UNIVERSITÀ DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Modern Optics

2627-2-E3004Q014

Aims

This course contributes coherently to the bachelor’s degree programme through the following learning objectives:
Knowledge, understanding and application of skills (Dublin Descriptors 1 and 2)
Students will acquire a coherent understanding of the physical principles of wave optics, laser operation, guided and integrated photonics, nonlinear optical processes, and elementary quantum optics. They will learn to use simplified electromagnetic and quantum models to analyse optical components and systems, including interferometers, resonators, waveguides, optical fibres, modulators, nonlinear frequency converters, and correlated-photon sources. They will be able to connect these models to applications in optical communications, sensing, spectroscopy, photonic information processing, energy-efficient photonic technologies, and quantum technologies.
Making judgements (Dublin Descriptor 3)
Students will learn to identify the essential physical mechanisms involved in an optical problem, select an appropriate level of modelling, assess the validity of the adopted approximations, and critically compare alternative solutions and technological trade-offs.
Communication skills (Dublin Descriptor 4)
Students will develop the ability to explain optical phenomena and present the analysis of an optical component or system clearly and rigorously in English, using appropriate scientific terminology and quantitative reasoning.
Learning skills (Dublin Descriptor 5)
Students will develop the ability to update their knowledge independently, consult advanced textbooks and scientific literature, and extend the concepts and methods acquired during the course to emerging photonic technologies and unfamiliar optical problems.

Contents

This course introduces the physical principles and basic tools of modern photonics. Building on prior courses in electromagnetism and quantum physics, it develops a practical understanding of wave optics, laser sources, guided and integrated photonics, nonlinear frequency conversion, and selected topics in quantum optics. The emphasis is on connecting simplified physical models to real components and systems for communication, sensing, spectroscopy, and emerging photonic technologies.

Detailed program

Module 1: Electromagnetic Theory and Wave Optics
• Brief review of electromagnetic wave propagation in dielectric media, complex field representation, and the Helmholtz equation.
• Polarization of light, Jones calculus, birefringence, wave plates, and polarizers.
• Reflection and refraction at dielectric interfaces, Fresnel coefficients, and Brewster angle.
• Interference and coherence: Michelson and Mach-Zehnder interferometers, fringe visibility, and optical path difference.
• Diffraction: Fraunhofer and Fresnel diffraction, diffraction gratings, and introductory Fourier optics.
• Lenses, ray optics, and imaging systems; introduction to dispersion and the linear optical response of materials.
Module 2: Lasers, Gaussian Beams and Photonic Devices
• Spontaneous and stimulated emission, Einstein coefficients, and population inversion.
• Optical gain, laser threshold, resonator modes, and basic laser operation.
• Gaussian beam propagation: beam waist, divergence, Rayleigh range, focusing, and collimation.
• Optical cavities, mode matching, and resonator-based photonic devices.
• Guided-wave optics: dielectric waveguides, optical fibres, coupling, dispersion, and basic propagation losses.
• Introduction to integrated photonics: directional couplers, Mach-Zehnder interferometers, and microring resonators.
Module 3: Nonlinear Optics and Applications
• Nonlinear polarization and frequency conversion in bulk crystals, optical fibres, and integrated waveguides.
• Harmonic generation, sum-frequency generation, and difference-frequency generation.
• Optical parametric processes: optical parametric amplification and oscillation.
• Phase matching, quasi-phase matching, and resonant enhancement, with applications to tunable sources and wavelength conversion.
• Optical modulation: electro-optic and acousto-optic effects; amplitude, phase, and frequency modulation for communications and laser control.
• Elements of ultrafast optics: group-velocity dispersion, Kerr nonlinearity, ultrashort pulses, and mode locking.
• Soliton concepts in fibres and resonators; applications to frequency combs, spectroscopy, sensing, and optical communications.
Module 4: Quantum Optics and Advanced Topics
• Photon statistics, second-order coherence, and second-order correlation functions.
• Hanbury Brown-Twiss experiment, photon correlations, coincidence measurements, and photon bunching and antibunching.
• Introduction to two-photon interference and the Hong-Ou-Mandel effect.
• Spontaneous parametric down-conversion (SPDC) as a source of correlated photon pairs and non-classical light.

Prerequisites

Basic calculus, complex numbers, and linear algebra. Students should be familiar with elementary electromagnetism and wave physics, including harmonic waves, interference, and boundary conditions, as well as introductory quantum mechanics, including quantum states, observables, and measurements.

Teaching form

The course comprises 48 hours of teaching, organized as follows:
• 32 hours of asynchronous online lectures, delivered through 16 recorded two-hour lectures, in remote Didactic Delivery mode (DE).
• 16 hours of in-person interactive teaching (DI), consisting of guided problem-solving activities, quantitative exercises, analysis of optical systems, and discussion of applications.

Textbook and teaching resource

• Main reference: B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, 3rd ed., Wiley, 2019.
• Additional reference: M. Born and E. Wolf, Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light, 7th expanded ed., Cambridge University Press, 1999.
• Selected nonlinear-optics reference: R. W. Boyd, Nonlinear Optics, 4th ed., Academic Press, 2020.
• Selected quantum-optics reference: M. Fox, Quantum Optics: An Introduction, Oxford University Press, 2006.

Semester

Second semester

Assessment method

No mid-term tests are scheduled. The final examination is an individual oral examination conducted in English. It includes a discussion of the main course topics and a simple quantitative problem or the analysis of an optical system.
The assessment evaluates knowledge and understanding of the physical principles, the ability to select and apply appropriate physical models to simple problems, quantitative reasoning, critical evaluation of assumptions and approximations, and clarity of presentation using appropriate scientific terminology.
A score below 18 indicates insufficient knowledge and results in failure. Scores from 18 to 23 indicate sufficient knowledge, scores from 24 to 27 indicate good knowledge, and scores from 28 to 30 indicate excellent knowledge. Within each range, the grade reflects critical analysis, reasoning, and communication skills. A grade of 30 with honours may be awarded for an outstanding examination demonstrating complete mastery of the subject, excellent autonomy of reasoning, and particularly clear and rigorous communication.

Office hours

By appointment.

Sustainable Development Goals

INDUSTRY, INNOVATION AND INFRASTRUCTURE