UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Quantum Electronics

2324-2-F5302Q035

Aims

The course aims to provide the fundamental notions on the design and fabrication of nanostructures by photons, electron beams and self-assembly. The electronic states of materials and devices will be studied through the discussion of their architectures and measurements of the optical, electronic and magnetic properties in order to understand the potential applications of quantum materials in quantum technologies.

Contents

• Introduction: Electronics for modern quantum technologies
• Quantum transport in low dimensional structures
• Spintronics
• Methods for the generation and manipulation of coherent optical radiation and microwaves
• Nanofabrication methods by photons, electrons, and by self-assembly
• Emergent functionalities: topological magnetism

Detailed program

INTRODUCTION
• Electronic devices for the modern quantum technologies. Overview of course pre-requisite, lecture contents, textbooks/literature, and assessment methods.

DESIGN AND FABRICATION OF NANOSTRUCTURES
• Introduction to lithography;
• Optical and Ultraviolet Lithographic techniques.

• Electron beam lithography (EBL) and Focused Ion Beam (FIB).
• Brief overview of the main thin film deposition techniques.

QUANTUM TRANSPORT
• Lenght scales and electron transport regimes.
• Quantum transport in zero, one and two dimensional systems.
• Coulomb and Pauli spin blockade. Quantum point contact. Single electron transistor.
• Multiterminal conductors and Buttiker-Landauer formula.
• Spins in a few electron quantum dots. Charge sensing. Spin-to-charge conversion and single electron read out.

METHODS FOR THE GENERATION AND MANIPULATION OF COHERENT OPTICAL RADIATION AND MICROWAVES
• Principle of laser emission and short pulse generation.
• Optical resonators, waveguides, and integrated circuits,.
• Microwave emitters and masers; Radio-Frequency cavities.

SPINTRONICS DEVICES AND APPLICATIONS
• Theory of spin transport in magnetic multilayers and device architectures for transport measurements.
• Giant magnetoresistance, anisotropic magnetoresistance, tunneling magnetoresistance and spin-dependent Hall effects.
• Optical and electrical magnetic resonance methods for electron spin injection, manipulation and detection.
• Functionalities of spintronic devices: spin–charge conversion, spin injection, spin tranfer torque, spin pumping, spin manipulation and spin read-out.
• Spin diodes, spin transistors and amplifiers, spin filters, MRAM with magnetic tunnelling junctions, molecular spin qubits and spin-qubits in semiconductor nanostructures.
• Molecular magnets for data storage and quantum information processing.

EMERGENT FUNCTIONALITIES: TOPOLOGICAL MAGNETISM
• Topology in condensed matter and chiral conduction.
• Topological magnetoelectric effects and topological spintronics.
• Néel-type and Bloch-type magnetic domains and skyrmions.

Prerequisites

Basic concept of quantum mechanics, physics of semiconductor, and solid state physics courses (or equivalent).

Teaching form

Frontal lectures and exercise sessions using slides and/or blackboard.

Textbook and teaching resource

1. Yuri M. Galperin (2014). Introduction to Modern Solid State Physics. CreateSpace Independent Publishing Platform.
2. Davies, J. (1997). “The Physics of Low-dimensional Semiconductors: An Introduction”, Cambridge University Press.

3. Zheng Cui (2008), Nanofabrication - Principles, Capabilities and Limits, Springer New York, NY.
4. T. Shinjo (2009), Nanomagnetism and Spintronics, Elsevier
5. Tsymbal, Evgeny Y. Handbook of spin transport and magnetism.
6. D. Gatteschi, R. Sessoli and J. Villain (2006) “Molecular nanomagnets”, Oxford University Press.
7. Hirohata, A.; Yamada, K.; Nakatani, Y.; Prejbeanu, I.-L.; Diény, B.; Pirro, P.; Hillebrands, B. Review on spintronics: Principles and device applications. J. Magn. Magn. Mater. 509, 166711 (2020).
8. Barla, P.; Joshi, V. K.; Bhat, S. Spintronic devices: a promising alternative to CMOS devices. Journal of Computational Electronics 2021, 20 (2), 805-837.

Slides will be made available to the students through the present e-learning platform.

Semester

First semester (from September to January)

Assessment method

Students’ knowledge will be evaluated through an oral exam focusing on the topics discussed during the course with presentation of quantitative analyses, equations, graphs, and schemes.

Office hours

From Monday to Friday at any working hour (an appointment should be arranged with the teacher by email).

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE