MICRO-410

Transducers for classical and quantum applications

Benea-Chelmus Ileana-Cristina

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA1, MA3	Opt.
Microtechnics	MA1, MA3	Opt.
Photonics minor	H	Opt.

Language of teaching	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Courses	2 weekly
Exercises	2 weekly
Number of positions	

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 and light-wave driven transducers), in different realizations (photonic integrated circuits, metasurfaces, bulk resonators and tip-based structures). Overall, applications in metrology, active photonics, information, and state transfer as well as imaging and microscopy 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, Schroedinger 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 application: chip-scale electro-optic modulators, free-space modulators, frequency combs, quantum transducers for electric field metrology.
9. Principle of piezoelectric coupling: piezoelectricity, acoustic modes, electromagnetic modes.
10. Classical and quantum applications: piezoelectric motors and quantum transducers for sound.
11. Principle of lightwave-driven electronics: Coulomb interaction.
12. Classical and quantum applications: terahertz scanning tunneling microscopy.

Keywords

transducers, electro-optic, quantum, classical, interconnects, interfaces, metrology, photonics, resonators, Bragg reflectors, terahertz, 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 accomodate students coming from different backgrounds.

Recommended courses

Electromagnetism,
Photonic systems and technology,
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 which 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.
- Communicate effectively, being understood, including across different languages and cultures.

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

2 hours of class + alternating 2 hours of class and 2 hours of exercise every other 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

- 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

Notes/Handbook

Notes will be provided during the course.

Moodle Link

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