Nonlinear Optics

Sylvie Roke

BM4112
31911
sylvie.roke@epfl.ch

Version 10.0

Course year, 2024-2025

Autumn semester

Teaching Assistants:

Zhi Li, BM4115

Nelson Correia, BM4115

Why this course?

Nonlinear optics is a sub-branch of optics that describes the optical response of materials when the interaction of the optical field results in an optical field whose amplitude depends nonlinearly on the amplitude of the incoming field. Such processes occur when the field strength of the incoming light is of the same order of magnitude as the electrical field that exists between the electrons and the nuclei of a material. Nonlinear optical phenomena have been predicted since the 1930's and were observed experimentally when laser where used as light sources in the early 1960's. With the technological advancements over the last decades resulting in lasers that can produce intense fields with ultrashort pulse lengths and tunable wavelengths, nonlinear optical phenomena have become commonplace in optical devices and materials.

Examples of nonlinear optical processes are:

- Second harmonic generation (SHG), or frequency doubling. Here, light with the double frequency (half the wavelength) of a fundamental beam is generated by a material.
- Third harmonic generation (THG). Here, light with the triple frequency of a fundamental beam is generated by a material.
- High harmonic generation (HHG), generation of light with multifold frequencies much greater than the fundamental (typically 100 to 1000 times greater).
- Sum frequency generation (SFG), generation of light with a frequency that is the sum of two incoming frequencies (SHG is a special case of this).
- Difference frequency generation (DFG), generation of light with a frequency that is the difference between two incoming frequencies.
- Optical parametric amplification (OPA), amplification of a signal input in the presence of a higher-frequency pump wave, at the same time generating an idler wave (can be considered as DFG)
- Optical parametric oscillation (OPO), generation of a signal and idler wave using a parametric amplifier in a resonator (with no signal input).
- Optical parametric generation (OPG), like parametric oscillation but without a resonator, using a very high gain instead.
- Optical rectification (OR), generation of quasi-static electric fields, by a DFG process of the a beam with itself.
- Optical Kerr effect, intensity dependent refractive index.
- Self-focusing, an effect due to the Optical Kerr effect (and possibly higher order nonlinearities) caused by the spatial variation in the intensity creating a spatial variation in the refractive index
- Stimulated Brillouin scattering, interaction of photons with acoustic phonons
- Hyper Rayleigh Scattering
- Stimulated Raman scattering

The processes can be used in devices such as spectrometers, and microscopes for e.g. materials and life science applications, or in switches (Pockels cel, Kerr lens mode locking) and fibers.

- Pockels effect, the refractive index is affected by a static electric field; used in electro-optic modulators;
- Acousto-optics, the refractive index is affected by acoustic waves (ultrasound); used in acousto-optic modulators.
- Kerr-lens modelocking (KLM), the use of self-focusing as a mechanism to mode lock laser.

During the course you will become familiar with a selection of the above topics and processes. The course format ensures that on top of that you will learn about presenting and explaining material as well deducing and delivering teaching material.

Course Material

R. W. Boyd, Nonlinear Optics, Third Edition

Other books:
Paul Butcher & David Cotter, The Elements of Nonlinear Optics
Y. Ron Shen, The Principles of Nonlinear Optics

The following table shows a layout of the course material:

Topics	Material
1. Introduction / overview of nonlinear optical phenomena	Chapter 1
2. Wave description of nonlinear optical processes	Chapter 2
3. The intensity dependence of the refractive index	Chapter 4
4. Optically induced damage	Chapter 12
5. Electrooptic and photorefractive effects	Chapter 11.1 – 11.3
6. Spontaneous and stimulated light scattering processes	Chapter 8 / 9.1 /10

Precise sections that are covered will be given during the course.

Examination and grading

The grade is based on the answers given to an exam at the end of the course. Most likely the exam will be an open book exam.

There will be an exam before the spring semester. During the autumn semester there will be an opportunity to test your knowledge: In the middle of the semester an intermediate test will be offered. The test will be conducted exactly like an exam and will be graded. The score of this test can be used to replace the question you have scored worst on during the exam. The participation to this mid-term test is voluntary; students who do not take the midterm test can obtain the maximum grade for the class (6) based on the final exam only.

Background knowledge

During the course we will assume a basic understanding of physics and optics. As a work of reference one can use:

Grant R. Fowles, Introduction of Modern Optics

Communication:

There is a moodle for this course: https://moodle.epfl.ch/course/view.php?id=16006. On the moodle the necessary course material and instructions can be found.