.
- The high specific surface area and small diameter make them have many unique and excellent properties.
- Have unique characteristics such as fast light response, excellent absorbance, and sensitivity.
- Used in light-emitting diodes (LEDs), PDs, solar cells, and even flexible electronics .

Quantum wire

- It is an electrically conducting wire in which quantum effects influence the transport properties. Also called as nanowires.
- Narrow structures.
- Electron is confined in two directions and can move freely only in the remaining direction.
- Can be used as electron waveguides.
- Quantum wire lasers would exhibit higher and narrower gain spectrum, low threshold currents
- Better stability with temperature, lower diffusion of carriers.
- The carbon nanotube is an example of a quantum wire.



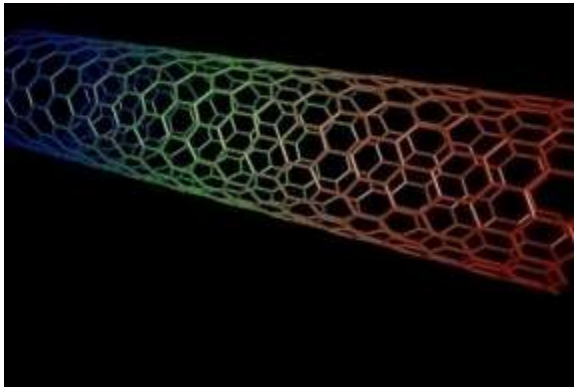


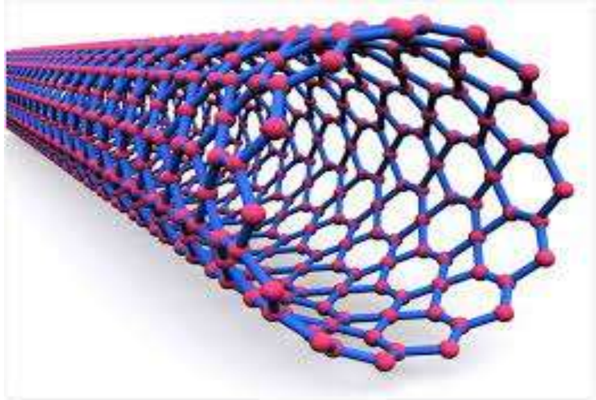
Nanowires

- Produced through chemical vapor deposition (CVD), alternating current electrode deposition, and thermal evaporation methods.
- They can be made from conducting and semiconducting materials like copper, silver, gold, iron, silicon, zinc oxide and germanium.
- **Nanowires** can also be made from carbon nanotubes.
- Nanowires are used in making nanosensors, just like CNTs. Also used for MOSFETs.

Nanotubes

- Carbon nanotubes (CNTs) are tubes made of carbon with diameters typically measured in nanometers.
- They are one of the most researched nanomaterials because of their excellent mechanical, electrical and thermal properties.
- They refer to single-wall carbon nanotubes with diameters in the range of a nanometer.
- A single wall carbon nanotube consists one cylinder of carbon atoms while multiwall carbon nanotubes have many concentric cylindrical lattices of carbon atoms.
- Used as additives to various structural materials for electronics, optics, plastics, and other materials of nanotechnology fields.



