ECE 2295: Simulation and Design of Photonic Integrated Circuits

COURSE DESCRIPTION:

Photonic integrated circuits (PICs) is a rapidly emerging industry with applications ranging from ultra-high bandwidth transceivers to light-based quantum computers and from near-eye virtual reality displays to lab-on-chip biosensors. While research into PICs has existed for the last few decades, the field is gaining significant traction in the industrial sector owing to the growing availability of low-cost manufacturing through photonics foundries. Like the growth of the microelectronics industry in the 1970's and 1980's, monolithic integration of PICs with electronic devices is expected to be the next technological leap forward in the semiconductor industry. This course will introduce students to the concepts of silicon integrated photonic device theory, simulation, fabrication, and characterization with an emphasis on foundry-compatible design methodologies.

COURSE OBJECTIVE:

The goal of this course is to enable students to design basic photonic integrated circuits by providing them with an intuitive understanding of core photonic components (e.g. waveguides, couplers, resonators, etc.) as well as a solid grasp of the tools needed to simulate multi-component designs. By the end of the course, students should understand the steps needed to take a PIC design from original concept to fabrication at a foundry. This includes such topics as:

- On-chip filtering/routing using ring resonators and Bragg gratings (with integrated thermal tuning).
- Methods for optimizing bandwidth and on/off-chip coupling efficiency using edge and grating couplers.
- Integrated high-speed silicon PN modulator design and optimization (i.e. tradeoff between losses, footprint, RF response, etc.).
- Integrated high-speed germanium PIN photodetector design and optimization (i.e. tradeoff between responsivity, RF bandwidth, etc.).
- Full photonic circuit simulation using the S-parameter method (Lumerical INTERCONNECT).

INSTRUCTOR:

Dr. Nathan Youngblood 1102 Benedum Hall email: nay32@pitt.edu office hours: TBD

LECTURES:

Time and location TBD

PREREQUISITES:

- An undergraduate course covering the fundamentals of electromagnetic waves. Acceptable courses offered by the University of Pittsburgh include:
  - ELECTROMAGNETICS (ECE 1259)
  - WAVE MOTION AND OPTICS (PHYS 1361)
  - INTRO LASERS & OPTCL ELECTNC (ECE 1232)
  - PHOTONICS 1 (cross listed as PHYS 1363, CHEM 1470, CHEM 1472, or ECE 1240)

TEXTBOOK AND REFERENCES:

Required:

- *"Silicon Photonics Design: From Devices to Systems,"* Chrostowski and Hochberg, Cambridge University Press, 2015.

References:

- *"Fundamentals of Photonics, 3rd edition,"* Saleh and Teich, Wiley, 2019
  - 1st and 2nd editions are available for students at the Engineering Library reserve desk
- "*Photonics: Optical Electronics in Modern Communications, 6th edition,"* Yariv and Yeh, Oxford University Press, 2007
  - Available for students at the Engineering Library reserve desk

REQUIRED SOFTWARE:

The following software will be used for some homework assignments. These are available for use in the ECE computer labs and for installation on your personal computer.

- **MATLAB:** Used to create figures and analyze Lumerical simulation data for homework assignments. Pitt students can install the full version of MATLAB on their personal computers for free (see www.software.pitt.edu for more information).
- **Lumerical:** A suite of photonics design tools that allow device, circuit, and system level simulation. This course will primarily use FDTD, MODE, and INTERCONNECT. An educational license for use during the semester will be made available to students for homework assignments (see course website for installation details).
- **Klayout:** An open source viewer and editor of GDS design files which are the generally accepted file type used by photonics foundries (download here: https://www.klayout.de/).

GRADING:

The following weights will be assigned to each student's submitted work:

Homework: 40%	Midterm exam: 30%	Final project: 30%

HOMEWORK:

Assigned homework will be collected on the day it is due at the beginning of lecture. Students should provide hardcopies of their assignments which may include written work, plots and figures, code, etc. Late homework will be penalized by 20% per day past the due date. Homework submitted more than four days after the due date will not be graded.

FINAL PROJECT:

In place of a final exam, there will be a final project which requires students to design, optimize, and simulate the performance of a photonic circuit (for example, a coherent transceiver). Students will submit a technical report which summarizes the results of optimization sweeps, final design parameters, simulated system performance, etc. A hardcopy of the final project will be due by 5pm EST on the date of the final exam for the course as scheduled by the University. See course website for specific details on the final project requirements.

