Nishad D. pandey NANO DEVICE ENGENEERING

Storage → RAM → EPRAM, DRAM, SRAM, PCRAM (Phase chang RAM), MRAM (magnetic RAM)

Storage → Rom

PCRAM → Nano ~~[illegible]~~ technology

Data Storage "vs" Information Storage devices ?

"NANO" → atleast one dimensions → in nanometer 1 - 100nm

"NANO" → Drastic Changes → Properties.

in nanometer 1 - 100nm →

- 0D: Quantum dots
- 1D: → Nano wires, → Nano tubes, → Nano rods
- 2D: → Nano Structed thin films.
- 3D: Nano Particles (powder)

Drastic change in the properties:

1. Increased Surface to volume ratio.
2. High concentration of atoms/molecules at the surface
3. Dominant Surface forces.
4. Plasmonic resonance effects.
5. Confined energy states [quantum Confinement]
6. Drastic physical chemical Biological changes.

Drastic physical chemical Biological changes → Size, Shape, Composition; lowered phase transitition temp; Increased mech strengths; Different optical effects; Altered electrical Conductivity.

no. of atoms:

1 - - - 10 - - - - 10^2 - - - - 10^3 - - - - 10^4 - - - - 10^5 - - - 10^6

$\underbrace{\qquad}_{\text{molecule}}$ $\underbrace{\qquad\qquad\qquad}_{\text{nano particles}}$ $\underbrace{\qquad\qquad\qquad}_{\text{Bulk.}}$

Q: A spherical particle $\longrightarrow$ 100nm diameter then

i) Volume $(4/3 \pi r^3)$ ii) surface area $(4\pi r^2)$

$$V = \frac{4}{3}\pi (50 \times 10^{-9})^3$$

$$V = 5.22 \times 10^{-22} m^3$$

$$S = 4\pi(50 \times 10^{-9})^2$$

$$S = 3.14 \times 10^{-14} m^2$$

NANO

$$S/V = \frac{3.14 \times 10^{-14}}{5.22 \times 10^{-22}} m^2/m^3 \Rightarrow \frac{S}{V} = 6 \times 10^7 m^{-1}$$

"SURFACE EFFECTIVE"

If diameter $\longrightarrow$ 100m.

$$V = 5.22 \times 10^{-22} \times \frac{1}{10^{-27}}$$

$$V = 5.22 \times 10^5 m^3$$

$$S = 3.14 \times 10^{-14} \times \frac{1}{10^{-18}}$$

$$S = 3.14 \times 10^4 m^2$$

BULK

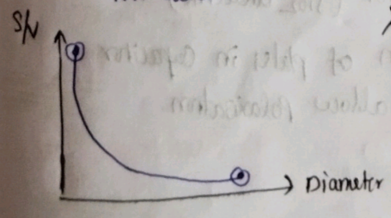
$$S/V = 0.06 \text{ units}$$

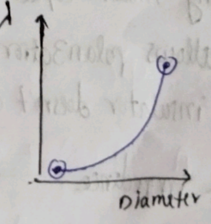
$$E_1 = hc/\lambda \Rightarrow \frac{hc}{100 \times 10^{-9}} = hc \times 10^7$$

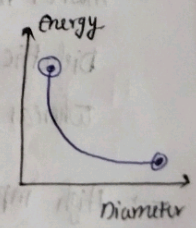
Not detectable

$$E_2 = \frac{hc}{\lambda} = \frac{hc}{100} = hc \times 10^{-2}$$

Radio region







Changed magnetic properties (Ferro, Dia, Anti, Ferri, Paramagnetic (Super para)*)?

Effective surface
Chemical reactions.

manish sir

NANO DEVICE ENGG (1 - 100 nm)

Device ⟶ Building blocks (Capacitor, BJT, MOSFET, - - -)

Circuit ⟶ Connecting devices

IC

- → SSI
- → MSI
- → LSI
- → VLSI
- → UVLSI

- → Analog
- → Digital

- → monolithic
- → Hybrid

-: IC fabrication:

Silicon wafer ⟶ on which fabrication takes place

→ MOSFET >> BJT

→ mosfet takes less place

→ ~~MOSFET~~ MOSFET has less power consumption than BJT

→ MOSFET is Voltage Controlled device

→ MOSFET having inbuilt Capacitor (SiO_2 dielectric)

Dielectric allows polarization of plates in capacitor whereas, insulator doesn't allow polarization.

