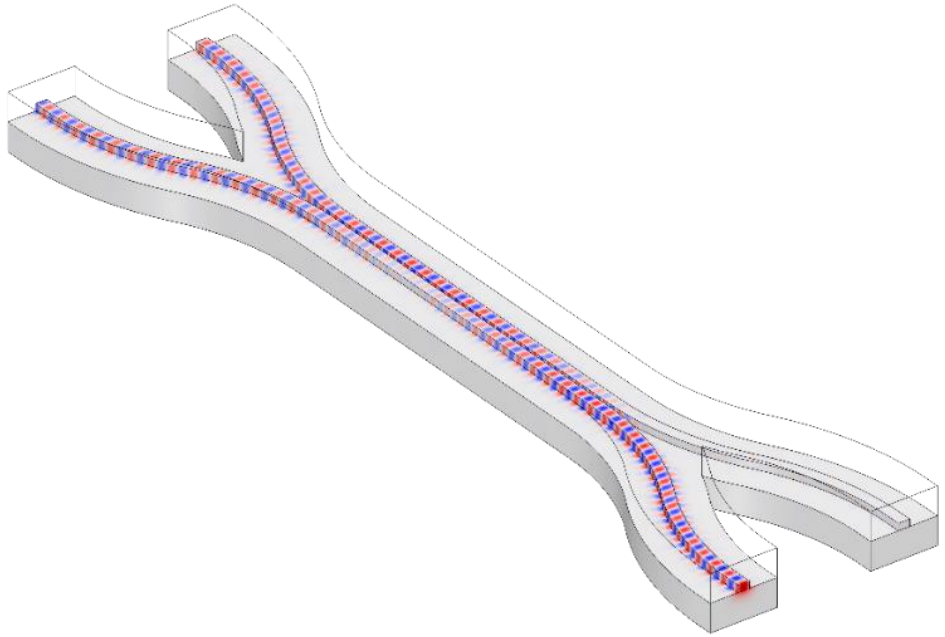
ETH zürich

P&S COMSOL® Design Tool
Lecture 1: Introduction to Optical Simulations

Manuel Kohli, Raphael Schwanninger

Welcome to the P&S:
COMSOL Design Tool – Design of Optical Components



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Outline for Today

- **General organization**
  - Presence check
  - Protection concept
  - Learning objectives
- **Why do we need simulations?**
  - Electromagnetics in our daily life
  - EM Simulation
    - What will you be able to do...
  - Examples
- **Tutorial**
  - Introduction to the Software

Learning Objectives

- In this course, we aim to teach you the process of optical component design
- You will learn to:

… **develop** a component idea into a specific design problem

… **create** the correct simulation environment (model the photonic device)

… **analyze** simulation results and **interpret** different physical effects involved

… **evaluate** the design according to initial specifications and recommend improved solution

… **summarize** the results and report them

Semester Outline

- Simulation concept
  - EM review
  - 2D EM simulation
- Intro to COMSOL tools
  - Wave optics
  - Mode solver
  - Boundary mode solver
- Project
  - Presentation
  - Report

Semester Outline

- Simulation concept
  - EM review
  - 2D EM simulation
- Intro to COMSOL tools
  - Wave optics
  - Mode solver
  - Boundary mode solver

6 weeks

- Project
  - Presentation
  - Report

6 weeks
Final presentation: Monday, 29.05.2022
Report : Monday, 05.06.2023

If there is a conflict, please let us know early

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Projects

- Design a passive optical structure for given specifications
  - Teams of 2 or individual
  - A list of possible projects will be given / implement own idea

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Projects

- Design a passive optical structure for given specifications
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- Steps of Project

1. Build model
2. Set physics and boundary conditions
3. Simulate
4. Evaluate preliminary results
5. Optimize
6. Analyze and report

Projects

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1. Build model
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- Evaluation

1. **Presentation** (12 minutes talk and 3 minutes questions, **Monday 29.05.2023**)
2. **Written report** (<10 pages with pictures and references, **Monday, 05.06.2023**)

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Practical Information – Administrative

- Time: Mondays from **13:15h** to ~**15:00 h**
- Location: **ETZ D61.1**
- Our availability: office hours ETZ K-floor

(*Send email to schedule a meeting*)

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Practical Information – Online Material

- Online material
  - https://blogs.ethz.ch/ps_comsol/
    - Presentations
    - Exercises
    - Literature
- Literature
  - B. Salah and M. Teich, *Fundamental of Photonics*, 2nd ed., 2007.
  - K. Okamoto, *Fundamentals of optical waveguides*, 2nd ed., Elsevier, 2006.

Questions?

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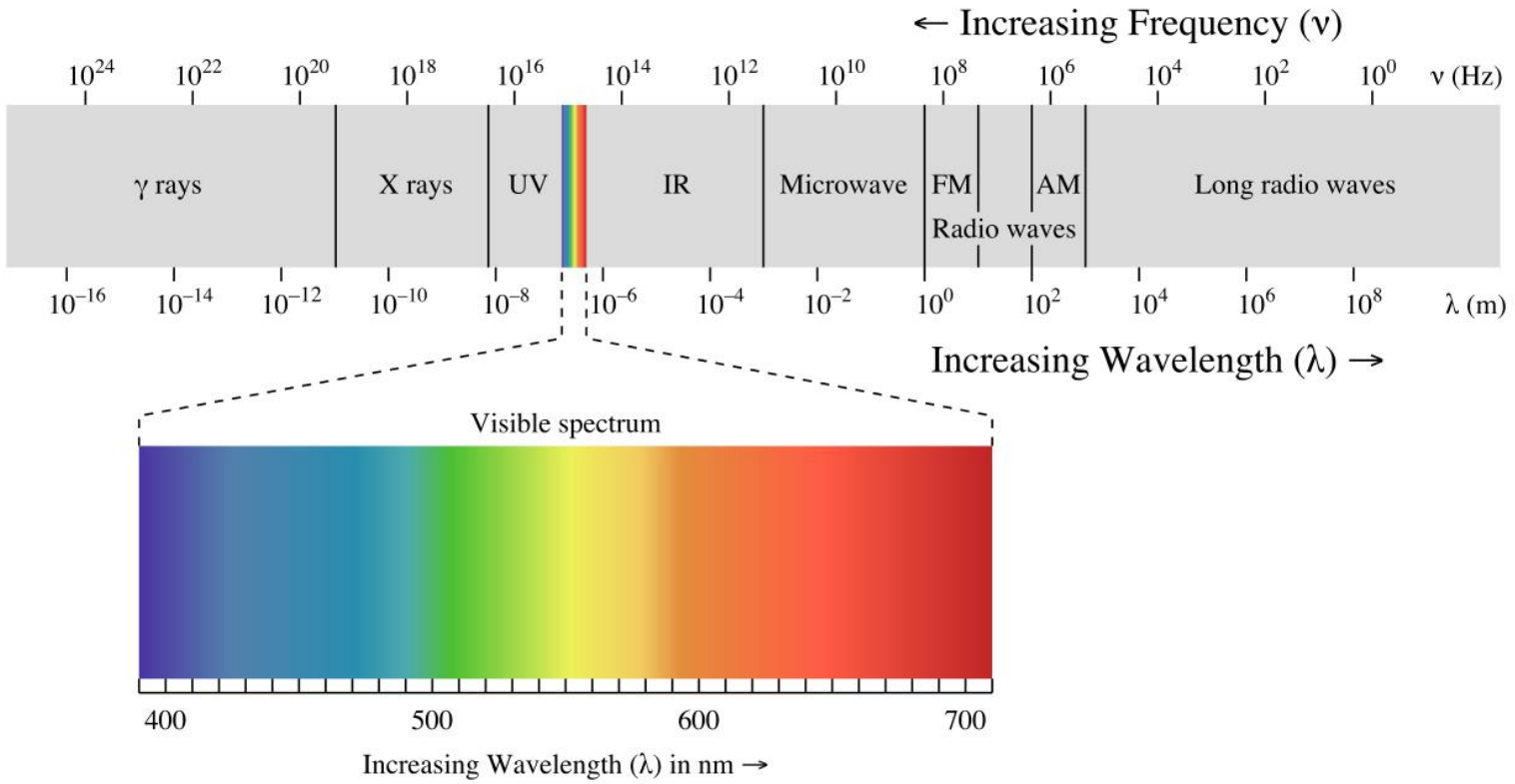
About us

