M2 QLMN

Track « Nanodevices and Technologies”

Labworks (6 ECTS)

Lab works: - Microscopy and spectroscopy -Fabrication and Characterization of Nanodevices and Nano-objects	6 ECTS

Core UE (9 UE =27 ECTS)

Microscopy and spectroscopy	3 ECTS
Solid states devices	3 ECTS
Fundamentals of micro and nanofabrication	3 ECTS
Advanced micro and nanofabrication	3 ECTS
Integrated optics and Nanophotonics	3 ECTS
Physics of MEMS	3 ECTS
Micro and nanodevice for biology and diagnostic	3 ECTS
Applied magnetic materials for spintronics and information technologies	3 ECTS
Nanoelectronics and molecular electronics	3 ECTS

Electives UE (2UE = 6 ECTS)

(you have to choose 2 UE among the list below)

Optoelectronics	3 ECTS
Composants semi-conducteurs THz (en français)	3 ECTS
Nanomedicine and nanotoxicology	3 ECTS
Circuit nanoarchitecture and deep learning	3 ECTS
Technological project	3 ECTS
Research project	3 ECTS
Quantum technologies: communication, computing and sensors	3 ECTS
Physics experiments in Quantum Technologies	3 ECTS
Other UE from “Light Matter” or “Condensed matter” track	3 ECTS

Internship: 21 ECTS

18 weeks minimum.

Lab works: microscopy and spectroscopy, Fabrication and Characterization of Nanodevices and Nano-objects

Duration : 60 h
ECTS : 6
Content :

This unit aims at implementing different fabrication and characterization technologies in Nanosciences. It enables to use different facilities of the participating institutions, such as microscopy labs at ISMO, microfluidic platform at ENS Cachan or the clean room of C2N at Université Paris-Saclay. Students follow such practical trainings in small group of 4 students.

Microscopy and spectroscopy

Duration : 30 h examen included
ECTS : 3

Content:

"How was that graph obtained in that article I just read?" "How can I learn more about the sample I just made?" "What are the state-of-the-art techniques used to explore the physical properties of materials today?" This course will help you answer these questions.

The goal of this course is to provide the student with a basic understanding of a set of microscopic, spectroscopic and diffraction techniques, particularly suited for nanoscience and condensed matter physics. Some of the different techniques to be explored include:

--scanning tunneling microscopy (STM)
--atomic force microscopy (AFM)
--transmission electron microscopy (TEM)
--scanning electron microscopy (SEM)
--electron energy loss spectroscopy (EELS)
--X-ray diffraction
--X-ray absorption
--angle-resolved photoemission spectroscopy (ARPES)
--X-ray magnetic circular dichroism (XMCD)

Some of the different questions to be answered include:

--What is the basic physical principle of the technique?
--What information can I gain from my sample thanks to this analysis?
--Which techniques have the best spatial and/or energy resolution? Why should I choose one technique over another?
--What are the advantages and disadvantages of such a technique?

Prerequisites:
Basic knowledge of quantum mechanics and solid state physics

Solid state devices

Duration : 30 h examen included
ECTS : 3

Objectives:
Study the solid states physics of semiconductors materials. The operation principles of the basic components of microelectronics will be described.

Content:
- Introduction, semiconductor materials and crystal lattices
- Vibration properties of a crystal lattice (phonons)
- Electronic structure, energy bands
- Light / matter interaction in semiconductors –
- Energy levels introduced by impurities –
- Density of carriers in a semiconductor
- Transport and phenomena out of equilibrium
- PN junction, Schottky diode
- Bipolar transistors, application to amplification
- Field effect transistors, application to the CMOS logic inverter.

Prerequisites:
Basic knowledge of quantum mechanics, solid state physics, electronics.

