ECE 480A8 Waves in Photonic Integrated Circuit Elements

Fall 2024

10:00am - 10:50pm MWF in Engineering B203 (Titan Design Studio)

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Important note: You must include "ECE480A8" as part of the subject line for all emails regarding this class, or else my email filters will not highlight them.
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COURSE DESCRIPTION: An introduction to components used in photonic integrated circuits (PICs) including optical waveguides, splitters, couplers, modulators, interferometers, reflectors, filters, and resonators. Treatment focuses on quantitative characteristics of individual components and combinations using analytical equations for electromagnetic wave propagation.

COURSE OBJECTIVES: Upon successful completion of this class, students will be able to:
1. List common elements used in PICs and describe the differences between them.
2. Identify, draw, and discuss the constituent layers used in PIC fabrication including typical materials and dimensions.
3. Recognize Maxwell's equations, the time-dependent electromagnetic wave equation, and the Helmholtz equation and solutions to these equations, and apply appropriate equations or solutions to modeling optical waves propagating in waveguides.
4. Calculate and plot the transverse mode profiles and complex effective indices for 1-D (slab) and 2-D rectangular cross-section dielectric waveguides.
5. Apply electromagnetic boundary conditions to distinguish and calculate modes with transverse electric and transverse magnetic polarizations.
6. Calculate the relationships between input and output amplitude and phase of optical waves passing through PIC elements in steady-state including the use of small, complex-valued matrices for interactions of multiple waves in PIC splitters and couplers.
7. Calculate confinement factors for waveguide modes and describe the impact of confinement factor on sensitivity to waveguide core and cladding optical properties.
8. Calculate coupling and overlap factors between different modes in individual and multiple waveguides including at interfaces of waveguides with different cross-sectional dimensions.
9. Analyze and discuss the operation and utility of multimode-interference devices.
10. Analyze and discuss the operation and utility of amplitude and phase modulators.
11. Analyze and design PIC-compatible interferometers using directional couplers and waveguides for reference and sample arms including their spectral response.
12. Analyze ring-resonators including their sensitivity to environmental factors and their spectral responses.
13. Analyze optical wave propagation in structures with periodically varying refractive index to determine their reflectivity and spectral characteristics.

PREREQUISITES: ECE 340 or ECE 342; MATH 340; PH142; CS164 or equivalent programming experience in Matlab

REQUIRED MATERIALS: There is no required textbook for this class in the experimental stage. Optional references include

- *Silicon Photonics: an introduction* by Graham Reed and Andrew Knights, Wiley, 2004
- *Diode Lasers and Photonic Integrated Circuits* by Larry Coldren and Scott Corzine, Wiley, 2012 [Only the PIC section is relevant; this course will only address lasers tangentially.]

Readings for the course will be curated from selected review papers, tutorial websites, and occasional commercial website pages written in the form of application notes.

Canvas: canvas.colostate.edu will have the syllabus, links, homework, course grades and other postings. It is your responsibility to check the course website each week for new postings.

COURSE SCHEDULE:

Week	Topics	Learning Objectives
1	Introduction to PIC components and layer structure	1, 2
2	Review of electromagnetic waves and boundary conditions	3, 5
3	• EM solutions for optical waveguides • Student mini-presentations on PIC foundry processes	1, 2, 3, 4, 5 2
4	Multimode waveguides, effective indices, optical length, loss, confinement factor, sensitivity to material optical properties	3, 4, 5, 6, 7
5	Directional couplers, super modes, coupling length, matrix equations for coupled modes	1, 3, 6, 8
6	Review / Midterm Exam	1-7
7	Splitters, combiners, multi-mode interference devices	1, 3, 4, 6, 8, 9
8	Amplitude and phase modulators	1, 3, 6, 10
9	Non-resonant interferometers such as Mach-Zehnder interferometers; use as sensors	1, 6, 8, 11
10	Resonant interferometers including ring-resonantors	1, 6, 12
11	Material and modal reflectivity at refractive index discontinuities; impact of optical length between discontinuities	3, 6, 7
12	Periodic reflectors including Bragg structures; reflectivity relationship between abrupt and sinusoidal refractive index variation	1, 3, 6, 13
13	Overflow / optional and recent topics in PICs	1-13
14	Student presentations on PIC applications	1-13
15	Optional and recent topics in PICs / Review	1, 3, 6, 7, 8, …
16	Final Exam	1-13

GRADING:

Assessment Components

Component	Weight
Homework assignments	40%
Projects	20%
In-class participation (via quizzes or classroom response system)	10%
Midterm exam	10%
Final exam	20%

Grading Scale

Final letter grades will be determined by the following scale with your overall score:

≥ 90% A	80-83.99% B	70-73.99% C
87-89.99% A-	77-79.99% B-	60-69.99% D
84-86.99% B+	74-76.99% C+	≤ 59.99% F

ACADEMIC INTERGRITY: Students are expected to adhere to the Academic Integrity Policy of Colorado State University, outlined in the CSU General Catalog. Students are also expected to follow the Student Conduct Code which can be found at www.conflictresolution.colostate.edu. Academic dishonesty is not accepted in this course, and any form of cheating (including plagiarism) will be reported. Penalties for academic misconduct may include zero credit for assignments or exams, a lowered course grade, loss of course credit, and expulsion from the university.

CSU PRINCIPLES OF COMMUNITY:

- Inclusion: We create and nurture inclusive environments and welcome, value and affirm all members of our community, including their various identities, skills, ideas, talents and contributions.
- Integrity: We are accountable for our actions and will act ethically and honestly in all our interactions.
- Respect: We honor the inherent dignity of all people within an environment where we are committed to freedom of expression, critical discourse, and the advancement of knowledge.
- Service: We are responsible, individually and collectively, to give of our time, talents, and resources to promote the well-being of each other and the development of our local, regional, and global communities.
- Social Justice: We have the right to be treated and the responsibility to treat others with fairness and equity, the duty to challenge prejudice, and to uphold the laws, policies and procedures that promote justice in all respects.