PHYS-434

Physics of photonic semiconductor devices

Grandjean Nicolas

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA2, MA4	Opt.
Ing.-phys	MA2, MA4	Opt.
Microtechnics	MA2, MA4	Opt.
Minor in Quantum Science and Engineering	E	Opt.
Photonics minor	E	Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

Language of teaching	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Series of lectures covering the physics of quantum heterostructures (including quantum dots), microcavities and photonic crystal cavities as well as the properties of the main light emitting devices that are light-emitting diodes (LEDs) and laser diodes (LDs).

Content

1. Semiconductor materials for optoelectronics
2. Semiconducting nanostructures, microcavities and photonic crystals

• Quantum wells, superlattices, quantum dots and single photon emitters

• Basic features of microcavities and photonic crystals, Purcell effect, strong-coupling regime

4. Electroluminescence

• Light-emitting diodes, quasi-Fermi levels, emission spectra, efficiency, radiative and nonradiative lifetimes

• Applications: displays and solid-state lighting

5. Laser diodes

• Stimulated emission, material and modal gain, transparency and threshold currents, spectral characteristics, far-field and near-field emission patterns, efficiency, waveguides

• Fabry-Perot laser diodes, distributed feedback and vertical cavity surface emitting laser structures

• Bandgap engineering, quantum well laser diodes, separate confinement heterostructures

• Beyond conventional laser diodes: physics of high-ß nanolasers

Learning Prerequisites

Recommended courses

Semiconductor physics and light-matter interaction (Master)
Quantum physics I and II (Bachelor)
Solid State Physics I and II (Bachelor), Quantum Electrodynamics and Quantum Optics (Master)

Learning Outcomes

By the end of the course, the student must be able to:

- Sketch - and explain the band diagram of quantum engineered heterostructures (quantum wells, superlattices, quantum dots) subjected or not to an electric field
- Explain - the impact of the dimensionality of a semiconductor on excitonic properties
- Assess / Evaluate - the properties of single photon emitters and entangled photon sources made from semiconductor quantum dots
- Use - basic notions of quantum optics to classify light emitters: assessment of the coherence of a light-source via photon statistics (2nd-order correlation measurements)
- Explain - the origin of the enhancement of the spontaneous emission rate via the Purcell effect
- Assess / Evaluate - the performance of dielectric cavities (microcavities and photonic crystal slabs) in terms of quality factor and photon lifetime, Lambertian vs non-Lambertian light emission spectra
- Assess / Evaluate - the performance of LEDs: internal quantum efficiency, extraction efficiency, wall-plug efficiency, luminous efficiency, color rendering index of white light sources
- Link - the radiative and nonradiative carrier lifetimes to microscopic recombination paths in the framework of the ABC model (Shockley-Read-Hall, bimolecular recombination coefficient and Auger term)
- Explain - the operating behavior of light-emitting diodes and laser diodes by relying on rate equations
- Compute - the material gain of bulk semiconductors and quantum wells (notions of transparency and threshold currents, modal gain)
- Assess / Evaluate - the performance of laser diodes: output power, internal quantum efficiency, wall-plug efficiency
- Explain - the origin of the temporal coherence of laser diodes (narrow linewidth) and their modulation frequency (several Gbit/s for telecom applications)
- Distinguish - the main features of edge-emitting laser diodes and vertical cavity surface emitting lasers
- Assess / Evaluate - the performance of cavities (microcavities and photonic crystal slabs) in terms of quality factor and photon lifetime, Lambertian vs non-Lambertian light emission spectra

Transversal skills

- Use a work methodology appropriate to the task.
- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Communicate effectively with professionals from other disciplines.
- Take feedback (critique) and respond in an appropriate manner.
- Summarize an article or a technical report.
- Access and evaluate appropriate sources of information.
- Demonstrate a capacity for creativity.
- Demonstrate the capacity for critical thinking

Teaching methods

Ex cathedra with exercises

Expected student activities

Read the bibliographical ressources in order to fully integrate and properly use the physical concepts seen in the lectures and the exercices

Assessment methods

Oral exam

Supervision

Office hours	Yes
Assistants	Yes
Others	Office hours: appoinments to be arranged by email.

Resources

Bibliography

"Optoelectronics", E. Rosencher & B. Vinter (Cambridge University Press, Cambridge, 2002)
"Wave mechanics applied to semiconductor heterostructures", G. Bastard (Les éditions de physiques, Les Ulis, 1991)
"Optical processes in semiconductors", J. I. Pankove (Dover, New York, 1971)
"Diode lasers and photonic integrated circuits", L. A. Coldren & S. W. Corzine (John Wiley & Sons, Inc., New York, 1995)

Ressources en bibliothèque

- Optical processes in semiconductors / Pankove
- Diode lasers and photonic integrated circuits / Coldren
- Wave mechanics applied to semiconductor heterostructures / Bastard
- Optoelectronics / Rosencher

Moodle Link

- https://go.epfl.ch/PHYS-434