→ High input impedence

→ Easy fabrication.

Drawback: "Low speed."

~~MOSFET~~ OPERATION:

NISHAD SIR:–

Energy levels and quantum Confinement Effects:

3D ⟶ 0D

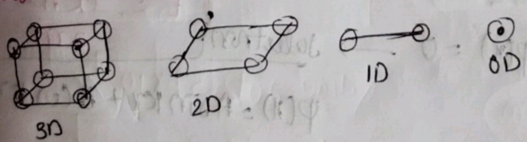
$D_f + D_c = 3$

Degree of freedom (D_f), Degree of Confinement (D_c)

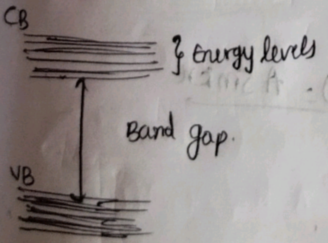
	D_f	D_c
3D	3	0
2D	2	1
1D	1	2
0D	0	3

Q: If 0D nano material is having 0 D_f then where is the particle going or moving? (Homework)!

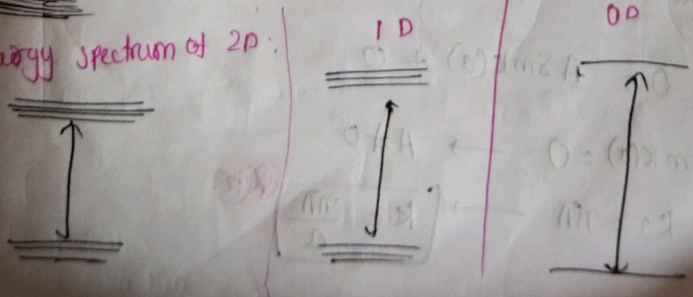
In case of Confinement we are decreasing the no. of atoms on the surface.



Energy spectrum of 3D: It is having more no. of electrons and more no. of Energy levels and less Band gap.

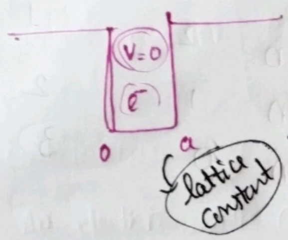


Energy spectrum of 2D:



As the no. of atoms decreses the no. of energy levels decreses and Bandgap increases. As the Bandgap increases the properties of the material changes.

1D nano material:



Electron can move inside the well but c'not move outside

Schrodhinger equation:

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E-V)\psi(x) = 0$$

Inside the 1-D well $\longrightarrow \boxed{V=0}$

$$\frac{d^2\psi}{dx^2} + \underbrace{\frac{2m}{\hbar^2}(E)}_{K^2}\psi(x) = 0$$

$$\boxed{\begin{aligned} K^2 &= \frac{2m}{\hbar^2}E \\ K &= \frac{\sqrt{2mE}}{\hbar} \\ E &= \frac{(K\hbar)^2}{2m} \end{aligned}}$$