- Raphael Schwanninger
  - Detector stuff...

- Manuel Kohli
  - Ferroelectric electro-optic modulators on SiN
    - Photonic integration of different platforms
    - Design, fabrication, and measurement
    - “Optical Machine” Assembly (PIC + EIC)
  - 3D Nanofabrication for novel components

Electromagnetics in Our Daily Life



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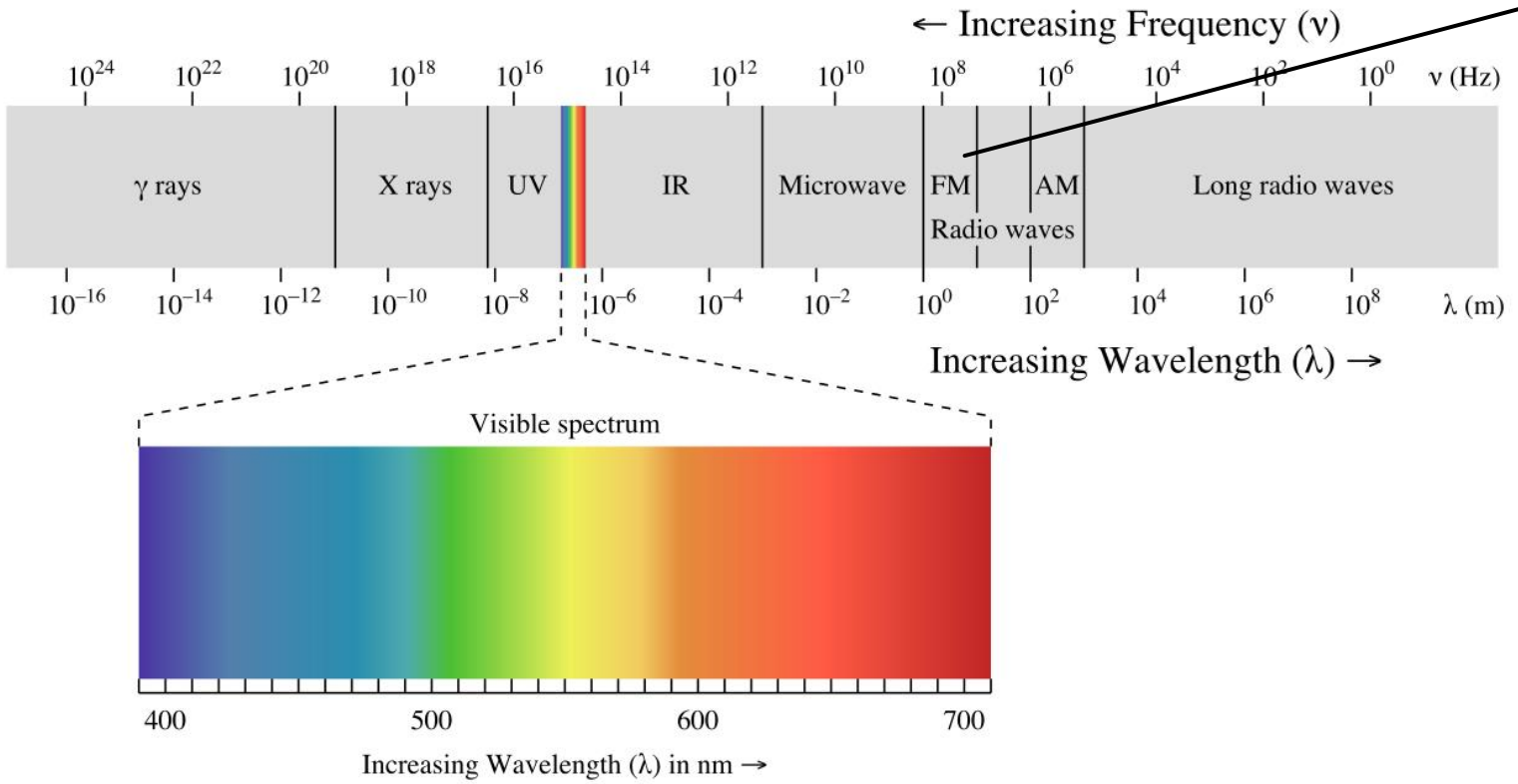

