Nanoscale electronics

The latest developments in electronics involve the usage of materials in nanoscale dimensions because of their improved performance.

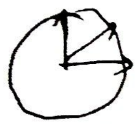
For eg. Display screens in electronic devices. Using nanomaterials ~~for~~ in fabrication of displays leads to reducing power consumption while decreasing the weight and thickness of the screens (QLEDs → Quantum dot LEDs)

Density of ~~ne~~ memory chips can be increased & the size of transistors can be decreased, by using nanomaterials.

Nanomaterials:-

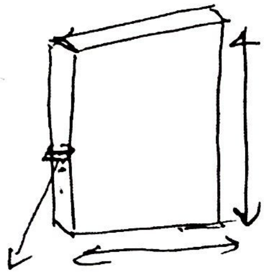
Materials having dimensions < 100nm.

Nanoparticle



All three dimensions < 100nm.

thin film

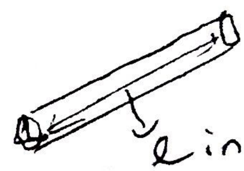


thickness < 100nm

length & breadth (in μm)

nanosize in one dimension

nano rod or wire



l in μm

diameter ~~is~~ < 100nm

2 dimensions < 100nm

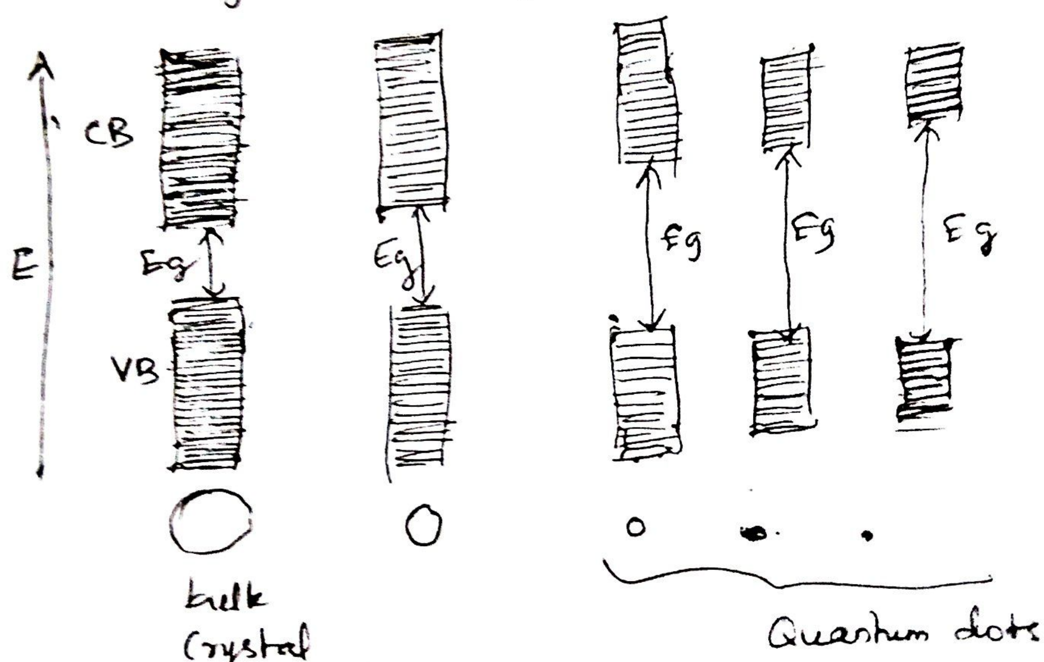
If a nanoparticles has all its three dimensions < 10nm it is called a Quantum dot; if a film has thickness i.e., one dimension < 10nm it is called a Quantum well; if a wire has its diameter < 10nm it is called a quantum wire.

The movement of electrons is confined to few nanometers in ~~certain directions~~ such nanostructures ~~etc~~ and the quantum effects lead to size dependent variation in properties. At nanoscale many of the bulk properties of materials change. As an example let us consider the optical properties of semiconductors.

Quantum dots - optical properties :-

Energy bands are formed by interaction of atomic orbitals in a solid semiconductor and there is an energy gap between the VB and CB.

As the crystal of semiconductor material becomes smaller ~~and smaller~~, fewer atomic orbitals are available to contribute to the bands. When the crystal is very small i.e., quantum dot, the bands are no longer a continuum of orbitals, but individual quantised orbital energy levels and this has an effect of increasing the band gap.



As size of the nanoparticles decreases, the band gap increases

For eg. the band gap in CdSe crystals is approximately 1.8 eV for crystals of diameter 11.5 nm, but approximately 3 eV for crystals of diameter 1.2 nm.

Because of this size confinement effect on band gaps interesting optical properties are observed

For eg. in a light emitting material like CdSe, (~~elect~~ excited electrons in the CB relax to the valence band by emitting light). as the size ~~decrease~~ of the

CdSe quantum dot decreases, the band gap increases, and hence, the shorter wavelength of light is emitted.

For eg. 5.5nm diameter particles of CdSe emit orange light whereas 2.3nm diameter particles emit turquoise light.

Thus, ~~the~~ a single material can be tuned to emit light with different colors by tuning the size of the material.

x

Chalcogenide semiconductors :-

Chalcogens (ore forming) materials or elements of oxygen family namely S, Se, Te. Compounds with transition metals ~~first & based materials~~ are semiconducting and find a wide range of applications

S-based materials → optoelectronic devices

Se based materials → imaging & biomedical applications, ion-selective sensors and solar cells.

