PHYSICS

Size dependent properties :

① Temperature (MP/BP)

Size decrease ⟶ MP decreases

② Color

$E_n \propto \frac{1}{L^2}$

Size decrease → More energy required to excite → Wavelength decreases

③ Optical changes in CdS

Red → Orange → Yellow → White

6 nm — 4 nm — 3 nm — 2 nm

④ Increase in Catalytic Activity of Gold Nanoparticles

Size decrease → Inertness lost

⑤ Size dependence of magnetism

Magnetic Moment μ increases.

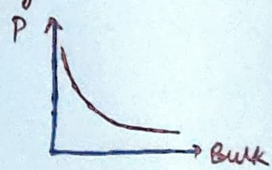
Rhodium (Bulk) Non magnet ⟶ Rh (Nano) Magnetic

⑥ Pressure & structural transition

Size ↓ ⇒ Pressure ↑

(Bulk) CdSe 2.0 GPa

(Nano) CdSe 3.6 - 5.0 GPa



⑦ Hardness Variation

Bulk : grain size ↓ Hardness ↑

Nano : grain size ↓ Hardness ↓

⑧ Dielectricity (K)

K: dielectric constant

Bulk ⟶ Nano

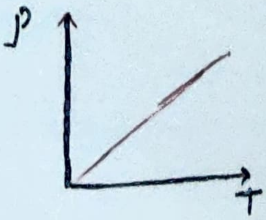
Small K — Large K

1000 (PZT) — 35000 (PZT)

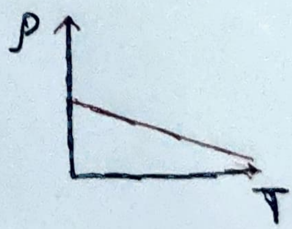
⑨ Electrical Resistivity

Metallic Behaviour ⟶ Semi-conductor Behaviour

~~+ve~~ -ve temp coeff (Bulk) — +ve temp coeff (Nano)



Temp ↑ ρ ↑



Temp ↑ ρ ↓

Nanofabrication

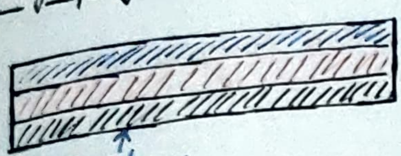
① Top-Down approach : Bulk Machined to Nano

Lithography : Printing method (chem. process) to create image.

Substrate + Resist (+ or - depending on solvent)
(silicon)

If solubility increases → Positive Resist

Photolithography



Types of Photolithography

① Proximity Method
Mask is held close to the resist
Limited by : Diffraction

② Contact Method
Mask held in contact to resist
Limitation : Mask degrades fast

③ Optical Method
Light radiation focused using lenses
Limitation : Slow & costly

Product out of Silica Gel / Sol

① Aerogels - Surfactant (lightweight - least dense, extremely strong 100x)
② Xerogel
③ Nano crystalline / wire / wells

Scanning Lithography

1. Electron Beam
2. Pulsed Laser Deposition
   - Bottom up
   - Laser generated plasma of required stoichiometry

Advantages: Stoichiometric transfer of material from target
high deposition rates

Limitation: Non-uniform thickness when large surface produced.

Applications of PLD:
- To deposit high temp superconductors thin film.

  $YBa_2Cu_3O_{7-x}$ (YBCO)

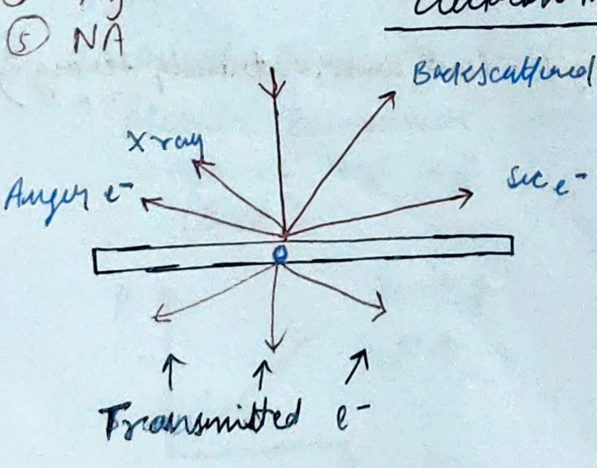
- To deposit optical materials.

