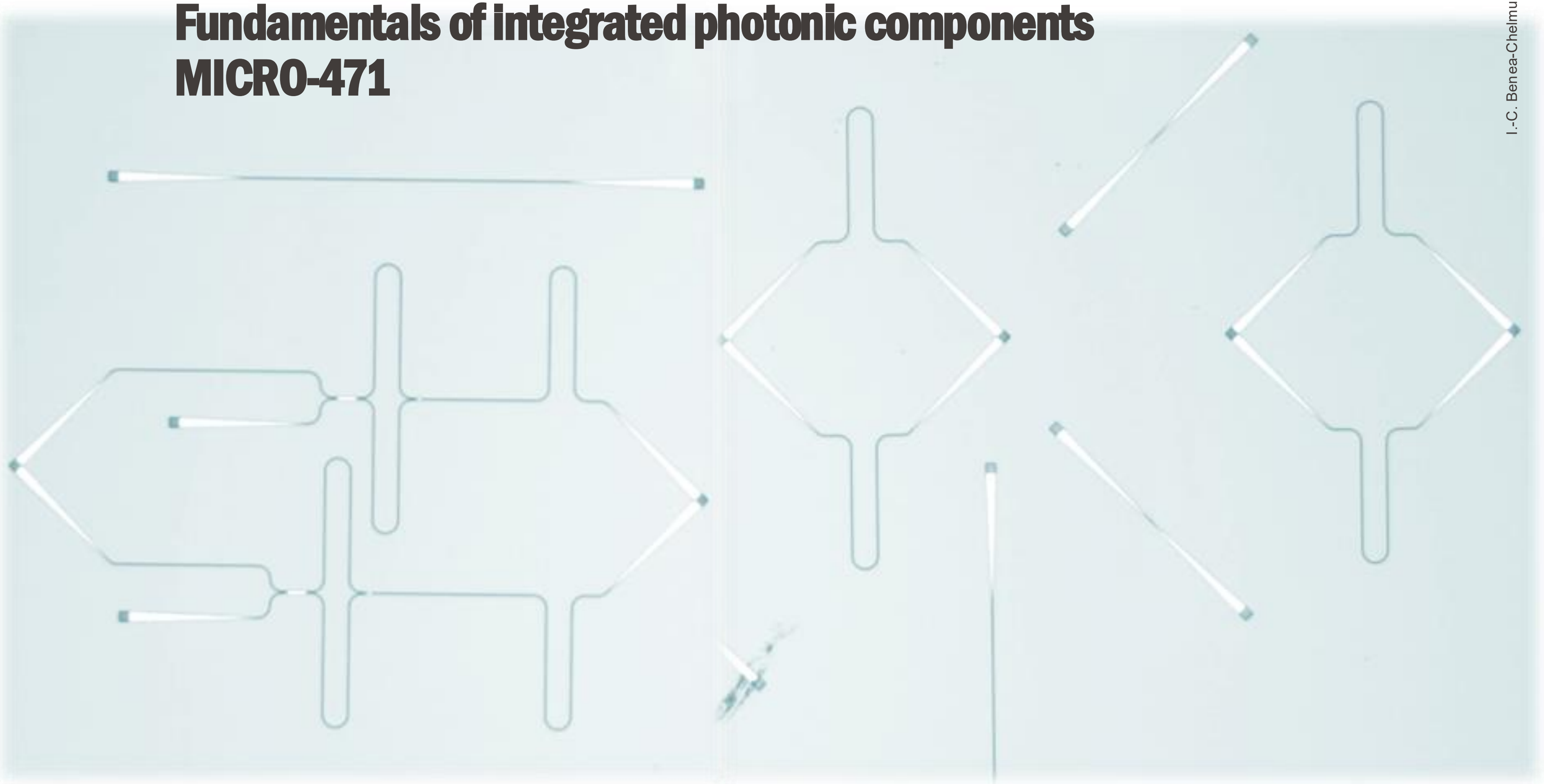
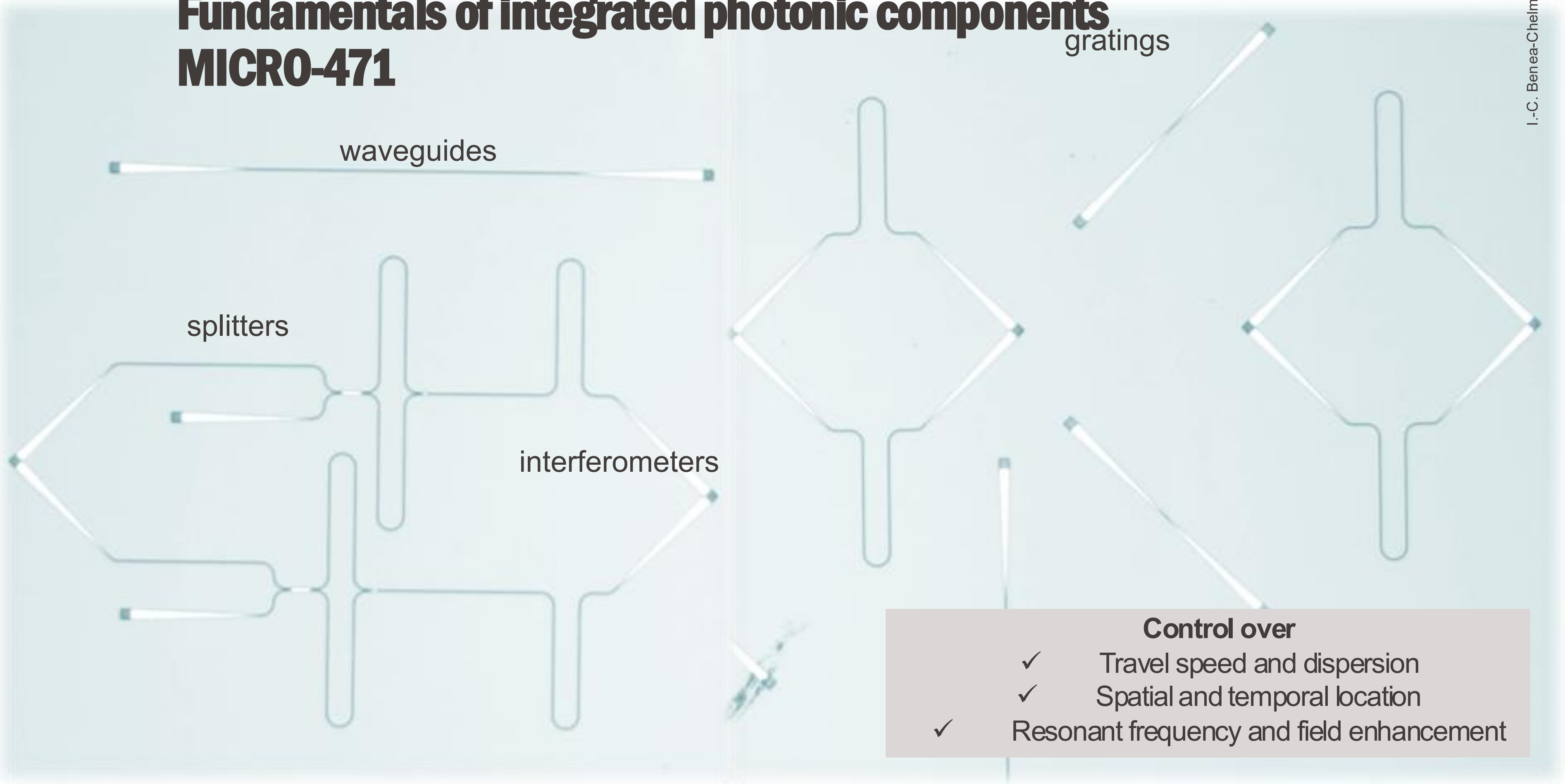
Welcome to
Fundamentals of integrated photonic components
MICRO-471



