MNT 539 Nanoteknolojide Seçilmiş Konular

Dr. Aydan Yeltik ayeltik@etu.edu.tr

Dersin İçeriği

Hafta	Konu
1	Malzeme Bilimi ve Teknolojisine Giriş
2	Atomik Yapı ve Atomlararası Bağlar
3	Katılarda Kristal Yapılar
4	Katılarda Kusurlar
5	Elektriksel Özellikler
6	Optik Özellikler
7	Yarıiletken Nanoyapılar ve Kuantum Sınırlandırma
8	Yarıiletken Nanoyapılarda Fiziksel Süreçler
9	Nano-Fabrikasyon Teknikleri
10	Nano-Karakterizasyon Teknikleri
11	Yeni Nesil Nanomalzeme Özellikleri ve Uygulamaları I
12	Yeni Nesil Nanomalzeme Özellikleri ve Uygulamaları II

Hedef: Malzeme yapısı, sentezi/üretimi, özellikleri, performansı ve uygulamaları arasındaki ilişkiyi kurması için altyapının oluşturulması.

Kaynaklar

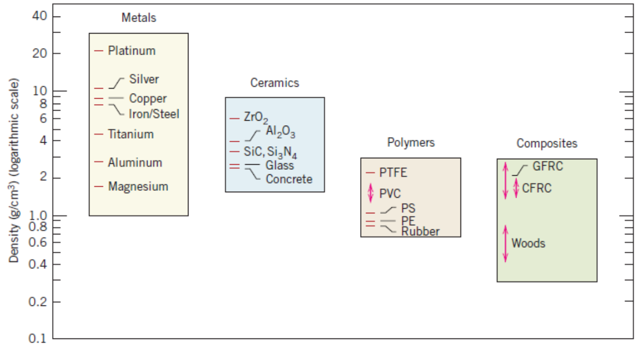
- William D. Callister & David R. Rethwisch, Materials Science and Engineering, 8th Ed. 2010, Wiley.
- Robert Kelsall, Ian Hamley & Mark Geoghegan Nanoscale Science and Technology, 1th Ed. 2005, Wiley.
- Malkiat S. Johal & Lewis E. Johnson, Understanding Nanomaterials, 2nd Ed. 2018, CRC Press.

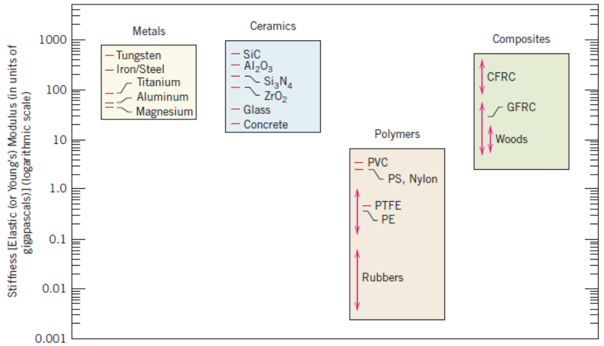
	İçerik	*Content*
Hafta	**Konu**	**Topic**
1	Malzeme Bilimi ve Teknolojisine Giriş	Introduction to Materials Science and Technology
2	Atomik Yapı ve Atomlararası Bağlar	Atomic Structure and Interatomic Bonding
3	Katılarda Kristal Yapılar	Crystal Structures in Solids
4	Katılarda Kusurlar	Imperfections in Solids
5	Elektriksel Özellikler	Elektrrical Properties
6	Optik Özellikler	Optical Properties
7	Yarıiletken Nanoyapılar ve Kuantum Sınırlandırma	Semiconductor Nanostructures and Quantum Confinement
8	Yarıiletken Nanoyapılarda Fiziksel Süreçler	Physical Processes in Semiconductor Nanostructures
9	Nano-Fabrikasyon Teknikleri	Nano-Fabrication Techniques
10	Nano-Karakterizasyon Teknikleri	Nano-Characterization Techniques
11	Yeni Nesil Nanomalzeme Özellikleri ve Uygulamaları I	New Generation Nanomaterial Properties and Applications I
12	Yeni Nesil Nanomalzeme Özellikleri ve Uygulamaları II	New Generation Nanomaterial Properties and Applications II

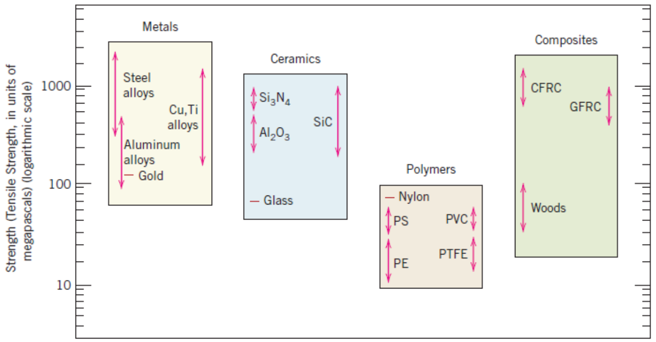
Introduction to Materials Science and Technology

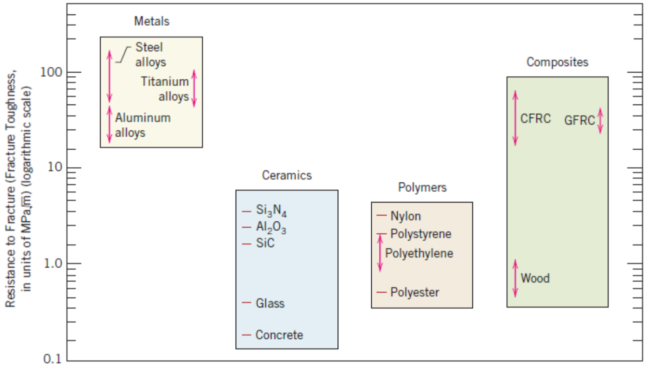
- Materials Science and Engineering
  - Processing/Structure/Properties/Performance Correlations
- Classification of Materials
  - Metals and Metal Alloys (Conductors)
  - Ceramics (Insulators)
  - Polymers (Insulators)
  - Composites (All three possible)
- Advanced Materials
  - Semiconductors
  - Biomaterials
  - *Smart* materials
  - Nanomaterials

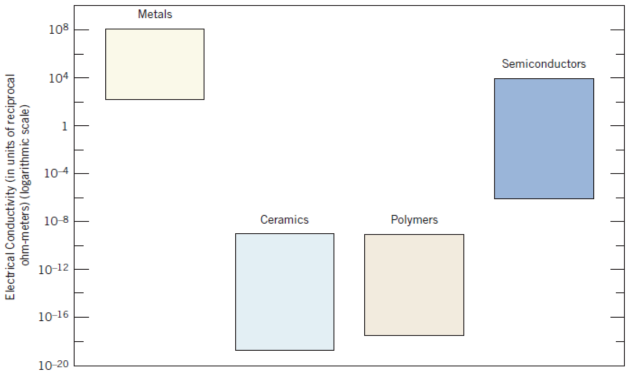
- Glossary
  - Transparent, Translucent, Opaque
  - Stiffness, Tensile strength, Resistance to fracture
  - Electrical conductivity, Heat conductivity









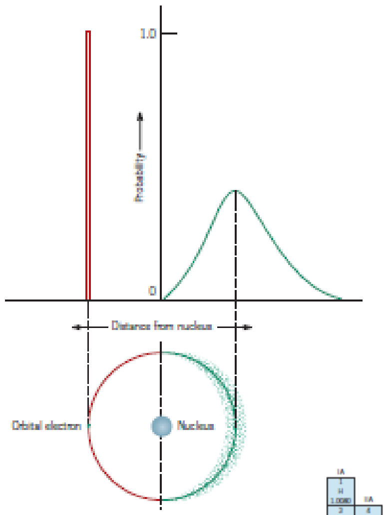


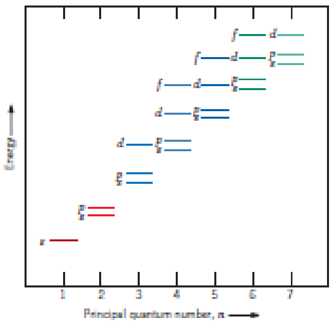
Atomic Structure and Interatomic Bonding

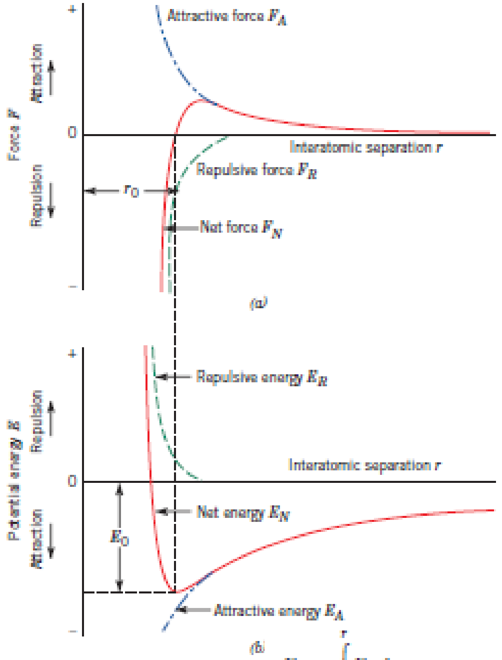
- Fundamental Concepts of Atomic Structure
  - ➢ Atomic Models (Bohr and Wave-mechanical)
  - ➢ Quantum Numbers
  - ➢ Electron Configurations
  - ➢ Periodic Table

- Atomic Bonding in Solids
  - ➢ Bonding Forces and Energies
  - ➢ Primary Interatomic Bonds (Ionics, Covalent, Metallic)
  - ➢ Secondary [Van der Waals] Bonding

- Glossary
  - Atomic mass unit, Valence electron, Isotope
  - Electronegative, Electropositive, electron state, ground state
  - Pauli exclusion principle, Bonding energy, Coulombic force

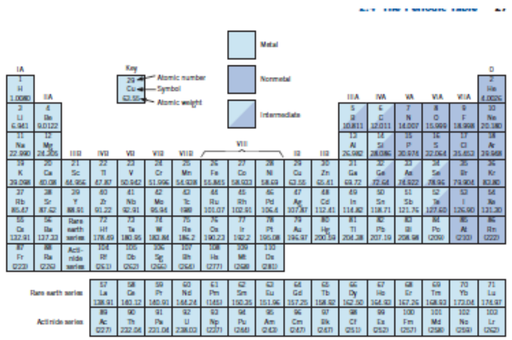


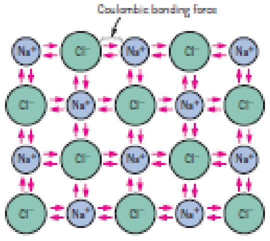


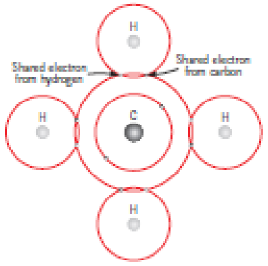


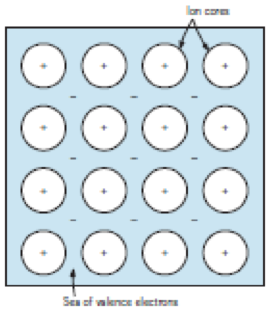
$$E = \int F\,dr$$

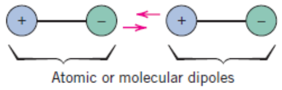
$$E_N = \int_{\infty}^{r} F_N\,dr = \int_{\infty}^{r} F_A\,dr + \int_{\infty}^{r} F_R\,dr$$





