# College of Optics & Photonics

# OSE-3053 Electromagnetic Waves for Photonics

*Spring 2022*

**Place & Time:** CREOL 0102, Mon, Wed, 3:00 PM – 4:15 PM From Jan 10 to May 4, 2022
**Prerequisites:** OSE3052 or consent of instructor.
**Credit Hours:** 3 hours
**Instructor:** Dr. Luca Argenti, e-mail: luca.argenti@ucf.edu
**Office Hours:** Tuesday 1:30pm – 2:30 pm on zoom, or by appointment.
**Description:** The course covers the foundation of electromagnetic optics, the propagation of optical plane waves within homogeneous, isotropic, and non-isotropic dielectric media, across planar boundaries between them, through dielectric layers, and in planar waveguides.

**Learning Outcomes:** Upon completing this course, the student will be able to:

- Explain the concept of electromagnetic fields and Maxwell's equations.
- Apply Maxwell's equations to determine the electric and the magnetic fields, radiative power, and their dependence on the medium electromagnetic properties.
- Analyze the propagation characteristics of plane waves including the propagation constants, electric and magnetic fields, and power flow.
- Determine the polarization state for a given field.
- Analyze the reflection and transmission of light at planar interfaces and the dependence on the incident wave polarization and angle of incidence.
- Analyze the reflection/transmission from a film on a substrate and design a thin film AR coating.
- Explain the principles of crystal optics and analyze simple components that control the polarization and the intensity of light.
- Explain the principles of waveguides and determine the guided modes.

**Reference Material:**

- *Class Notes*
- *Fundamentals of Photonics*, 2nd Edition, by B. E. A. Saleh and M. C. Teich (Wiley, 2009)
- *Optics*, 5th Edition, by E. Hecht (Pearson, 2017)

**Content of the course:**

**PART A. Mathematical Background, Electromagnetism, and E&M Waves in Vacuum**

**A1: Mathematical Background (3 lectures):**

- Scalar and vector representation.
- Coordinate systems and vector coordinate transformation
- Vector algebra – Scalar and vector products.
- Vector integration: The divergence theorem and Stoke's theorem
- Vector Calculus: Gradient, divergence, curl of vector function, and Laplacian.

**A2: Electromagnetism in Vacuum (2 lectures):**

- Overview of the Maxwell's Equations and Lorentz Force:
    - electric field, magnetic field, electric displacement, magnetic induction, charge density, current density
    - constitutive relations, electric permittivity, magnetic susceptibility, and speed of light in vacuum
- Système International d'unités:
    - Base units: meter, kilogram, second, ampere

  - Derived mechanical units: hertz, newton, joule, watt, pascal
  - Derived electric units: coulomb, volt, farad, ohm, siemens
  - Derived magnetic units: weber, tesla, henry
- Static Maxwell's Equations in vacuum: Electrostatics
  - Gauss law, Coulomb law
  - Electrostatic potential, Poisson equation, Laplace equation, general solution with zero boundary conditions at infinity
- Static Maxwell's Equations in vacuum: Magnetostatics
  - Ampere law, application of Stokes theorem
  - Vector potential, gauge invariance, Coulomb gauge and the transversality condition
  - Biot-Savart Law

**A3: Maxwell's Equations and Plane Waves in Vacuum (4 lectures):**

- Maxwell's Equations in non-static conditions as a coupled system
  - Faraday law and displacement current
  - Maxwell's Equation in integral form
  - Continuity equation.
- Wave equation
  - Decomposition of ME in transverse and longitudinal components
  - Fields in terms of scalar and vector potential in Coulomb gauge
  - Solution of the longitudinal time-dependent ME
  - Transverse ME: the inhomogeneous wave equation for the E, B, and A fields
- Monochromatic plane-wave solutions to the wave equation in vacuum
  - wave vector, wavenumber, wavelength, angular frequency, frequency, period, amplitude, dispersion relation, polarization
  - Helmholtz Equation
  - temporal periodicity, longitudinal periodicity, transverse constancy
  - linear, circular, and elliptical polarization
  - relation between orientation and magnitude of the E, B, and A fields
  - non-uniform solutions and complex wave vectors in vacuum
  - Poynting vector for electromagnetic waves in vacuum

**PART B. EM Waves in isotropic media and across planar boundaries**

**B1: Plane Wave Propagation in Materials (3 lectures):**

- Overview of the interaction of EM radiation with matter
- Outline of the derivation of the macroscopic ME from the microscopic equations
  - spatial average of fields, charge density and currents: definition of the macroscopic electric field and magnetic induction
  - polarization, magnetization, and the definition of electric displacement and magnetic field
- Constitutive relations
  - the linear hypothesis: general relation between polarization and electric field, and between magnetization and magnetic induction
  - electric and magnetic susceptibilities
  - classification of linear response: local (spatially non dispersive), homogeneous, invariant under time shift, instantaneous (non-dispersive), and isotropic. Examples
  - Electric permittivity and dielectric constant, Magnetic permeability and relative magnetic permeability, conductivity
- Complex Harmonic Maxwell's Equations
  - Constitutive relations for monochromatic fields
  - Frequency dependent dielectric constant, permeability, and conductivity
  - Maxwell's Equations for monochromatic fields
  - Complex Harmonic Maxwell's Equations for linear isotropic non-magnetic media, in absence of free charges and currents
  - Helmholtz equation: similarities and differences with the vacuum case

- The concept of refractive index.
- Propagation vector, phase velocity, wavelength.
- Relationship between the propagation vector and electric and magnetic fields.
- uniform and non-uniform solutions in media: comparison with the vacuum case
- The Poynting's theorem and Poynting vector: electromagnetic power in general, and for a plane wave, in particular.
- Boundary conditions and continuity equation at the boundaries

**B2: Plane Wave Reflection and Transmission at Planar Boundaries: (4 lectures)**

- Plane wave reflection and transmission at plane boundary between two media.
- Parallel (TM) and perpendicular (TE) polarizations.
- Brewster angle and total transmission, the critical angle and total reflection.
- Surface and evanescent waves.
- Plane wave reflection at a perfectly conducting plane.

**B3: Reflection and Transmission at multiple interfaces: (2 lecture)**

- Quarter and half-wave transformers
- Applications include anti-reflection coating

**PART C. Optical propagation through anisotropic media and waveguides**

**C1: Crystal Optics (3 lectures)**

- Anisotropic media
- Propagation of light through anisotropic media
- Phase retardation and Jones' calculus
- Polarization devices – wave plates, polarization rotators, amplitude modulators

**C2: Metallic planar waveguides (2 lectures)**

- TEM, TE, and TM modes in two plate planar waveguides.
- Dispersion relation, cut-off condition, field distribution, and power flow.

**C3: Dielectric planar waveguides (3 lectures)**

- Symmetric waveguides
- TM and TE modes in planar waveguides.
- Dispersion relation, cut-off condition, field distribution, and power flow.
- Single mode waveguides

**Webcourses:** Course materials, homework assignments, solutions, notes and announcements will be posted on Webcourses. The preferred mode of communication is through the email within Webcourses. It is the student's responsibility to check the "coursemail" tool frequently. All communication between student and instructor and between student and student should be respectful and professional. If you need to directly write to the instructor at the @ucf.edu address, prepend the string "[OSE 5053]" to the subject.

**Modality:** This course will be held in person. However, all assignments will be managed online. The instructor will try to stream and post the recording of most if not all the classes. Remote students will be able to upload the portion of an exam that requires handwriting by scanning and uploading it online. While in-person attendance is strongly encouraged, students who have reasons to believe they may be contagious or that they or their acquaintances would be exposed to an unacceptable risk, should remain home. Conversely, students who decide to come to class are expected to take all the necessary actions to protect their and their peers' health. In particular, students who participate in person are strongly encouraged to take all the vaccinations available to them, to take the covid test when appropriate, and to wear a mask when indoor.

**Record of Academic Engagement:** All faculty are required to document students' academic activity at the beginning of each course. Please, complete the activity online by the end of the first week of classes. Failure to do so may result in a delay in the disbursement of your financial aid.

**Attendance:** Students are expected to attend in person during their designated day. Attendance will be taken using the **UCF Here mobile app** during live in-person and zoom lessons, using your smartphone. The app is available for iOS and Android smartphones. Attendance does not count towards the grade, but it will be used by the instructor to keep track of students' synchronous engagement with the course.

**Online meetings:** While class meetings will take place in person, this course will tentatively use Zoom for streaming those meetings as well. Meeting dates and times will be scheduled through Webcourses@UCF and should appear on your calendar. Please take the time to familiarize yourself with Zoom by visiting the UCF Zoom Guides. You may choose to use Zoom on your mobile device (phone or tablet). You must sign in to my Zoom session using your UCF NID and password. You can contact Webcourses@UCF Support if you have any technical issues accessing Zoom.

**Homework**: Homework will be assigned on a weekly basis, with occasional gaps in proximity of recess, exams, and at the beginning and end of the course. It is anticipated that there will be 9 total assignments, three for each of the main three parts of the course (HA1-3, HB1-3, HC1-3). A typical assignment will comprise a list of exercises to be solved online or in writing. Students are free to interact outside class time and discuss homework assignments. However, the solutions must be worked out individually, *formulated in clear handwriting*, scanned, and uploaded *as a single legible pdf file* to the webcourse page. Late homework will receive zero points.

