UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

# SYLLABUS DEL CORSO

## Fisica dei Materiali con Laboratorio

**2526-3-ESM01Q017**

### 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**

**Introduction to the laboratory**. Photons, Spectroscopy, Transmission, Absorption, Emission, Interference, Sources, Lenses and mirrors, Dispersive elements, Monochromator, Detectors, Spectrophotometer, Spectroscopic measurement parameters, Safety, Semiconductors, Electrons and holes, Dopants, PN junction, Diode, Photodiode, Photovoltaic cell, LED, Conductivity, Mobility, Contact ohmicity, Hall method, VanDerPauw method, Optical absorption in semiconductors.

**Crystals.** Crystalline structures, Bonds in solids, Miller indices, Plane waves and lattice, Fourier series, Reciprocal lattice.

**Mechanical properties.** Stress-strain curves, Poisson ratio, Elasticity, Plastic deformation, Point and extended defects, Stress-strain matrix notation.

**Vibrational and thermal properties.** Boltzmann distribution, equipartition theorem and DP heat capacity, Independent oscillators, Linear monoatomic chain, Phase and group velocity, Dispersion of crystals with multiple atoms per cell, Interaction between optical branch and radiation, Finite crystal, Oscillator quantization recalls, Phonons, 3D solid dispersion, Dispersion for silicon crystal, Bose-Einstein statistics recalls, Einstein model, Density of states, Debye model, Thermal conductivity, Thermal expansion, Phase transitions, Fusion, Lindemann criterion

**Classical properties of metals.** Drude model for metals, Mobility, Conductivity, Hall effect, Dielectric function, Complex epsilon, Refractive index, Extinction coefficient, Reflectivity of metals, Omega of plasma, Penetration of light in metals, Wiedemann-Franz law, Effect thermoelectric, Limits of the Drude model.

**Quantum electronic properties.** Free electrons, Fermi energy, Density of electronic states, Fermi-Dirac statistics reminders, Electronic heat capacity, Statement and meaning of Bloch's theorem, Crystalline momentum, Nearly free electrons, Band structure of 3D solids, Group velocity, Density of states, Equation of motion, Transport in metals and semiconductors, Effective mass, Analysis of band structures, Transport in a real metal, Hole, Band structure of Si Ge GaAs.

**Semiconductors.** Intrinsic and extrinsic semiconductors, Hydrogen-like atom model, Degenerate semiconductors, Qualitative statistics, Majority and minority, Quantitative statistics: problem statement, Approximate Fermi function, Quantitative statistics of the intrinsic semiconductor, Position of the Fermi energy, Quantitative statistics of extrinsic semiconductors, Mass action law, Extrinsic-intrinsic relation, Transport properties in real semiconductors.

**Devices.** Introduction to the pn junction, Fermi level in the junction, Band alignment, Internal potential from thermodynamics, Internal potential from electrostatics, Dimension of the depleted zone, Forward and reverse bias, Generation and recombination currents, Current balance and diode equation, Non-ideal diode. Illuminated pn junction, Photovoltaic cell, LED, BBS transistor, J-FET, Metal-oxide-semiconductor system, MOS-FET, Memory cell, Cell array, Semiconductor technology.

**Magnetism.** Characteristic quantities of magnetism in materials, Recall of the origin of magnetism in atoms, Paramagnetism, Microscopic origin of ferromagnetism, Ferromagnetism of a two-level system, Weiss domains and Bloch walls, Hysteresis cycle, Soft and hard magnets.

**Dielectrics.** Introduction to dielectrics, Dielectric function, Polarization in materials, Lorentz model without and with dissipation, Imaginary EPS and dissipated power, EPS with many resonances, Static EPS and gap, Absorption in solids, TART model, Color, Static EPS and gap, Impurities and color, Notes on ferroelectrics, Notes on piezoelectrics, Notes on electrical breakdown.

**Superconductors.** Discovery of superconductivity. Properties of superconductors. Meissner effect. Type I and II superconductors.

## Prerequisites

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

## Teaching form

34 lessons of 2 hours and 1 lesson of 1 hour held in classroom for the Materials Physics module and the introduction to the lab;
9 experimental activities of 4 hours each 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)
- Notes from the lecturer.

## Semester

Second 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 10 CFU. The exam is divided into 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).

The two modules of Physics of Materials are instead focused on the theory of physics of materials. 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

QUALITY EDUCATION | AFFORDABLE AND CLEAN ENERGY | DECENT WORK AND ECONOMIC GROWTH | INDUSTRY, INNOVATION AND INFRASTRUCTURE | RESPONSIBLE CONSUMPTION AND PRODUCTION | CLIMATE ACTION