



UNIVERSITÀ  
DEGLI STUDI DI MILANO-BICOCCA

## SYLLABUS DEL CORSO

### Fisica dei Materiali con Laboratorio

2425-3-E2701Q045

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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

### **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

### **Bonds 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 Break

### **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**

First Semester

## **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 lectures or by appointment.

## **Sustainable Development Goals**

INDUSTRY, INNOVATION AND INFRASTRUCTURE

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