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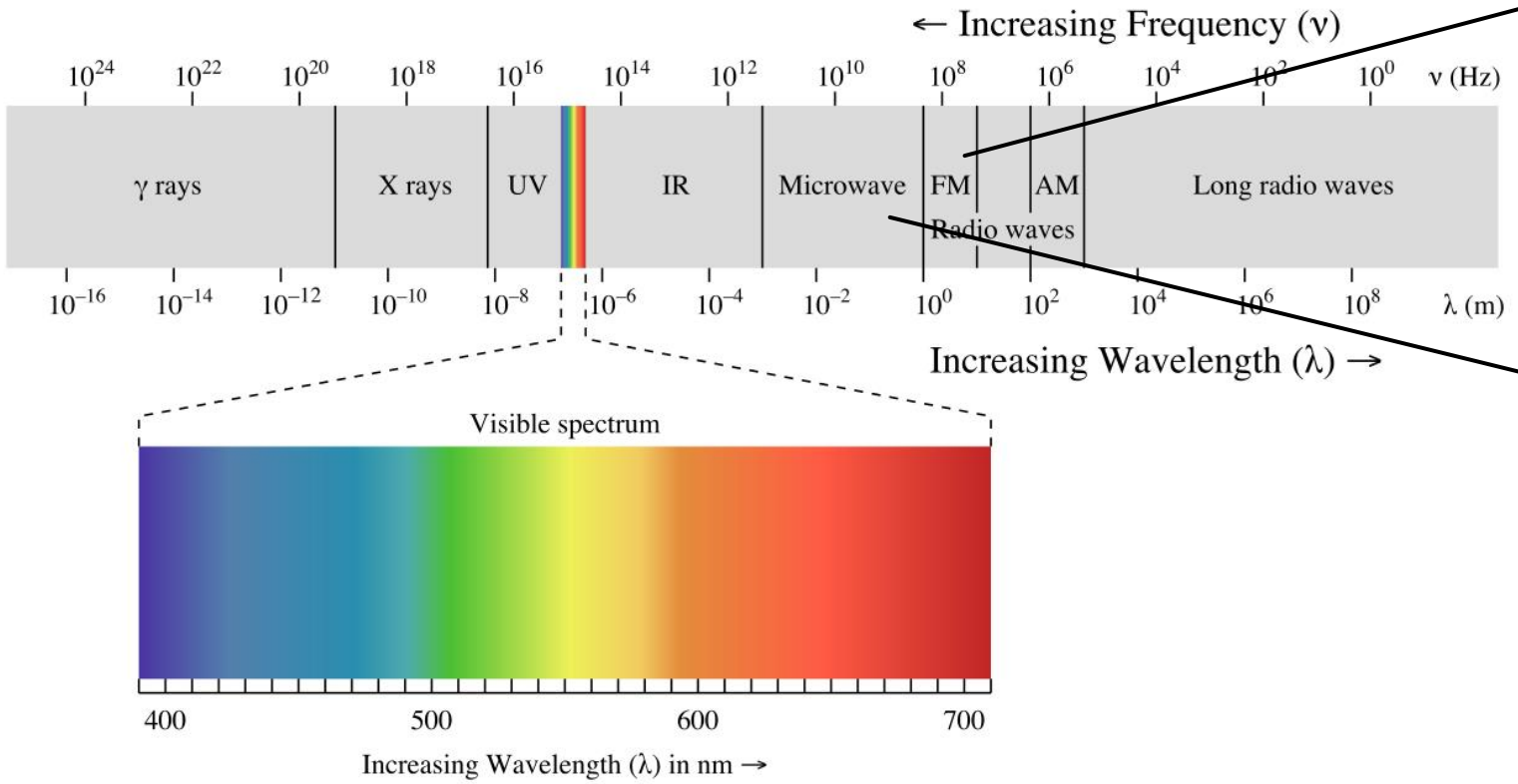

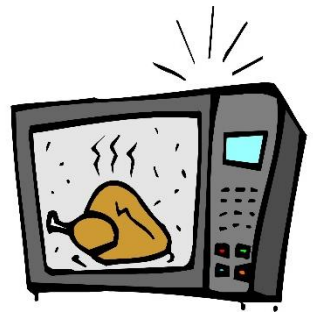

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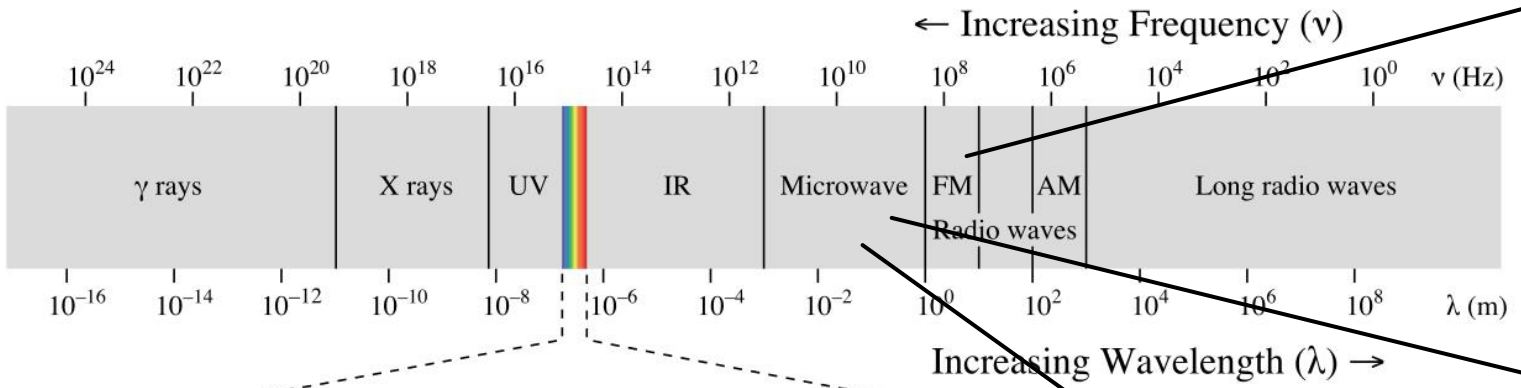