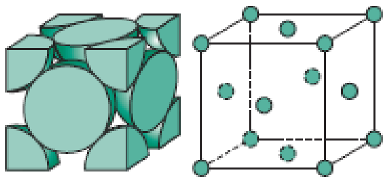
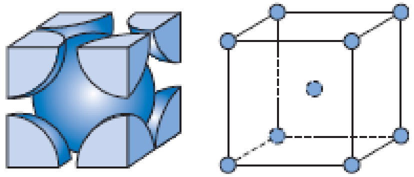
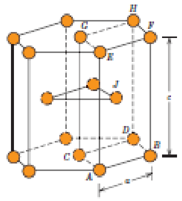
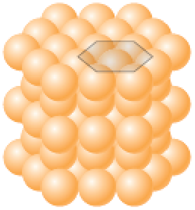
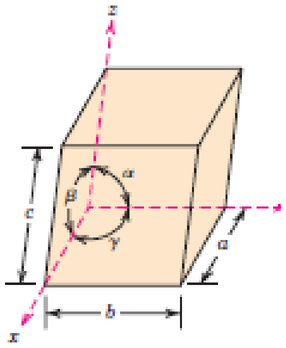
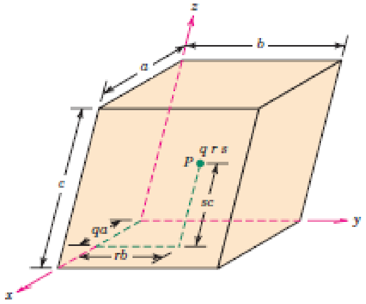
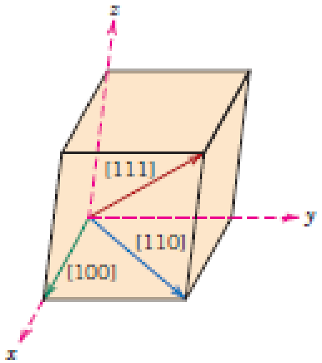


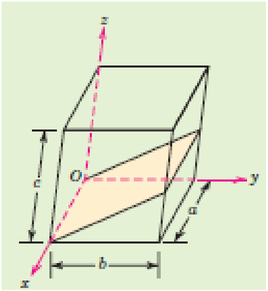


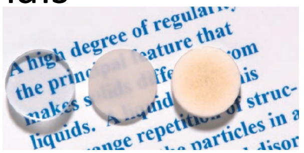


Structure of Crystalline Solids

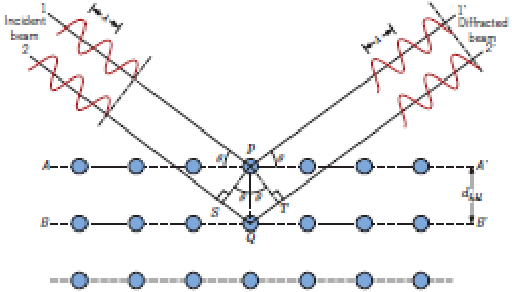
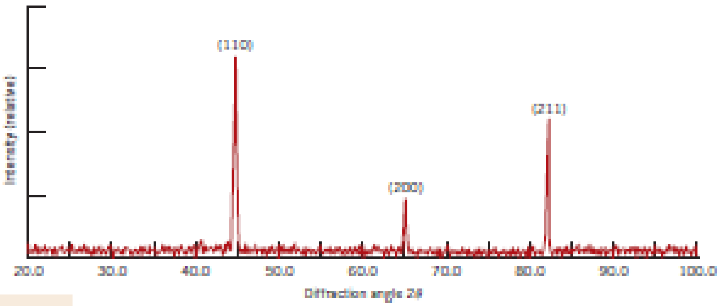
- Fundamental Concepts
  - ➢ Crystal Structure
  - ➢ Unit Cell
- Crystal Structures (metallic-nondirectional)
  - ➢ FCC, BCC, HCP
  - ➢ Density computations
- Crystal Systems (based on unit cell geometry)
- Crystallographic Points, Directions and Planes
- Crystalline and Noncrystalline Materials
  - ➢ Single Crystals
  - ➢ Polycrystalline Materials
  - ➢ Anisotropy
  - ➢ X-Ray Diffraction: Determination of Crystal Structures
- Glossary
  - Lattice, unit cell, atomic packing factor, Miller indices
  - Grain boundary, isotropy, diffraction, Bragg's law





$$\rho = \frac{nA}{V_C N_A}$$

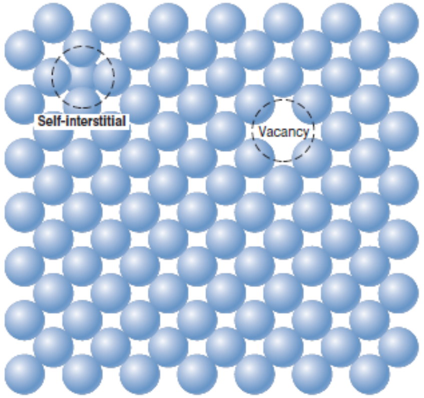
$$n\lambda = d_{hkl} \sin\theta + d_{hkl} \sin\theta$$

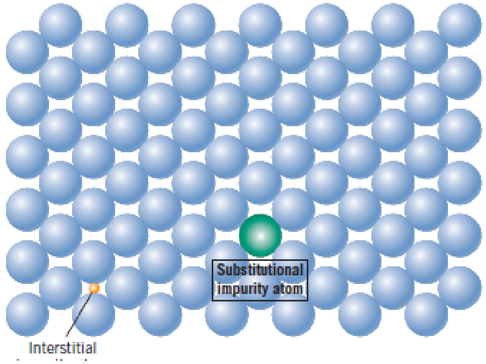
$$= 2d_{hkl} \sin\theta$$

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

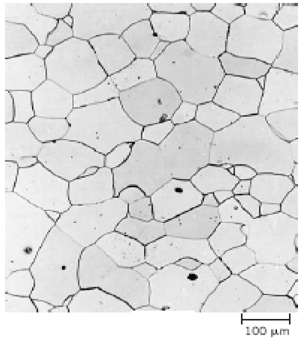
Imperfections in Solids

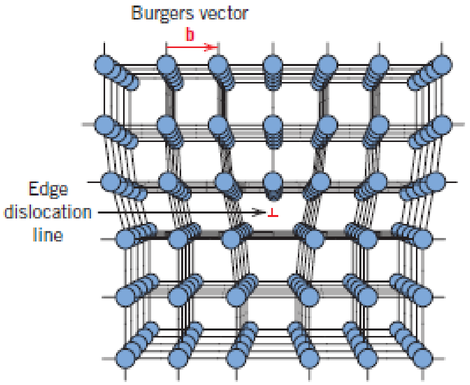
- Point (0D) Defects
  - Vacancies and Self-Interstitials
  - Substitutional and Intertitial Impurities
  - Specification(Computations) of Metal Alloy Compositions
- Linear (1D) Defects-Dislocations
- Interfacial (2D) Defects
- Grain Bondaries and Size Determination
- Glossary
  - Alloy, solute, solvent, weight&atom percents, atomic weight
  - Edge&screw dislocations, Burgers vector

