M2 QLMN- Track « Nanodevices and Technologies”

Labworks (6 ECTS)

		Track	Localisation	Hours
Lab works: - Fabrication and Characterization of Nanodevices and Nano-objects - Microscopy and spectroscopy	6 ECTS	ND	UFR, UVSQ, ENS, IPP, IOGS, CS, Thales	60h TP

Core UE (9 UE =27 ECTS)

		Track*	Localisation	Hours
Fundamentals of Micro and Nanofabrication	3 ECTS	ND	UFR	30h exam included
Advanced micro and nanofabrication	3 ECTS	ND	UFR	30h exam included
Microscopy and spectroscopy	3 ECTS	ND/CM	UFR	30h exam included
Solid states devices	3 ECTS	ND/CM	UFR	30h exam included
Nanoelectronics and molecular electronics	3 ECTS	ND/CM	UFR	30h exam included
Integrated optics and Nanophotonics	3 ECTS	ND/CM	UFR	30h exam included
Applied magnetic materials for spintronics and information technologies	3 ECTS	ND	UFR	30h exam included
Physics of MEMS	3 ECTS	ND	UFR	30h exam included
Micro and nanodevices for biology and diagnostic	3 ECTS	ND	UFR	30h exam included

* ND = Nanodevices and Technologies,

CM = Condensed Matter and its interfaces,

LM = Light and Matter

Electives UE (2UE = 6 ECTS)

Choice of 2 UE among this list

		Track*	Localisation	Hours
Technological project	3 ECTS	ND	UFR, UVSQ, ENS, IPP, IOGS, CS, Thales	30h project
Research project	3 ECTS	ND, CM	UFR, UVSQ, ENS, IPP, IOGS, CS, Thales	30h project
Quantum technologies: communication, computing and sensors	3 ECTS	LM, CM, ND	CS	30h exam included
Recent Experiments in Quantum Information	3 ECTS	LM, CM, ND	IOGS	30h exam included
Optoelectronics	3 ECTS	ND	UFR	30h exam included
Circuit nanoarchitecture and deep learning (NARCHI)	3 ECTS	ND	UFR	30h exam included
Nanomedicine and nanotoxicology	3 ECTS	ND	UFR	30h project
Other UE from "Light Matter" or "Condensed matter" track. Example: Nanoscale energy conversion and harvesting (NECH)	3 ECTS	LM, CM		

* ND = Nanodevices and Technologies,

CM = Condensed Matter and its interfaces,

LM = Light and Matter

Course code:	**Lab works: microscopy and spectroscopy, Fabrication and Characterization of Nanodevices and Nano-objects**	Semester 1

Volume: Period:	60 hours First and second periods	6 ECTS
Language of tuition:	English	

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.

Course code:	**Fundamentals of Micro and Nanofabrication**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers:	E. Dufour-Gergam (UPSaclay) E. Dufour-Gergam (UPSaclay), B. Bartenlian (CNRS), F. Fortuna (CNRS)	
Volume: Period:	27 hours First period	3 ects
Assessment:	Bibliographic synthesis on a technological issue (report + oral defense) + one question on a method seen in class)	
Language of tuition:	English	

Course objectives: Knowledge of the main methods used for the manufacturing of thin films and components

Course prerequisites: M1 level in physics, chemistry, materials and electronics

Syllabus

- Short introduction about micro-nanotechnologies
- Generalities on thin films
- Cinetic gas theory
- Physico-chemical surface characterization
- Surface reconstruction and the different modes of growth
- Different classical method of growth:Evaporation, sputtering, CVD, thermal oxidation, …
- Molecular beam epitaxy
- Classical lithography
- E-beam lithography
- Etching technologies

On completion of the course students should be able to: Propose the growth and etching technics the most adapted to the material or the size of the device/Understand the limitations of the different technologies/Write a bibliographical study

Textbooks/bibliography: Materials Sciences of Thin Films, ISBN 9781493301720/Handbook of Thin Film Deposition, ISBN 9780128123126/FUN-MOOC: comprendre les nanosciences/Understanding Nanosciences

Course code:	**Advanced Micro and nanofabrication**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers :	A Pallandre (UPS) A Pallandre (UPS), A Cattoni (Politecnico Milano), J. Gierak (CNRS), C. Sicard (UPS), J. Gamby (CNRS), I Le Potier (UPS), J.-C Galas (CNRS), B. Bartenlian (CNRS)	
Volume: Period:	27 Hours Second period	3 ects
Assessment:	Written examination+Practical training+Project	
Language of tuition:	English	

Course objectives: technologies for the development of nano-objects/nano-devices:

1-recent micro- and nanofabrication technologies in the top-down approach, i.e. very high-resolution lithography and unconventional methods such as soft lithography and nanoimprinting.

