UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Materials Spectroscopy and Microscopy

2324-1-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. The course includes lessons, discussions of specific case studies and applications to group exercises, and an experimental activity carried out in small groups.
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 exercises, and in the laboratory part. Students acquire solid competences and skills in such topics, becoming able to apply them also in cross-disciplinary contexts. During the group exercises and the laboratory part, 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
Readings:
Slides uploaded in the e-learning page of the course

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)

Readings:
F. Wooten, “Optical properties of solids”, Academic Press
J. G. Sole?, L.E. Bausa?, D. Jaque, “Optical spectroscopy of Inorganic Solids”, Wiley

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

Readings:
J. G. Sole?, L.E. Bausa?, D. Jaque, “Optical spectroscopy of Inorganic Solids”, Wiley
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

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)

Readings:
B.E.A. Saleh and M.C. Teich, “Fundamentals of Photonics”, Wiley
R. Feynman, “Lectures on Physics” vol. 1, part 2, Inter European Editions

- 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

Readings:
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

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.

Readings:
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.

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

Readings:
N.E. Cusak, The physics of structurally disordered matter, IOP, sec. 1.1-1.9, 2.1-2.3, 10.6.
J. G. Sole?, L.E. Bausa?, D. Jaque, “Optical spectroscopy of Inorganic Solids”, Wiley
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.

C. FUNDAMENTALS OF MICROSCOPY AND EXPERIMENTAL ACTIVITIES

SECTION C.1. LIGHT MICROSCOPY
a. Basic principles of geometric optics;
b. Light diffraction and Abbe criterion;
c. Design and layout of a light microscope;
d. Fluorescence microscopy and Confocal microscopy;
e. Beyond the Abbe limit: two-photon microscopy and structured-illumination microscopy;
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);
e. Scanning Near-Field optical Microscopy (SNOM).

Readings:

- 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.

Prerequisites

Fundamentals of the structure of matter.

Teaching form

Lessons, discussions, group exercises, and lab activities.

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
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D. Weaire, M.F. Thorpe, Electronic properties of an amorphous solid. I. A simple tight-binding theory, Phys. Rev. B 4 (1971) 2508.
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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 the lab part - are in the second semester.

Assessment method

The exam is in the form of an oral interview on the 1st semester lessons after the end of Part A, and in a written test on the contents of Part B and Part C after the end of the 2nd semester.

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