Bibliography:

- C. Kittel, Introduction à la physique de l'état solide (ou Wiley en langue anglaise) - P.Y. Yu, M. Cardona, Fundamentals of semiconductors, Springer - S. M. Sze, Physics of semiconductor devices, Wiley - Nanoscience : Nanotechnologies et Nanophysique, edité par C. Dupas, P. Houdy, M. Lahmani, Belin (Springer en langue anglaise).

Fundamentals of micro and nanofabrication

Duration : 30 h examen included
ECTS : 3

Content :

This course presents different fabrication methods of micro and nano-devices using very high technological processes classicely used in Micro-Nanotechnologies. Some of these techniques are directly derived from microelectronics. For others, they concern the manufacture of MEMS, NEMS, micro and nanodevices using nanostructured material.
Outline:
- Introduction
- Material structures
- Growth technics (oxidation, CVD, PVD, MBE, …)
- UV lithography/ Electron beam lithography
- Etching technics
- Specific processes for hybrid systems: transfer technics, advanced micromolding...

Advanced micro and nanofabrication

Duration : 30 h examen included
ECTS : 3

Content :

This teaching unit is about technologies dedicated to the fabrication of tiny objects that have typical sizes from micro to nanometer. Like a complement to the teaching unit « Fundamentals of micro and nanofabrication » dealing with common technologies of micro and nanofabrication, here we will go deeper by studying :

- Novel technologies of nanofabrication by the top-down approach, in other words high resolution lithographies (deep UV lithography, EUV and FIB) and unconventional methods, such soft lithographies and nanoimprinting (soft lithographies, PDMS stamp fabrication, nanoimprint, microfluidic fabrication)

- Molecular Self-assembly onto surfaces by using the bottom-up route by introducing the physic-chemistry of surfaces (auto-organization, molecular grafting and so on..)

- Building of nanostructures by electrografting

- Nanoparticles synthesis to obtain nanooxydes, quantum dots, nanotubes, …

- Heterostructures growth by chemical synthesis (dielectric assemblies, DNA multiplex formation, supramolecular chemistry and molecular motors).

Required knowledge: basics knowledge in physics and materials

Integrated optics and nanophotonics

Duration : 30 h examen included
ECTS : 3

Content :

The objective of this module is to train students in the fields of nanophotonics and its applications through the study of the properties of light propagation in nanostructured environments as well as the benefits from nanostructures for optoelectronics.

Outline:

I- Photonic integrated circuits
Properties of light waves
Guiding, photonic integrated circuits : building blocs
Example of application : silicon photonics

II - Propagation of light in nanostructured environments
Photonic crystals
Plasmonics
Metamaterial

III - Photonics active devices
Nanostructures for optoelectronics (quantum well, quantum dots, nanowires).

IV - Non-linear optics
Integrated non-linear optics, supercontinuum generation, frequency comb generation, application in Silicon photonics

Requirements:
Basic knowledge of electromagnetism and semiconductor device physics.

Physics of MEMS

Duration : 30 h examen included
ECTS : 3

Content :

Overview of MEMS/NEMS/MOEMS: applications, devices, industry and research

Mechanics of MEMS (stress, strain, vibrations)

Transduction and dissipation in MEMS

Reduced-order modeling of multiphysical systems

Resonators and resonant sensors

Finite-element modeling of a pressure sensor

Characterization using optical vibrometry

Characterization using electrical measurements

Requirements - basic knowledge of (classical) physics

Micro and nanodevice for biology and diagnostic

Duration : 30 h examen included
ECTS : 3

Content :
1) Basic biology concept

The cell, DNA, transcription-translation, genetic code, messenger RNA, example to COVID19, recombinant proteins, gene therapy, post-translational modifications, protein structures, antibodies, pathogenic bacteria.

2) Micro and nanodevice for Biology

- Molecular motors and thermodynamics of living organisms : introduction to cell biology, review of important concepts in statistical mechanics, instruments to study molecular motors, examples : F0 / F1, kinesin, myosin, some theoretical aspects.

- Molecular grafting applied to biology : protein structure (landscape theory), molecular interactions, surface chemistry, biological molecules on nanodrawn surfaces.