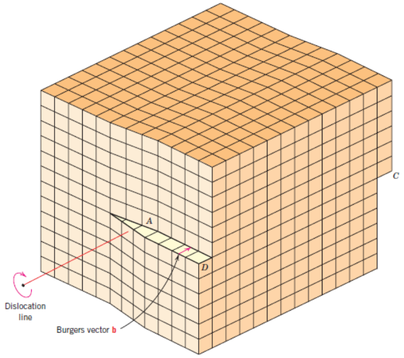




Equation
$N_v = N\exp\left(-\frac{Q_v}{kT}\right)$
$N = \frac{N_A\rho}{A}$
$C_1 = \frac{m_1}{m_1 + m_2} \times 100$
$C_1' = \frac{n_{m1}}{n_{m1} + n_{m2}} \times 100$
$C_1' = \frac{C_1 A_2}{C_1 A_2 + C_2 A_1} \times 100$
$C_1 = \frac{C_1' A_1}{C_1' A_1 + C_2' A_2} \times 100$
$C_1'' = \left(\frac{C_1}{\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}}\right) \times 10^3$
$\rho_{ave} = \frac{100}{\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}}$
$A_{ave} = \frac{100}{\frac{C_1}{A_1} + \frac{C_2}{A_2}}$
$N = 2^{n-1}$

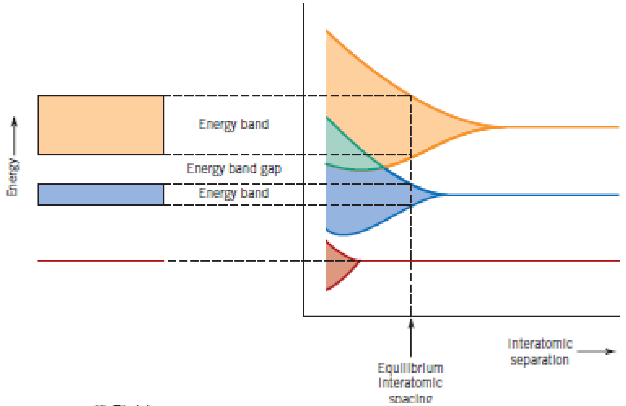


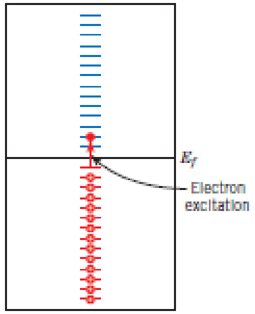


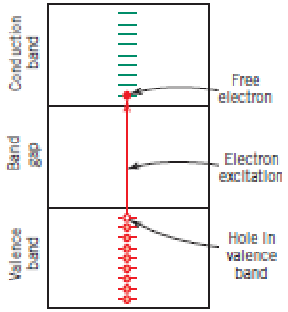


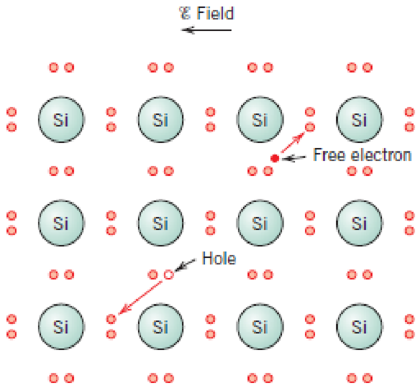
Electrical Properties of Materials under E-Field

- Electrical Conduction
  - ➢ Ohm's Law
  - ➢ Electrical Conductivity
  - ➢ Energy Band Structures in Solids
  - ➢ Conduction&Resistivity based on Band and Bonding Models for Metals, Semiconductors, Insulators
  - ➢ Electron Mobility
- Semiconductivity
  - ➢ Intrinsic Semiconduction
  - ➢ Extrinsic Semiconduction
  - ➢ Semiconductor Devices
- Dielectric Behavior
  - ➢ Capacitance
  - ➢ Field Vectors & Polarization
- Ferroelectricity and Piezoelectricity
- Glossary
  - Electrical resistivity, Electronic&Ionic conduction, Fermi energy
  - Valence&Conduction band, Bandgap, Free electron, hole
  - Intrinsic&Extrinsic semiconductor, Donor&Acceptor states, Doping
  - Diode, Rectifying junction, Forward&Reverse bias, Transistor, Integrated circuit