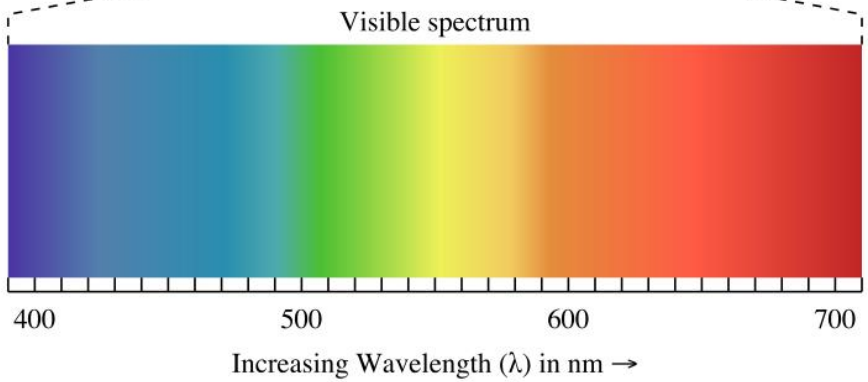

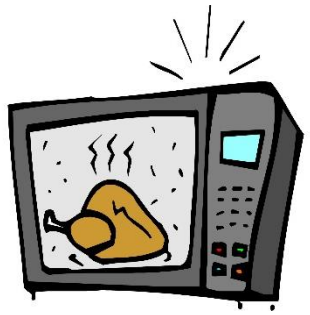

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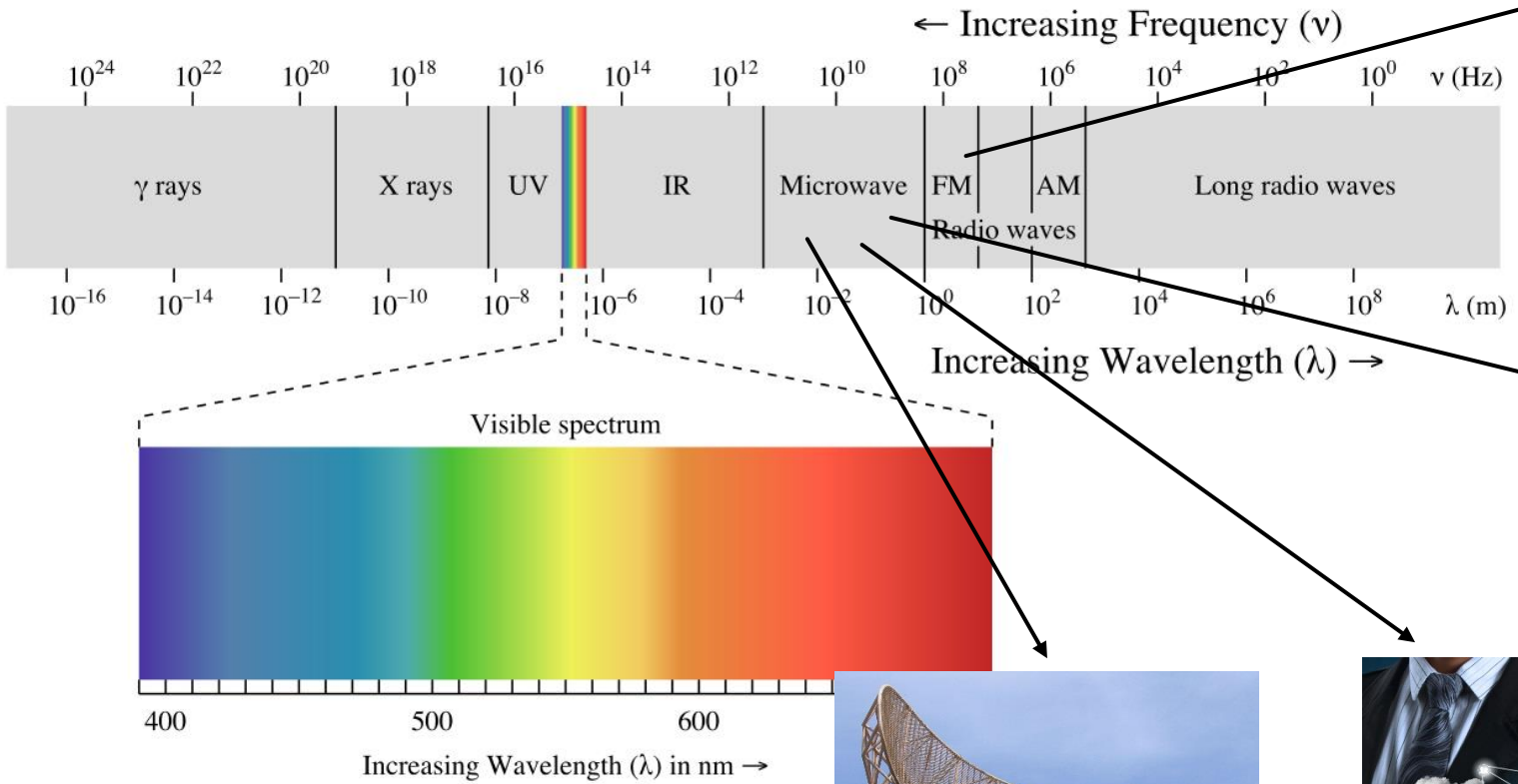

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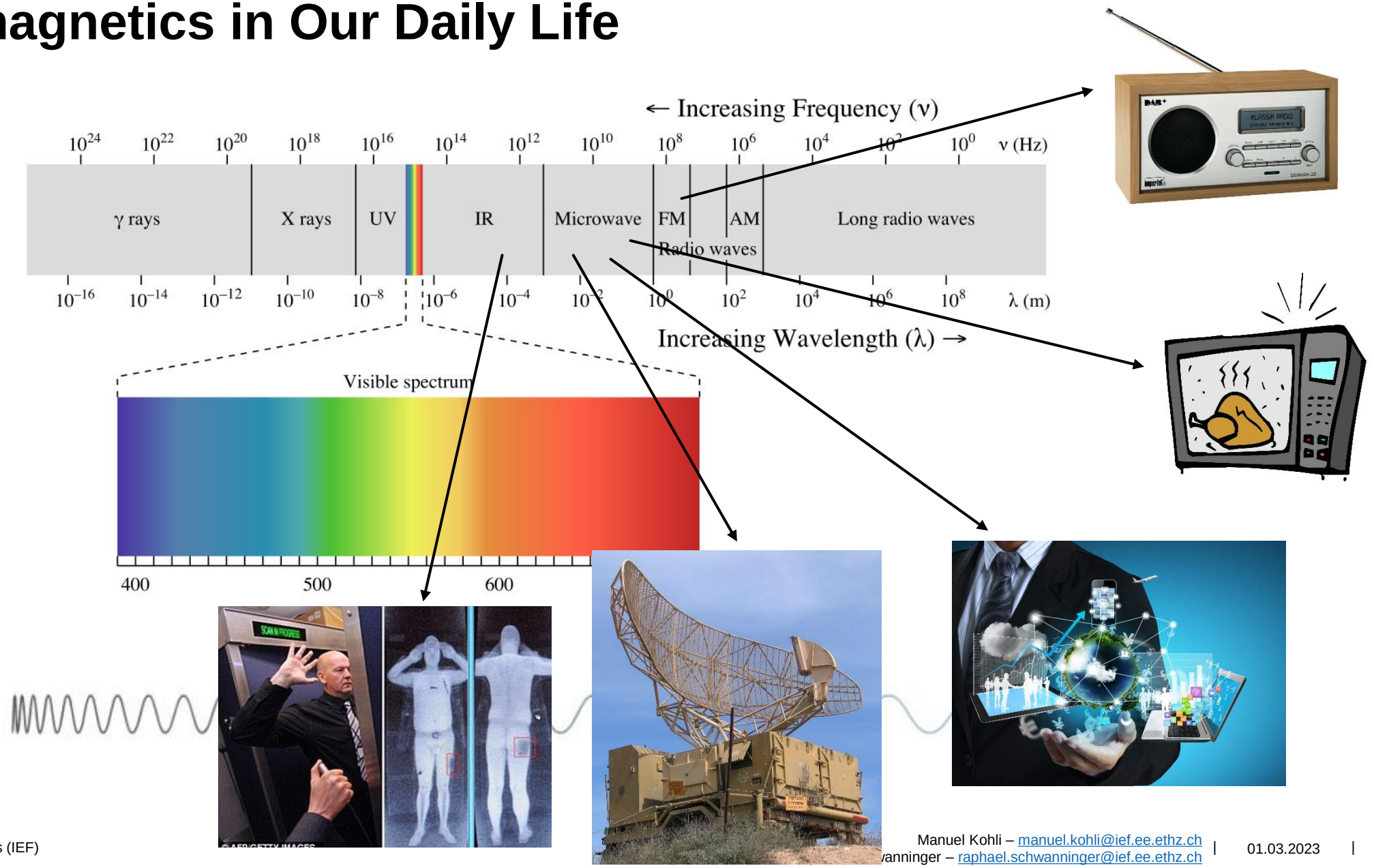