2-strategies to fabricate functional nanodevices, determine the adapted pathway to pretreat, to sort and to detect (micro and nanofluidic devices, electrochemical sensors, optical amplification to analyze fluorescence, epitaxial growth…)

3-molecular self-assembly on surfaces in the bottom-up approach, surface physicochemistry

4-FIB: Focused ion beam

Course prerequisites: Have succeeded at UE « Fundamentals of Micro and Nanofabrication », Fluid Mechanics, Solid State Physics, physicochemistry and Thermodynamics

Syllabus

This teaching unit is to assemble the most common technologies for the fabrication of micro and nanodevices. It corresponds to the second part of the first teaching unit "Fundamentals of Micro and Nanofabrication". We will study:

-Novel technologies of nanofabrication by top-down approaches, sometime including high resolution lithographies (deep UV lithography, EUV and FIB) and also unconventional methods such as soft lithographies and nanoimprint

-Molecular self-assembly and supramolecular structures by using bottom-up routes to adjust the properties of the interfaces and the sensing area

-Building nanostructures with focus ion beam and epitaxial growth

-Nanoparticles synthesis, characterization, functionalization of the surface and applications for diagnosis

-Heterostructures growth of DNA multiplex and molecular motors

On completion of the course students should be able to: define the best pathway to design and fabricate fully functional nanodevices

Textbooks/bibliography:

-All textbooks from these teachings will be available on the server of the university
-"Micro and nanoscale fluid mechanics-Transport in Microfluidic devices" Brian J. Kirby
-"Microfluidics for Pharmaceutical applications" ed. by H. A. Santos, D. Liu and H. Zhang
-"Electroanalytical Methods for biological materials" Ed. by A. Brajter-Toth and J. Q. Chambers

Course code:	**Microscopy, Spectroscopy and Diffraction**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers:	E. Boer-Duchemin (ISMO) E. Boer-Duchemin (ISMO), C. Laulhé (LPS), A. Zobelli (LPS)	
Volume: Period:	27 Hours First period	3 ects
Assessment:	Homework (5%), Final examination (95%)	
Language of instruction:	English	

Course objectives: "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.

Course prerequisites: Basic knowledge of quantum mechanics and solid state physics

Syllabus

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)
- advanced X-ray diffraction techniques at synchrotrons and X-ray free electron lasers
    - resonant diffraction, coherent diffraction, ultrafast time-resolved diffraction
- X-ray and UV absorption spectroscopies:
    - X-ray absorption fine structures (XAFS), X-ray magnetic circular dichroism (XMCD), X-ray emission spectroscopy (XES), angle-resolved photoemission spectroscopy (ARPES)

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?

On completion of the course students should be able to: answer the questions asked in the Course objectives and Syllabus

Textbooks/bibliography: provided at the start of the class

Course code:	**Solid State Devices**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers:	S. Matzen (C2N, UPSaclay) S. Matzen	
Volume: Period:	27 Hours First period	3 ects
Assessment:	Written exam	
Language of instruction:	English	

Course objectives:
- Study the solid states physics of semiconductors materials (crystal lattice, phonons, electronic band structure, transport of carriers).
- Study the operation principles of the basic components of microelectronics devices (pn junction, bipolar transistor, field effect transistor, CMOS logic gates)

Course prerequisites: Basic knowledge of quantum mechanics, solid state physics, electronics

Syllabus:

1. Introduction and crystallographic lattice
2. Vibrational properties of the semiconductor lattice (phonons)
3. Electronic band structure
4. Energy levels induced by impurities
5. Carrier density in a semiconductor
6. Transport and non equilibrium phenomena
7. PN junction
8. Bipolar transistors, application as an amplifier
9. Field effect transistors, application to CMOS logical gate

On completion of the course students should be able to: understand the physics behind the operation of usual semiconducting devices in microelectronics

Textbooks/bibliography:
C. Kittel, Introduction to solid state physics, Wiley
P.Y. Yu, M. Cardona, Fundamentals of semiconductors, Springer
S. M. Sze, Physics of semiconductor devices, Wiley
Nanoscience: Nanotechnologies and Nanophysics, edited by C. Dupas, P. Houdy, M. Lahmani, Springer

Course code:	**Nanoelectronics and molecular electronics**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers:	Jérôme Saint-Martin (C2N, ENS Paris-Saclay) Jérôme Saint-Martin, Arianna Filoramo (CEA/SPEC/LEM), Damien Querlioz (C2N)	
Volume: Period:	27 Hours Second period	3 ects
Assessment:	Written exam	
Language of instruction:	English	

Course objectives: 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.