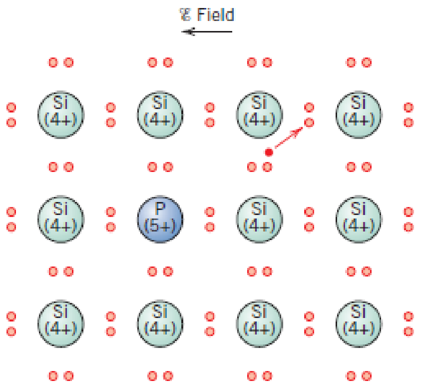




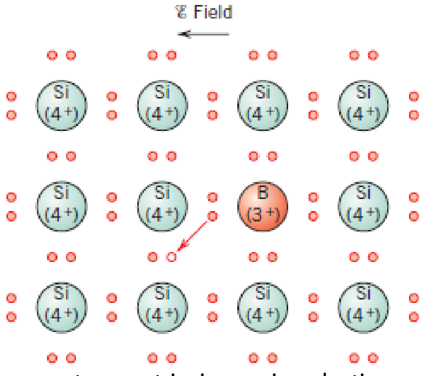




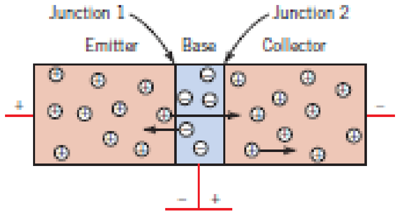
Intrinsic semiconduction



n-type extrinsic semiconduction



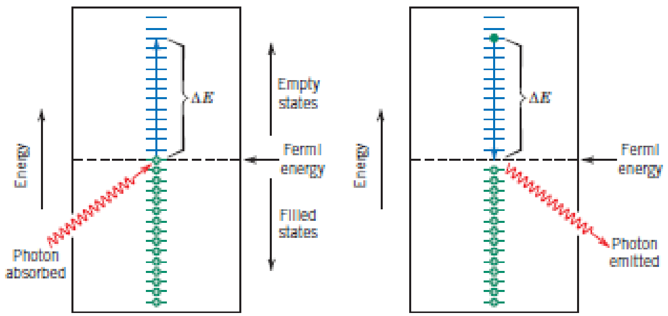
p-type extrinsic semiconduction



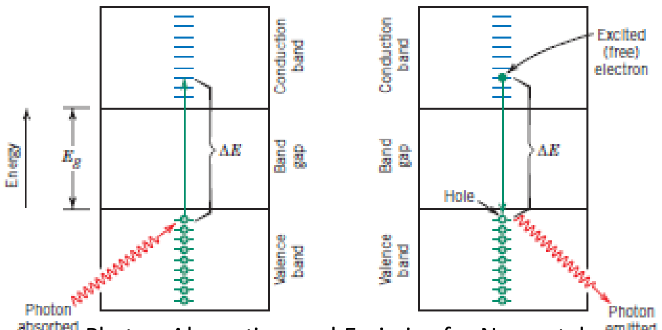
Equation		
$V = IR$	$\sigma = n\|e\|\mu_e + p\|e\|\mu_h$ $= n_i\|e\|(\mu_e + \mu_h)$	$\epsilon_r = \frac{\epsilon}{\epsilon_0}$
$\rho = \frac{RA}{l}$	$\sigma = p\|e\|\mu_h$	$D_0 = \epsilon_0 \mathscr{E}$
$\sigma = \frac{1}{\rho}$	$C = \frac{Q}{V}$	$D = \epsilon \mathscr{E}$
$J = \sigma \mathscr{E}$	$C = \epsilon_0 \frac{A}{l}$	$D = \epsilon_0 \mathscr{E} + P$
$\mathscr{E} = \frac{V}{l}$	$C = \epsilon \frac{A}{l}$	$P = \epsilon_0(\epsilon_r - 1)\mathscr{E}$
$\sigma = n\|e\|\mu_e$		

Optical Properties

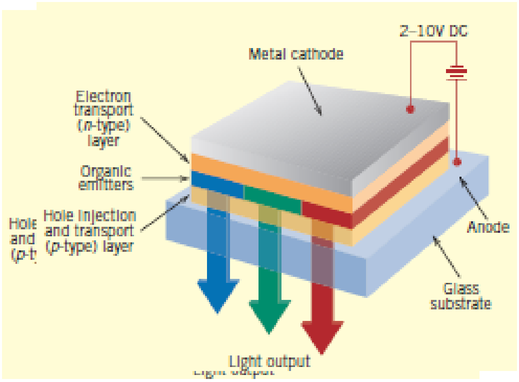
- Fundamental Concepts
  - Electromagnetic Radiation
  - Light Interactions with Solids
  - Electronic Interactions
- Optical Properties of Metals
  - Reflection & Absorption
- Optical Properties of Nonmetals
  - Refraction & Reflection & Absorption & Transmission
- Applications of Optical Phenomena
  - Luminescence & Photoconductivity
  - Lasers
  - Optical Fibers
- Glossary
  - Index of refraction, Fluorescence
  - Phosphorescence, LED

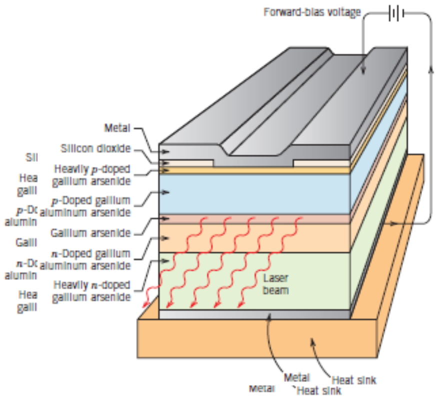


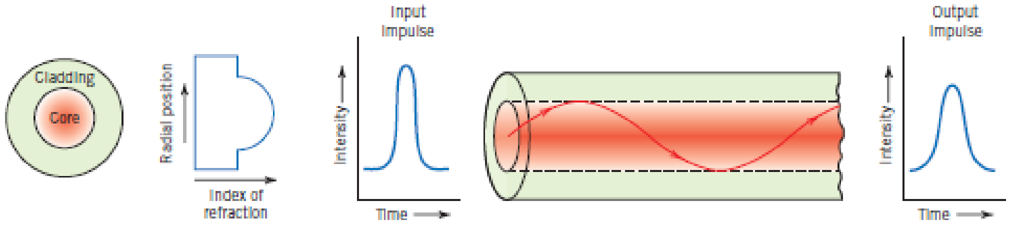
Photon Absorption and Emission for Metals



Photon Absorption and Emission for Nonmetals







Equation

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$c = \lambda \nu$$

$$E = h\nu = \frac{hc}{\lambda}$$

$$\Delta E = h\nu$$

$$v = \frac{1}{\sqrt{\epsilon \mu}}$$

$$n = \frac{c}{v} = \sqrt{\epsilon_r \mu_r}$$

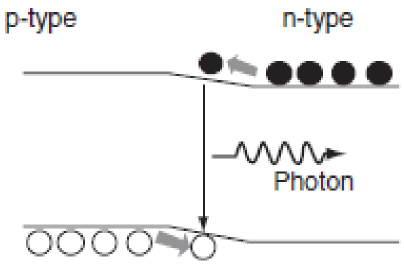
$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

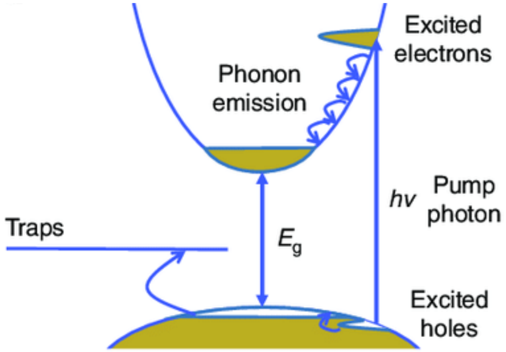
$$I'_T = I'_0 e^{-\beta x}$$

$$I_T = I_0(1 - R)^2 e^{-\beta l}$$

Semiconductor Nanostructures and Quantum Confinement

- Overview of Relevant Semiconductor Physics
  - Doping
  - Carrier Transport
  - Excitons
  - The pn Junction
  - Phonons