  ZnO as
  TiO_2

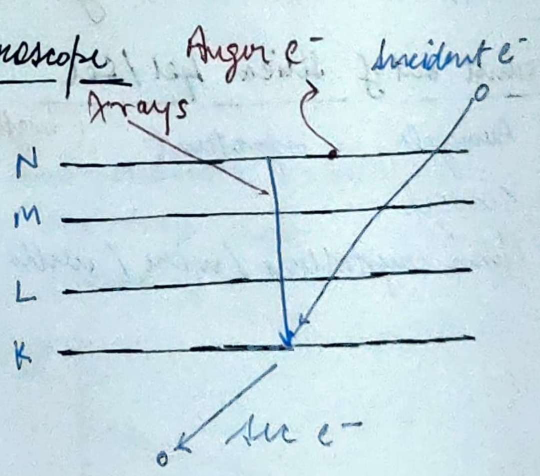
Electron Microscope

- Max usable magnification = $\frac{\text{Res. Power of Eye}}{\text{Res Power of instrument}}$
- Light microscope = 1000   electron microscope $\approx 10^9$
  Poor depth of field   good dof

1. Resolving Power $R \propto \frac{\lambda}{NA}$ NA: Numerical Aperture
2. Mag
3. Dof
4. Dofoc
5. NA



Electron Microscope



Backscattering - Atomic Number

X-rays - Crystal Structure

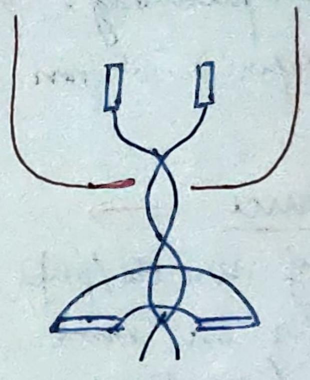
Thick sample - SEM   Thin Sample - TEM

Transmitted e^- → gives info about thickness

Sec e^- → Surface info

SEM chars -

- Topography ∃ few nm
- Morphology
- Composition - um
- Crystallographic info >20 μm



SEM Sample Prep

- Cleaning surface of specimen
- Stabilizing Speciment
- Rinsing spec.
- Dehydrating Spec.
- Mount & coat (coating layer ~ 20-30 nm)

Setup of SEM 5×10^5

- e^- focused into a beam of 5nm
- Various transmission takes place
- Sem has lower energy of e^-

Electron guns

- Thermionic gun - Tungsten filament, La Hex Bo (LaB_6) Using heat energy
- Field emission gun - uses the principle of Quantum Tunnelling

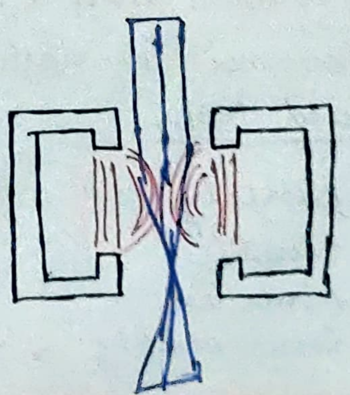
	W (TG)	LaB_6	FEG
Brightness	$10^4 - 10^5$	$10^5 - 10^6$	$10^7 - 10^9$
Vacuum	$10^{-4} - 10^{-5}$	$10^{-6} - 10^{-7}$	$10^{-7} - 10^{-9}$
Crossover diameter (spot)	20 nm	~~10^{-7} 10^{-9}~~	10 nm ~~10^{-7} 10^{-9}~~

Electromagnetic lenses

The image is inverted and rotated

F leads to helical trajectory of e^- and to magnetic rotation.

