PHYS 415 – Optics

Course Content:

This is intended to be a first optics course for advanced undergraduates or beginning graduate students in STEM fields. It is designed as a survey course aiming to expose students to a broad array of topics in optics, with an emphasis on understanding over-arching concepts, general physical principles that dictate the behavior of light, as well as practical knowledge about common optical components and devices, and analytical tools for engineering simple optical systems. Because this is a mixed undergraduate-graduate course, I will attempt to present both basic concepts and advanced reasoning behind the principles in the same lecture; in many cases, the textbook reading jumps around in order to provide multiple levels of insight about the same topic. We will do a mixture of analytical and numerical problems, emphasizing topics of most interest to an experimentalist wishing to apply knowledge from this course to his/her laboratory.

Pre-requisites:

PHYS 311 and PHYS 412 (Electromagnetism I & II), or permission of instructor.

Required Textbook:

B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, 2nd edition. ISBN: 978-0-471-35832-9.

Topics / Typical day-by-day schedule

Note: Special Topics are adjustable by student interest

1. Electromagnetic Theory: The wave equation, monochromatic waves, intensity, units of measure
2. Refractive index, refraction, proof of Snell's law, simple optical components
3. Ray optics: Postulates, refraction, simple optical components, total internal reflection, beginnings of waveguides
4. The ray-transfer matrix, cascaded optical components, stability of resonators
5. Gaussian optics: Relation with ray optics, properties of Gaussian beams, invariance in diffraction theory
6. Gaussian-transfer matrices, practical examples of designing optical systems
7. Fourier optics: Review of Fourier transforms, spatial-spectral analysis and diffraction gratings, zone plates
8. Free space propagation, optical Fourier transform (far field, lenses)
9. Diffraction through apertures, Fraunhofer vs. Fresnel
10. Image formation: magnification, 4f and telecentric imaging systems, apodization, spatial filtering
11. Absorption/dispersion: Beer's Law, absorption as related to refractive index, Sellmeier equation as related to light-matter interactions, dispersion
12. Consequences of dispersion: prisms, chromatic aberration, spectral content of pulsed light, pulse propagation in dispersive media
13. Fiber Optics: Numerical aperture, fiber types, single/multi-mode, mode cutoff, effects of attenuation and dispersion
14. Polarization: Linear, circular, Poincare sphere representation, examples with waveplates
15. Jones vector/matrix representation, cascaded polarization devices
16. TE and TM polarizations (and impact on choice of optical components), Brewster's angle
17. Crystalline optical media, birefringence, liquid crystals
18. Coherence and Interference: Interference of monochromatic waves, interferometers, double slit experiment
19. Applications of interference: dielectric mirrors, Fabry-Perot interferometry, pulsed lasers, optical ranging
20. Temporal coherence and spectrum, spatial coherence, applications in imaging and astronomy
21. Lasers: Photon-atom interactions, spontaneous and stimulated emission, Einstein A and B coefficients
22. Gain and bandwidth, rate equations, laser oscillation conditions
23. Hermite-Gaussian beams, transverse and longitudinal laser modes, types of lasers: solid-state (Nd:YVO4, Ti:Sa, fiber), atomic (argon, He-Ne), excimer
24. Semiconductors: energy bands in semiconductors, electron/hole concentrations, recombination, p-n junction, transitions, absorption/emission/gain
25. LEDs, semiconductor optical amplifiers, diode lasers, photodiodes
26. Special Topic I: Nonlinear Optics: EM theory, SHG, Wave Mixing/Phase Matching, Kerr effect
27. Special Topic II: Quantum Optics: Coherent vs. thermal light, squeezed light, entanglement
28. Special Topic III: Microscopy Cornucopia: Transmission/Darkfield/Phase/Fluorescence, Confocal, PALM/STORM, STED/GSD
29. Final Project Presentations in class