DETAILED COURSE SCHEDULE:

Spring 2021	Date	Topics Covered
Week 1	Jan 11	Introduction to silicon photonics; review of light propagation in materials
Week 2	Jan 18	MLK Holiday (no class)
Week 2	Jan 18	Introduction to photonics modelling tools and approaches (Lumerical MODE and FDTD)
Week 2	Jan 22	Spring term add/drop period ends
Week 3	Jan 25	Passive components: waveguide theory and design
Week 4	Feb 1	Passive components: integrated directional couplers and Y-splitters
Week 5	Feb 8	On-chip interference: interferometers and ring resonators
Week 6	Feb 15	On-chip interference: waveguide Bragg grating filters
Week 7	Feb 22	Optical I/O: grating couplers
Week 8	Mar 1	Optical I/O: edge couplers
Week 8	TBD	Midterm
Week 9	Mar 8	Spring Holiday (no class)
Week 10	Mar 15	Modulation in silicon (plasma dispersion and thermal-optic effects)
Week 11	Mar 22	System design: photonic circuit modelling; optical S-parameters (Lumerical INTERCONNECT)
Week 12	Mar 29	Active components: MZI and ring modulators
Week 13	Apr 5	Active components: lasers and photodetectors
Week 14	Apr 12	Fabrication: submitting your design to a foundry (PDK and design rules)
Week 15	Apr 19	Novel photonic devices: phase-change photonics and 2D materials
Week 16	Apr 26	Finals week (Final project due)

ACADEMIC INTEGRITY:

All students are expected to adhere to the standards of academic honesty. Any student engaged in cheating, plagiarism, or other acts of academic dishonesty would be subject to disciplinary action. Any student suspected of violating this obligation for any reason during the semester will be required to participate in the procedural process, initiated at the instructor level, as outlined in the University Guidelines on Academic Integrity http://www.provost.pitt.edu/info/ai1.html. This may include, but is not limited to, the confiscation of the examination of any individual suspected of violating the University Policy. Furthermore, no student may bring any unauthorized materials to an exam.

DISABILITY SERVICES:

If you have a disability for which you are or may be requesting an accommodation, you are encouraged to contact both your instructor and Disability Resources and Services (DRS), 140 William Pitt Union, (412) 648-7890, drsrecep@pitt.edu, (412) 228-5347 for P3 ASL users, as early as possible in the term. DRS will verify your disability and determine reasonable accommodations for this course.

STATEMENT ON CLASSROOM RECORDING:

To ensure the free and open discussion of ideas, students may not record classroom lectures, discussion and/or activities without the advance written permission of the instructor, and any such recording properly approved in advance can be used solely for the student's own private use.

STUDENT OPINION OF TEACHING SURVEYS:

Students in this class will be asked to complete a *Student Opinion of Teaching Survey*. Surveys will be sent via Pitt email and appear on your CourseWeb landing page during the last three weeks of class meeting days. Your responses are anonymous. Please take time to thoughtfully respond, your feedback is important to me. Read more about *Student Opinion of Teaching Surveys*.

DIVERSITY AND INCLUSION:

The University of Pittsburgh does not tolerate any form of discrimination, harassment, or retaliation based on disability, race, color, religion, national origin, ancestry, genetic information, marital status, familial status, sex, age, sexual orientation, veteran status or gender identity or other factors as stated in the University's Title IX policy. The University is committed to taking prompt action to end a hostile environment that interferes with the University's mission. For more information about policies, procedures, and practices, see: http://diversity.pitt.edu/affirmative-action/policies-procedures-and-practices.

I ask that everyone in the class strive to help ensure that other members of this class can learn in a supportive and respectful environment. If there are instances of the aforementioned issues, please contact the Title IX Coordinator, by calling 412-648-7860, or e-mailing titleixcoordinator@pitt.edu. Reports can also be filed online: https://www.diversity.pitt.edu/make-report/report-form. You may also choose to report this to a faculty/staff member; they are required to communicate this to the University's Office of Diversity and Inclusion. If you wish to maintain complete confidentiality, you may also contact the University Counseling Center (412-648-7930).

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