- Microsystems-biology (counting, capture on chips, cell culture) : microfluidics, hydrodynamics at this scale, microfluidics of drops, concentration of biomolecules or cells using magnetic fluidized beds, detection of bacteria, capture and cell culture (neurons, epithelial cells for vascularization, intestines) on chips, organs (brain, lung, heart) and tumors on chips, cell sorting, microfluidics on paper, microfluidics using textile technologies.

3) Micro and nanodevice for diagnostics

- Nanoparticles for biomedical (theranostics: therapeutic and diagnostic) : magnetic nanoparticles (NP), polymer grafting on NP, physicochemical characterizations of NP, biofunctionalization of NP for the diagnosis of diseases (Alzheimer's), NP and hyperthermia for therapy, principle of theranostics.

- Analysis of the transcriptome by microarray : transcriptome study techniques (high throughput approaches), affymetrix chips, study of molecular signatures of depression.

- Microtechnology for cell biology - electrophoresis : cell-chips, electronic and microfluidic microsized devices for the analysis and treatment of living cells, BioMEMS, cell tissue reconstruction, dielectrophoresis to handle cells, cells electro-permeabilization, cells electro-rotation, towards organ on chip for biomimicking (microvascularization, bile secretion, lung), spheroid vascularization.

4) Pharmacological Lab visit for biology methods (Agilent biochips)

This teaching is a way of bringing concrete elements on biology which most of the students have never heard of after the baccalaureate diploma. It includes the presentation of the transcriptomics and proteomics platform (Trans-Prot) at the Faculty of pharmacy with two examples of studies :

- real-time PCR or quantitative PCR (qPCR) : prevention of contamination by aerosols, RT-qPCR for the detection of SARS-CoV-2;

- the principle of RNA-Transcriptome : extraction and purification of total RNA, control by microfluidic electrophoresis on a chip (Agilent), presentation of the Agilent Bioanalyser 2100, analysis of the transcriptome on microarrays (on expression microarrays) with statistical analysis of the data.

Applied magnetic materials for spintronics and information technologies

Duration : 30 h examen included
ECTS : 3

Objectives : Provide the background to understand nano-scale devices based on magnetic nano-structures. Provide an overview of the latest industrial and scientific challenges in the fields of magnetism and spin electronics such MRAM memories or beyond-CMOS computation.

Content :

- Understanding magnetism and magnetic materials. Exchange energy, magnetic anisotropies
- Magnetism at the nano-scale: ultra-thin magnetic heterostructures for spintronics.
- Characterization technics. Magneto-optical phenomena. Magneto-photonic applications
- Magnetisation dynamics and spin waves. Spin-torque phenomena. Spin transport.
- Growth and nano-fabrication technics, Back-end devices integration with CMOS. Illustrative technological use cases. Challenges in spintronics research.

Nanoelectronics and molecular electronics

Duration : 30 h examen included
ECTS : 3

The objectives are to acquire the basic knowledge of (i) the physics of transport in semiconductor nanodevices through different formalisms of semiclassical and quantum transport description, computational methods, and typical examples of nanodevices, (ii) the physics of transport in molecular electronics from both theoretical and experimental perspectives, including conjugate/functionalized molecules and carbon-based materials, and (iii) the possible use of nanodevices in appropriate circuit architectures through examples from neuromorphic electronics.

Outline:
I. Nanoelectronics
- Introduction to nanoelectronics: Typical examples, the limitations of the semi-classical approach of transport
-. From classical to quantum transport: Transport equations from Boltzmann to Wigner, Landauer equation, Green's functions, Computational methods, Decoherence phenomena
- Nanotransistors: ballistic and quantum effects
- Resonant tunneling effect and applications
- Quantum dots – Coulomb blockade – Single electron devices
II. Molecular electronics
- Introduction to molecular electronics: an overview
- Conjugate and functionalized molecules, molecular transport: Nanoparticles, synthetic molecules, DNA/RNA, transport properties
- Fullerenes, carbon nanotubes, graphene devices: Principles, theory and experiments
III. Nanoarchitectures and Neuromorphic electronics
- Introduction to the integration of nanodevices
- The neuromorphic electronics, Unsupervised learning.