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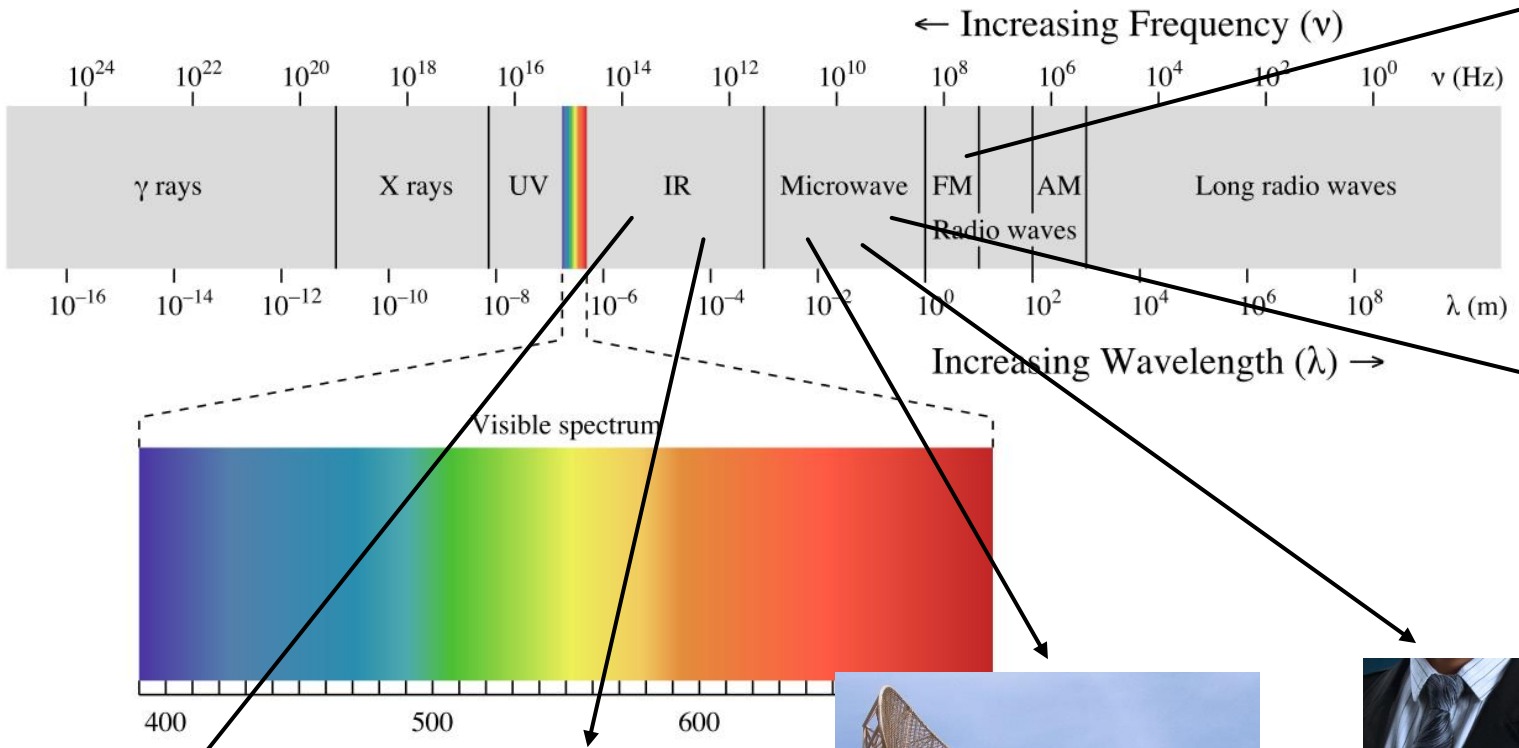

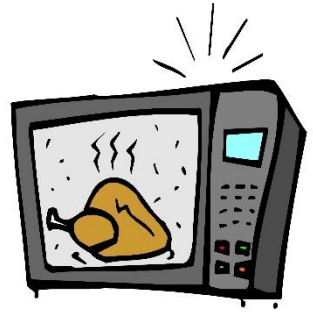

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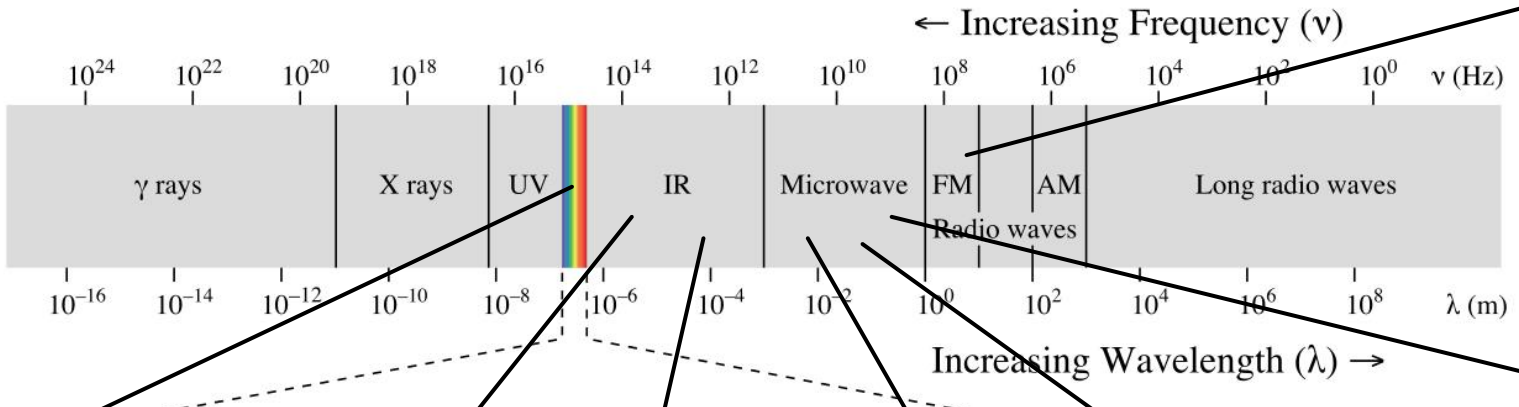


Electromagnetics in Our Daily Life

← Increasing Frequency (ν)

10^{24} 10^{22} 10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4} 10^{2} 10^{0} ν (Hz)

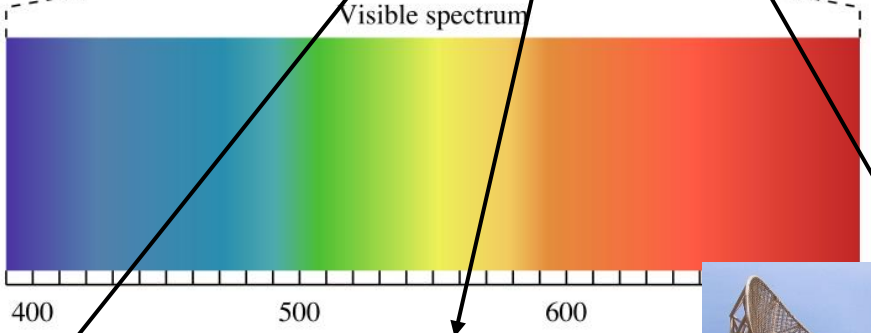
γ rays | X rays | UV | IR | Microwave | FM | AM | Long radio waves

Radio waves

10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} λ (m)