I.-C. Benea-Chelmus

Welcome to
Fundamentals of integrated photonic components
MICRO-471

I.-C. Benea-Chelmus



Control over

- ✓ Travel speed and dispersion
- ✓ Spatial and temporal location
- ✓ Resonant frequency and field enhancement

Today

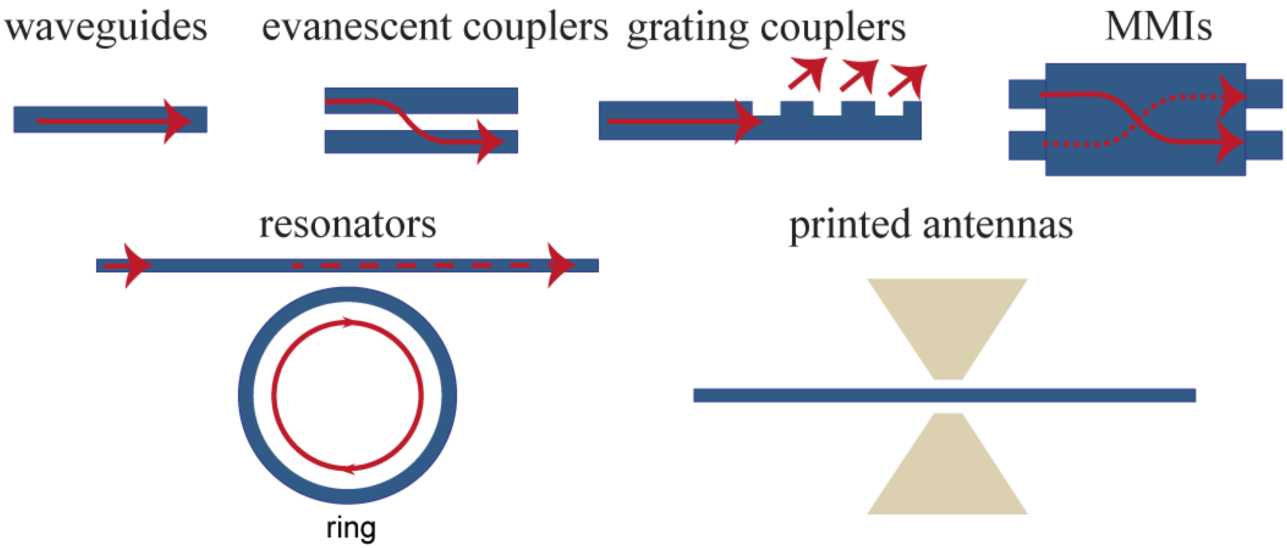
- Introduction:
  - Why should we care about integrated photonic circuits?
  - What is this course about?
- Organisational things:
  - Syllabus and moodle
  - Exercise/simulation classes and exam
- Introduction to integrated photonic circuits
- Revision of Maxwell equations

Poll students

- Which background?
- Why interested in this class? What are you hoping to learn?
- Which other courses (past/present)?

Course overview

This course gives an introduction to the basic building blocks of integrated photonic circuits



The vision

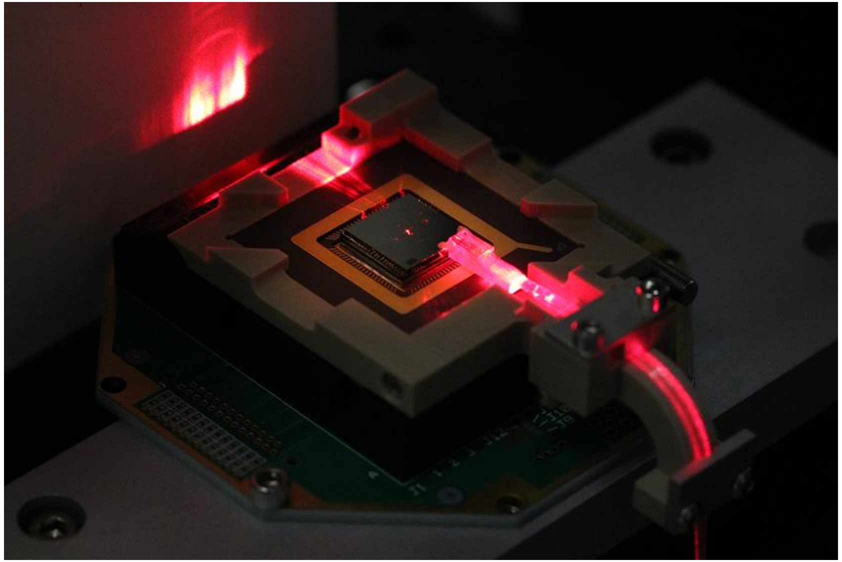
”