Course prerequisites: Basic knowledge of quantum mechanics and of semiconductor device physics

Syllabus:

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

On completion of the course students should be able to: answer the questions asked in the Course objectives and Syllabus

Textbooks/bibliography:

- 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.

Course code:	**Integrated optics and Nanophotonics**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers :	D. Morini (C2N, UPSaclay) D. Morini, X. Checoury (C2N, UPSaclay)	
Volume: Period:	27 Hours 1st period	3 ects
Assessment:	Written examination	
Language of tuition:	English	

Course objectives:

The objective of the course is to give a general understanding of today challenges in the domain of integrated optics and nanophotonics. The theorical parts will be accompanied by a discussion of device fabrication and characterization, and the corresponding limitations.

The lectures are made of:

- Classical courses with slides
- Research publication analysis
- Quiz to review parts of the course

Course prerequisites:

- Basics of semiconductor physics (bandstructure, quantum well)

- Basics of electromagnetism: Maxwell equation, wave propagation

Syllabus

The course starts with a refresher about optical waveguide and modal confinement properties in photonic integrated circuits. Building blocks of photonics circuits will then be studied: resonators, interferometers, waveguide coupleurs, etc… Examples will be taken in silicon photonics area, and applications related to optical sensing or telecommunications will be given. The course will follow by a focus on nanoscale devices, will a lecture dedicated to photonic crystals. Then we will move to active devices and we will see how nanostructures (quantum well, quantum dots, etc…) can improve the properties of lasers and modulators. Finally the course ends with the study of current hot topics in research: non linear integrated optics in photonics circuits, and mid-infrared photonics.

On completion of the course students should be able to: to follow a conference or to read a research paper in the area of photonics and to understand the main challenges.

Textbooks/bibliography:
There are many books about integrated optics that can be used.

Course code:	**Applied magnetic materials for spintronics and information technologies**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers :	Yves Dumont (GEMAC), Abdelmadjid Anane (Albert Fert Lab.) Yves Dumont (GEMAC), Abdelmadjid Anane (Albert Fert Lab.)	
Volume: Period:	27 Hours 1st period	3 ects
Assessment:	Written examination	
Language of tuition:	English	

<u>Course objectives:</u>

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.

<u>Course prerequisites</u>: Basic knowledge of solid state physics

<u>Syllabus</u>

- 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
- Magnetization 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

<u>On completion of the course students should be able to</u>: answer the questions asked in the Course objectives and Syllabus

<u>Textbooks/bibliography</u>: provided at the start of the class

Course code:	**Physics of MEMS**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers :	J. Juillard (CentraleSupelec CS) J. Juillard (CS), E. Lefeuvre (UPSay), A. Brenes (UPSay), A. Bosseboeuf (CNRS), L. Rakotondratsimba (CS)	
Volume: Period:	28h30 + 1h30 exam 1st period	3 ects
Assessment:	Written examination + Lab reports	
Language of tuition:	English	

Course objectives:

Knowing the main MEMS sensors/actuators, their applications, and understanding the fundamentals of their fabrication

Understanding the principles of operation and design / fabrication challenges of MEMS inertial sensors (accelerometers, gyroscopes) and MEMS resonant devices (time references, energy harvesters)

Knowing the main physical phenomena at play at the micro-scale both conservative (mechanics, transduction) and dissipative / random (fluidics, thermal phenomena, noise)

Course prerequisites:

Basic knowledge of classical physics.

Syllabus

General introduction 1h – Fundamentals of fabrication (2h)
Inertial sensors 1h30 + Tutorial on inertial sensors 1h30
Mechanics 1h30 + Tutorial on mechanics 1h30
Transduction 1h30 + Tutorial on transduction 1h30
Resonators 3h
Exam 1h30 + Dissipation 1h30
Preparation to Labs (3h)
Lab 1 – Finite element analysis of MEMS resonant sensor (3h)
Lab 2 – Electrical characterization of MEMS resonant sensor (3h)
Lab 3 – Optical characterization of MEMS resonator (3h)

On completion of the course students should be able to:

Make "back of the envelope" calculations for assessing a MEMS device's performance (sensitivity, precision, etc.)