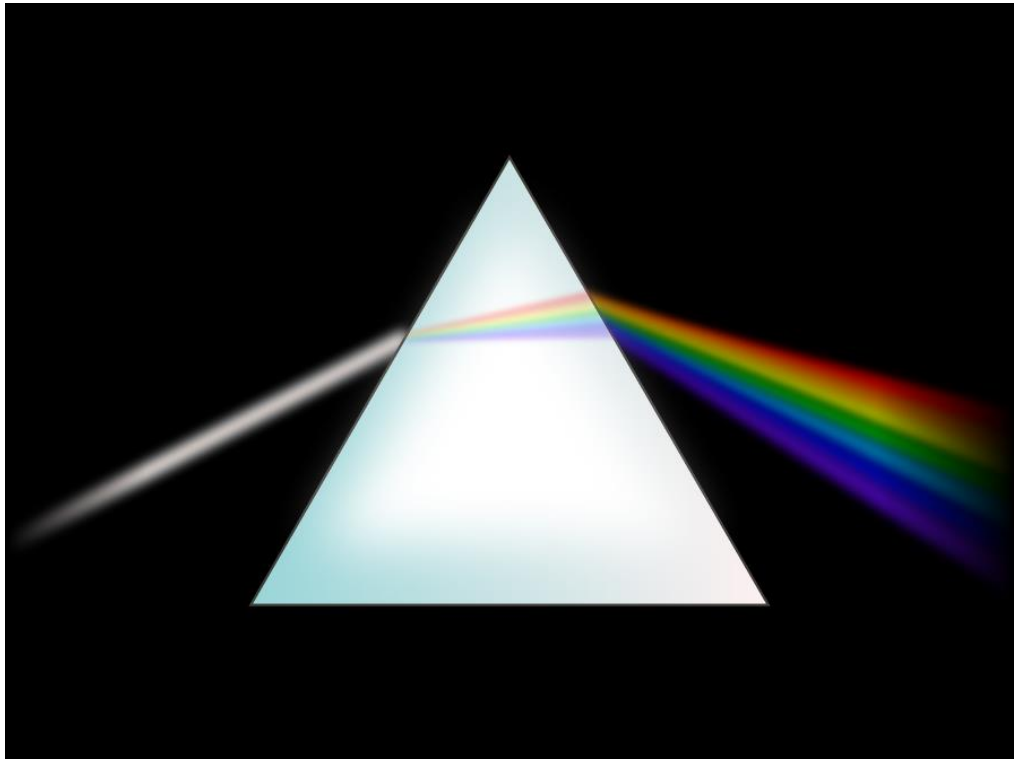
Increasing Wavelength (λ) →

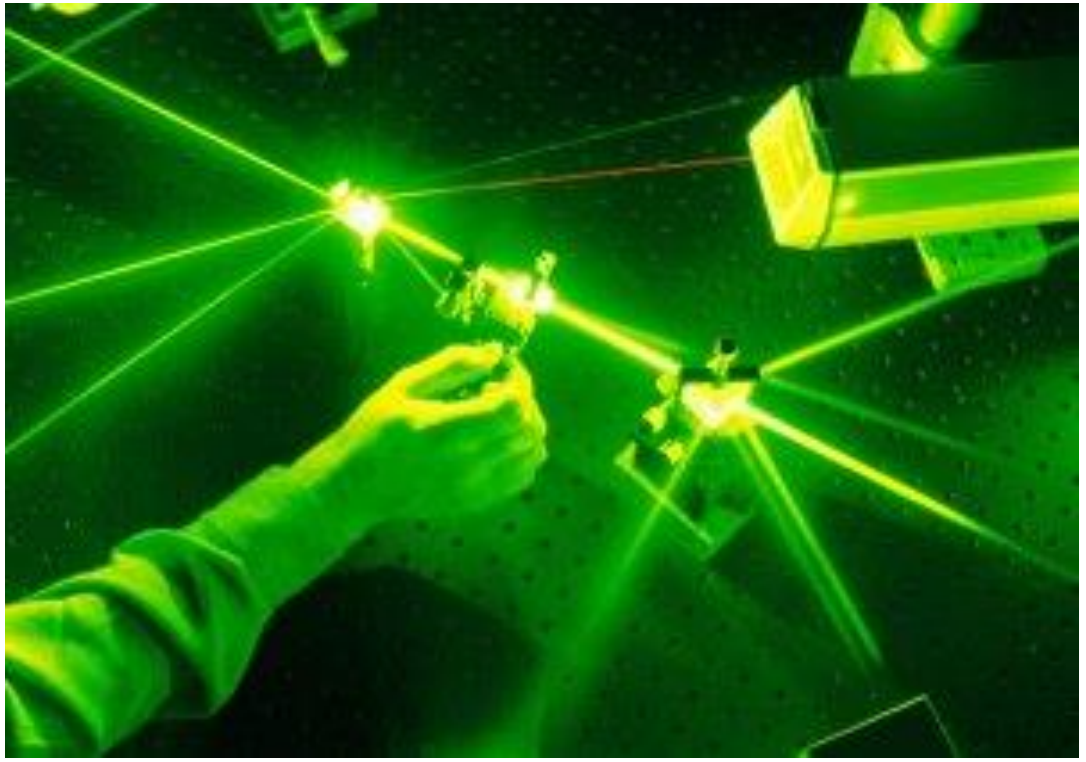
Visible spectrum



Photonics

- Photonics – studying the properties of light





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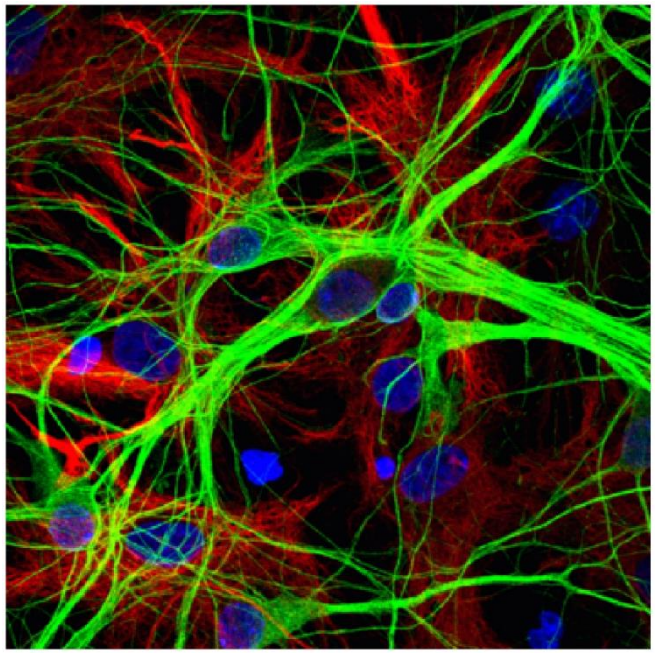
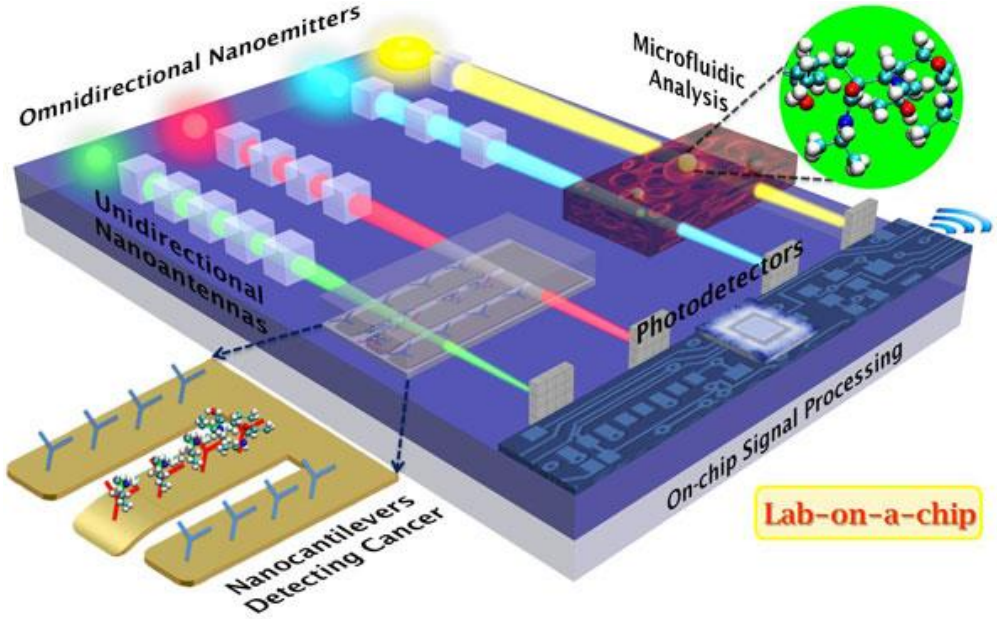
Photonics Today