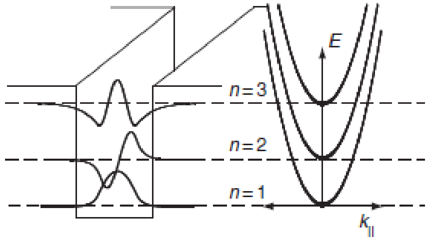




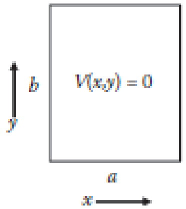
- Quantum Confinement in Semiconductor Nanostructures
  - Basic Introduction to Quantum Mechanics
  - 1D confinement: Quantum Wells
  - 2D confinement : Quantum Wires
  - 3D confinement : Quantum Dots
  - Superlattices

$$-\frac{\hbar^2}{2m^*}\frac{d^2\psi_n(x)}{dx^2}+V(x)\psi_n(x)=E_n\psi_n(x)$$

$$E_{n,k_\parallel}=\frac{\hbar^2 n^2}{8m^* L^2}+\frac{\hbar^2 k_\parallel^2}{2m^*} \qquad \psi_n(x)=\sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right) \qquad (n=1,2,3,\ldots,\infty)$$

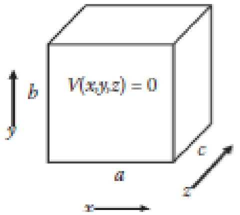


$$E=\frac{h^2}{8m}\left(\frac{n_x^2}{a^2}+\frac{n_y^2}{b^2}\right) \qquad \psi(x,y)=\sqrt{\frac{2}{a}}\sin\frac{n_x\pi x}{a}\sqrt{\frac{2}{b}}\sin\frac{n_y\pi y}{b}=\sqrt{\frac{4}{ab}}\sin\frac{n_x\pi x}{a}\sin\frac{n_y\pi y}{b}$$



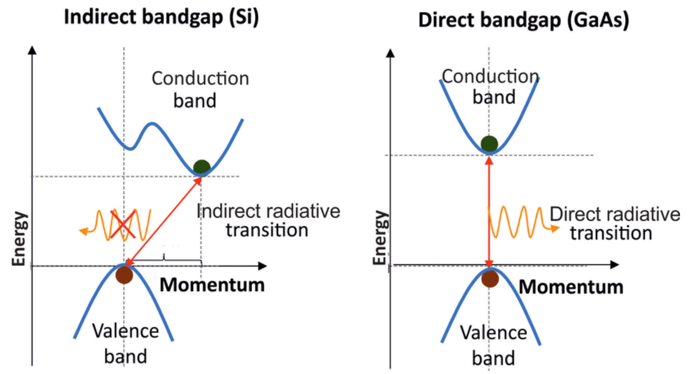
- Glossary
  - Effective mass, Band offset, Uncertainty Principle
  - Quantization, Wavefunction, Schrödinger Equation

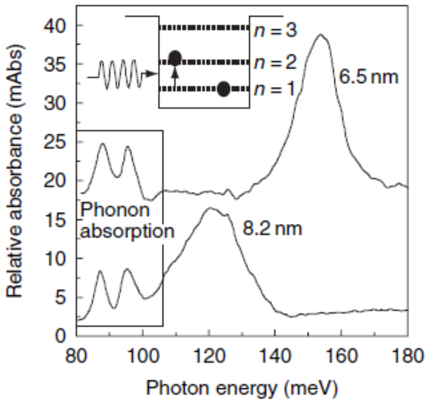
$$E=\frac{h^2}{8m}\left(\frac{n_x^2}{a^2}+\frac{n_y^2}{b^2}+\frac{n_z^2}{c^2}\right) \qquad \psi(x,y,z)=\sqrt{\frac{8}{abc}}\sin\frac{n_x\pi x}{a}\sin\frac{n_y\pi y}{b}\sin\frac{n_z\pi z}{c}$$

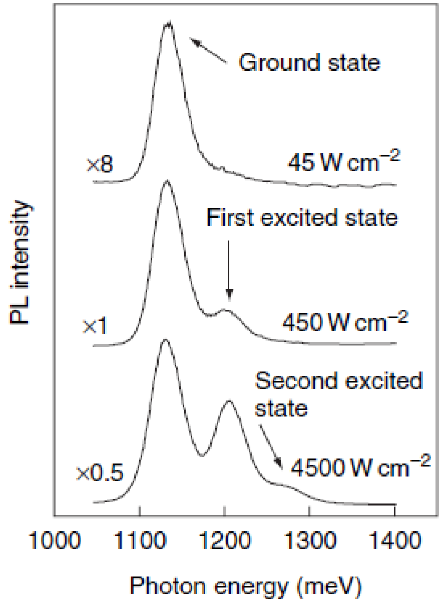


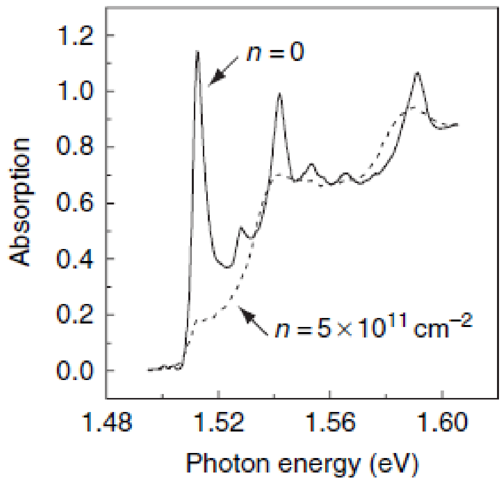
Physical Processes in Semiconductor Nanostructures

