COURSE DESCRIPTION
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SSD: ELETTROTECNICA (ING-IND/31)

DEGREE PROGRAMME: INGEGNERIA ELETTRICA (M60)
ACADEMIC YEAR 2022/2023

COURSE DESCRIPTION

TEACHER: FORESTIERE CARLO
PHONE: 081-7682007
EMAIL: carlo.forestiere@unina.it

GENERAL INFORMATION ABOUT THE COURSE

INTEGRATED COURSE: NOT APPLICABLE
MODULE: NOT APPLICABLE
CHANNEL: FG A-Z
YEAR OF THE DEGREE PROGRAMME: II
PERIOD IN WHICH THE COURSE IS DELIVERED: SEMESTER I
CFU: 6

REQUIRED PRELIMINARY COURSES

None

PREREQUISITES

None

LEARNING GOALS

This course aims at introducing students with the basic concept of Nanotechnology from the perspective of an electrical engineer. This course presents a gentle introduction to selected arguments of quantum mechanical, electric transport, nano-optics, and metamaterials. Such concepts are then applied to describe the working principle of nanodevices, such as quantum dots, graphene, carbon nanotubes, plasmonic sensors, photonic crystals, metamaterial devices based on negative-refraction and cloaking.

EXPECTED LEARNING OUTCOMES (DUBLIN DESCRIPTORS)

Knowledge and understanding

This course will introduce the students to the basic methodologies from quantum mechanics, electric transport, nano-optics, and metamaterials required for a critical understanding of the working principles of nanodevices. The students will then be gently guided to apply this knowledge to the modelling of *electrical devices* such as graphene and carbon nanotubes, *quantum devices* such as quantum dots and resonant-tunneling diode, *optical devices* such as plasmon nano-sensors, *metamaterial devices* such as negative-refraction / cloaking devices.

Applying knowledge and understanding

The students will be able to determine and design the energy level of artificial atoms (quantum dots) by solving the Schrodinger equation. The students will be able to solve problems of electric conduction in graphene and carbon nanotubes using their band structures and the semiclassical modes. The student will be able to determine the electromagnetic scattering resonances of simple metal nanoparticle, determine the effective permeability and permittivity of 3D metamaterials. The student will be able to describe the basic principles of nanodevices using the appropriate jargon.

COURSE CONTENT/SYLLABUS

1. ELEMENT OF QUANTUM MECHANICS The origin of quantum theory. Black body radiation and quanta hypotheses, photoelectric effects, matter waves. Free wave packet. Phase velocity and group velocity. Schrodinger equation. Linear Operators. Dual, Hermitian, and Commuting Operators. Operators. Wave equation of a free particle. Particle in a scalar potential. Hamiltonian and Canonical Quantization. Probability density and normalization condition. Probability Current. Continuity equation. Mean Values. Time independent Schrodinger equation. Stationary Solutions of Schrodinger Equation. Infinite 1D potential well. Finite 1D potential well. Infinite 2D potential well. Tunneling through a rectangular barrier. Quantum dots. Postulates of Quantum Mechanics. Hilbert spaces. Physical states and “ket vectors”. Dual spaces and “bra” vectors. Scalar product. Eigenvalue problems and observable. Probability. Postulates concerning measurement. Wavefunction collapse. Heisenberg’s Uncertainty relations. The equation of motions: evolution operators and the Schrödinger Equation.

2. ELEMENTS OF NANOFABRICATION Top-down approaches. The planar process. Resist. Exposure: Photolithography. Electron Beam. Pattern transfer: Wet etching, Dry etching, Lift-off. Material deposition: Spin Coating; Sputter deposition; Chemical Vapor Deposition. Bottom-up approaches: Self-assembly; Molecular Beam Epitaxy. Metrology: Scanning Electron Microscopy. Scanning Electron Microscopy. Near-field scanning optical microscopy (NSOM). Atomic force microscope. Scanning tunnel microscopy.

3. CONDUCTION IN METALS AND SEMICONDUCTORS The Drude theory of Metals. Assumption. DC electric conductivity of metals. AC electric conductivity. Dielectric function and plasma Frequency. Thermal Conductivity. Hall effect and magnetoresistance. Specific heat of a *classical* electron gas. The Sommerfeld theory of Metals. Ground state properties of a *quantum* electron gas. Density of states. Fermi-Dirac distribution. Specific heat of a *classical* electron gas. Failures of the Free Electron model. Bravais lattices and Primitive Vectors. Primitive cell and Wigner-Seitz cell. Lattices with a basis. Honeycomb lattice. The Reciprocal lattice. Brillouin zones. Bloch’s Theorem. Periodic (Born-van Karman) boundary conditions. Kronig-Penney model. Crystal

Momentum. Energy Band Diagrams. Density of States. Semiclassical model. Filled Bands. Partially filled bands. Holes. Effective mass.

4. GRAPHENE AND CARBON NANOTUBES Graphene. Bravais lattice and basis vectors. Reciprocal lattice and first Brillouin zone. Hamiltonian based on a tight-binding model with nearest-neighbor hopping. Band structure. Fermi Energy and Dirac points. Gated/doped graphene. Applications. Carbon Nanotubes (CNT). CNT chirality: armchair and zig-zag nanotubes. Quantization of the wave-vector transverse to the long axis. Metallic and semiconducting nanotubes. CNT transistor. CNT mechanical properties. Applications.

5. ELEMENTS OF NANO-OPTICS Localized surface plasmons (LSP). Solution of the quasi-electrostatic problem of a spherical particle in a uniform electric field: polarizability, resonance condition, electric fields. Electric field enhancement and its application. Sensitivity of the resonance to local variations of the refractive index. LSP sensors. Surface Plasmon Polaritons (SPP). Propagating surface wave at the interface between a metal and a dielectric. Excitation configurations: Otto / Kretschmann configurations; grating coupler. SPP sensors. Photonic Crystals (PC): optical modes in a 1D photonic crystal (transmission matrix and Bloch theorem). PC Point defects and cavities. Line defects and waveguides. Metamaterials. Natural and artificial materials: artificial atoms. Left-handed materials and negative refraction.

READINGS/BIBLIOGRAPHY

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[1] Messiah, Quantum Mechanics, Dover

[2] D. Griffiths, D. Schroeter, Introduction to Quantum Mechanics (3rd ed.). Cambridge: Cambridge University Press (2018)

[3] I. Mayergoyz, Quantum Mechanics: For Electrical Engineers World Scientifics (2016)

[4] N. W. Ashcroft, and N. D. Mermin. "Solid State Physics Harcourt College Publishers." New York (1976)

[5] Novotny, Lukas, and Bert Hecht. Principles of nano-optics. Cambridge university press (2012)

[6] J. D. Joannopoulos, S. G. Johnson, J. N. Winn, and R. D. Meade. "Molding the flow of light." Princeton Univ. Press, Princeton, NJ (2008)

TEACHING METHODS OF THE COURSE (OR MODULE)

Lectures for approx..90% of total hours; practical exercises for approx.10 % of total hours

EXAMINATION/EVALUATION CRITERIA

a) Exam type

- ☐ Written
- ☑ Oral
- ☐ Project discussion
- ☐ Other

In case of a written exam, questions refer to

- ☐ Multiple choice answers

- [ ] Open answers
- [ ] Numerical exercises

b) Evaluation pattern