UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Materials Spectroscopy and Microscopy

2425-1-FSM01Q003

Aims

The course aims at the understanding of the fundamental concepts of the response of materials to electromagnetic radiation, including the implications for applications in photonics, fibre optics, and optoelectronics, as well as the fundamentals of the main microscopy techniques.
At the end of the course, the student will be able to:
• Understand material requirements for specific functionalities in which interaction with electromagnetic radiation is implied.
• Design a strategy for the experimental characterization of material properties in relation to their applications, either by means of spectroscopy or microscopy approaches.
• Acquire a proactive and responsible attitude during group works and laboratory activities.

Contents

The course addresses the fields of: i) spectroscopy, intended as the study of the interactions between electromagnetic radiation and materials and on its very extended applications; and ii) microscopy, mainly focused on light, electron and scanning probe microscopies. Fundamental aspects of spectroscopy and microscopy are treated alongside the experimental approaches that can be adopted. Classical techniques and advanced tools are proposed both during lessons and during the analysis of case studies and group works. Students acquire solid competences and skills in such topics, becoming able to apply them also in cross-disciplinary contexts. During the group works, the students are invited to address specific research problems and to find original solutions in a mature and collaborative way.

Detailed program

- 1st semester -

A. LESSONS

SECTION A.1. INTRODUCTION
• Outline of the contents and of assessment methods

SECTION A.2. INTERACTION OF ELECTROMAGNETIC RADIATION WITH MATERIALS IN THE LINEAR RESPONSE REGIME
• Solution of the electromagnetic wave equation in a material
• Dielectric function and refractive index
• Lorentz and Drude models
• Kramers-Kronig relations
• Response to electromagnetic radiation of real materials (metals, semiconductors and insulators)

SECTION A.3. INVESTIGATION OF MATERIALS THROUGH RESONANCE PHENOMENA
• Impedance spectroscopy
• Electron spin resonance
• Optical absorption
• Steady state and time resolved luminescence
• Anti-Stokes luminescence

SECTION A.4. INTRODUCTION TO NON LINEAR RESPONSE OF MATERIALS TO ELECTROMAGNETIC RADIATION
• Fundamentals of the non linear response
• Second and third order non linearity
• Electro-optic and Kerr effects
• Origin of non linearity in materials (crystals, glasses, polymers)

- 2nd semester -

B. APPLICATIONS AND EXERCISES ON MATERIALS SPECTROSCOPY

SECTION B.1. From fundamentals to technology - Practical aspects of the relation between polarization and transmission
• Why the propagation speed of light is reduced in transparent materials
• Physical meaning and practical use of the Sellmeier parametrization in the design of optical materials
• Thermo-optic and elasto-optic coefficients and their technological importance in fibre-optics and -sensors

SECTION B.2. Bragg gratings - fundamentals and applications
• Mechanisms of photosensitivity for functionalizing dielectric materials.
• Glass materials engineering and tools for the description of wave propagation in layered dielectrics
• From Fresnel coefficients to transfer matrix and scattering matrix.

SECTION B.3. Role of structure, disorder, and phonon spectrum in the design of glass-based optical materials
• Amorphous dielectrics in optical technology
• Quantifying and controlling structural disorder – diffraction and light scattering techniques
• Effects of disorder on the energy gap and transitions at localized states
• Spectroscopy of transition metal ions and rare earth ions in glass-based materials

C. FUNDAMENTALS OF MICROSCOPY AND EXPERIMENTAL ACTIVITIES

SECTION C.1. LIGHT MICROSCOPY
a. Basic principles of geometric optics;
b. Light diffraction and Abbe theory of imaging;

c. Design and layout of a light microscope;
d. Fluorescence microscopy and Confocal microscopy;
e. Beyond the Abbe limit: structured-illumination microscopy (STED);
f. Super-resolution microscopy: PALM and STORM.

SECTION C.2. ELECTRON MICROSCOPY
a. Wave-nature of electrons and basic principles of electron optics;
b. Interaction between electron and matter;
c. Transmission Electron Microscopy (TEM)
i. Layout of a TEM microscope;
ii. Imaging modes (bright and dark field), diffraction and crystallography;
iii. Amplitude, diffraction and phase contrasts in TEM;
iv. High-Resolution TEM, magnetic TEM, and Scanning TEM;
v. TEM sample preparation;
d. Scanning Electron Microscopy (SEM)
i. Layout of a SEM microscope
ii. Secondary electron contrast and imaging modes;
iii. Electron Back-Scatter Diffraction (EBSD)
e. Electron and Photon Spectroscopies in SEM and TEM
i. Energy-Dispersive X-Ray spectroscopy (EDX)
ii. Electron Energy Loss Spectroscopy (EELS);
iii. Auger Electron Microscopy (AEM)
iv. Cathodoluminescence (CL)

SECTION C.3. SCANNING-PROBE MICROSCOPY
a. General concepts on scanning probe techniques;
b. Tip-sample forces and piezo-electric scanners;
c. Atomic Force Microscopy (cantilevers, detection methods, and imaging modes);
d. Scanning Tunnelling Microscopy (tunnelling phenomenon, detection methods, imaging modes, and spectroscopic capabilities).

Prerequisites

Fundamentals of the structure of matter.

Teaching form

The course includes both lessons, with discussions of specific case studies and applications, as well as interactive activities in group work and practical experiences in small groups. In particular, the following activities are planned:

- 12 lessons of 2 hours with in-person classes.
- 28 2-hour exercises carried out in frontal mode in the initial part, aimed at involving students in an interactive way in the subsequent part. All activities are carried out as in-person classes.
- 6 2-hour exercises carried out in interactive mode in interdependent groups. All activities are carried out as in-person classes.
- 2 2-hour exercises initially carried out independently by the students and then discussed interactively in the next part. All activities are carried out as in-person classes.

Textbook and teaching resource

F. Wooten, “*Optical properties of solids*”, Academic Press
J. G. Solé, L.E. Bausà, D. Jaque, “*Optical spectroscopy of Inorganic Solids*”, Wiley
H. Kuzmany, “*Solid State Spectroscopy*”, Springer
B.E.A. Saleh and M.C. Teich, “*Fundamentals of Photonics*”, Wiley
R. Feynman, *“Lectures on Physics*” vol. 1, part 2, Inter European Editions
J.C. De Mello, *“An Improved Experimental Determination of External Photoluminescence Quantum Efficiency*”, Advanced Materials vol. 9, 230 (1997)
G. Blasse and B.C. Grabmaier, *“Luminescent materials”,* Springer Verlag
A.V. Chadwick and M. Terenzi, *“Defects in solids: Modern techniques”*, NATO ASI Series B: Physics, vol. 147, Plenum Press, 1986

M.B.James,D.J.Griffiths,Why the speed of light is reduced in a transparent medium,Am.J.Phys.60(1992)309
K.S. Potter, J.H. Simmons, Optical Materials, Elsevier, 3rd chapter
A. Othonos, K. Kally, Fiber Bragg Gratings, Artech House, ch.1, ch. 2 from 2.8 to 2.9, ch. 3, from 3.1 to 3.2…
B.E.A. Saleh, M.C. Teich, Fundamentals of Photonics, Wiley, section 6.2, 7.1.
N.E. Cusak, The physics of structurally disordered matter, IOP, sec. 1.1-1.9, 2.1-2.3, 10.6.
F.L. Geleener, Planar Rings in Glasses, Sol. St. Commun. 44 (1982) 1037.
D. Weaire, M.F. Thorpe, Electronic properties of an amorphous solid. I. A simple tight-binding theory, Phys. Rev. B 4 (1971) 2508.
G.D. Cody et al., Disorder and the optical absorption edge of hydrogenated amorphous silicon, Phys. Rev. Lett. 47 (1981) 1480.
L. Skuja, Optical properties of defects in silica, in “Defects in SiO2 and related dielectrics: science and technology” ed. G. Pacchioni, L. Skuja, D.L. Griscom, Kluwer Academic, pp. 73.

E. Hecht, Optics, 4th ed.; Addison-Wesley, 2002.
D. B. Murphy, Fundamentals of Light Microscopy and Electronic Imaging, 1st Edition; Wiley-Liss, 2001.
D. B. Williams and C. B. Carter, Transmission Electron Microscopy; Springer, 2009.
R. F. Egerton, Physical Principles of Electron Microscopy: An introduction to TEM, SEM, AEM; Springer, 2008.
E. Meyer, H. J. Hug, R. Bennewitz, Scanning Probe Microscopy: The Lab on a Tip; Springer, 2003.

Additional resources:
Slides provided by the professors
Specific scientific papers, tables, and diagrams, are available on the e-learning platform.

Semester

The course has an annual duration. Lessons of Part-A are given in the first semester. Part B and Part C - comprising discussions on applications and case studies, group exercises, fundamentals of microscopy and practica group part - are in the second semester.

Assessment method

a) Ongoing tests. The course includes three ongoing tests, one for each of the three parts of the program. There is an oral interview on the contents of the first part, which can be taken from the end of the first semester, by appointment. Then, there is a written test, including multiple choice questions and an open-ended question, at the end of the second part during the second semester. At the end of the third part of the course, at the end of the semester, there is a second written test with a few open-ended questions. The two written tests can be replaced, at the student's request, by an oral interview, by appointment, at the end of the activities of the second or third part, during or after the end of the second semester.

b) Skills assessed. In the ongoing tests the following competences are evaluated: 1. To identify the electromagnetic response a material must possess to be suitable for specific functions; 2. To design measurement strategies for the spectroscopic and microscopic characterization of material properties in relation to applications.

c) Criteria for evaluation. Interviews and written tests evaluate the following parameters: i) percentage of questions which are answered correctly; ii) for each answer, percentage of experimental and theoretical details provided by the student compared to those exposed, discussed and applied during the course; iii) for each topic proposed during the test, percentage of comments on applicative aspects compared to those discussed and included in the contents of the program. The final evaluation is the average of the evaluations on the three parts of the course, each according to all the indicated criteria.

Office hours

8 - 18

Appointments between professors and students can be agreed by e-mail.

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE | RESPONSIBLE CONSUMPTION AND PRODUCTION