UNIVERSITÀ DI PISA

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Corso di Laurea Magistrale in Materials and Nanotechnology
Anno accademico 2016/2017

SPECTROSCOPY OF NANOMATERIALS
(266BB – 12 cfu – FIS/03)

General program of the <u>second semester</u> lectures

0. Required knowledge
Concepts of spectroscopy methods and related tools as discussed in the first semester of the course; basics of electromagnetism, optics, light-matter interaction in the semiclassical frame.

1. Generalities on the topic
Aims and motivations for spectroscopy of nanomaterials, specific properties of nanostructures, size limits of the nanoworld, technological issues. The main problem of optics in the nanoworld: interference and diffraction in optics. Electron microscopy as a benchmark and a reference for nanoscopy.

2. Optical microscopy and nanomaterials
Scattering (Rayleigh and Mie) from nanostructures and related problems. Ray and Fourier optics: resolving power and its evaluation according to Rayleigh and Sparrow criteria. Conventional optical microscopy and its variants (epi-fluorescence, dark field, polarization, differential interference contrast). Illumination and stray light: confocal scanning optical microscopy, its ultimate resolution, examples.

3. Quantum confinement and optical properties of semiconductor nanostructures
Reminders of bulk semiconductor properties, direct and indirect transition. Basics of quantum mechanics and the problem of the potential well (infinite and finite). Confinement and 2-D (quantum wells), 1-D (quantum wires), 0-D (quantum dots) nanostructures: quasi-discrete levels, interband and intraband transitions, exciton in confined systems, density of states and dimensionality. Absorption and emission properties in quantum dots, including core-shell systems, related technology and some applications, in particular in optical nanoscopy.

4. Super-resolution microscopy
Stimulated emission in a multi-level system, pumping and saturation. Gaussian shape of laser beams, interaction with retarding plates (including reminders of polarization control), creation of doughnut modes. STED and its resolving power, examples, few words on PALM and STORM.

5. Plasmonics
Introduction to plasmonics: plasma frequency in metal, interband transition and their role, complex dielectric constant and refractive index, Drude model. Surface plasmon polariton at plane interfaces: longitudinal e.m. waves and surface charge oscillation, solution of the wave equation, evanescent behavior and dispersion relation. Excitation of plasmon modes through charge collision, Kretschmann and Otto methods, diffraction gratings, near-field. Examples and applications, surface plasmon specroscopy. Localized surface plasmon resonances, optical extinction, dispersion relation: their role in optics and photonics, transfer of e.m. energy through plasmonic waveguides. SERS-active substrates.

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6. Photonic band-gap structures and metamaterials

Bragg interference in planar and non-planar structures, transmission and reflection, occurrence of a photonic band-gap: similarities with the electron wavefunctions in solid-state materials and energy gap in crystalline semiconductors. Survey of photonic band-gap nanostructures and examples of their application. Basics of metamaterials: tuning the e.m. properties of a system through structural engineering, possibilities and perspective applications.

7. Scanning probe microscopies for spectroscopy of nanomaterials

Concepts and basic elements of SPMs: the invention of STM and the role of feedback, applications and examples of tunneling spectroscopies. AFM and variants of scanning force microscopies, examples of applications (EFM, LFM, tribology and adhesion spectroscopy) and technical issues. Optical near-field: diffraction from nanosized apertures/tips, Bethe-Bouwkamp solution of the e.m. fields. Evanescent behavior of the near-field. Technical realization of SNOMs in aperture and apertureless configurations, variants, including tip-enhanced spectroscopies (TERS), examples and limitations.

Teaching materials: commented slides of the lectures are available at the lecturer's website (http://www.df.unipi.it/~fuso/dida), including a list of relevant textbooks and tutorial/review papers.