Course Title: ECE4960: Electromagnetic and Optical Metamaterials
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Credit Hours: 4 hours
Catalog Description:

This is an introductory Senior-level course on electromagnetic and optical metamaterials. The properties of matter can be molded and tailored on subwavelength spatial scales yielding 'metamaterials' with properties very different from naturally occurring materials thereby opening up new directions for applications. The course introduces the electromagnetic and optical properties of surface plasmons and polaritons, negative dielectric constant materials, negative index materials, and nanostructured optical materials, and discusses the applications of these materials in diverse areas including electromagnetic and optical cloaking, stealth technologies, negative refraction, optical super-lensing, conformal optics, meta-surfaces, and non-reciprocal devices.

Course Frequency:

Special Topics Course

Prerequisites:

ECE 3030 or AEP 3560 or permission of instructor

Corequisites:

None

Student Preparation Summary:

Math: Students need to be comfortable with the basics of vector calculus (vector fields, gradient, divergence, curl, etc.), linear algebra (vector spaces, matrix operations, eigenvalues, eigenvectors, etc.), Fourier series and transforms, basics of complex analysis (functions of complex variable, the Residue Theorem, etc.), ordinary and partial differential equations (Laplace's equation, wave equation, etc.).

Physics: Students should be familiar with concepts (at an undergraduate level) of electromagnetic fields, wave propagation in free space and inside materials, charges and currents, fundamentals of optics, reflection, refraction, etc.

Textbook(s) and/or Other Required Materials:

- The course is intended as a self-contained treatment of electromagnetic and optical metamaterials. The following textbooks may be helpful, although not required:
  - J. D. Jackson, Classical Electrodynamics. Wiley, 1998. https://newcatalog.library.cornell.edu/catalog/3485152
  - L. Novotny and B. Hecht, Principles of Nano-Optics. 2rd edition, Cambridge University Press, 20012. https://newcatalog.library.cornell.edu/catalog/7862378
  - C. F. Bohren and D. R. Huffman, Absorption and Scattering of Light by Small Particles. Hoboken: John Wiley & Sons, 2007.https://newcatalog.library.cornell.edu/catalog/9302663
  - J. D. Joannopoulos, et al., Photonic Crystals: Molding the Flow of Light (Second Edition). Princeton University Press, 2008. http://ab-initio.mit.edu/book/photonic-crystals-book.pdf
  - S. Tretyakov, *Analytical Modeling in Applied Electromagnetics*. Artech House, 2003.
- Course notes, additional course material and references will be distributed via Blackboard.

ECE Open CourseWare Link [if available]:

Class and Laboratory Schedule:

Lectures: Two 75-min lectures per week. Tuesday, Thursday, 10:10am - 11:25am. Phillips Hall 407
Recitations: One 50-minute discussion per week. Wednesday 9:05am - 9:55am. Phillips Hall 213
Labs: None

Assignments, Exams and Projects:

Homework: Assignments due every two weeks (except in prelim week). Total of 5 homework assignments per semester (1 per course module).

Exams: Two preliminary exams and a comprehensive final.

Course Grading Scheme: 30% Homeworks, 40% Prelims, 30% Final Exam

Details List of Topics Covered:

- Constitutive relations for continuous media. Frequency dispersion, Kramers Kronig relations, energy relations, and Poynting's theorem.
- Polarizability in quasi-static and dynamic form. Point-dipole models. Fundamentals of homogenization theory.
- Artificial plasmas, artificial magnetic media, negative-index media, near-zero media.
- Transmission-line models of conventional media and metamaterials. Plane-wave propagation in metamaterials. Reflection and refraction at metamaterial interfaces.
- Optical properties of metals. Volume plasmons, surface plasmon polaritons, localized surface-plasmon resonances.
- Plasmonic films, waveguides, nanoparticles, and nanoantennas. Applications.
- Sub-diffractive light confinement and super-resolution imaging with negative-index and plasmonic media and structures.
- Scattering/extinction cross sections, optical theorem, extinction paradox.
- Anomalous scattering, super-scattering, and invisibility.
- Overview of photonic crystals. Perfect dielectric mirrors. Photonic-crystal fibers. Applications.
- If time permits: Frequency-selective surfaces and metasurfaces. Applications.
- If time permits: Nonreciprocal metamaterials. Microwave and optical isolators and circulators.

Student Outcomes [ABET]:

1. Demonstrate fundamental understanding of electromagnetic and optical properties of materials and metamaterials, as related to the underlying material composition and structure.
2. Be able to analytically model, calculate, and design the propagation properties of waves in homogenous metamaterials, plasmonic media, and simple periodic structures.
3. Be able to numerically simulate electromagnetic scattering from metamaterial structures, and plasmonic nanoparticles and nanoantennas.
4. Be able to assess the conditions of applicability of conventional and metamaterial-based designs, and understand the fundamental and practical limits of these designs.
5. Be able to compare different approaches and choose the best design strategy to achieve light confinement, field enhancement, scattering suppression, anomalous light propagation, and invisibility.

Academic Integrity:

Students expected to abide by the Cornell University Code of Academic Integrity with work submitted for credit representing the student's own work. Discussion and collaboration on homework and laboratory assignments is permitted and encouraged, but final work should represent the student's own understanding. Specific examples of this policy implementation will be distributed in class. Course materials posted on Blackboard are intellectual property belonging to the author. Students are not permitted to buy or sell any course materials without the express permission of the instructor. Such unauthorized behavior will constitute academic misconduct.