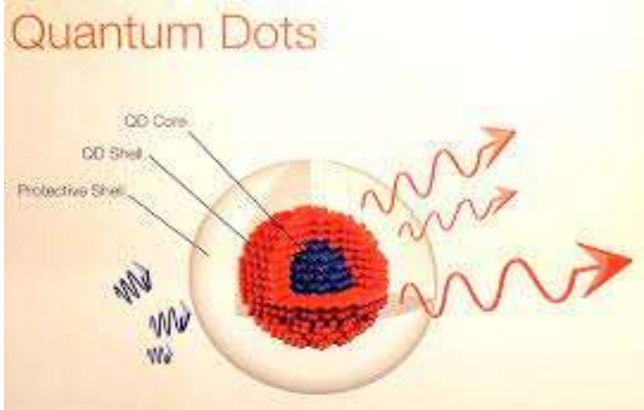


Zero-dimensional [0D] semiconductor materials

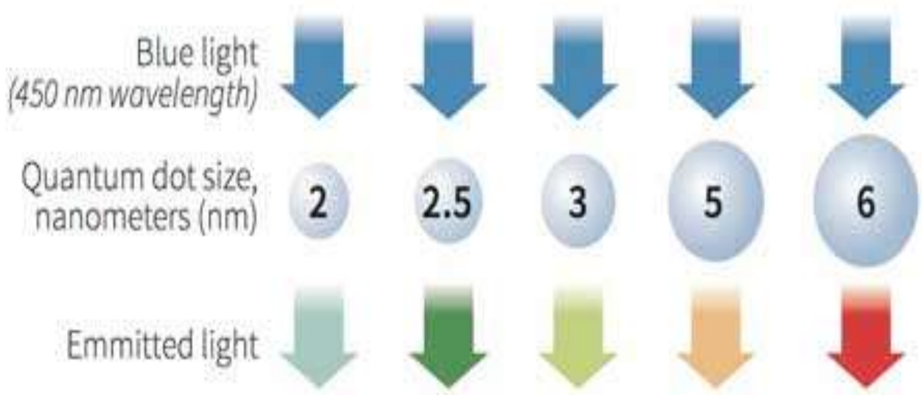
- 0D nanomaterials are nanoparticles.
- Ex: Graphene quantum dots (GQDs), carbon quantum dots (CQDs), fullerenes, inorganic quantum dots (QDs), magnetic nanoparticles (MNPs), noble metal nanoparticles, upconversion nanoparticles (UCNPs) and polymer dots (Pdots).
- They have attracted extensive research interest in the field of biosensing in recent years.
- Used in ion detection, biomolecular recognition, disease diagnosis and pathogen detection

Quantum dots

- **Man-made** nanoscale crystals that can transport electrons.
- **Artificial** nanostructures .
- A few nanometres in size.
- Having optical and electronic properties that differ from larger particles.
- Manufactured by a number of processes from colloidal synthesis to **chemical vapour deposition** (CVD).
- The cheapest and simplest method is benchtop colloidal synthesis.
- Electrochemical techniques also used.



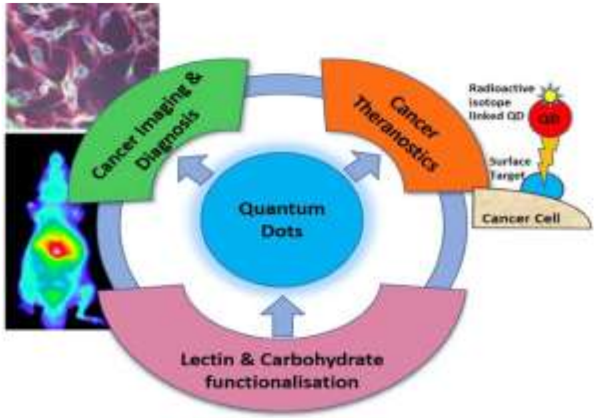
- When UV light hits these semiconducting **nanoparticles**, they can emit light of various colors.
- Light-emitting nanocrystals that absorb light of one wavelength and convert it to another.
- Ability to convert a spectrum of light into different colors.
- Each dot emits a different color depending on its size.
- Composites, solar cells and fluorescent biological labels.
- Due to their particular electronic properties they can be used as active materials in single-electron transistors.



Applications

In Medicine:

- Used in bioanalytics and biolabeling,
- Used in very artificial environments.
- They have simply precipitated in 'real' samples, such as blood.
- These problems have been solved and QDs have found numerous use in real applications.
- Used to study cell processes at the level of a single molecule.
- Improve the diagnosis and treatment of diseases such as cancers.
- Used as active sensor elements in high-resolution cellular imaging.



In photovoltaics

- For making solar cells
- Applied to a variety of inexpensive and even flexible substrate materials, such as lightweight plastics.