Prérequis :

Basic knowledge of quantum mechanics and of semiconductor device physics.

Bibliographie :

- M. Lundstrom, Fundamentals of Carrier Transport, Cambridge University Press, 2009 - D.K. Ferry, S.M. Goodnick and J. Bird, Transport in Nanostructures, Cambridge University Press, 2009 - D. Querlioz and P. Dollfus, The Wigner Monte Carlo Method for Nanoelectronic Devices: A Particle Description of Quantum Transport and Decoherence, ISTE/Wiley, 2010.

Technological project

Duration : 30 h examen included
ECTS : 3

Objective: Initiation to technological research by integrating a research team on a specific project.

Contents: Integration into a research team on a topic related with a strong technological part. Minimum, 10 half-days distributed along the academic year. Clean room fabrication on one of the subjects, with a strong collaboration with a previously defined mentor. Ideally fabrication will be related with design or characterization of the device.

Examples: electrostatically actuated microbeams, optical polarization rotator, etc.

Evaluation : oral defense

Research project

Duration : 30 h examen included
ECTS : 3

Objective: Initiation to research by integrating a research team on a specific research project.

Contents: Integration into a research team on a topic related to the QLMN master. Minimum 10 half-days distributed along the academic year. Bibliographic research, simulation, or characterization on one of the associated subjects.

Evaluation : oral defense

Optoelectronics

Duration : 30 h examen included
ECTS : 3
Langue d'enseignement : Anglais

I- Optoelectronic components

- Waveguides. The different types of waveguides
- Cavities, Bragg gratings, ring resonators
- Light / matter interaction in a semiconductor:
    - band diagram in sc, density of states, transition rates, Fermi golden rule
    - Absorption, stimulated emission, spontaneous emission (definition, line width, rates and Einstein coefficients) and non-radiative recombination transitions surfaces, Auger effect.
    - Statistics in a system out of balance, Bernard and Durrafoug condition, gain

- Substrates and Materials for Optoelectronics: III-V, Si ..
- Semiconductor laser:
    - laser diodes: homojunction, heterojunction, quantum well
    - laser diode cavity: Fabry-Perot, distributed feedback, DBR, VCSEL
    - Spectral properties: linewidth, Henry factor, NIR,
- Semiconductor amplifier
    - principle, design, bandwidth, noise figure
    - Non-linearity: gain saturation, self / cross phase modulation, FWM,
- Optical Modulators:
    - Physical effects for modulation: electro-optical effect, electro-absorption modulators

II- Inter-sub-band optoelectronics in the mid-infrared photonics

- Inter-sub-band transition, Population inversion in three level system.
- Mid-Infrared: what for, Applications
- Technology: Epitaxial growth, micro-nano fabrication, mounting techniques and associated technologies
- Emitters: Quantum cascade lasers, active region, material system, optical waveguides and cavities
- Detectors: Principles (response, dark current, detectivity...), applications, focus on QWIP.

III- Advanced semiconductor laser dynamics

- Dynamics of carriers, Bloch optical equations, non-linear effects, frequency response, reservoir theory, phase-amplitude coupling.
- non-linear effects photonics: operating class, dynamics, relaxation oscillation, dumping, Lang et Kobayashi equations, Wronskien and Green functions, Jacobien, eigen values, phase space, chaos, bifurcation, injection and optical feedback, gain effect.
- Applications on advanced optoelectronic devices: nanostructured lasers, qcl, mode locking (active/passive), nano-lasers.

