

MICRO-410

Classical and quantum photonic transducers

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

Language of teaching	English
Credits	3
Session	Summer
Semester	Spring
Exam	Oral
Workload	90h
Weeks	14
Hours	3 weekly
Courses	2 weekly
Exercises	1 weekly
Number of positions	

Remark

pas donné en 2024-25

Summary

This course gives an introduction to transducers by both considering fundamental principles and their application in classical and quantum systems. The course builds up on the fundamental concept of coupling of two subsystems as a mean to use one subsystem to extract information about the other.

Content

Topics that are covered include the theory of coupling in the classical and quantum regime, rate equations and physical effects as a mean to establish coupling between two subsystems of choice.

In addition to the basic concepts, a variety of transducers and their applications will be introduced (optical-optical, electro-optic, acousto-optic transducers), in different realizations (photonic integrated circuits, metasurfaces, bulk resonators). Overall, applications in metrology, active photonics, information, and state transfer will be addressed across all frequency ranges: from microwaves, terahertz to the visible and near-infrared regime.

1. Introduction (Overview: History of transducers, classes of transducers, market relevance)
2. Basics of coupled systems in the classical regime and rate equations.
3. Brief introduction to notions in quantum mechanics (in particular the concept of wavefunction, quantum states, Hamiltonian, Schrodinger equation, operators, quantum harmonic oscillator).
4. Important figures of merit: coupling rates, loss rates, cooperativity.
5. Principle of evanescent and Bragg-grating coupling: waveguide modes, supermodes, momentum conservation.
6. Classical and quantum applications: Bragg reflectors and single-photon multiplexers and demultiplexers.
7. Principle of electro-optic coupling: Pockels effect, phase modulation, resonance modulation.
8. Classical and quantum applications: chip-scale electro-optic modulators, free-space modulators, frequency combs, quantum transducers for electric field metrology.
9. Principle of acousto-optical coupling: piezoelectricity, acoustic modes, electromagnetic modes.
10. Classical and quantum applications: acousto-optic deflectors, frequency shifters, quantum transducers for sound.

Keywords

transducers, electro-optic, quantum, classical, interconnects, interfaces, metrology, photonics, resonators, Bragg reflectors, coupling

Learning Prerequisites**Required courses**

This course requires an understanding of introductory physics in wave theory (including complex numbers, Maxwell equations, electromagnetism), photonic systems (dielectric interfaces, waveguides, gratings), nonlinear optics (second order and third order nonlinear susceptibility) as well as to notions in quantum mechanics (wave function, quantized energy levels, quantum state, operators). A brief revision of these

concepts will be provided during the course to accommodate students coming from different backgrounds.

Recommended courses

Electromagnetism,
Photonic systems and technology,
Fundamentals of integrated photonic components,
Nonlinear optics,
Quantum mechanics.

Learning Outcomes

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

- Derive dynamics of transducers from rate equations: phase modulation, resonance shift, side-band creation, amplification
- Explain in detail the figures of merit of transducers and their relevance.
- Assess / Evaluate the limitations of various classes of transducers.
- Explain the working principles of various transducers.
- Reason high physical quantities are relevant to the performance of certain transducers and why: coupling constant, overlap, frequency.
- Sketch generic geometries of different transducers.
- Generalize the concept of transducer.
- Elaborate where certain types of transducers are useful and why.

Transversal skills

- Communicate effectively with professionals from other disciplines.
- Make an oral presentation.

Teaching methods

Script will be made available.

Powerpoint presentation and recent papers from scientific literature will be used to discuss specific transducers.

Derivations will be performed at the blackboard.

Expected student activities

3 hours of class + 1 hour of exercise every week. The exercise classes will treat in detail selected examples of transducers from current literature, together with their theoretical derivation of dynamics and limits. Students will read research results from state-of-the-art literature independently and discuss it in class.

Assessment methods

The course grading is based on a final oral exam which counts for 80% of the grade and two quizzes/assessments during the semester which count for 20% of the grade.

Supervision

Office hours	Yes
Assistants	Yes
Forum	Yes

Resources

Bibliography

Selected chapters from:

Saleh, B. E. A., and M. C. Teich.: Fundamentals of Photonics.

Yariv, A.: Optical Electronics in Modern Communications.

Yariv, A.: Quantum Electronics.

Boyd, B.: Nonlinear optics.

Haus, H.A.: Waves and Fields in optoelectronics.

Hecht, E.: Optics.

Tannoudji, C.: Introduction to quantum mechanics.

Loudon, R.L.: The quantum theory of light.

Ressources en bibliothèque

- [Introduction to quantum mechanics / Tannoudji](#)
- [Waves and Fields in optoelectronics / Haus](#)
- [Optics / Hecht](#)
- [Nonlinear optics / Boyd](#)
- [Quantum Electronics / Yariv](#)
- [Fundamentals of Photonics / Saleh, Teich](#)
- [Optical Electronics in Modern Communications / Yariv](#)
- [The quantum theory of light / Loudon](#)

Moodle Link

- <https://go.epfl.ch/MICRO-410>