For different samples, setup can be modified by changing focal length.



TEM 5×10^6

- Ultra thin specimen
- High resolution 2D magnification
- e^- accelerated 100 KeV to 1 MeV
- Penetrate the sample (scattered/unscattered)
- Elastic scattering gives rise to diffraction
- Inelastic scattering leads to spatial variation.

Nanophysics (from Slides) 10^{-9} m

Nanoscale: 1-100 nm scale
Nanotechnology: Technique for making & characterizing nanostructures and putting them in applications.
Nanomanufacturing: commercial ways of producing nanostructs.

Newspaper: 10^5 nm   Fingernails grow @ 1nm ps

N Science →	Nanophysics →	Nano-Tech
Study of structs/props of matter in nano range / ns time	physical props of nanost. & develope devices	Understanding & control of matter at nano-scale.

Restriction	Assembly	Structure
3-D	0D	Quantum Dot
2-D	1D	Quantum Wire - Nano wire/tubes
1-D	2D	Nano-film
	3D	Diamond crystal

Non-intentionally: Naturally occuring
Intentionally: Fabricated

- Electrical conductivity, color, strength & weight change
- Fabricated atom by atom
- Increase in ratio of surface to volume

Affected props.

↓	↑	
Density	Ductility	Coeff. of Thermal Expansion
Elastic Modulus	Strength	
Conductivity	Hardness	
	Toughness	
	Diffusivity	

Props of Ni crystal

Frictional coeff : Half
Corrosion resist. : Reduced
Magnetic Props : Lower coercivity
H_2 Diffusion : Higher
Electro Catalysis : Improved

Sol-gel Property changes:

1. Viscosity ↑
2. Heat loss ↓
3. Stress ↓
4. Master-Slave Idea
5. Anisotropic (direction-dependent)

Sol gel Synthesis

1. Synthesis $MOR + H_2O \rightarrow MOH + ROH$ (hydrolysis)
2. $MOH + ROM \rightarrow M{-}O{-}M + ROH$ (condensation)
3. Gelation (Acid Catalyzed / Base Catalyzed)
   - Acid: entanglement of branched structs
   - Base: formation of agglomerated clusters condense to 3D network
4. Syneresis - Ageing of gels - upto 7 days
5. Calcination - 800°C volatile liquids removed - aerogel

Pulsed Laser Decomposition

- High powered laser focused on target in vaccum.
- Plasma proceeds to deposit on substrate, forming a thin film.
- UHV 10^{-9} mBar $\simeq 10^{-12}$ Bar
- Target to substrate : 2 to 10 cm

Drawbacks

- Uneven coating
- Large scale prod not possible

OM vs EM

OM	EM
• light source	• electron source
• Film mounted specimen	• special, held inside vaccum chamber
• Uses lenses	• Coil shaped electromagnets
• Mag. image is seen	• Image formed as a photograph
Max mag 1000	Max mag 10^9
4x – 1400	10x – 5×10^5
Small DoF	Large DoF

Emission in Sem

① Cathodoluminiscence : $0 < h\nu < 10$ eV

X-Ray : $0 < h\nu < E_0$

Auger : $E < 10$ eV ~10 nm

Backscattered : $E_0 \simeq E$ ~500 nm

Secondary : $E \leq 20 \simeq 50$ eV >50 nm

~5 μm

SEM

- Images a sample by scanning it with high energy beam of e^-
- Detailed 3D image, res of few nm

Characteristics

- Topography – surface texture
- Morphology – Shape size arrangement
- composition – elts & compounds
- Crystallographic Info – Degree of order, crystal arrangement

Info:

- Sec e^- : Surface struct
- Backscattered e^- : surface struct + elemental info (atomic number)
- X-Ray / Auger-e : elemental comp + thickness sensitivity

Sample Prep:

① cleaning
② Stablizing
③ Rinsing
④ Dehydrating
⑤ Drying
⑥ Mounting
⑦ coating → 20 to 30 nm