- Interband Absorption in Semiconductor Nanostructures
- Intraband Absorption in Semiconductor Nanostructures
- Light Emission in Semiconductor Nanostructures
- Phonon Absorption & Emission in Semiconductor Nanostructures
- Quantum Confined Stark Effect
- Glossary
  - Index of refraction, Fluorescence
  - Phosphorescence, LED



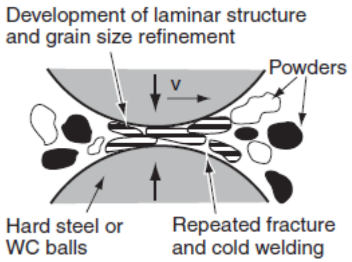


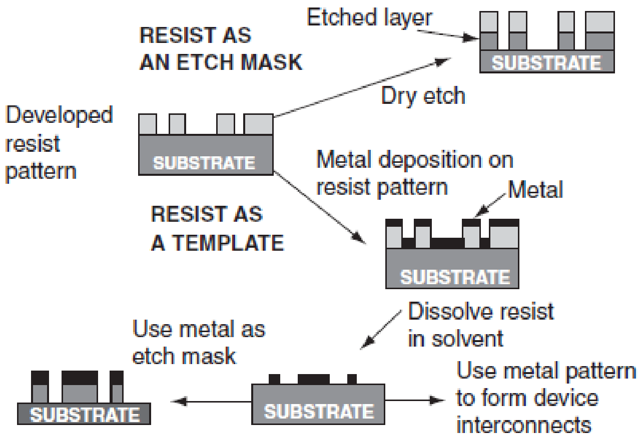


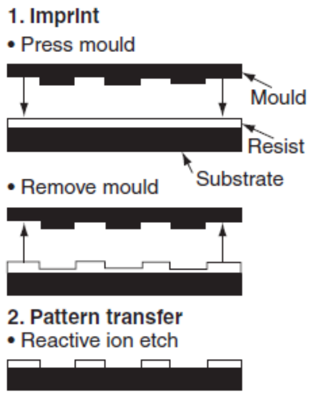


Nano-Fabrication Techniques

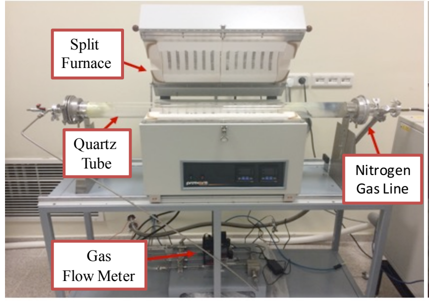
- Top-down Processes
  - Milling
  - Litography
  - Machining (FIB)

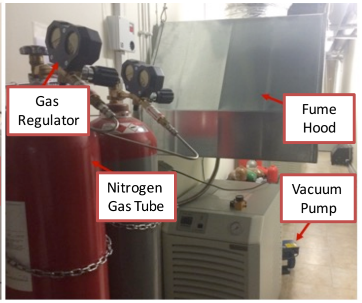


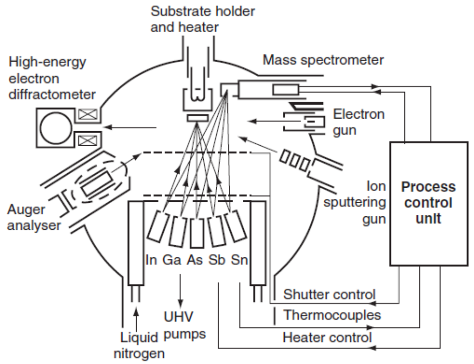




- Bottom-up Processes
  - Vapour Phase Deposition (PVD/CVD)
  - MBE & MOCVD
  - Colloidal Methods
  - Sol-Gel Methods
  - Self-Assembly



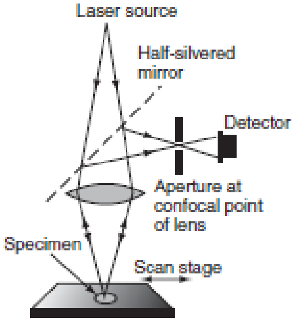




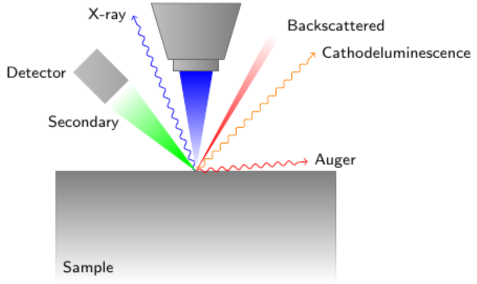
- Glossary
  - Mechanical alloying, Photoresist, Mask, Dry Etch
  - Imprint, Molding, Mechanical patterning, Reactive gas,
  - Flowmeter, Deposition meter, Gas inlet, Vacuum chamber
  - Anode, Cathode, Ion gun, Electron gun, Diffractometer, Mass spectrometer

Nano-Characterization Techniques

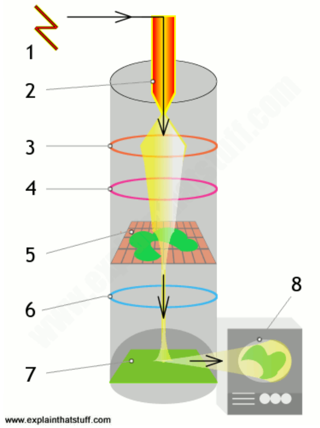
- Microscopy Techniques
  - Light Microscopy
  - Electron Microscopy
    - Scanning electron microscopy (SEM)
    - Transmission electron microscopy (TEM)
  - Scanning Probe Microscopy
    - Scanning tunneling microscopy (STM)
    - Atomic force microscopy (AFM)
- Diffraction Techniques
  - X-Ray diffraction (XRD)
- Spectroscopy
  - Optical Spectroscopy
    - Fluorescence Spectroscopy
    - Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)
  - Mass Spectroscopy
    - Inductively Coupled Plasma Mass Spectroscopy (ICP-MS)
- Glossary
  - Various



