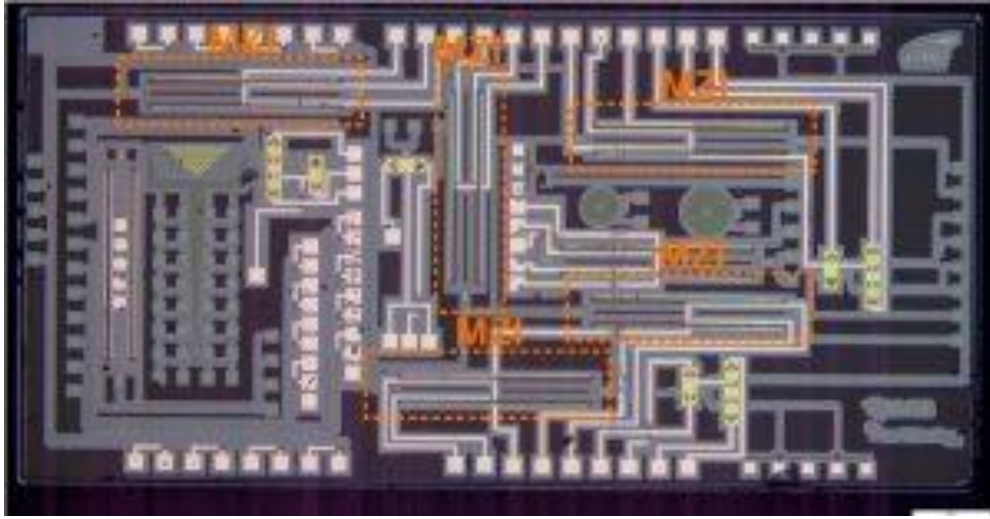


# Silicon Photonics Design – ECE544



A Mach-Zehnder (MZI) Based Silicon Photonic Switch (Figure from [C24]).

**Instructor:** Prof. Mahdi Nikdast (E-mail: [Mahdi.Nikdast@colostate.edu](mailto:Mahdi.Nikdast@colostate.edu)).

**Office Hours (online):** Monday; 1:00 PM to 2:00 PM. Check your Canvas for the Zoom call info.

**Course Assistant:** Amin Shafiee (E-mail: [Amin.Shafiee@colostate.edu](mailto:Amin.Shafiee@colostate.edu)). Office hours (online): Wednesday; 3:00 PM to 4:00 PM. Check your Canvas for the Teams call info.

**Lectures:** Tuesday and Thursday, 3:30 PM to 4:45 PM at Weber Building Rm. 202.

**Course on Canvas:** Click [here](#)

[LinkedIn Group](#)

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## Course Summary

### Why Silicon Photonics?

Silicon photonics is a rapidly growing field in communication (e.g., data centers, high-performance computing systems), bio-sensing, Light Detection and Ranging (LIDAR) for autonomous driving, and in many other areas. Many companies are actively working and investing in silicon photonics (e.g., Intel, IBM, HPE, Facebook, Google, Microsoft, Global Foundries), addressing design and implementation challenges associated with this technology, paving the way to introduce this technology to the future systems in market. Meanwhile, many research groups in universities

are studying silicon photonics, further pushing the application of this technology and addressing design, co-packaging, etc. challenges.

This course discusses the fundamentals and design principles of emerging silicon photonic integrated circuits. This is a multidisciplinary course, where we discuss photonics, circuits, simulations, design automation and tools, design techniques, numerical methods, application of silicon photonics in high-performance computing, etc. Topics related to design and analysis of fundamental silicon photonic devices as well as system architecture design and requirements will be discussed. In addition, the course will discuss advanced topics related to silicon photonic design requirements and challenges for emerging applications, such as neural networks. Simulation tools from Lumerical will be used in the course. *Would you like to be a part of this amazing journey? If so, then this is the course for you!*

## Course Learning Objectives

Here is a summary of ECE544 learning objectives:

1. Learn fundamental concepts and operating principles of silicon photonic devices and circuits.
2. Evaluate, analyze, and design primary passive and active silicon photonic devices.
3. Evaluate, analyze, and design passive and active silicon photonic integrated circuits and interconnects.
4. Work with Lumerical photonic tools and simulations and Klayout for chip layout design and verification.
5. Explore applications of silicon photonics in high-performance computing systems and data centers, while studying various performance metrics, design challenges, and opportunities.

## Course Textbook and Materials

- Instructor will introduce and discuss some Research Papers during the lectures;
- [TXT1] Lukas Chrostowski, Michael Hochberg, "[Silicon Photonics Design: From Devices to Systems](#)," ISBN-13: 978-1107085459, ISBN-10: 1107085454, Cambridge University Press 2015. (**main textbook**)

**Other useful/OPTIONAL references:**

- [TXT2] Amnon Yariv, Pochi Yeh, "Photonics: Optical Electronics in Modern Communications," 6th Edition, ISBN-13: 978-0195179460, ISBN-10: 0195179463, Oxford 2007.
- [TXT3] Michael J. Flynn, Wayne Luk, "Computer System Design: System-on-Chip," ISBN: 978-1-118-00991-8, Wiley 2011.