$$\frac{d^2\psi}{dx^2} + K^2\psi(x) = 0 \longrightarrow \text{Solution}$$

$$\psi(x) = A\sin Kx + B\cos Kx$$

If $x=0 \rightarrow \psi(x)=0$

$$\psi(0) = A\sin K(0) + B\cos K(0)$$

$$\boxed{0 = B}$$

$$\psi(x) = A\sin Kx$$

If $x=a \longrightarrow \psi(a)=0$

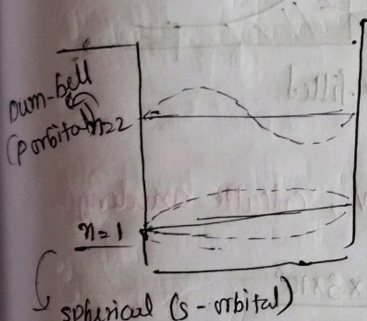
$$0 = A\sin K(a) + 0$$

$$\sin K(a) = 0 \longrightarrow A \neq 0$$

$$Ka = n\pi \longrightarrow \boxed{K = \frac{n\pi}{a}}$$

then energy $E = \dfrac{(n\pi/a)^2 \hbar^2}{2m}$

$$E = \frac{n^2\pi^2\hbar^2}{a^2(2m)}$$

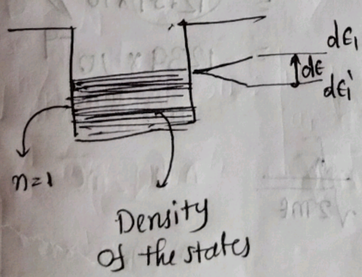


$E = \dfrac{4\pi^2\hbar^2}{2m(a^2)}$

$E = \dfrac{\pi^2\hbar^2}{a^2(2m)}$

As we are studying for more no. of atoms we will have more no. of states at "equidistance" of the energy level

$dn \Rightarrow$ no. of allowed energy states given the study/reference



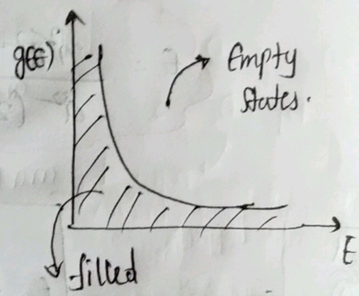
$$\boxed{g(E) = \frac{dn}{dE}}$$

$$dE = \frac{2n\,dn\,\pi^2\hbar^2}{2ma^2} \longrightarrow \frac{dE}{dn} = \frac{n\pi^2\hbar^2}{ma^2}$$

$$g(E) = \frac{dn}{dE} = \frac{ma^2}{n\pi^2\hbar^2} \longrightarrow \frac{ma^2}{\pi^2\hbar^2}\,\frac{\pi\hbar}{a\sqrt{2mE}}$$

$$\boxed{g(E) = \frac{dn}{dE} = \frac{a}{\pi \hbar}\sqrt{\frac{m}{2E}}}$$

$$g(E) \propto E^{-1/2}$$



Q: An electron with Energy 1eV, calculte wavelength (KE)

$$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{h \times 3\times10^{8}}{1\,eV}$$

$$\lambda = \frac{6.62\times\cancel{10^{-34}}^{\,10^{-15}}\times 3\times10^{8}}{1.602\times\cancel{10^{-19}}} \rightarrow \frac{6.62\times3\times10^{-7}}{1.602}$$

$$= 12.39\times10^{-7} \times \frac{100}{100}$$

$$= 1239\times10^{-9}$$

$$\lambda = 1240\,nm$$

Calculate a = ?

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$$

MANISH :-

1st → oxygen

3rd → Iron

C

Si → 2nd largest available element
→ Temperature stability.
→ oxidizes easily $\boxed{SiO_2}$ and SiO_2 is stable also
→ Environmental safe
→ Si in elemental semiconductor is stable

Ge

Sn

Pb

Si → 150°C – 200°C

Ge → 75°C — 100°C

Direct bandgap & Indirect bandgap semiconductors?

Si → Indirect Bandgap (emitts heat)

GaAs → High speed (Direct Bandgap) (Emmits IR light)

SiC, GaN

LED

MEMS → micro electronic mechanical systems

mobility → Si (μ_n) = 1500 $cm^2/V\text{-}s$

Ge (μ_n) = 4000 $cm^2/V\text{-}s$

GaAs (μ_n) = 8600 $cm^2/V\text{-}s$

$\boxed{\mu = V_d \times E}$

V_d → drift velocity

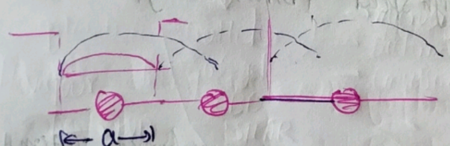
E → Electric field

NISHAD:-

Energy levels & quantum confinement effects:-

	KE	λ	a
electron	1eV	1.22nm	0.613nm
	5eV	0.55nm	0.274nm

Quantum-tunnelling effect: As we confined (or) trapped the electron in the potential well but it's wave can travell out of the "potential well."



Interference of waves

$\boxed{\lambda \sim a}$ → De-Brogli's wave effect
→ Then it is called as quantum confinement effect.

Density of states?