- Photonics – studying the properties of light
- Where do we use it today?
  - ***Biology – Lab-on-Chip***





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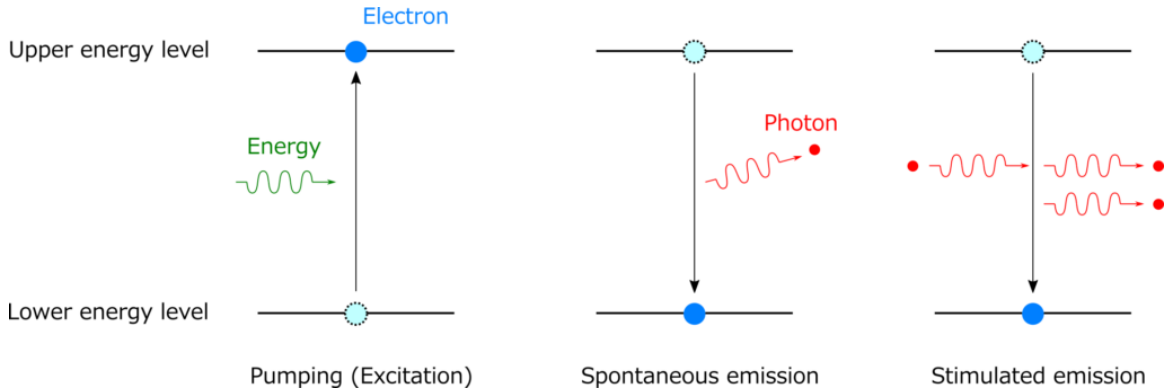
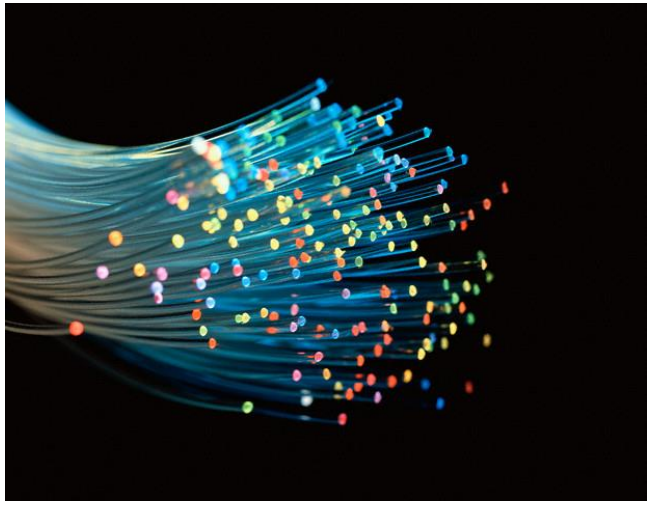
  - ***Quantum effects***

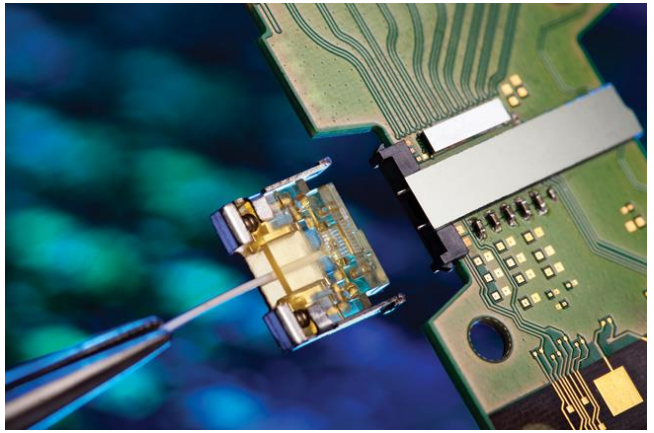


Laser Pointer

Photonics Today

- Photonics – studying the properties of light
- Where do we use it today?
  - *Biology – Lab-on-Chip*
  - *Quantum effects*
  - ***Telecommunications***
    - ***Fiber replaces traditional copper wires***
    - ***5G***





Source: Intel

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Photonics for Communications: Basic Principles

- Light manipulation
  - *Generation*

LED generates light

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Photonics for Communications: Basic Principles

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  - *Guiding*

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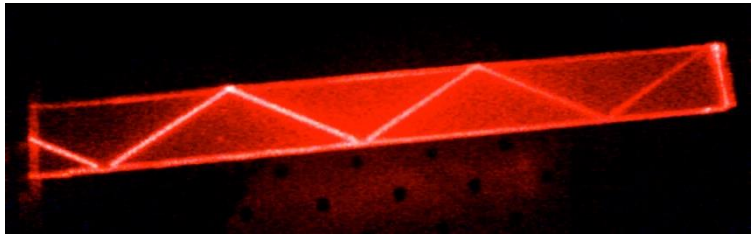

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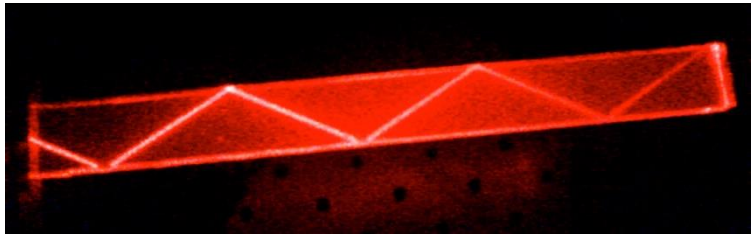
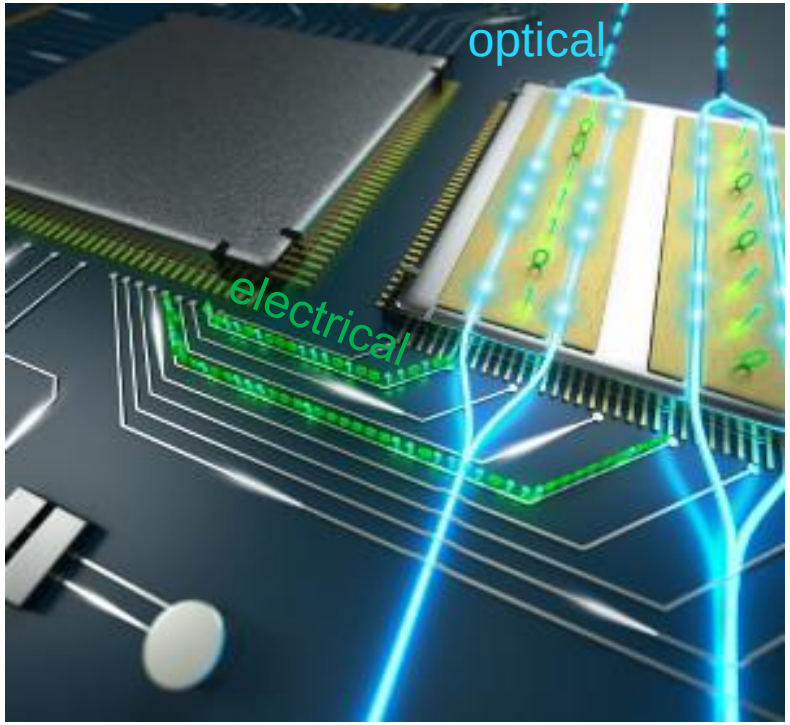
Photonics for Communications: Basic Principles

