University of Illinois at Urbana-Champaign
Department of Electrical and Computer Engineering
ECE 598 YZ/ ECE 598 YZO – Fundamentals of light-matter interactions (4 credits)
Course Syllabus

Course Description:
This course will provide an overview of how light interacts with materials. Although such interaction is most rigorously described using quantum mechanics, the approach used here is mainly classical. We will first introduce classical dipole oscillators coupled with Maxwell's equations. We will study the linear optical properties (dielectric function, susceptibility, refraction, dispersion and absorption) of gases, liquids and solids, including metals, semiconductors and dielectrics. We will also study dispersion relations, which allow us to completely describe the dielectric function of a material by only measuring the full spectrum of a single property. We will consider how quantum mechanics modifies our picture of the optical properties of materials. The effect of magnetic polarization will be considered, as we look at optical activity and Faraday rotation. In addition, we will study nonlinear contributions to the polarization, and understands how this leads to the generation of new frequencies and to irradiance-dependent refractive index and absorption. Finally, we will introduce the unique interaction of light with artificial materials such as metamaterials.

Prerequisites: ECE 350, one of ECE 460 or PHYS 402, or consent of the instructor.

Requirements: ECE major, graduate level course.

Professors: Dr. Yang Zhao
Office Location:
Holonyak Micro and Nanotechnology Lab, Rm 1106
208 N. Wright Street
Urbana, IL 61801
Office Hours: TBD
Email: yzhaoui@illinois.edu

Teaching Assistants: Vary by semesters

Lecture: This class will meet for 2 hours 50 minutes per week for 16 weeks
Proposed days (Tuesday/Thursday, the course calendar is based on these days). Specific days/times: TR 3:30-4:50.

Course website: http://bionanophotonics.ece.illinois.edu/ece-598yz

Synchronized Zoom Link:
https://illinois.zoom.us/j/99868424142?pwd=VmRxWk1heGlkWlNLZmJGOXh5WUE4UT09
Meeting ID: 998 6842 4142
Password: LMI20Fall

Course Objectives:
This class aims to provide a rigorous introduction to what happens to the material medium in its interaction with light through classical optics approach. To gain a broad understanding of the optical properties of materials, we will aim to survey physical descriptions of both linear and non-linear optical processes in several classes of materials including natural materials such as dielectric materials, semiconductors, and metals, as well as recently developed artificial materials such as metamaterials.

List of Topics:
Three main topics of light-matter interaction will be covered in this course.

Detailed Description and Outline:
I. Linear Interaction of EM Waves with Matter

- Maxwell's equations: Microscopic, macroscopic, susceptibility & polarization.
- Dipole radiation: vector & scalar potential; electric & magnetic dipoles; dipole radiation.
- Basic optical properties of materials: Lorentz oscillators; absorption spectra, refractive index dispersion, Kramers-Kroenig relations; Drude model; Sum rules; optical properties of semiconductors and dielectrics; sellmeier formulae; local fields.
- Optical properties of molecules: Dipole-active modes, vibrations, rotations; rotations in dense media.
- Macroscopic optical properties: Inhomogeneous broadening and orientation averages.
- Effects of induced dipoles on the electromagnetic waves: dilute media, "sheet of dipoles", absorption and refraction.
- Optical activity and Faraday rotation.

II. Nonlinear Interaction of EM Waves with Matter

- Introduction to nonlinear optics and nonlinear susceptibility, classical anharmonic oscillator
- Second order phenomena including three wave mixing and sum frequency generation, $\chi^{(2)}$ materials
- Third order phenomena including Kerr nonlinear absorption and refraction.

- Molecular nonlinear optics

III. Interaction of EM Wave with Small Particles and Metamaterials
- Light scattering by small particles
- Surface plasmon polaritons
- Excitations of surface plasmons and optical antenna.
- Localized surface plasmon resonances and surface plasmon propagation. Applications in light concentration, sensing, and radiative decay engineering.
- Homogenization theory
- High-index and negative-index metamaterials, superlens
- Epsilon-Near-Zero (ENZ) and Mu-Near-Zero (MNZ) metamaterials
- Metasurfaces
- Metamaterial and metasurface applications in devices
- Nearfield optics and nanoscopic imaging

Textbook:
There is no required textbooks for this course. Any required readings for a lecture will be posted on the course website as a pdf file. Students who desire supplementary reading for further detail can use the following textbook:

I. Fundamentals, Maxwell’s equation, optics, dispersion, etc.:
- “Maxwell Equations”, J. A. Kong, (EMW Publication, 2002); or “A student's guide to Maxwell's equations”, Daniel A. Fleisch, (Cambridge University Press, 2008). Hard copies available at UIUC library through I-Share.
- “Fundamentals of Photonics”, B.E.A. Saleh, M.C. Teich (John Wiley& Sons, 2007). Hard copies available at UIUC library.
- “Waves and fields in inhomogeneous media”, W. C. Chew, (New York, IEEE Press), Ebook available from UIUC library website.
- “Optical waves in crystals: propagation and control of laser radiation.” A. Yariv and P. Yeh, (John Wiley and Sons, 2003). Hard copies available at UIUC library.
- “Physics of optoelectronic devices”, Chuang, S. L., (Wiley, 1995). Hard copies available at UIUC library; or “Optical Properties of Solids”, F. Wooten, (Academic Press). Ebook available from UIUC library website.
- “Nonlinear Optics”, R. Boyd, (Academic Pres, 2008). Ebook available from UIUC library website.

II. Optical wave interactions with metals, surface plasmon polaritons:
- “Absorption and Scattering of Light by Small Particles”, C. Bohren and D. Huffman (Wiley, 1983). Ebook available at UIUC library website.
- “Optical Materials”, J Simmons and K S. Potter (Academic Press). Ebook

available at UIUC library website.

- "Surface plasmons on smooth and rough surfaces and on gratings", Raether (Springer-Verlag, New York, 1986). Ebook available at UIUC library website.
- "Plasmonics: Fundamentals and Applications", S. Maier (Springer Verlag, New York 2007). Ebook available from UIUC library website.
- "Near-field optics and surface plasmon polaritons," Edited by: Satoshi Kawata (2001). Ebook available UIUC library website.

Exams:
There will be one mid-term exam (take home). The exam will account for 20% of the final grade. There will be no final exam. No use of cell phones, PDAs, digital music players or other personal electronics is allowed in the lecture room during exams. Use of electronic devices during an exam may be construed as a violation of the student code of conduct.

Final Report/Presentation:
There will be a final report due on the last day of class. The report combined with in-class presentation account for 32% of the final grade (the equivalent of one normal final exam). The report will involve writing a review paper on a subject of the students' choice. Several potential subjects will be provided by the instructor, but students can choose an original topic as well with the instructor's approval. The final three lecture periods of the course will be reserved for in-class student presentation. A one-page topic proposal (worth 2% grade included in the final report grade) will be due two weeks after the midterm (**on Oct 22**) to ensure that all students will have an individual topic for the project.

Homework:
There will be 6 homework assignments, accounting for 48% of the final grade.

Contesting Grades:
If you feel that your assignment or exam has been graded inappropriately, you are welcome to contest grades via a written statement within one week of receiving the graded assignment. To contest a grade, you must submit a written statement (preferably via email) of what you believe was graded incorrectly and why the grade should be altered. No oral contesting of grades will be considered, nor will we consider any contest of grades submitted after one week. Note, that contesting a grade means the item in question will be completely regraded, which may result in a lower grade overall.

Final Grade Breakdown:

Exam 1	20 %
Final Report (including proposal 2%)	17 %
Final presentation	15 %
In class/zoom participation	5 %
Homework 1	8 %
Homework 2	8 %
Homework 3	8 %
Homework 4	8 %
Homework 5	8 %
Homework 6	8 %
Total	**105 %**

Course Grading Philosophy:
I. I use the following grade system. Depending on the distribution of points at the end of the semester I may drop the cut off points slightly (e.g., 85% might become the A cut off) but I will not raise the cut-offs; I will not "curve" the exams or assignments.

A+	>= 95%
A	90% to <95%
A-	85% to <90%
B+	80% to <85%
B	75% to <80%
B-	70% to <75%
C+	67% to <70%
C	63% to <67%
C-	60% to <63%
D+	57% to <60%
D	53% to <57%
D-	50% to <53%
F	<50%

II. ~~I will use the iClicker to evaluate student comprehension during lectures and in class discussion. iClicker responses will be used to assess attendance and participation that account for 5% of the bonus grade.~~ To get the 5% participation*, the student will need to attend for at least 90% of the lectures**.
*Participation of class will account for 5% of the final grade. **Note:** if you are located in a different time zone and cannot log in for the lecture at the designated time, please watch the recording **within 24 hours**, which will count for your 'in-class' participation.

