MASTER OF SCIENCE IN ENGINEERING

Module Description

The Physics of Materials and Engineering Devices

General Information

Number of ECTS Credits

3

Module code

FTP_Physics

Responsible of module

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Language

Explanations regarding the language definitions for each location:

- Instruction is given in the language defined below for each location/each time the module is held.
- Documentation is available in the languages defined below. Where documents are in several languages, the percentage distribution is shown (100% = all the documentation).
- The examination is available 100% in the languages shown for each location/each time it is held.

	Berne	Lausanne			Lugano	Zurich		
Instruction	☐ E 100%	☐ E 100%		☒ F 100%	☐ E 100%	☒ E 100%		☐ D 100%
Documentation	☐ E 100%	☐ E 100%	☒ E 70-80%	☒ F 20-30%	☐ E 100%	☒ E 100%	☐ E %	☐ D %
Examination	☐ E 100%	☐ E 100%	☐ E 100%	☒ F 100%	☐ E 100%	☒ E 100%	☐ E 100%	☐ D 100%

Module category

☒ FTP Fundamental theoretical principles

☐ TSM Technical/scientific specialization module

☐ CM Context module

Lessons

2 lecture periods and 1 tutorial period per week

Entry-level competencies

Prerequisites, previous knowledge

A solid knowledge of the fundamentals of physics is essential. Notions such as energy, force, thermal energy $k_B \cdot T$, specific heat capacity, oscillations, resonance frequency, waves, electromagnetic field vectors: $\vec{E}$, $\vec{D}$, $\vec{B}$ and $\vec{H}$, electric capacitance C, dielectric constant ε_r and Bohrs model of atoms are mandatory. Also required are simple differential equations and complex numbers, in particular $e^{-i\omega t}$.

Brief course description of module objectives and content

The students understand and are able to explain the basic principles of important engineering devices in relation to material properties and by applying microscopic concepts. These concepts include electrons and holes in solids, energy band structures of metals and semiconductors, polarization mechanisms in in dielectrics and in piezoelectric materials, elementary dipole moments in magnetic materials and pairing of electrons in superconductors (Cooper pairs). Actual applications such as thermocouples, photovoltaic cells (solar cells), light emitting diodes (LED), piezoelectric actuators, magnetic sensors and data storage devices can be discussed by means of these concepts. This module will allow the students to understand modern concepts of innovative technologies and use them in the future.

Aims, content, methods

Learning objectives and acquired competencies

The students

- understand the thermal and electric conduction in solids using the kinetic description of particles
- can relate thermal conduction to electric conduction via microscopic models
- are able to describe the principles of thermocouples and diodes by means of energy bands, Fermi energy and contact potential
- can explain the physical origin and technical realization of vertical resolution of scanning probe microscopes (atomic force microscope, scanning tunnelling microscope) in the nanometer range
- know the classification of magnetic materials and can name examples of their technological applications

- understand the difference between the Meissner effect of a superconductor and a perfect diamagnetic material
- are capable to solve quantitative problems to all topics of this module.

Contents of module with emphasis on teaching content

Elementary concepts of materials are studied with emphasis on applications. The module is divided into five topics:

1. Concept of thermal and electrical conduction in solids.
   - Basic principles of quantum physics.
   - Thermal fluctuations and thermal activation (Arrhenius plots).
   - Crystal structure and crystal symmetry (*bcc*, *fcc*, *hcp*), types of bonds and bond energy.
   - Bravais lattices and crystal defects.
2. Concept of thermal and electrical conduction in solids.
   - Electrical conduction (Drude model), drift velocity, relaxation time, mean free path.
   - Lorentz force and Hall effect, Hall voltage, new Ohm standard.
   - Temperature dependence of resistivity of ideal pure metals.
   - Thermal conduction (Wiedemann-Franz law).
3. Concept of energy bands in semiconductors, metals and insulators.
   - Schrödinger equation and some applications
   - Electrons and holes, effective electron mass.
   - Doping: *n*-type, *p*-type.
   - Ensemble of particles, Fermi-Dirac statistic of conduction electrons.
   - Contacts: ideal *p-n* junction (diode), pure metal contact and thermocouples.
   - Devices: diode, photovoltaic cell (solar cell), light emitting diode (LED).
4. Dielectric and piezoelectric materials.
   - Electric polarization mechanisms, dipole moment, polarizability.
   - Local electric field, Clausius Mossotii relation between the polarizability and the dielectric constant.
   - Dielectric constant as a complex quantity, absorption of electromagnetic waves and loss factor.
   - Piezoelectricity, actuators and sensors, scanning tunneling and atomic force microscope (STM/AFM), pyroelectricity.
5. Magnetic properties and superconductivity.
   - Magnetization and magnetic permeability.
   - Different classes of magnetic materials: diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic, ferrimagnetic.
   - Magnetic domains and magnetic data storage
   - Superconductivity: zero resistance and critical current density, generation of large magnetic fields.
   - Measuring magnetic fields: Hall effect, magnetic flux quantization and SQUID (Superconducting Quantum Interference Device).

Teaching and learning methods

Instruction teaching: presentation and discussion of fundamental concepts.
Exercises: solving quantitative problems and analyzing the physical concepts.
Individual learning using the lecture notes and the textbook.

Literature

Principles of Electronic Materials and Devices, Safa O. Kasap, McGraw Hill

Assessment

Certification requirements for final examinations (conditions for attestation)

Defined by the professors, for example a certain number of problems solved.

Basic principle for exams:
All the standard final exams for modules are written exams.
The repetition exams can be either written or oral.

Standard final exam for a module and written repetition exam

Kind of Exam	written
Duration of exam	120 minutes
Permissible aids	☐ No aids ☑ Permissible aids ☑ calculator ☑ writing paper ☑ writing material, pen, ruler ☑ NOT allowed are lecture notes, exercises and textbooks ☑ NOT allowed are notebooks, smart phones and other electronic devices for telecommunication

Special case: Repetition exam as an oral exam

If an oral exam is set (only possible for ≤ 4 students), the following applies:

Kind of Exam	oral
Duration of exam	30 minutes
Permissible aids	No aids