Nanomaterials and nanotechnology

Teaching period

Second semester

Prerequisites

Solid State Physics

Quantum mechanics and structure of matter concepts at Bachelor level

SSD

CHIM/02

Course objectives

The course is part of the general objective of the Master to provide students, starting from solid basic physical knowledge, good skills in modeling and experimental techniques that allow them to tackle basic and applied scientific problems. In particular, the course will allow students to acquire specific knowledge of quantum mechanics and solid-state physics concepts useful for an in-depth understanding of the structural, electronic and functional properties of materials at the nanoscale which can be exploited to build devices for advanced applications.

Results of learning outcomes

Knowledge and understanding

At the end of the course, the students must know and understand:

- the physical models to interpret phenomena occurring at the nanoscale;
- the electronic, structural and optical properties at the nanoscale from molecules to nanomaterials;
- the main bottom-up and top-down synthesis techniques of nanomaterials;
- both laboratory-based and synchrotron-based techniques for the characterization of nanomaterials.

Applying knowledge and understanding

The students must also acquire autonomy of judgment useful for critically applying the modeling and experimental techniques presented to real cases of technological interest. In particular, they should be able to:

- apply the modeling techniques to guide the design of nanomaterials;
- select the most suitable synthesis approach for specific nanomaterial applications;
- combine different characterization techniques to assess the functional properties of nanostructured materials and devices, also under working conditions.

Program

- Introduction to nanomaterials and nanotechnology: basic concepts and historical development.
- Predicting the electronic, structural and optical properties at the nanoscale: eigenvalues and eigenfunctions of the Hamiltonian operator for homonuclear and heteronuclear diatomic molecules; bonding and antibonding orbitals; polyatomic molecules and hybrid atomic orbitals; solution of the Schrödinger equation in 1D, 2D and 3D crystals in LCAO approximation; band-gap engineering.
- Synthesis techniques for nanomaterials: top-down and bottom-up approaches; epitaxial growth methods (LPE, VPE, MBE, CBE, MOCVD); lithography; nucleation theory and fundamentals of crystalline growth.
- Characterization techniques for nanomaterials: X-ray and electron diffraction, electron microscopy, electronic and vibrational spectroscopies, photoemission spectroscopy, characterization techniques based on synchrotron radiation.
- Case studies: nanostructures for optoelectronics and fiber-optic communication; nanomaterials for energy and environment.

Course delivery

The course consists in 48 hours of theoretical lessons and exercises involving the use of molecular modeling programs. The course will take place with interactive methods aimed at stimulating student involvement. In the section devoted to teaching materials, the slides presented during the lessons are available.

Learning assessment methods

The exam consists in an oral test on the topics of the theoretical lessons in which the use of molecular modeling programs may be required. The overall evaluation will take into account the critical reasoning ability on the topics covered and the quality of the exposure (competence in the use of specialized vocabulary, effectiveness, linearity).

Suggested readings and bibliography

- Slides presented during the lessons.

- Further reading about electronic properties calculation: W. Atkins, R.S. Friedman, Molecular Quantum Mechanics, OUP Oxford, 2011.
- Further reading about the characterization techniques: G. Agostini, C. Lamberti, Characterization of Semiconductor Heterostructures and Nanostructures, Elsevier Science, 2013.