



UNIVERSITÀ  
DEGLI STUDI DI MILANO-BICOCCA

## COURSE SYLLABUS

### Materials Physics

2425-3-E2701Q045-E2701Q048M

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#### Aims

Provide the student with the knowledge base for understanding the physical properties of materials and their measurement.

The main training objectives are:

- knowledge and ability to understand the physical properties of materials;
- knowledge and ability to understand the physical properties of materials applied to the main uses;
- autonomy of judgment in the analysis of physical properties and in the setting up of scientific experiments;
- communication skills in the presentation of complex physical theories and in the reporting of scientific experiments;
- ability to learn independently from additional teaching material, manuals and technical specifications of the instrumentation.

#### Contents

- Material properties (mechanical, vibrational, thermal, electronic, magnetic, dielectric, optical,...)
- Materials (metals, semiconductors, dielectrics, magnets, piezoelectrics,...)
- Solid state devices (photovoltaic cell, LED, thermocouple, transistor, ...).
- Instrumentation of a materials physics laboratory (electrical measurements, optical measurements, ....)

#### Detailed program

LABORATORY OF PHYSICS OF MATERIALS

The laboratory consists of a series of experiences with a duration of two or three afternoons each, focusing mainly on the properties of semiconductor materials. The purpose of the experiences is mostly to develop a critical sense and autonomy in the process of measuring the physical properties of the materials. Experiences include:

- the Hall measurement of electrical and doping properties of semiconductors;
- voltage-current characteristics of a p-n junction;
- measurement of absorption and reflection properties;
- measurement of the efficiency of photovoltaic cells as a function of the wavelength of the incident light;
- life time measurements of photo-excited carriers.

## **PHYSICS OF MATERIALS**

### **Crystal Structures**

- General Description of Crystal Structures
- Some Important Crystal Structures
- Cubic Structures
- Close-Packed Structures
- Structures of Covalently Bonded Solids
- Crystal Structure Determination
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### **X-Ray Diffraction**

- Bragg Theory
- Lattice Planes and Miller Indices
- General Diffraction Theory
- The Reciprocal Lattice
- The Meaning of the Reciprocal Lattice
- X-Ray Diffraction from Periodic Structures
- The Ewald Construction
- Relation Between Bragg and Laue Theory

### **Bonding in Solids**

- Attractive and Repulsive Forces
- Ionic Bonding
- Covalent Bonding
- Metallic Bonding
- Hydrogen Bonding
- van derWaals Bonding

### **Mechanical Properties**

- Elastic Deformation
- Macroscopic Picture
- Elastic Constants
- Poisson's Ratio
- Relation between Elastic Constants
- Microscopic Picture
- Plastic Deformation
- Estimate of the Yield Stress
- Point Defects and Dislocations
- The Role of Defects in Plastic Deformation
- Fracture

## **Thermal Properties of the Lattice**

- Lattice Vibrations
- A Simple Harmonic Oscillator
- An Infinite Chain of Atoms
- One Atom Per Unit Cell
- The First Brillouin Zone
- Two Atoms per Unit Cell
- A Finite Chain of Atoms
- Quantized Vibrations, Phonons
- Three-Dimensional Solids
- Generalization to Three Dimensions
- Estimate of the Vibrational Frequencies from the Elastic Constants
- Heat Capacity of the Lattice
- Classical Theory and Experimental Results
- Einstein Model
- Debye Model
- Thermal Conductivity
- Thermal Expansion
- Allotropic Phase Transitions and Melting

## **Electronic Properties of Metals: Classical Approach**

- Basic Assumptions of the Drude Model
- Results from the Drude Model
- DC Electrical Conductivity
- Hall Effect
- Optical Reflectivity of Metals
- The Wiedemann–Franz Law
- Shortcomings of the Drude Model

## **Electronic Properties of Solids: Quantum Mechanical Approach**

- The Idea of Energy Bands
- Free Electron Model
- The Quantum Mechanical Eigenstates
- Electronic Heat Capacity
- The Wiedemann–Franz Law
- The General Form of the Electronic States
- Nearly Free Electron Model
- Energy Bands in Real Solids
- Transport Properties

