ECE 574 Nanophotonics (Spring 2015)

Course Website:  
http://wasserman.ece.illinois.edu/S15_574.htm

Instructor:  
Dan Wasserman  
2258 Micro and Nanotechnology Lab  
x3-9872  
dwass@illinois.edu  
Office Hours: Thursday 1-2pm, or by appointment (2258 MNTL)

Teaching Assistant:  
William Streyer  
streyer2@illinois.edu  
Office Hours: Wednesday 4-5 pm, ECEB 3003

Description:  The field of Nanophotonics, most literally, is the fusion between nanotechnology and photonics, and can be described as encompassing the set of devices, structures, and materials where the electronic and optical properties of a system begin to diverge strongly from the bulk properties, and depend strongly on both size and geometry. Nanophotonics is an emerging contemporary area of research with a wide range of new applications. Understanding the optical properties of nanometer scale structures of semiconductors, metals, and composites will be crucial for future optoelectronic devices and technology designed to couple with, complement, or possibly even replace, present and future nano-electronic devices. Separated from any electronic components, nano-scale or subwavelength photonic structures offer new possibilities for sensing, imaging, waveguiding, and many other applications. This course will examine the quantum mechanical interaction between light and semiconductors, metals, and composites; including plasmonics, cavity electrodynamics, polaritons, cavity condensation, sub-wavelength structures, metamaterials, plasmonics and applications. Presentations by students are included to develop oral communication skills as well as to incorporate leading-edge research into the course.

Prerequisites:  ECE455 and PHY486 or equivalent course in quantum mechanics

Text:  
Class notes and journal papers

Supplementary:  
The Physics of Semiconductors, M. Grundmann (Springer 2006)  
Semiconductor Optics, C. Klingshirn (Springer, 2005)  
Introduction to Nanophotonics, S. V. Gaponenko (Cambridge 2010)  
Optical Processes in Semiconductors, J. Pankove (Dover 1971)  
“Physics of Light and Optics” http://optics.byu.edu/textbook.aspx

Grading:  
Homework/Attend.  30%  Due one week after assigned  
Midterm Exam  15%  In class March 11th  
Quizzes (5)  10%  In class, ~10 minutes each  
Final Project  25%  Presentation & questions  
Final Exam  20%  TBD

Presentation:  Each student will give an in-class presentation focused on a cutting edge research topic in nanophotonics or a numerical program (developed by the student) used for advanced simulation or calculation of a nanophotonic phenomenon. Presentations will be 15 minutes long, including 2-3 minutes for questions following the presentation. Presentations will be graded on technical content, oral communication and visual presentation skills, as well as the presenter’s ability to answer questions and discuss the presentation topic and its place in the larger context of nanophotonics.
Course Administration

Lectures: Lecture will consist of ppt slides as well as blackboard/ppt annotations. The basic ppt slides will be posted online at the course website, but for detailed notes or annotations to the slides, students are expected to attend lecture. Attendance will not be formally taken, but in a small class such as this, participation and attendance throughout the semester will be noted and can be used, at the instructor’s discretion, to marginally improve a student’s score (in the 2-3% range). If a student misses a lecture for any reason, they will be expected to use the on-line notes to bring themselves up to speed. They may also ask classmates to share notes taken in lecture.

Homework: Homework is due at the beginning of class, one week after it is assigned. All homework will be posted on the course website and their due dates listed on the website. No late homework will be accepted. In extreme circumstances, with a letter from Health Services and/or the Emergency Dean, a homework can be dropped, but only with course instructor approval.

Homework will primarily be a mix of analytical, conceptual, and numerical problems. Students may work in groups to understand the homework problems and to work out approaches to solving them. However, the homework turned in should represent the individual student’s own work, and cannot be copied from another student. Copied/reproduced homework constitutes a violation of the honor code, and will be treated as such.

Analytical Problems: Solutions must be legible, and must indicate the approach taken to solve the problem, as well as each step used in the approach. It is the students’ responsibility to make clear to the grader how the problem was solved and what the solution to the problem is. Illegible, or poorly annotated/described solutions will receive no credit. For clearly presented, well thought-out solutions, partial credit will be granted even if the solution is not correct.

