Course guide
230563 - NLO - Non-Linear Optics

Last modified: 11/04/2025

Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 748 - FIS - Department of Physics.

Degree: MASTER'S DEGREE IN PHOTONICS (Syllabus 2013). (Optional subject).

Academic year: 2025 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: CRINA MARIA COJOCARU

Others: Primer quadrimestre:
CRINA MARIA COJOCARU - 10
JOSE FRANCISCO TRULL SILVESTRE - 10

PRIOR SKILLS

25 students

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CE2. Demonstrate the understanding of the peculiarities of the quantum model for light-matter interaction.
CE9. Ability to synthesize and present photonics research results according to the procedures and conventions of scientific presentations in English.
CE4. Demonstrate knowledge of the fundamentals of image formation, propagation of light through different media and Fourier Optics.

Generical:
CG1. Ability to project, design and implement products, processes, services and facilities in some areas of photonics, such as photonic engineering, nanophotonics, quantum optics, telecommunications and biophotonics.

Transversal:
1. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

2. ENTREPRENEURSHIP AND INNOVATION: Being aware of and understanding how companies are organised and the principles that govern their activity, and being able to understand employment regulations and the relationships between planning, industrial and commercial strategies, quality and profit.

3. FOREIGN LANGUAGE: Achieving a level of spoken and written proficiency in a foreign language, preferably English, that meets the needs of the profession and the labour market.

4. TEAMWORK: Being able to work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.

Basic:
CB6. Possess and understand knowledge that provides a basis or opportunity to be original in the development and/or application of ideas, often in a research context
CB7. Students should know how to apply the knowledge acquired and their problem-solving ability in new or little-known environments within broader (or multidisciplinary) contexts related to their area of ¿¿study.
CB10. Students should possess the learning skills that allow them to continue studying in a way that will be largely self-directed or autonomous.
CB8. Students should be able to integrate knowledge and face the complexity of formulating judgments based on information that, being incomplete or limited, includes reflections on the social and ethical responsibilities linked to the application of their knowledge and judgment.

TEACHING METHODOLOGY

- Lectures
- Problems
- Applications

LEARNING OBJECTIVES OF THE SUBJECT

This course will render an overview on the basic principles of second and third order nonlinear effects in optics and their most important applications, providing a sound background in this field. Starting from the basic equations governing different nonlinear processes, detailed solutions and approximations will be discussed. We will then extend to more complex systems, interactions and applications of nonlinear effects. The last part of the course aims to provide an overview in recent advances and state of the art of the field.

STUDY LOAD

Type	Hours	Percentage
Hours large group	24,0	32.00
Self study	51,0	68.00

Total learning time: 75 h

CONTENTS

1. Maxwell equations and polarization

Description:
1.1 Maxwell equations
1.2 Polarization and susceptibility: Lorentz model for bounded charges, index of refraction, hydrodynamic model for free electrons.

Full-or-part-time: 1h
Theory classes: 1h

2. Optics of Crystals

Description:
2.1 Maxwell equations and material relations in birrefringent crystals
2.2 Normal modes of propagation in crystals
2.3 Propagation of ordinary and extraordinary waves in crystals

Full-or-part-time: 1h
Theory classes: 1h

3. Nonlinear polarization

Description:
3.1 Nonlinear polarization
3.2 Classical derivation of nonlinear susceptibility: second and third order interactions
3.3 Nonlinear susceptibility symmetries
3.4 Effective nonlinear coefficient

Full-or-part-time: 1h
Theory classes: 1h

4. Nonlinear wave equations

Description:
4.1 Wave equations for nonlinear optics
4.2 Coupled mode theory for plane waves: quasi-monochromatic plane wave approximation, separation on frequencies approximation, slowly-varying amplitude approximation
4.3 Energy and phase relations in nonlinear optics

Full-or-part-time: 1h
Theory classes: 1h

5. Second order nonlinear effects (plane wave approximation)

Description:
5.1 General description of the second order processes
5.2 Coupled-wave equations for sum-frequency generation: coupled-amplitude equations, solution for non-depleted input waves, phase-matching considerations, Manly-Rowe relations, the case of one depleted input beam.
5.3. Second harmonic generation: phase matching techniques, different materials for SHG, applications
5.4 Difference-frequency generation and parametric amplification (OPA);
5.5 Optical parametric oscillations (OPO)

Full-or-part-time: 8h
Theory classes: 8h

6 Third order nonlinear effects (plane wave approximation)

Description:
6.1 Third harmonic generation and optical Kerr effect
6.2 Self and cross-phase modulation
6.3 Four-wave mixing: coupled wave theory for three wave mixing and third harmonic generation
6.4 Optical phase conjugation

Full-or-part-time: 4h
Theory classes: 4h

7. Nonlinear optics with beams and pulses

Description:
7.1 Basic equations for beams and pulses
7.2 Nonlinear interactions in Kerr media: self-phase modulation, self-focusing, filamentation and optical solitons
7.3 Parametric processes in quadratic media
7.4 Short pulse characterization

Full-or-part-time: 3h
Theory classes: 3h

8. Nonlinear light scattering and absorption

Description:
8.1 Light scattering
8.2 Brillouin scattering
8.3 Raman scattering
8.4 Two-photon absorption

Full-or-part-time: 2h
Theory classes: 2h

GRADING SYSTEM

- Written exam (60%) (exam week)
- Homework and deliverables: exercises and problem collection (40%) (to be delivered during the course)

BIBLIOGRAPHY

Basic:
- Boyd, R. Nonlinear optics [on line]. 3rd. Boston: Academic Press, 2008 [Consultation: 27/05/2016]. Available on: http://www.sciencedirect.com/science/book/9780123694706. ISBN 9780123694706.
- Yariv, A. Quantum electronics. 3rd. John Wiley and Sons, 1989. ISBN 9780471609971.
- Akhmanov, S. A; Nikitin, S. Y. Physical optics. Oxford University Press, 1997. ISBN 0198517955.
- Saleh, B.E.A.; Teich, M.C. Fundamentals of photonics. 3rd ed. Hoboken: John Wiley & Sons, 2019. ISBN 9781119506874.

Complementary:
- Shen, Y.R. The Principles of nonlinear optics. New York: John Wiley, 1984. ISBN 0471889989.
- Moloney, J.V.; Newell, A.C. Nonlinear optics. Boulder: Westview Press, 2004. ISBN 0813341183.

RESOURCES

Other resources:
Specific notes and guidelines on the virtual course ATENEA: slides, problem collection, scientific articles, etc.