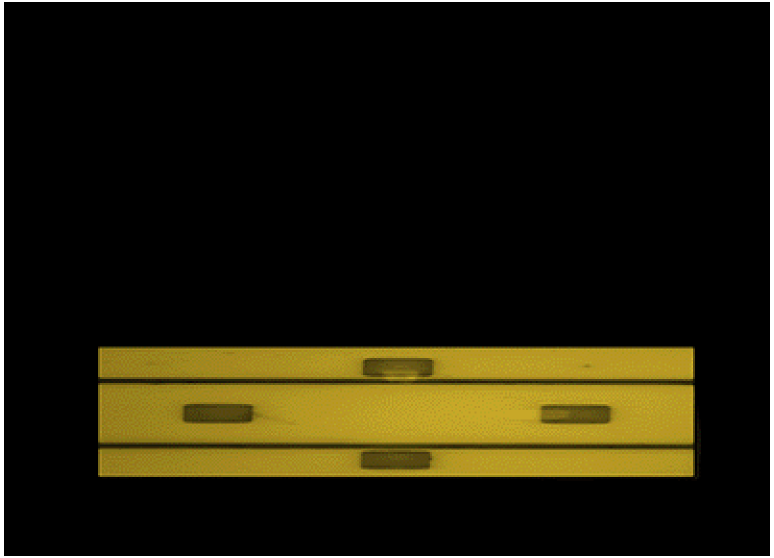
In most cases, integrated photonic circuits aim to emulate and then surpass table-top optical setups, with the particular advantage of compactness.

Miniaturisation comes with many benefits: larger bandwidth, more power-efficient, stable, quantum-compatible.

In many applications these unique figures of merit are main drivers of innovation.

PICs in the news: ion traps for quantum applications



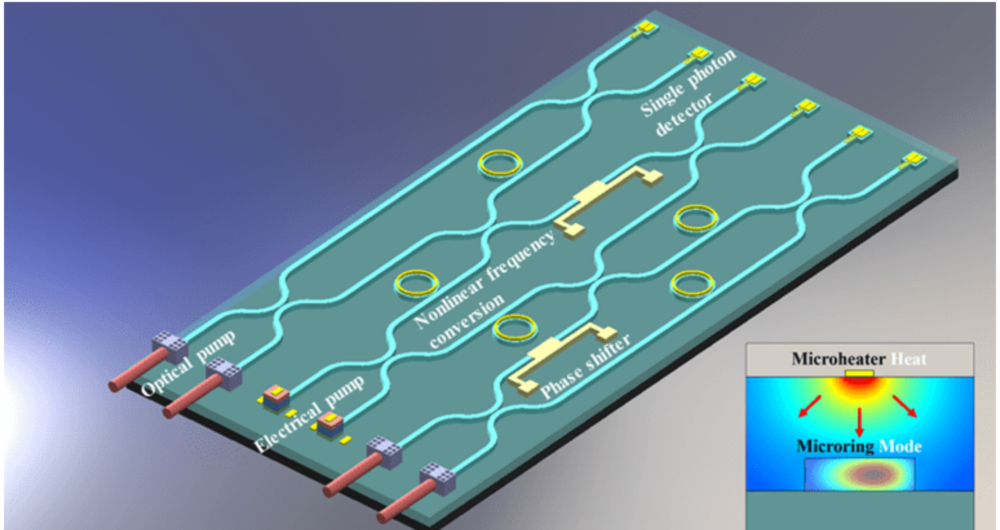


Need of many colors on a single chip:

✓ Customized photonic circuits & Compactness are key to deal with low-dimensional systems like single ions.