Lab class : Simulation of optoelectronic modulators.
Journal club: students lecture on given selection of scientific papers
Final exam : written, 3 hours duration

Textbooks/bibliography (not mandatory):

- A. Yariv, optical electronics in modern communication,
- L. A. Coldren, S. W. Corzine Diode Lasers and Photonic Integrated Circuits, John Wily and sons.
- Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, John Wily and sons.
- J. Faist, Quantum Cascade Lasers, Oxford.
- H-c. Liu F. Capasso, Intersubband Transistions in Quantum Wells Physics and Device Applications, Academic Press.

Nanomedicine and nanotoxicology

Organisation : 30 h sous forme de projet en laboratoire

ECTS : 3

Objective:
Acquire knowledge on the different types of nanoparticles used for diagnosis and therapy.

Contents:
This teaching unit will focus on the contribution of nanoparticles for diagnosis, in particular imaging, therapy, nanotoxicology of nanoparticles will also be addressed.

Prerequisites:
Knowledge of notions of biology acquired by following Micro and nanodevices for biology and diagnosis in the 1st semester of M2 Nano.

Bibliography:
Nanosciences: Volume 3, Nanobiotechnologies and nanobiology (M. Lahmani, P. Boisseau, P. Houdy).

Composants semi-conducteurs Terahertz

Duration : 30 h examen compris
ECTS : 3
Langue : Français

La gamme de fréquence térahertz suscite un intérêt croissant pour des applications comme par exemple la détection sécuritaire, l'analyse biologique non invasive et les réseaux locaux de télécoms ou la spectroscopie moléculaire. Les technologies à base de semi-conducteurs permettent progressivement de rendre plus compacte les sources et les détecteurs THz, par voie électronique (onde submillimétrique) et par voie optique (lointain infrarouge).
Cette UE est l'occasion de présenter le contexte et l'état de l'art des innovations dans le domaine THz. Les différentes solutions technologiques qui visent à combler le « gap » THz seront abordées. Le cours sera l'occasion de passer en revue les sources (et les détecteurs) THz les plus classiques ou les plus originaux. Seront abordés les transistors à effet de champs ultra courts ou bipolaires à hétérojonction III-V et IV-IV les plus performants tout comme les diodes Schottky, les photo-commutateurs THz les diodes à effet tunnel résonant ou les lasers à cascade quantique….

Prérequis :

L'étudiant doit maîtriser les bases de la physique des semi-conducteur, de l'électromagnétiqme et des micro-ondes.

Bibliographie :

[1] « Optoélectronique Térahertz », Jean Louis Coutaz, EDP Sciences, 2011 [2] "Introduction to THz Wave Photonics », X.-C. Zhang, Jingzhou Xu, Springer, 2010 [3] "Plasmonics : Fundamentals ans applications », S. A. Maier, Springer, 2007.

Circuit nanoarchitecture and deep learning

Duration : 30 h examen compris
ECTS : 3

Content :

Objectives :
- Discovering the new electronic devices obtained using nanotechnologies and the associated problems linked to their use.
- Studying a pre-industrial case : integration of new non-volatile memories with CMOS technology.
- Studying a research case : new bio-inspired paradigms for nanodevices exploitation.

Contents :
nanodevices for microelectronics :
- More Moore devices (FinFET and FDSOI) - Beyond CMOS devices(graphene, nanotubes/nanowires?)
- More Than Moore devices (non-volatile memories, energy havesting, sensors)
Focus 1 : embedded non-volatile memories (preindustrial case)
- New resistive memories thanks to nanotechnologies : magnetic (MRAM), phase changing (PCM) and resistive (RRAM, CBRAM)
- Standalone and embedded applications
- choice of project : circuits design for non-volatile processor (recommended to M2 ICS Students) or sizing and design of memory cells (recommended to students of M2 Nanosciences without CMOS design experience) Focus 2 : bioinspired nanoelectronics (research case)
- Biology as a model of extreme energetic efficiency.
- Bioinspired nanoelectronics examples

Practical : simulation of a neuromorphic circuit with memristors.