- [TCT4] Mahdi Nikdast, Gabriela Nicolescu, Sebastien Le Beux, and Jiang Xu, “Photonic Interconnects for Computing Systems,” ISBN-13: 978-8793519800, ISBN-10: 879351980X, River Publishers, 2017.

## Grading Policy

Homework Assignments	20%
Lab Assignments	35%
Course Project (40%)	Project proposal and presentation: 15% (Midterm) Project final presentation: 10% Project final report: 15%
Class Reports and Discussions	5%

The +/- grading scheme will be used, with the following scale

>95%	90 - 94%	85 - 89%	80 - 84%	75 - 79%	70 - 74%	65 - 69%	55 - 64%	40 - 54%	<40%
A+	A	A-	B+	B	B-	C+	C	D	F

## Homework and Lab Assignments Procedures, Submission Policy

**Homework Assignments:** To receive full credit for your homework, show all reasonable steps in solving problems. All the homework assignments should be uploaded electronically on Canvas.

**Lab Assignments:** Lab assignments are a very important component of this course. You will learn how to design and simulate silicon photonic components and devices, and by the end of the semester, will be able to design more sophisticated circuits. We use a set of simulation tools from Lumerical. After the first two to three labs, you will become comfortable with the tools and will be on your way to designing some interesting devices/circuits. Lumerical webpage is a good resource to learn the tools.

Similar to homework assignments, lab reports should be uploaded electronically on Canvas.

**Late Submission Policy:** Late homework **will not be accepted** unless the lateness is due to circumstances beyond your control (**proof is required**). To receive full credit, lab reports must be turned in on the date due. Late lab reports will be accepted, but points will be deducted from the score (**-5 per day**).

**Instructions to submit your files:** All the submitted files should be in **PDF format**. Use the following instructions to name your file:

Homework

assignments: FamilyName\_FirstName\_StudentID\_SiPhFA21\_HW"number"

Lab reports: FamilyName\_FirstName\_StudentID\_SiPhFA21\_LB"number"  
Replace "FamilyName" with your family name. Replace "FirstName" with your first name. Replace "StudentID" with your CSU student ID. Replace "number" with either the homework or the lab report number. **Submitted files NOT based on these instructions will NOT be graded!**

***Important information for students:*** *All students are expected and required to report any COVID-19 symptoms to the university immediately, as well as exposures or positive tests from a non-CSU testing location. If you suspect you have symptoms, please fill out the COVID Reporter (<https://covid.colostate.edu/reporter/>). If you know or believe you have been exposed, including living with someone known to be COVID positive, or are symptomatic, it is important for the health of yourself and others that you complete the online COVID Reporter. Do not ask your instructor to report for you. If you do not have internet access to fill out the online COVID-19 Reporter, please call (970) 491-4600. You will not be penalized in any way for reporting. If you report symptoms or a positive test, you will receive immediate instructions on what to do, and CSU's Public Health Office will be notified. Once notified, that office will contact you and most likely conduct contact tracing, initiate any necessary public health requirements and/or recommendations and notify you if you need to take any steps.*

*For the latest information about the University's COVID resources and information, please visit the CSU COVID-19 site: <https://covid.colostate.edu/>.*

### **Academic Integrity**

This course will adhere to the CSU Academic Integrity Policy as found in the General Catalog (<http://www.conflictresolution.colostate.edu/academic->

[integrity](http://www.conflictresolution.colostate.edu/conduct-code)) and the Student Conduct Code (<http://www.conflictresolution.colostate.edu/conduct-code>). At a minimum, violations will result in a grading penalty in this course and a report to the Office of Conflict Resolution and Student Conduct Services. All submitted work should be your own. Copying of language, structure, images, ideas, or thoughts of another, and representing them as one's own without proper acknowledgement (from web sites, books, papers, other students, solutions from previous offerings of this course, etc.) and failure to cite sources properly is not acceptable. Sources must always be appropriately referenced, whether the source is printed, electronic, or spoken. My policy is that of **zero tolerance**. Minor first infraction in HWs and presentations will lead to a zero score as well as one letter level (e.g. A to B) reduction in the course grade. Project or Major or repeated infractions in HWs and presentations will result in "F" grade for the course as well as reporting to the Dean's Office.

### **Diversity Statement**

As the instructor in ECE544, I am deeply committed to helping build an inclusive culture in this classroom, in the Department of Electrical and Computer Engineering, in the Walter Scott, Jr. College of Engineering, and at CSU. Each individual brings diversity to our class in the identities they hold, the ways they think, their interests and skills, their background and past experiences. To me, inclusion means not only accepting these differences, but embracing them and understanding that we can leverage these differences to be better engineers.