Niffenegger, R.J., Stuart, J., Sorace-Agaskar, C. *et al.* Integrated multi-wavelength control of an ion qubit. *Nature* **586**, 538–542 (2020). https://doi.org/10.1038/s41586-020-2811-x

PICs in the news: photonics for computing

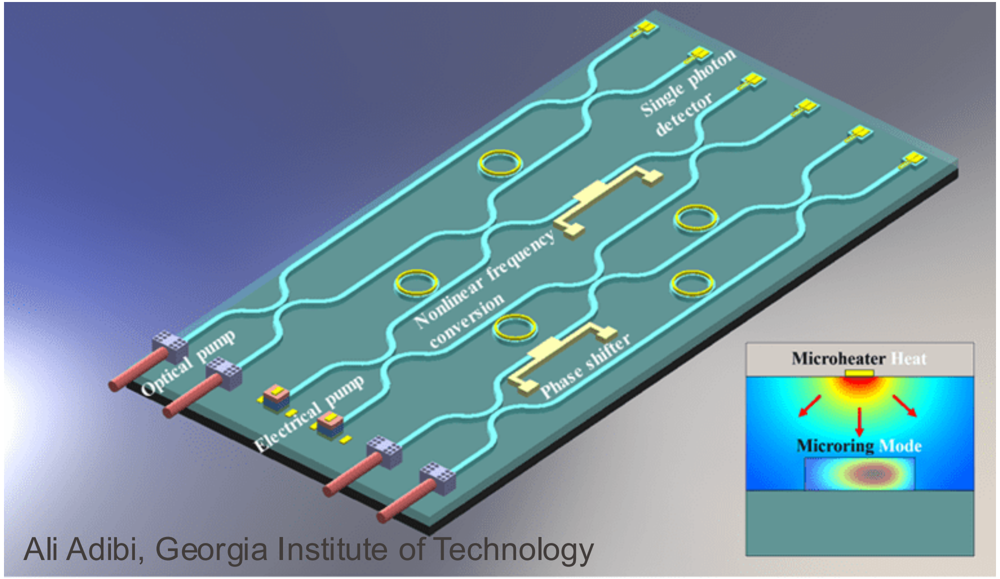


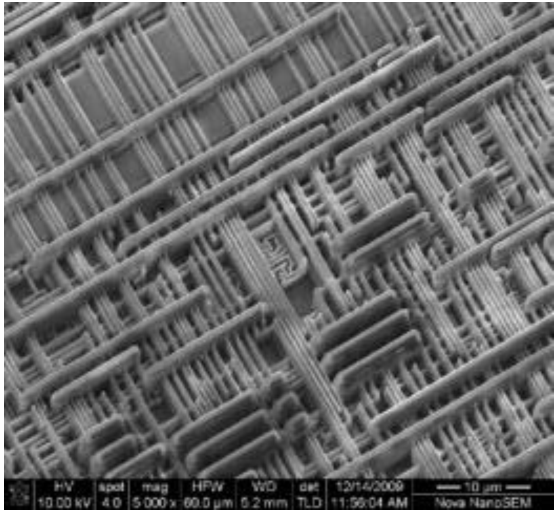
Ali Adibi, Georgia Institute of Technology

Several things need to be addressed:

- ✓ Logic **on-chip**: Often rely on two-arm interferometers
- ✓ Compactness: many components need to work in parallel

PICs in the news: photonics for computing





Electronic circuits

Several things need to be addressed:

- ✓ Logic: Often rely on two-arm interferometer.
- ✓ Compactness: many components need to work in parallel
- ✓ Less heat dissipation than electronics (but less tightly packed!)