Propose adjustments to a MEMS device's design or fabrication process to improve its performance

Use multiphysics simulation / make measurements to verify these insights

Textbooks/bibliography:

Sensors and MEMS, J. Juillard, CentraleSupélec, 2022
Practical MEMS, V. Kaajakari, Small Gear Publishing, 2009
Micro-Mechanical Transducers - Pressure Sensors, Accelerometers, Gyroscopes, M.H. Bao, Elsevier, 2000

Course code:	**Micro and nanodevices for biology and diagnostic**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers :	J. Gamby (CNRS) C. Smadja (UPSaclay), A. Pallandre (UPSaclay), J. Gamby (CNRS), J.-P Guilloux (UPSaclay), P. Pierobon (INSERM) B. Le Piouf (ENS)	
Volume: Period:	27 Hours First period	3 ects
Assessment:	Written examination	
Language of tuition:	English	

Course objectives:

• to give a broad overview of the complexity of the molecular machinery within the cell

• show how we mimic the functionalities of living cells or interact with them thanks to the contributions of micro nanotechnologies

• review the success story of microfluidics for the progress of microelectronics from MEMS to miniaturized systems (example of lab-on-a-chip or organ-on-a-chip fields.

Course prerequisites: None

Syllabus

1) Basic biology concept

2) Molecular motors and thermodynamics of living organisms

3) Molecular grafting applied to biology

4) Microsystems-biology: theory and application

5) Nanoparticles for biomedical (theranostic: therapeutics and diagnostics with the same system)

6) Transcriptome analysis (microarray)

7) Microtechnology for cell biology – electrophoresis

8) Lab visit: Transcriptomics and Proteomics

On completion of the course students should be able to:

have a general knowledge of the basics of biology concepts related to nanotechnologies.

know and be able to identify technological strategies and methods for concentration and detection of biomolecules and or biomarkers (early diagnostics) and for trapping, immobilizing, analyzing cells or genetic material with microfluidics

Textbooks/bibliography: No

Course code:	**Technological project**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Volume: Period:	30h First period	3 ects
Assessment:	Oral examination	
Language of tuition:	English	

Course objectives: Initiation to technological research by integrating a research team on a specific project

Content

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:
Thin-film visible micro-LED technology for integration of LED devices into flexibles substrates and circuits
Opto-electrical characterization of electricaly-injected, guided-wave polariton lasers
Electrostatically actuated microbeams …

Course code:	**Research project**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Volume: Period:	30h First period	3 ects
Assessment:	Oral examination	
Language of tuition:	English	

Course objectives: Initiation to research by integrating a research team on a specific research project

Content

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.

Examples :
Study of artificial neural networks from spintronics nanodevices
Integration of a single hBN quantum emitter in a photonic waveguide
Numerical simulation of integrated optic devices for sensing …

Course code:	**Quantum technologies: communication, computing and sensors**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers :	Thomas Antoni (CentraleSupelec).	
Volume: Period:	27h Second period	3 ects
Assessment:	Written examination	
Language of tuition:	English	

Course objectives:

To present three main axes identified as both critical and promising by the Commission Europeans as part of the second quantum revolution. Currently in the process of leaving the laboratories general public impact is expected at 5-15 years.

The lessons will be in the form of a case study starting from the physical concepts brought into play to lead to the dimensioning of a system making it possible to address a concrete issue.

Content:

Course in the form of a quantum case study:

Communication and cryptography

Computer and calculation

Sensors

Course code:	**Recent Experiments in Quantum Information**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers :	J.-P. Hermier (UVSQ) J.-P. Hermier (UVSQ), S. Buil (UVSQ), A. Delteil (CNRS)	
Volume: Period:	27 Hours Second period	3 ects
Assessment:		
Language of tuition:	English	

Course objectives:

1. Analyze recent experiments in the field of nanophysics and quantum information.
2. Enlighten and illustrate concepts addressed in other courses through articles, with an emphasis on the techniques used for real-world implementation.
3. Provide an overview of the scientific publishing field.

Various physical systems (NV, T centers, QDs, atomic physics, spin qubits). Various concepts and their physical implementation: coherence, entangled states, fidelity, Bloch sphere, logic gates, quantum sensing, quantum networks. Progressivity: from the simplest to complex protocols.

Methodology:
– short course on the topic of the day
– guided document analysis (general structure of an article, detailed analysis, overview).
– general discussion

Course prerequisites: General concepts in nanophysics, nanophotonics and a first approach in quantum information processing. Key concepts for each paper will be exposed at the beginning of each session.

Syllabus

1. Generation and control of single photons using solid-state emitters and quantum devices
2. Quantum sensing using diamond color centers
3. Spin qubits and spin-photon interfaces for quantum networks and cluster states

On completion of the course students should be able to:

- Analyze a scientific paper in detail.
- Quickly identify the key points of a publication.