**Exams:** The provisional schedule for the mid-term exams is **Monday February 14th** and **Monday March 28th**, during normal lecture time (3:00 PM – 4:15 PM). The final exam will be on **Wednesday April 27th**, from 1:00 PM to 3:50 PM. Exams are comprehensive and closed book; each student will be allowed to bring a single-page formula sheet of his/her own making for each of the three parts of the course.

**Make-up exams:** Only given to students taking part in University-sanctioned activities. Authentic justifying documentation must be provided in advance. Exceptions are to be made for medical and family emergencies at the discretion of the instructor.

**Grading Policy:**

- Engagement Quiz **(1%)**
- Homework assignments (**27%**),
- Mid-term exam #1 (**20%**)
- Mid-term exam #2 (**20%**)
- Final exam (**32%**)

**Grading Scale (%) Interpretation:** Plus and minus grades will be used

| | | |
|---|---|---|
| 85 – 100 | A, A- | Excellent, has a strong understanding of all concepts and is able to apply the concepts in all and novel situations. Has full mastery of the content of the course. |
| 75 – 84.9 | B+, B | Good, has a strong understanding of most or all of the concepts and is able to apply them to stated and defined situations. |
| 60 -74.9 | B-, Cx | Average, has a basic understanding of the major concepts of the course and is able to apply to basic situations. |
| 50 – 59.9 | Dx | Below average, has a basic understanding of only the simple concepts and is able to apply to only a limited number of the most basic situations. |
| 0 – 49.9 | F | Demonstrates no understanding of the course content. |

**Calendar:** The codes HA1-3, HB1-3, HC1-3, indicate the 9 homework assignments. Each assignment will normally be due the week after it is made available on Webcourses.

| **A: EM Field Theory** | | | **B: Electromagnetic Optics** | | | **C: OWP In layered media** | | |
|---|---|---|---|---|---|---|---|---|
| M | W | F | M | W | F | M | W | F |
| J10 | J12 | | **F14 MT1** | F16 | | **M28 MT2** | M30 | |
| **MLKD** | J19 | **HA1** | F21 | F23 | **HB1** | A4 | A6 | **HC1** |
| J24 | J26 | **HA2** | F28 | M2 | **HB2** | A11 | A13 | **HC2** |
| J31 | F2 | **HA3** | **SPRING BREAK** | | | A18 | A20 | **HC3** |
| F7 | F9 | | M14 | M16 | **HB3** | A25 | **A27 FE** | |
| | | | M21 | M23 | | | | |

**Accessibility Services for Students:** UCF is committed to providing reasonable accommodations for all persons with disabilities. Students with disabilities who need accommodations must be registered with Student Accessibility Services (SAS) http://sas.sdes.ucf.edu/ (Ferrell Commons 185, sas@ucf.edu, phone 407-823-2371) before requesting accommodations from the instructor. Students who are registered with SAS and need accommodations to attend class must contact the instructor at the beginning of the semester to discuss accommodations that might be necessary and reasonable.

**Notifications in Case of Changes to Course Modality**: Depending on the circumstances, the class may exceptionally move online. If that happens, please look for announcements or messages in Webcourses@UCF or Knights email about changes specific to this course.

**Plagiarism and cheating:** Many incidents of plagiarism result from students' lack of understanding about what constitutes academic misconduct. However, students are expected to familiarize themselves with UCF's Golden Rule, which defines plagiarism as follows: ``whereby another's work is used or appropriated without any indication of the source, thereby attempting to convey the impression that such work is the student's own.'' Plagiarism and cheating of any kind on an exam or assignment will result in zero points (and may, depending on the severity of the case, lead to an "F" for the entire course) and may be subjected to appropriate referral to the Office of Student Conduct for further action. See the UCF Golden Rule for further information. Students are assumed to adhere to the academic creed of this University and maintain the highest standards of academic integrity. The instructor will also adhere to the highest standards of academic integrity.

**Diversity and Inclusion:** Diversity of students, faculty, and staff is a strength of UCF and a critical component of its educational mission. Dimensions of diversity can include sex, race, age, national origin, ethnicity, gender identity and expression, intellectual and physical ability, sexual orientation, income, faith and non-faith perspectives, socio-economic class, political ideology, education, primary language, family status, military experience, cognitive style, and communication style. Participants to OSE6111 are expected to contribute creating an inclusive and respectful classroom environment.