I.-C. Benea-Chelmus

PICs in the news: optical communications

Transparent links:

- ✓ Transform microwaves to the telecom and back
- ✓ Microwaves: transmission through air, telecom: along optical fibers
- ✓ From the end-user: not possible to tell if all over fiber or an additional link in between.

I.-C. Benea-Chelmus

PICs in the news: optical communications

Millimetre waves for the last mile

by Oliver Morsch, ETH Zurich

The "last mile" to the internet connection at home is also the most demanding. …

Transparent links:

- ✓ Transform microwaves to the telecom and back
- ✓ Microwaves: transmission through air, telecom: along optical fibers
- ✓ From the end-user: not possible to tell if all over fiber or an additional link in between.

The vision

”

The skill lies in understanding working principle of the most basic components and optimizing their properties to benefit an application of choice.

There are fundamental principles that are at the heart of all of these components and in this lecture, we’ll identify the most important ones.

(it will be theoretical at times, but hopefully worth it!)

Startups

Telecommunications

POLARITON TECHNOLOGIES

HYPERLIGHT

Lumiphase
Enabling every chip to interact through light

Foundries

LIGENTEC

LioniX INTERNATIONAL

amf ADVANCED MICRO FOUNDRY

Sensing and quantum

Nexus Photonics

MIRAEX

…. And many many more …

Today

- Introduction:
  - Why should we care about transducers?
  - What is this course about?
- Organisational things:
  - Syllabus and Moodle
  - Exercise classes and exam
- Introduction to photonic integrated circuits
- Revision of Maxwell equations

Content

- 1. Introduction & revision of Maxwell's equations
- 2. Basics of fibers and waveguides.
- 3. Basics of evanescent couplers and grating couplers.
- 4. Basics of splitters based on multi-mode interference (MMIs).
- 5. Basics of interferometers.
- 6. Basics of resonators (Fabry-Perot and ring resonators).
- 7. Basics of printed antennas.

The lecture

- **Lecture:** This course introduces the basic components of integrated photonic circuits by both treating fundamental principles and their simulation using CST microwave studio

  by Cristina Benea-Chelmus (cristina.benea@epfl.ch)

Lecture material:
You will be provided with these slides and a script that contains all derivations performed in class. I nevertheless recommend that you write down all derivations by yourself too.

Philosophy:
We gain an understanding about the main mechanisms at work and then simulate these during exercise class to see whether we find what we expect.

Organisation of the script

Chapter title

Optical waveguides

Brief motivation

What you need to learn in the end

This chapter introduces waveguides as a mean to confine propagating electromagnetic waves to a specific region of space.

Key questions:

- What is a waveguide and what are waveguide modes?
- What is the effective and the group refractive index and what is the group velocity dispersion?
- What are the fundamental modes of slab waveguides?

Key concepts: total internal reflection, self-consistency condition, evanescent wave

Key equations: effective refractive index, cut-off frequency, multimode and single mode, numerical aperture, propagation constant

Literature: Saleh and Teich, chapter 9

Use these concepts to explain

Where to read further

The exercise class

- **Exercise:** analytical exercises to deepen understanding of subjects treated in class and then time domain simulations using CST microwave studio.
- Where: in CO4, Fridays 11:15-13:00 (first class: 12.09.2025)

Exercise material:
Consists of 1-2 analytical exercises and complementing simulation exercises which will let you discover various built-in functionalities of CST Microwave studio.

Philosophy:
You derive by yourself further characteristics and map your learnings to state-of-the art integrated photonic components.