Textbooks/bibliography:

Course code:	**Optoelectronics**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Course director: Course teachers:	Adel Bousseksou (C2N-Paris-Saclay) Adel Bousseksou (C2N-Paris-Saclay), Xavier Chécoury (C2N-Paris-Saclay), Frédéric Grillot (Telecom Paris Tech)	
Volume: Period:	27 hours Second period	3 ECTS
Assessment:	Written exam, report and oral presentation	
Language of tuition:	English	

Syllabus

I- Optoelectronic components
- Waveguides. The different types of waveguides
- Cavities, Bragg gratings, ring resonators
- Light / matter interaction in a semiconductor
- Substrates and Materials for Optoelectronics: III-V, Si ..
- Semiconductor laser
- Semiconductor amplifier
- Optical 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.

Textbooks/bibliography:

- 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.

Course code:	**Circuit Nanoarchitecture and Deep Learning (NARCHI)**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers:	Damien Querlioz (C2N) Damien Querlioz (C2N)	
Volume: Period:	27 hours Second period	3 ECTS
Assessment:	Written exam + Project	
Language of tuition:	English	

Course 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.

Course prerequisites: basic knowledge of electronics

Syllabus

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

Focus 2: bioinspired nanoelectronics (research case)
- Biology as a model of extreme energetic efficiency.
- Bioinspired nanoelectronics examples

Project: 12h

Physics-driven project: Adapting the physics of a magnetic nanodevice to brain-inspired applications

Circuits-driven project: Design hybrid-CMOS nanodevice circuits for an AI application

Application-driven project: Study (by computer simulation) how nanodevices can reduce the energy consumption of a small AI

Course code:	**Nanomedicine and nanotoxicology**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	

Volume: Period:	27 hours (lab project) Second period	3 ECTS
Assessment:	Report and oral exam	
Language of tuition:	English	

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

Course prerequisites: notions of biology acquired by following the course "Micro and nanodevices for biology and diagnosis" in the 1st period.

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

Course code:	**Nanoscale energy conversion and harvesting (NECH)**	Semester 1
Contributes to:	M2 Quantum, Light, Materials and Nano Sciences (QLMN)	
Course director: Course teachers:	B. Palpant (CentraleSupelec) E. Deleporte (ENS P-S), J. Saint-Martin (ENS P-S), B. Palpant (CentraleSupélec)	
Volume: Period:	27 hours Second period	3 ECTS
Assessment:	Written examination and homework projects	
Language of tuition:	English	

Course objectives: Energy conversion and management at small scales have become a pivotal point in many new technologies. Miniaturization no longer allows the application of simple scale laws but brings out new properties that must be understood, mastered, and exploited for all these developments. Hence, nanosciences bring new prospects in many fields. This course offers students to approach the energy conversion mechanisms through three emblematic aspects: light into electricity, light into heat, heat into electricity. We will see how conversion and transport phenomena are modified at small scales and how they can be exploited in photovoltaics, thermoelectricity, new biomedical approaches, functional materials. On the one hand, the objective is to link the physical effects at stake in the conversion and the performances of a device, and on the other hand, to apprehend the new improvement strategies allowed thanks to nanotechnologies.

Course prerequisites: Solid-state physics, optics and electromagnetism in matter, thermodynamics (L3 level)

Syllabus

1. **Thermoelectric conversion (7h)**
   - Introduction to thermoelectric conversion (2h)
   - Thermoelectrics at the nanoscale (3h)
   - Current developments in thermoelectrics (2h)

2. **Photovoltaic conversion (8h)**
   - Silicon solar cells: PN junction
   - Dye-sensitized solar cells
   - Hybrid perovskites solar cells
   - Si/Perovskite tandem solar cells

3. **Photothermal conversion (12h)**
   - Bulk noble metals: From electronic to optical properties (2h)
   - Localized plasmon resonance (2h)
   - Converting far-field radiation into optical near-field: principle and applications (1h)
   - Influence of morphological parameters (1.5h)
   - Historical illustrations in the domain of Decorative Arts (0.5h)
   - Light-heat nano-conversion (5h)
   - Melting point depression in metal nano-objects.

On completion of the course students should be able to:
- Understand the mechanisms involved in different kinds of energy conversion at different scales
- Master some fundamentals of optical, thermal and electronic properties in nanostructures
- Conceive nanoscale functional materials for applications in different fields such as biomedicine, photovoltaics, energy harvesting, storage and transport

Textbooks/bibliography:
Documents will be provided by the teachers at the beginning of each part.