Structure and Properties of Materials (MAT 509)
Fall 2020

This course aims to give a general understanding of the relationship between observed properties of materials and the internal structure with emphasis on materials for electronic and optical applications. As the topic covers a vast amount of phenomena, we will focus on the fundamental principles, today's methods for characterization of electrical and optical properties and how the physics of the solid state is tailored in today's technological applications.

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Office hours: E-mail beforehand and we shall set the meeting time.

Date and classroom: N/A yet

Grading: % 20 Homeworks, %30 Midterm, %20 Term project, % 30 Final. There will be around one homework every two weeks.

Important: Late homeworks and assignments WILL NOT BE accepted and will receive zero. Attendance to classes is not obligatory but full attendance will be considered as a sign of interest in the class topics and motivation.

Textbook: There is no textbook requirement for this class and I compile the notes from a variety of books that are also available at the IC. Recommended references at the IC:

a. Structure of Materials, Samuel M. Allen and Edwin L. Thomas (1999).
b. Elementary Solid State Physics, M. Ali Omar (1975).
c. The Principles of Engineering Materials, C.S. Barrett, W.D. Nix, and A.S. Tetelman (1974).
d. Electronic Properties of Materials, 3rd Edition, Rolf Hummel (2001).
e. Electronic Properties of Engineering Materials, James D. Livingston (1999).
f. Solid State Physics, Neil D. Ashcroft and N. David Mermin (1976).
g. An Introduction to the Optical Spectroscopy of Inorganic Solids, J. Garcia Sole, L.E. Bausa and D. Jaque (2005).
h. Introduction to Solid State Physics, 8th International addition, Charles Kittel (2005).
i. Electrons in Solids – An Introductory Survey, 3rd Edition, Richard H. Bubbe (Check if it has arrived).

j. Band Theory and Electronic Properties of Solids, Oxford Master Series in Condensed Matter Physics, John Singleton, (2004).
k. Solid state physics / J.R. Hook, H.E. Hall. Hook, J. R. (John R.) Chichester
l. Solid state physics for engineering and materials science / John P. McKelvey. McKelvey, John Philip.

Other than the above, feel free to consult me for any resources I might have.

Subjects to be covered in the course (Note that there might be some slight modifications to the content during the course of the semester) :

1. Atomic bonding (an introductory lecture)

1.1. Brief overview: Structure of an atom.

1.2. Types of atomic bonds in condensed matter (solids and liquids).

1.3. Overview of impact of bonding state on commonly observed physical properties.

2. An introduction to waves and oscillations

2.1. Vibrations on a string.

2.2. Electromagnetic wave equation and the black body radiation.

2.3. Waves in crystals (An overview of phonons).

2.4 The Schrödinger Equation.

3. Electrons in Solids and Band Theory

4.1. Wave-particle duality.

4.2. Solution of the Schrödinger equation for a single potential well.

4.3. Solution of the Schrödinger equation for a periodic potential (Bloch approach, Krönig-Penney model).

4.4. Density of states and population density (Fermi-Dirac statistics).

4.5. Diffraction of waves, reciprocal lattice, Brillouin zone concept, Fourier analysis of a crystal structure.

4.6. Condition of diffraction for waves in a crystal, origin of the bandgap.

4.4. Energy bands in ordered solids, crystals, construction of free electron energy-wave vector diagrams.

4. Electrical and Thermal Conduction

5.1. Classical approach to electrical conduction (Drude model).

5.2. Quantum mechanical approach to electrical conduction.

5.3. Semiconductors, Schottky junctions, Ohmic junctions, depletion/interface capacitance definition, current flow at a junction.

5.4. Thermal properties: (Phonon and electronic contribution), heat capacity (Einstein model, Debye Model, discussion of the Dulong-Petite Law), thermal conductivity and its relation to phonon population and free electron density (population density in the conduction band) in a crystal.

5. Optical properties of solids

6.1. Electromagnetic wave equation and index of refraction.

6.2. Continuum approach to explain optical properties of solids (harmonic oscillator treatment of electrons as dipoles).

6.3. Atomistic approach (Classical dynamics using eqn. of motion of an electron under an oscillating electric field).

6.4. Quantum approach, inter-band, direct/indirect gap transitions in semiconductors and insulators, absorption of radiation by materials.

6.5. Lasers, Raman effect.

6. Magnetism in solids, dielectrics and ferroelectrics

7.1. Theories to explain magnetism in materials.

7.2. Paramagnetism, ferromagnetism, antiferromagnetism, diamagnetism, ferrimagnetism.

7.3. Origin of dielectric behavior.

7.4. Ferroelectric phenomena.

7.5. Superconductivity: An overview.

We will mostly use the chapters in the following books:

Richard H. Bube, “Electrons in Solids”.

Rolf Hummel, “Electronic Properties of Materials”.

Charles Kittel, “Introduction to Solid State Physics”.

Any other information related to topics such as “fundamental equations in electrostatics” and similar will be given in the class.