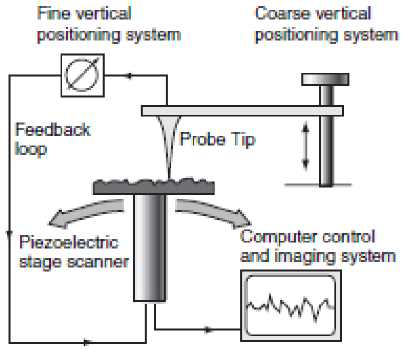
Optic Microscope



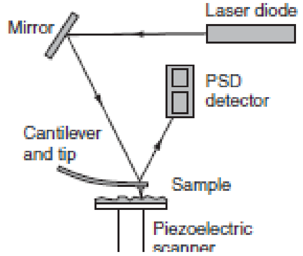
SEM



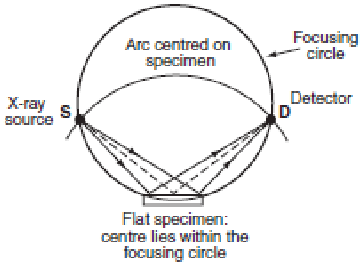
TEM



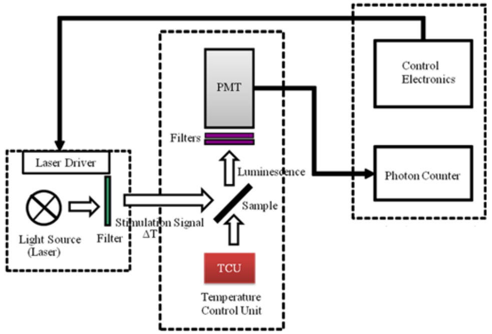
STM



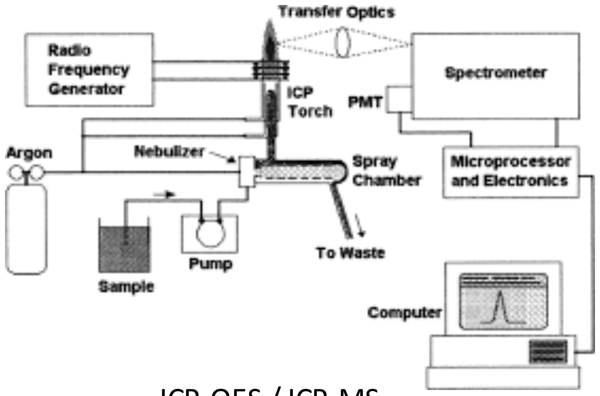
AFM



XRD



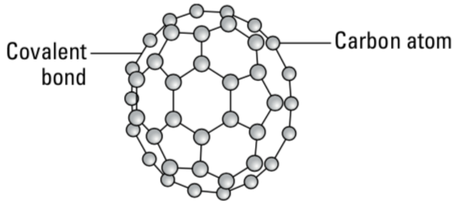
Fluorescence Spectroscopy



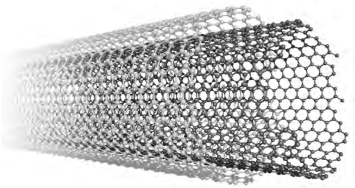
ICP-OES / ICP-MS

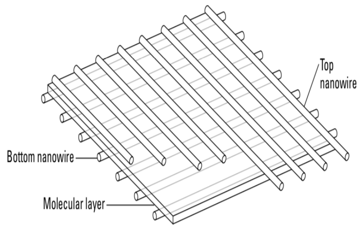
Nanomaterial Properties and Optoelectronic Applications I & II

- Carbon based Nanostructures

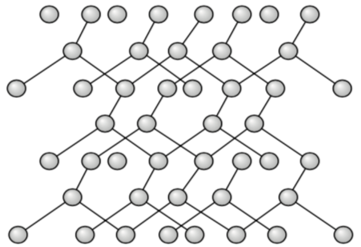


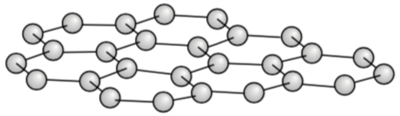
Buckyball

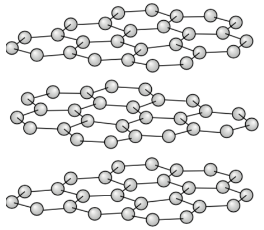

Nanotube



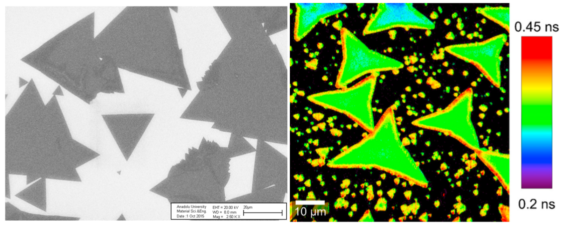
Nanowires


Diamond


Graphene

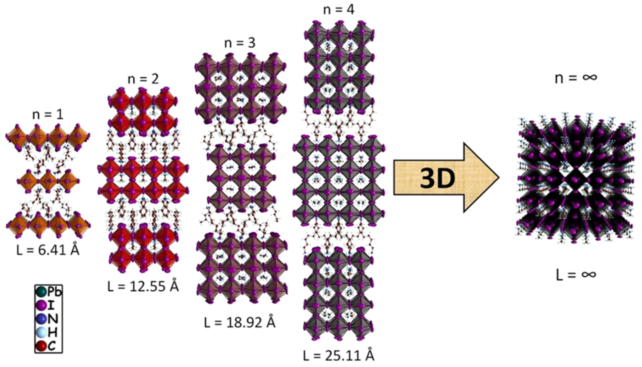

Graphite

- Transition Metal Dichalcogenites (TMDs)



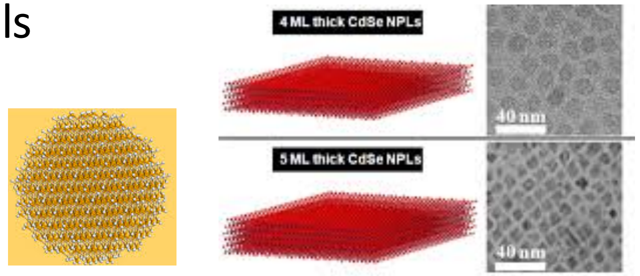
TMDs

- Perovskites



Perovskites

- Colloidal Quantum Dots (QDs) and Wells



Colloidal QDs and Wells

- Glossary
  - Various