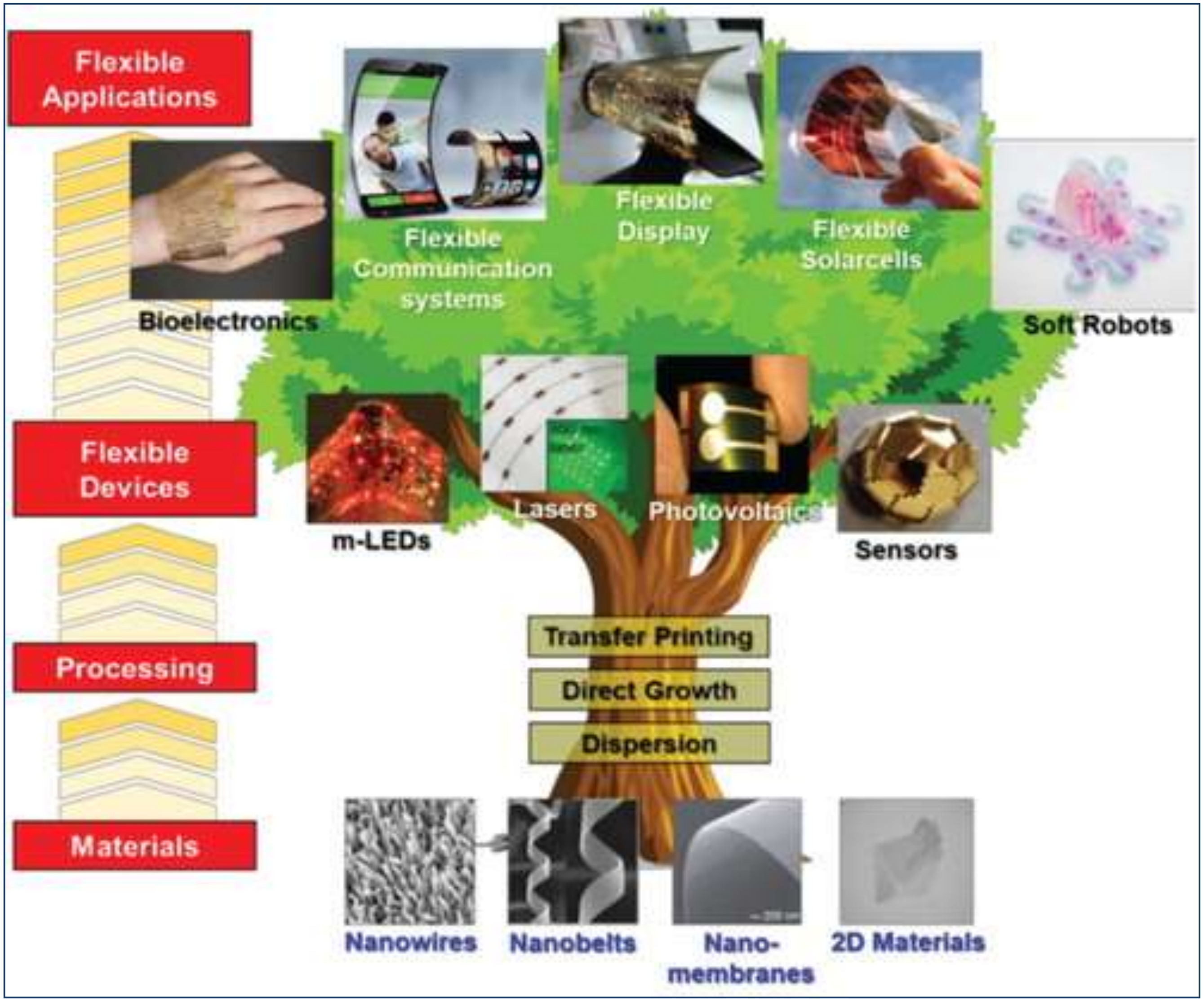
Graphene quantum dots

- Material for nanoscale electronics.
- Show great potential in the fields of photoelectronics, photovoltaics, biosensing, and bioimaging.
- Biocompatibility, low toxicity, and high stability against photobleaching and photoblinking.