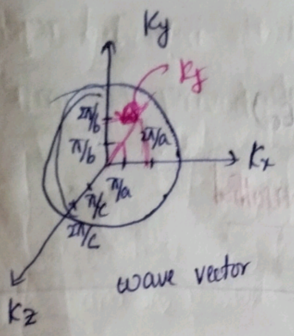
$$g(E) = \frac{dn}{dE} = \frac{m a^2}{\pi^2 \hbar^2} \frac{\pi \hbar}{a\sqrt{2mE}} = \frac{ma}{\pi \hbar \sqrt{2mE}}$$

$$= \frac{(m)(0.613 \times 10^{-9})}{\pi \hbar \sqrt{(2)(m)(1eV)}}$$

Density of states for 3D:

WKT; $k = \frac{n\pi}{a}$; $E = \frac{\hbar^2 k^2}{2m}$ $\Rightarrow$ $k = \frac{\sqrt{2mE}}{\hbar}$

wave vector



wave vector

no. of states $= \dfrac{\text{Vo. of Sphere}}{\text{Vo. of Single cell}}$? Consider any unit cell.

$$\text{no. of States} = \frac{\frac{4}{3}\pi (k_f)^3}{(2\pi/a)^3} \quad (a=b=c)$$

$$= \frac{1}{6}\frac{k_f^3 a^3}{\pi^2} \Rightarrow \frac{1}{6}\left(\frac{\sqrt{2mE}}{\hbar}\right)^3 \frac{a^3}{\pi^2}$$

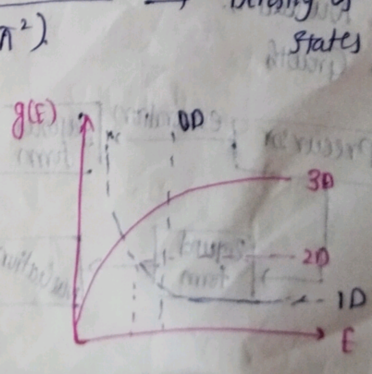
$$n = \frac{a^3 (2mE)^{3/2}}{6\hbar^3\pi^2}$$

$$\frac{dn}{dE} = \frac{a^3}{\cancel{2}6\hbar^3\pi^2}\left(\frac{3}{2}\right)E^{(1/2)}(2m)^{3/2} \longrightarrow \text{multiply by } 2$$

$$\frac{dn}{dE} = \frac{1}{2}\frac{a^3}{\hbar^3(\pi)^2}(2m)^{3/2}E^{1/2}$$

$$g(E) = \frac{dn}{dE} = \frac{a^3(2m)^{3/2}E^{1/2}}{(2)\hbar^3(\pi^2)} \longrightarrow \text{Density of States}$$

3D case: $\boxed{g(E) \propto E^{1/2}}$



Home work

Do it for 2D, 0D

for 2D $\longrightarrow$ $g(E) \propto E^0$

for 0D $\longrightarrow$ $g(E) \propto 2\delta(E-E_c)$

Synthesis meathod

- TOP - Bottom Approach
- Bottom-up approach

Lithography

- Physical
  - mechanical
    - Ball milling
    - melt mixing
    - lithography *
  - vapour
    - PVD
    - laser ablation $\rightarrow$ spray-Pyrolsis
    - Sputtering
    - Ion implantation *
- Chemical
  - Collid
  - Sol-gel
  - CBD * $\rightarrow$ Chemical Bath deposition.
  - SILAR
- Biological
  - microorganisms
  - Bacterial meathods
  - Emulsim
- Hybrid
  - Electro-Deposition meathod
  - Industrial viable

Principles for synthesis meathod:

$\rightarrow$ Precursor, Evaporation/liquid/gases

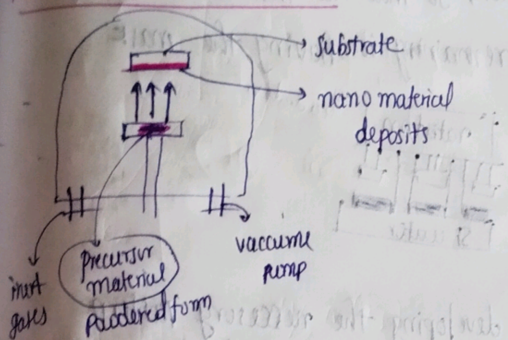
$\rightarrow$ Nucleation.

