Course type: Graduate/senior undergrad

Course description: Quantum electronics, the study of light and matter interaction, has become the cornerstone in many areas of optical science and technology. The course will start with reviewing the principle of lasers followed by introducing the generalized nonlinear wave equations. This course will cover typical nonlinear effects and their applications in telecommunication, ultrafast laser, quantum computing/information and chemical/bio spectroscopy.

Course Objectives:
• Provide a thorough foundation of nonlinear optics origin and the approaches to solve nonlinear Maxwell equations, including both second order and third order nonlinear effect.
• Provide students with an understanding of nonlinear optics effect and phase matching in optical fibers, chip-based waveguide semiconductor device and microresonators.
• Provide detailed discuss of several significant nonlinear devices including frequency doubler, parametric oscillator, electro-optics modulator and mode-locked femtosecond lasers.
• Provide an introduction to on-going nonlinear research, including quantum information/computing, nonlinear spectroscopy, optical frequency comb and etc.

Prerequisites
ECE 3209-Electromagnetic field

Course time: Twice a week (1.5 hours each time).

Textbook (recommend)
Nonlinear optics, by Robert W. Boyd
Nonlinear fiber optics, by Govind P. Agrawal.

Examinations and Grading:
Homework (40%), midterm (30%) and Final presentation (30%).

Outline

1) Brief introduction to nonlinear optics.
   a) Nonlinear effects in physics and optics.
   b) Review of Maxwell equations.
   c) Solve Maxwell wave equation.
   d) Linear susceptibility in Maxwell equations.

2) Nonlinear susceptibility
   a) Descriptions of Nonlinear Optical Processes.
   b) Formal Definition of the Nonlinear Susceptibility.
   c) Nonlinear Susceptibility of a Classical harmonic Oscillator

d) Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility

3) Wave equations of nonlinear interaction
   a) The Wave Equation for Nonlinear Optical Media.
   b) The coupled-wave equations.
   c) Phase matching.
   d) Quasi-phase matching.
   e) second-harmonic and sum/difference-frequency generation.
   f) Parametric oscillation.
   g) Pockels/electro-optics effect.

4) Intensity-Dependent Refractive Index
   a) Third-order nonlinear susceptibility.
   b) Kerr nonlinearity and self/cross phase modulation.
   c) Optical phase conjugation.
   d) Optical Bistability and Optical Switching.
   e) Self-Focusing of Light and saturated absorption.
   f) Brillouin and Raman Scattering.

5) Wave equations in fiber, waveguide and resonator
   a) Linear propagation equation in fiber and waveguide.
   b) Chromatic dispersion.
   c) Nonlinear term in wave equations.
   d) Pulse propagation and temporal solitons.
   f) Nonlinear wave equation in resonator.

6) Nonlinear optics device and applications
   a) Saturated absorption revisits (Kerr lens and semiconductor).
   b) Ultra-fast mode locked lasers.
   c) Supercontinuum generation and frequency comb.
   c) Nonlinear optics for quantum information/computation.
   d) Nonlinear spectroscopy for chemical/bio sensing and imaging.