Quantum dot TVs and displays

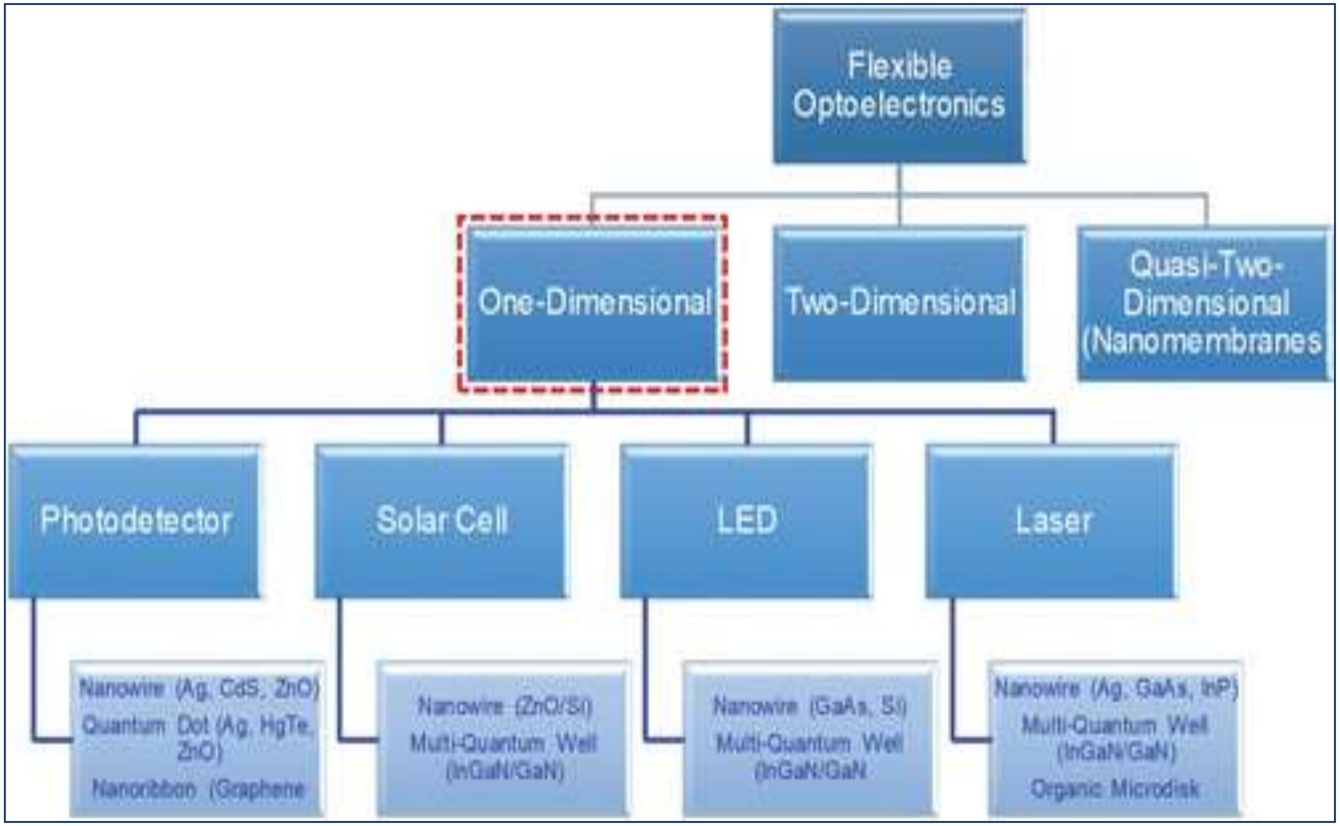
- Used as TV screens.
- Uses less power, produces less heat, and requires less space.
- So much thinner and more power efficient.
- Purer colors, longer lifetime, lower manufacturing cost, and lower power consumption.
- Quantum dot technology is closer to a plasma.
- Picture quality.
- Printable and flexible – even rollable.
- Next generation displays.

Applications in Optoelectronics



Flexible Optoelectronics using Nanomaterials

- Used in photodetectors, solar cells, LEDs, and lasers.
- The use of CNT offers fa.st photodetection due to their high mobility value.



- Used as thick, rigid, and planar form factors.
- Fexible and Rollable display mechanically durable displays, ideal for compact and lightweight mobile communications
- Flexible optoelectronic devices can be bent, twisted, and stretched because they are mechanically flexible, stable, and durable.
- Graphene is a highly promising material for photo-detection.
- It can be used as a core material for various types of photodetectors.
- 1D materials are also used in the fabrication of solar cells.
- High absorption coefficient.
- Graphene is also commonly used in conjunction with other materials to form a hybrid photodetector.