$\rightarrow$ Growth

Precursor $\xrightarrow{\text{Evaporation}}$ gaseous form $\rightarrow$ Nucleation $\xrightarrow{\text{intermidiate}}$ gaseous-Solid interaction $\xrightarrow{\text{reaction}}$

Precursor $\rightarrow$ liquid form $\rightarrow$ Nucleation $\xrightarrow{\text{intermidiate}}$ liquid-Solid Interactions $\xrightarrow{\text{reaction}}$ growth

Thermal evaporation meathod :



Lithography process : devicing nano structures : —

↳ transferring of geometric patterns to devolep nano structures.

- Photo lithography (200 - 300 nm) λ
- X-ray litho (50nm - 2nm) λ
- E-beam litho

① Coating the photoresist on Si wafer.

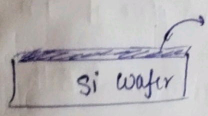
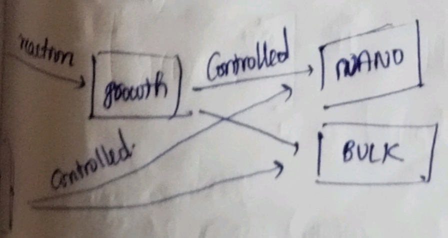
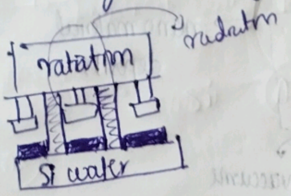


Photo resist ⟶ Photo sensitive (Polymeric material)

PTO ⟶

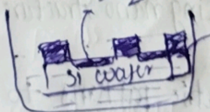


② Exposure to radiations: So that the intrested region gets exposed and the remaining is having the mask.



③ use developer for developing the necessary pattern.

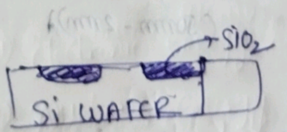
SiO_2 (insulating layer).



alkaline Solution (oxidizes)

Should'nt have much pH

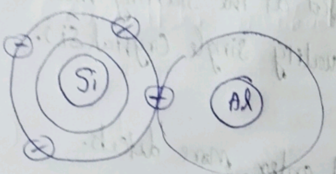
④ Etching process:- This process removes the photo resist (HF)

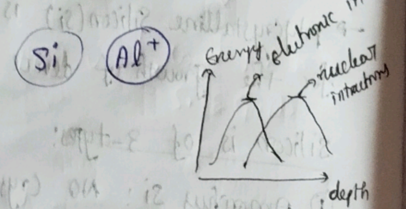


MEMES → micro level fabrication

NISHAD:

Ion Implantation





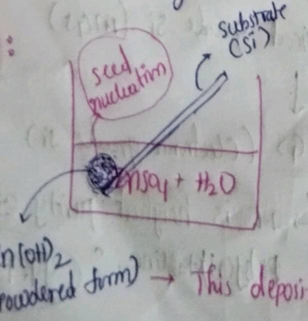
- when Al^+ moves with very high speed then it is called as Swift heavy ion process.

- when we give sufficient energy to Al^+ so that it just stops after intraction with Si then it is called as Ion implantation meathod.

Al^+ experiences ① Electronic energy loses
② Nuclear energy loses.

Simple process (But not so accurate) in place of ion implantation meathod for doping is "C.B.D" → Chemical Bath deposition.

CBD:



→ This deposited on Si

Zn^{+2} SO_4^{-2} + H^+ - OH^- = $Zn(OH)_2$ (nano Particle) + H_2SO_4

when we heat the "sol" then $Zn(OH_2)$ goes oxidation & gives "ZnO"

- we can control the quantity of nano particle by how much chemical we are using.
- when we keep the Si for more time then it corrodes & ZnO removed due to Acidic H_2SO_4.

- we can also dope another nano particles by changing the chemical and also in what ratio we are using them for deposition.

1:2 ratio of 1 → $ZnSO_4$ & 2 → Al_2SO_4 we get $ZnAl(OH)_2$ nano particle for deposition.

NISHAD :-

SRIM/TRIM → Software for stopping potential (Ion implantation method).

Ostwald's ripening ?

- Concentration precursor sol
- Volume of sol
- temperature

- pH
- time

} these control the "CBD"

SILAR (Succesive ionic layer adsorption and reaction).

we have to dip the rod succesivly into the beakers.