My goal for this class is to create an environment where we do not discriminate against individuals because of their identities (e.g., race, ethnicity, sex, gender identity, sexual orientation, religion, nationality, age, levels of ability). It is also important to understand that even when we hold egalitarian beliefs, we can hold implicit or unconscious biases that can also influence the way we treat others or approach engineering design. It is my expectation that students in this class will:

1. Adhere to the CSU Principles of Community <https://diversity.colostate.edu/principles-of-community/>;
2. Work in teams in ways that recognize the contributions of all team members and provide all team members the opportunity to learn;
3. Examine their own behaviors and refrain from acting in biased ways;
4. Reflect on the ways bias can influence engineering work;

5. Speak with the professor when biased behaviors may occur from other students, their TAs, and the professor;
6. Be sensitive to context and acknowledge that hurtful comments can sometimes be inadvertent but they still have an impact.

**Topics** (Dates/Topics may change with reasonable notice. Important dates are in **red**)

Week	Summary of Topics	Readings	HW	La b
W1 (Aug. 23)	<b>Introduction to Silicon Photonics (Lec1, Lec2):</b> limitations of electrical interconnects, history of silicon photonics, primary building blocks of a silicon photonics link, applications of silicon photonics.	Chapters 1, 2 [1-9]		
W2 (Aug. 30)	<b>Optical Waveguides I (Lec1, Lec2):</b> fundamental concepts and properties of silicon photonics waveguides, basics of guided waves, Silicon on Insulator (SOI) wafers, strip and rib waveguides.	Chapter 3, [10], Chapters 1 and 2 from [11]		
W3 (Sep. 6)	<b>Optical Waveguides II (Lec1, Lec2):</b> approximate methods to model optical waveguides (effective index method, Marcatili's approach), numerical methods and simulations, MODE simulation. <b>Choose a Project Topic and Group (Sep. 10, 2021)</b>	Chapter 3 from [TXT1] and Chapter 3 from [TXT2], [12-15]		
W4 (Sep. 13)	<b>Optical Waveguides III (Lec1, Lec2):</b> waveguide loss, waveguide bends, Y-branches, splitters, fundamentals of interferometers.	Chapters 3 and 4 from [TXT1], [16]		
W5 (Sep. 20)	<b>Coupling Light into Chips (Lec1, Lec2):</b> fundamentals of edge coupling and vertical coupling, grating couplers, brag gratings.	Chapters 4 and 6 from [TXT1], [20-26]		
W6 (Sep. 27)	<b>Silicon Photonics Devices I (Lec1, Lec2):</b> Mach-Zehnder Interferometers (MZIs), design, simulation and analysis. <b>Project Proposal Due (Sep. 28, 2021)</b>	Chapter 4 from [TXT1], [27-31]		

W7 (Oct. 4)	<b>Silicon Photonics Devices II (Lec1, Lec2):</b> mirroring resonators (MRs), applications, design, simulation and analysis. <b>Project Proposal Presentations Due</b>	Chapters 4 and 6 from [TXT1], [32-42]		
W8 (Oct. 11)	<b>Silicon Photonics Devices III (Lec1, Lec2):</b> directional couplers, layout design and simulation of mirroring resonators, KLayout, layout design and optimization, KLayout, programmable design kits (PDKs).	Chapters 4 and 6 from [TXT1], [43-48]		
W9 (Oct. 18)	<b>Compact Models (Lec1, Lec2):</b> compact photonic models, circuit simulation and design using compact models.	Chapter 9 from [TXT1] and [49-52]		
W10 (Oct. 25)	<b>Silicon Photonics Interconnects for HPC Systems (Lec1, Lec2):</b> optical interconnects in manycore system, optical routers, communication protocols, performance.	[53-58] [J9-J11], [J16]		
W11 (Nov. 1)	<b>Advanced Topics I (Lec1, Lec2):</b> optical loss and crosstalk in silicon photonics.	[J6], [J8], [J14], [J17], [J19], [C6], [C16], [59]		
W12 (Nov. 8)	<b>Advanced Topics II (Lec1, Lec2):</b> fabrication non-uniformity and design for manufacturability (DFM).	Chapter 11 and 12 from [TXT1], [61]-[66]		
W13 (Nov. 15)	<b>Advanced Topics III (Lec1, Lec2):</b> fabrication process variation modeling and analysis, design for reliability/robustness.	[J20], [C20], [C21], [C25], [C26]		
W14 (Nov. 22)	<b>No Classes (University Break)</b>	<b>Semester Break</b>		
W15 (Nov. 29)	<b>Advanced Topics IV (Lec1, Lec2):</b> Nanophotonics neural networks, deep learning and silicon photonics.	[67]-[71]		
W16 (Dec. 6)	<b>Final Presentations</b>	-		

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