## **Semiconductors**

- Intrinsic Semiconductors
- Temperature Dependence of the Carrier Density
- Doped Semiconductors
- n and p Doping
- Carrier Density
- Conductivity of Semiconductors
- Semiconductor Devices
- The pn Junction
- Transistors
- Optoelectronic Devices

## **Magnetism**

- Macroscopic Description
- Quantum Mechanical Description of Magnetism
- Paramagnetism and Diamagnetism in Atoms
- Weak Magnetism in Solids
- Diamagnetic Contributions
- Contribution from the Atoms
- Contribution from the Free Electrons
- Paramagnetic Contributions
- Curie Paramagnetism
- Pauli Paramagnetism
- Magnetic Ordering
- Magnetic Ordering and the Exchange Interaction
- Magnetic Ordering for Localized Spins
- Magnetic Ordering in a Band Picture
- Ferromagnetic Domains
- Hysteresis

## **Dielectrics**

- Macroscopic Description
- Microscopic Polarization
- The Local Field
- Frequency Dependence of the Dielectric Constant
- Excitation of Lattice Vibrations
- Electronic Transitions
- Impurities in Dielectrics
- Ferroelectricity
- Piezoelectricity
- Dielectric Breakdown

## **Prerequisites**

Good knowledge of General Physics and techniques of integral and differential calculus. Basic knowledge of Quantum Physics.

## **Teaching form**

Physics of Materials Module

- 28 lessons of 2 hours held in classroom;

Laboratory of Physics of Materials Module

- 10 lessons of 2 hours and 1 lesson of 1 hour held in classroom;
- 9 experimental activities of 4 hours held in the laboratory;

Lectures and workshops are held in Italian.

## Textbook and teaching resource

- [Solid State Physics: An Introduction, di Philip Hofmann](#) (Main reference book)
- [Principi di Fisica dei Semiconduttori di Mario Guzzi](#) (Semiconductor book)
- Notes from the lecturer.

## Semester

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## Assessment method

In summary the tests consist of:

- Interviews on the topics covered in class;
  - Interview on the laboratory report;
  - Interview on laboratory experiences.
- The details of the tests are described below.

The Physics examination of the Materials with the Laboratory is divided into oral tests, with the compilation of a laboratory report. The Materials Physics course with Laboratory is composed of 14 CFU. The exam is divided into three modules, one relative to the laboratory and two modules dedicated to theory. These three modules can be passed either simultaneously or separately.

The laboratory module includes the evaluation of a report on one of the practical experiences of the laboratory. The mark on the report is based on the correctness, completeness and clarity of the exposure of the measurements. The oral test instead analyzes the knowledge of all the demonstrations that the student carried out in the laboratory. For this module it is not necessary to have a thorough knowledge of the theory, which is instead the object of the other modules, but it is sufficient to know the minimum notions of physics of the materials necessary for understanding the experiment. These minimum notions are those reported in the laboratory sheets related to the experiences carried out. Obviously, it is assumed that the arguments of the laboratories of previous years are known. This module mainly analyzes the understanding of the experiment methodology, the understanding of the instrumentation (for example the operation, instrumental limits, procedures), and the analysis of data (uncertainties, processing, presentation). This module weighs about 3/14 in the final mark.

The two modules of Physics of Materials are instead focused on the theory of physics of materials and have a greater relative weight equal to 5/14 and 6/14. The details of the subdivision of the two modules are reported in the e-learning section. For these modules, the understanding of physical phenomena, the ability to reduce complex phenomena to simple models, the ability to use mathematical models to quantify the physical properties of materials will be evaluated.

The Laboratory module and the first Materials Physics module are delivered first and therefore can be taken even before the end of the course (ongoing evaluation).

## **Office hours**

At the end of the lessons or by appointment.

## **Sustainable Development Goals**

AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE

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