The exercise class: evaluation

- **Exercise:** there will be 6(+1) assignments to hand in.
- For each assignment you have 2 weeks to solve and hand in (hand-in at the latest on Thursdays at 24:00 via moodle)
- Each exercise sheet will amount to a maximum of 100 points
- Average of all 7 exercise sheets will count 50% of final grade.
- to have a full grade, you need a total of 600 points out of 700 maximal points

Assignment no	Exercise class	Hand in (until 24:00)
1	17.09 & 26.09	02.10
2	3.10 & 10.10	16.10
3	17.10 & 31.10	6.11
4	7.11 & 14.11	20.11
5	21.11 & 28.11	4.12
6	5.12 & 12.12	18.12
7	19.12	8.1

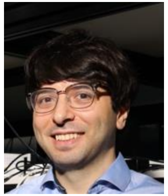
About us

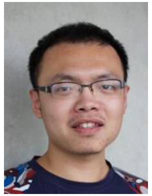
- Me:
  - I’m assistant prof. of Hybrid photonics laboratory (HYLAB): https://www.epfl.ch/labs/hylab/
  - We study photonic circuits, fabricate them and measure their properties in the lab.

- Your TAs:
  - Kailyn Vaillancourt
  - Yazan Lampert
  - Xuhui Cao

  - Dr. Jiawen Liu
  - Dr. Alessandro Tomasino
  - Dr. Andre Garcia

  Working on different material platforms: Silicon-on-insulator & thin film lithium niobate.



Your TAs

TA	E-mail address
Yazan Lampert	Yazan.lampert@epfl.ch
Kailyn Vaillancourt	Kailyn.Vaillancourt@epfl.ch
Xuhui Cao	Xuhui.cao@epfl.ch
Andre Garcia	Andre.garciaprimo@epfl.ch
Alessandro Tomasino	Alessandro.tomasino@epfl.ch
Jiawen Liu	Jiawen.liu@epfl.ch

- Ask your TAs questions during exercise class, or reach out to schedule a meeting with them!

The exam preparation

- **Exam:** final oral exam which counts for 50% of the grade and 6(+1) assessments during the semester which count for 50% of the grade.

- **Preparation:** each chapter contains key questions that you need to be able to answer at the end of the semester.

Material

- All on Moodle. Everyone has access?

Microengineering (MT) / MT - Master

Fundamentals of integrated photonic components

Course Settings Participants Grades Reports More

General

Collapse all

This course gives an introduction to basic integrated photonics components that are at the core of photonic nanotechnologies today. The course combines theoretical description with practical lab work where students will do simulations in CST Microwave Studio.

Content

The course starts from a basic revision of Maxwell's equations in linear, homogeneous, isotropic materials, followed by in-depth derivations of the following components:

Recommended books

Selected chapters from:

- Saleh, B. E. A., and M. C. Teich.: Fundamentals of Photonics.
- Yariv, A.: Optical Electronics in Modern Communications.
- Yariv, A.: Quantum Electronics.
- Haus, H.A.: Waves and Fields in optoelectronics.
- Hecht, E.: Optics.

By the end of the course

You should know:

- How the most basic integrated photonic components work and which physical properties can be controlled by means of chip-scale design. Use simple formulas to support your arguments.

- Which material platforms exist today, why are they so successful and what makes them uniquely suited to certain applications of integrated photonics.

Remember

- This is the second time that this course is being taught.

We welcome feedback!

- This course takes knowledge you may have gathered in electromagnetism and applies it to only a small subset of components.

It can be challenging at times, but it teaches you new skills:

  - How to derive analytical formulas that describe a simplified version of an integrated photonic component.
  - How to picture the waves inside these components.
  - Which properties to be careful about when simulating these with numerical solvers.

- We'll organize lab visits at the end & hopefully you'll see PICs in action.

Other useful courses

- EE 440 – Photonic systems and technology
  - Show how transducers are key building blocks in optical communications
- PHYS-501 Nonlinear optics
  - Study nonlinear optical phenomena which may be used in photonic integrated circuits
- MT-516 Nanophotonics
  - Study low-dimensional materials and their nanophotonic properties that are at the core of transducers

Overview of participants' background

- Small quiz (15 mins)
- Discussion of the quiz

Today

- Introduction:
  - Why should we care about transducers?
  - What is this course about?
- Organisational things:
  - Syllabus and Moodle
  - Exercise classes and exam
- Introduction to integrated photonic circuits
- Revision of Maxwell equations