**Students are encouraged to contact the instructor directly to discuss their absence due to illness/medical conditions.

Course Calendar (Fall 2020):

Week	Date	Topic	Unit	Comments
1	Aug 25	Introduction and Maxwell's equations	I	
	Aug 27	Wave propagation	I	HW 1 posted
2	Sept 1	Kramers-Kronig relations	I	
	Sept 3	Lorentz model	I	HW 1 due, HW 2 posted
3	Sept 8	Microscopic and macroscopic properties	I	
	Sept 10	Dipole radiation (1)	I	HW 2 due, HW3 posted
4	Sept 15	Dipole radiation (2)	I	
	Sept 17	Drude model	I	HW3 due, HW 4 posted This lecture will be a recording, no sync lectures
5	Sept 22	Molecular reorientation	I	
	Sept 24	Optical activity and magneto-optics	I	HW 4 due, HW 5 posted
6	Sept 29	Vibrations in molecules and solids (1)	I	
	Oct 1	Vibrations in molecules and solids (2)	I	HW 5 due, HW 6 posted
7	Oct 6	Introduction to nonlinear optics, nonlinear susceptibility	II	
	Oct 8	Second order phenomena	II	Take home mid-

				term exam HW 6 due
8	Oct 13	Third order phenomena	II	
	Oct 15	Nonlinear propagation	II	
9	Oct 20	Light scattering by small particles	III	
	Oct 22	Surface plasmon polaritons and Surface plasmon excitation	III	One-page proposal due
10	Oct 27	Localized surface plasmon resonances and optical antenna	III	
	Oct 29	Surface plasmon propagation	III	
11	Nov 3	Homogenization	III	
	Nov 5	Negative index, super lens	III	
12	Nov 10	ENZ and MNZ metamaterials	III	
	Nov 12	Metasurfaces	III	
13	Nov 17	Metamaterial and metasurface applications in devices	III	
	Nov 19	Nearfield optics & nanoscopic imaging	III	
14	Nov 24	No class		Fall break
	Nov 26	No class		Fall break
15	Dec 1	Student presentations		
	Dec 3	Student presentations		
16	Dec 8	Student presentations		
	Dec 10	Student presentations		Final report due

Course Website:
We will establish a course website. As an enrolled student, you will have access to the course website. If you do not have access, contact your TA immediately.
What you will find on the course website:

- The syllabus for lecture

- Course calendar
- Updates from the instructor and/or TAs
- Resources, lecture notes, and handouts.

Course Policies:
All students are assumed to have read and understood the "Code of Policies and Regulations Applying to All Students," University of Illinois, and will be expected to act accordingly. The Code is available online at:
http://www.admin.uiuc.edu/policy/code/index.html

Academic Integrity:
According to the Student Code, `It is the responsibility of each student to refrain from infractions of academic integrity, from conduct that may lead to suspicion of such infractions, and from conduct that aids others in such infractions.' Please know that it is my responsibility as an instructor to uphold the academic integrity policy of the University, which can be found here: http://studentcode.illinois.edu/article1_part4_1-401.html

Disabilities and Religious Observances:
Please contact your instructors or TAs during the first week of classes to make requests for disability accommodations or observation of religious holidays.

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES you may visit 1207 S. Oak St., Champaign, call 333-4603 (V/TTY), or e-mail a message to disability@illinois.edu

To obtain waivers for student athlete (cheerleader, marching band, etc.) activities, submit your documentation in person during the first week of class.

Emergency Response Recommendations:
The Department of Homeland Security and the University of Illinois at Urbana-Champaign Office of Campus Emergency Planning recommend the following three responses to any emergency on campus: RUN> HIDE > FIGHT. Please refer to the following websites for more detail:
https://www.dhs.gov/sites/default/files/publications/active_shooter_pocket_card_508.pdf
https://police.illinois.edu/emergency-preparedness/campus-emergency-operations-plan/