UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Physics of Homogeneous and Nanostructured Dielectrics

1819-1-F5302Q015

Aims

The course gives the fundamental tools for the understanding and the design of the electromagnetic response of optical dielectric materials – specifically concerning the applications in photonics, fibre optics, and optoelectronics – through the analysis of the relevant physical properties of dielectrics and focusing on the role of structure, nanostructures, and short- and long-range order.

Contents

The course starts from the description of polarization effects in materials to achieve the consciousness of the physical mechanisms responsible for the refractive index dispersion, optical absorption, light emission yield and nonlinear response in homogeneous, composite, and nanostructured systems as a function of materials features, structural order and disorder, and working parameters as temperature, stress, and light intensity. The lectures highlight the main properties making silica-based oxides key dielectric materials in photosensitive systems for the fabrication of fibre filters and fibre sensors, in optical amplifiers as doped active glasses, and in even more complex systems via nonlinear response.

Detailed program

Topics include three main blocks:

1. *Response of Dielectrics to electromagnetic waves*

From Maxwell equations to the refractive index of optical materials. The reason why the propagation speed of light is reduced in dielectrics. Dissipation and dispersion in dielectrics: the Kramers Kronig relations between real and imaginary parts of the response functions. Relationship between refractive dispersion and optical absorption spectrum. Physical meaning of the Sellmeier parametrization. From Clausius-Mossotti and Lorenz-Lorents relations to the thermo-optic and elasto-optic coefficients and their technological importance in fibre-optics and fibre-sensors. 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: transfer matrix and scattering matrix.

2. *Amorphous dielectrics: structure and effects on optical functions*

Description of amorphous structures: ordering rules, deviations from order, topological disorder, defectiveness, bond angle and length distribution in amorphous structures. Raman spectrum of amorphous dielectric oxides and contributions from the statistics of coordination rings. Dependence of energy gap on the structural disorder: Tauc and Urbach spectral region. Effects of static and dynamic disorder in the Urbach spectral region of the absorption edge. Homogeneous and inhomogeneous contributions to the spectral broadening of transitions at localized states. Configurational coordinate diagram and cross-correlation effects on the spectral parameters. Electron-phonon coupling and relaxation energy. Huang Rhys factor and relationship with the Stokes shift and spectral band homogeneous broadening.

3. *Structural effects on localized transitions*

Crystal field effects. From the electrostatic potential of ligands to the Stevens operators in the description of the crystal field Hamiltonian. Introduction to the use of Tanabe-Sugano diagrams. Energy of the electronic configurations. Crystal field spectroscopic terms and relationships with free ion terms. Racah parameter. Spin allowed and spin forbidden transitions. Static and dynamic Crystal Field effects, spectral broadening of transitions between field dependent e field independent configurations. Judd-Ofelt theory and related parameters for the analysis of Crystal field effects on rare earth ions.

Nonlinear response in amorphous dielectrics. Anharmonic effects and asymmetry of the local potential on the polarization response: Second and third order effects and role of poling processes. Physical mechanisms responsible for the nonlinear refractive index. Experimental methods for the analysis of third order nonlinear refractive and dissipative response of amorphous dielectrics.

Prerequisites

Basic knowledge of electromagnetism.

Teaching form

The course mainly comprises lectures in the classroom and includes sets of collective exercises of design and evaluation of materials for technology. In the final part of the course, students are involved in the analysis of experimental data collected in laboratory, intended to apply knowledge in practical situations of investigation of dielectric materials.

Textbook and teaching resource

Reference textbooks:

The physics of thin film optical spectra – O. Stenzel – Springer 2016

Optical Materials – J. H. Simmons, K. S. Potter – Academic press. 2000

An introduction to the optical spectroscopy of inorganic solids – J. García Solé, D. Jaque, L. E. Bausà – Wiley 2005

Additional resources:

Specific scientific papers, tables, and diagrams, are available on the e-learning platform.

Semester

2nd semester

Assessment method

Students must demonstrate in an interview to know how the main principles for the description of the electromagnetic response of dielectrics can be used as a tool for the analysis and the design of optical functions of technological relevance. During the assessment, a specific material system is analyzed as an example for the application of the acquired knowledge to solve a technological problem.

Office hours

9:00-13:00 Monday, Wednesday, Friday

14:00-17:00 Friday