Conceptual Problems: Conceptual problems will ask for the student to explain in words and/or equations, a physical phenomenon or concept from the course. Answers are expected to be in clear and concise English, and free from grammatical and typographical errors. Students are expected to use their own words, but are free to cite from the literature, as long as all references are clearly noted. Students may also be asked to respond to questions regarding state of the art nanophotonics concepts or research, which will require use of the literature.

Numerical problems: Numerical problems are to be performed in Matlab. You should have free access to Matlab through the University webstore (http://webstore.illinois.edu/home/). For those of you not familiar with Matlab, do not despair! Initial numerical problems will be mathematically and conceptually simply and will give you a chance to understand the basic operation and functioning of the program. Later numerical problems will be more complex, both conceptually and mathematically. All numerical homework programs will be turned in electronically to both the TA and the course instructor before class starts on the HW due-date. Outputs (plots, graphs, tables, etc.) should be clearly labeled and turned with the written HW. A basic example Matlab program is available on the website. This program calculates the normal incidence reflection from a dielectric surface as a function of wavelength and plots the results. Your program files should be named using the problem name and your initials (i.e. “Reflection_DW.m”). The first two lines of the script should have the HW, problem name, your full name, your University ID number, and a brief description of the program, as shown in the example script. All numerical homework problems should be clearly and concisely annotated.

Quizzes: There will be approximately five 10 minute quizzes over the course of the semester. These will be given in class and will consist of brief and straightforward questions on topics covered in recent lectures and homeworks. Quizzes will not be computationally or analytically
challenging, but instead will be designed to test your conceptual understanding of the material, and more importantly, to give me feedback as to how well the class is retaining the course material.

**Exams:** There will be two exams for this course, one midterm and one final exam. The midterm exam will be in class and will cover all material in the course up to the exam date. Make-up exams will not be given.

**Course Topical Outline.**

A full course calendar is available on the ECE 574 course website.

**Foundation**

I. Light
   a. Ray Optics
   b. Wave Optics
   c. Electromagnetics, Maxwell’s Equations
   d. Photon Optics

II. Matter
   a. Basic description of atoms and crystals, free and bound electrons
   b. Semiconductors, metals, and insulators: band structure
      i. Kronig-Penney Model
      ii. Band diagrams
      iii. Effective mass

III. Electrons, Photons
   a. Comparison, dispersion
   b. Confinement, density of states, localization

IV. Phonons
   a. Classical oscillator
   b. 1-atom chain
   c. diatomic atom chain
   d. Quantum harmonic oscillator
   e. Phonon Statistics

V. Light-Matter Interaction
   a. Bulk Optical Properties of Matter
      i. Refractive index/optical permittivity
      ii. Reflection/refraction
      iii. Kramers-Kronig relations
   b. Absorption
      i. Interband direct transitions
      ii. Semiclassical treatment
      iii. Franz-Keldysh effect
      iv. Indirect transitions
      v. Impurity absorption
      vi. Excitons and Biexcitons
   c. Emission
      i. Band-to-band recombination
      ii. Auger recombination
      iii. Probability amplitude
iv. Rabi oscillations  
v. Second quantization  
vi. Spontaneous emission  
d. Non-linear Effects  
i. Raman scattering (quantum/classical)  
ii. SHG, SFG, DFG, 2PA  

VI. Optical/Electronic Dielectric Confinement  
a. Quantum wells  
b. Dielectric slabs, Nanomembranes  

Midterm Exam (In Class)  
c. Nanowires, whispering gallery  
d. Quantum dots (self-assembled and colloidal)  
e. Mie scattering  

VII. Resonant scattering confinement  
a. Bragg-mirrors  
b. Photonic Crystals  
c. Photonic crystal defects  

VIII. Sub-wavelength Optics  
a. Gratings (reflection and diffraction)  
b. The diffraction limit  
c. Beating the diffraction limit  

IX. Metallic Optics  
a. Propagating Surface Plasmons  
i. Plasmonic waveguides  
ii. Nano-apertures, aperture arrays  
b. Perfect electrical conductors waveguides  
c. Localized surface plasmons  
i. nano- spheres, -rods, -shells  
ii. Surface enhanced Raman scattering  

X. Metamaterials  
a. Negative index  
b. Optical transformations  

XI. Nanoscale light matter interaction  
a. Purcell Effect  
b. Fano Effect  
c. Nano-emitters and detectors  
d. Nano-scale energy transfer  

XII. In-Class presentations  

Final Exam