Te based materials → memory devices

Examples $\left\{ ZnS, ZnSe, ZnTe \right\}$,

CdS, CdSe, CdTe

HgCdTe

used in solar cells

↑

$CuInSe_2$

$CuInTe_2$

PbS, PbSe, PbTe → nanostructures (quantum dots)

Band gap tuning between 0.3 to 1.1 eV

Se and Te are semiconductors

In this group outer electronic configuration $ns^2 p^4$

$Se \rightarrow [Ar]\, 3d^{10} 4s^2 4p^4$

$Te \rightarrow [Kr]\, 4d^{10} 5s^2 5p^4$

$Zn \rightarrow [Ar]\, 3d^{10} 4s^2$

$Cd \rightarrow [Kr]\, 4d^{10} 5s^2$

In the compounds ZnSe, CdS, CdSe, CdTe, the bonding is covalent with a tetrahedral orientation of the

$Zn \rightarrow [Ar]\, 3d^{10}$ $\overset{4s}{\boxed{\uparrow\downarrow}}$

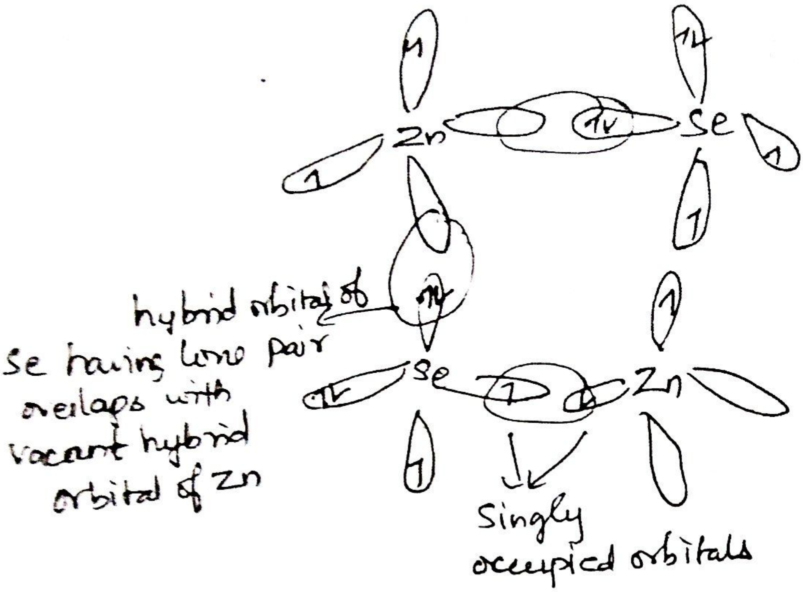
excited Zn $[Ar]\, 3d^{10}$ $\overset{4s}{\boxed{\uparrow}}$ $\overset{4p}{\boxed{\uparrow\ \ \ \ }}$ → sp^3 hybridization

$Se \rightarrow [Ar]\, 3d^{10}$ $\overset{4s}{\boxed{\uparrow\downarrow}}$ $\overset{4p}{\boxed{\uparrow\downarrow\ \uparrow\ \uparrow}}$ → sp^3 hybridization

$Zn \rightarrow 4\ sp^3$ hybrid orbitals (2 orbitals having one electron each and the other two vacant)

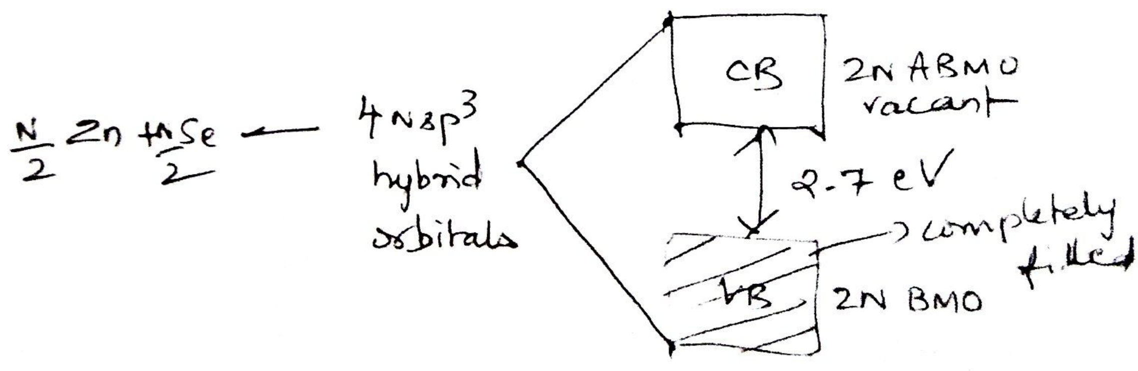
Se → 4 sp³ hybrid orbitals (2 orbitals having lone pairs of electrons and the other two one electron each).

overlapping of Zn & Se hybrid orbitals



In one mole of ZnSe solid. there are N atoms $\frac{N}{2}$ Zn atoms and $\frac{N}{2}$ Se atoms. Each atom provides 4 sp^3 hybrid orbitals, ∴ total no. of hybrid orbitals involved in bonding is 4N. Total no. of valence electrons 6 from Se & 2 from Zn. (per ZnSe).

On average $\frac{6+2}{2}$ = 4 valence electrons



similar kind of bands are formed in all other chalcogenide semiconductors

CdSe → Band gap → 1.74 eV   CdSSe → 1.98 eV

CdS → 2.42 eV

ZnS → 3.54 eV

All are direct band gap semiconductors