- Light manipulation
  - *Generation*
  - *Guiding*
  - *Modulation*
  - *Detection*

LED generates light

Fiber guides light





Modulator: From electrical data to optical data

Detector: From optical data to electrical data

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Communication: From Radio to Fiber

- Radio waves
  - Broadcasting
  - Copper wires (TV/Phone)

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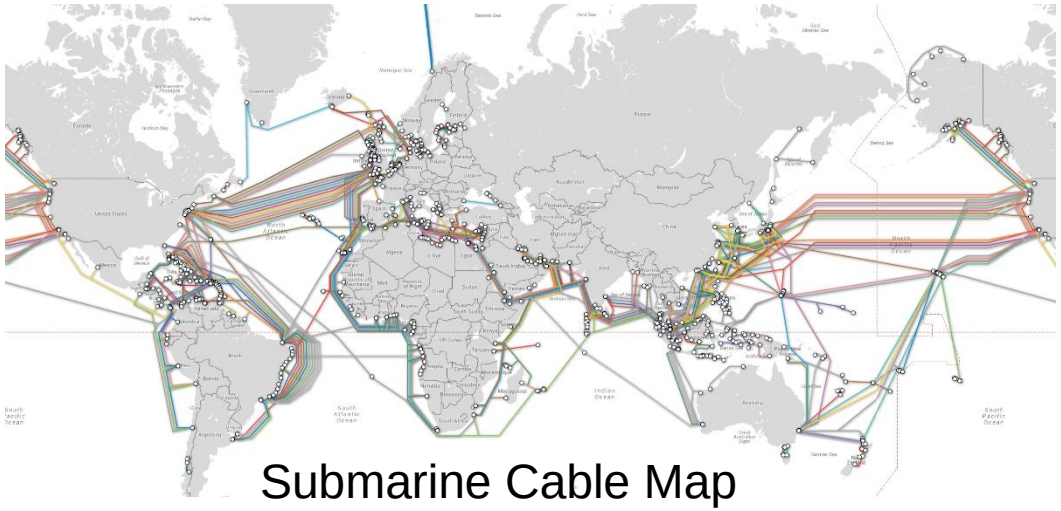
Communication: From Radio to Fiber

- Radio waves
  - Broadcasting
  - Copper wires (TV/Phone)
- Fiber optics (NIR)
  - Advantages
    - Large bandwidth
    - Low losses
  - Fiber deployment
    - Long distances: Submarine Cables
    - Short distances: Server



Submarine Cable Map

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Why do we need simulations?

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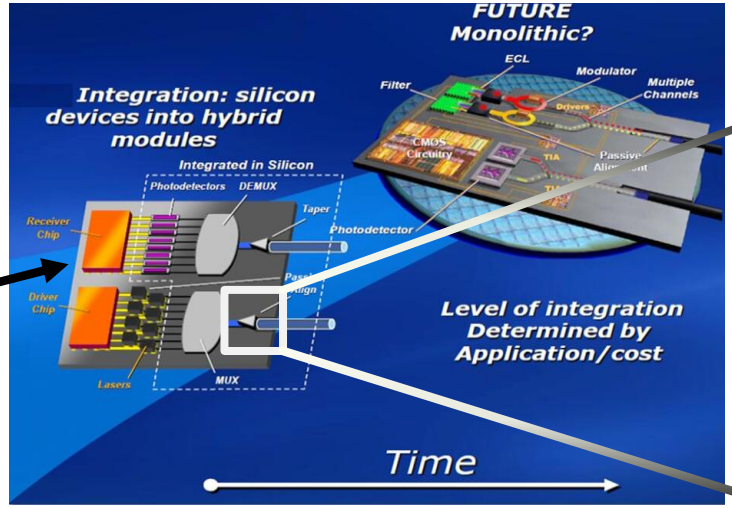
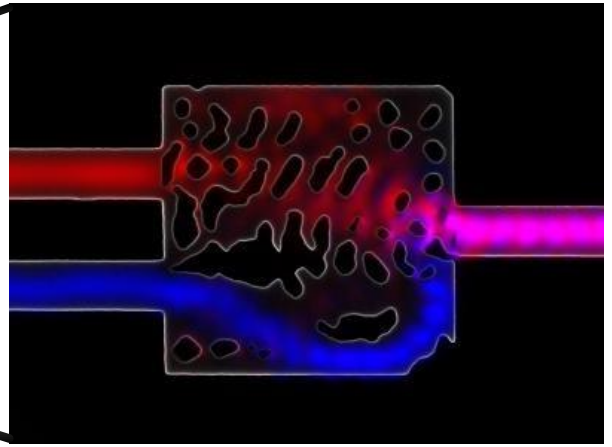
Why Simulate?

- Implementation of devices
  - Devices need a design**!**
  - Fabrication & characterization (test)
  - Improvement of the design

} Time & money





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Why Simulate?

- Implementation of devices
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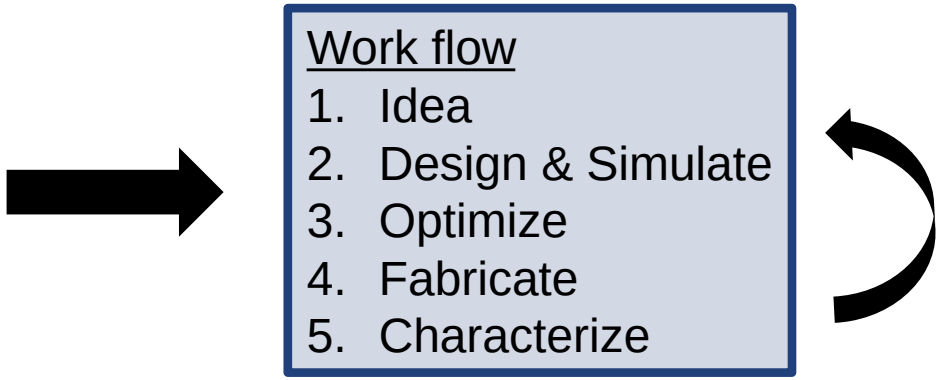
  - Fabrication & characterization (test)
  - Improvement of the design

} Time & money

- We perform simulations to…
  - Shorten the developing time
    - Fast
    - Cost effective
  - Test physical models
  - Confirm experimental data
  - Investigate ideas



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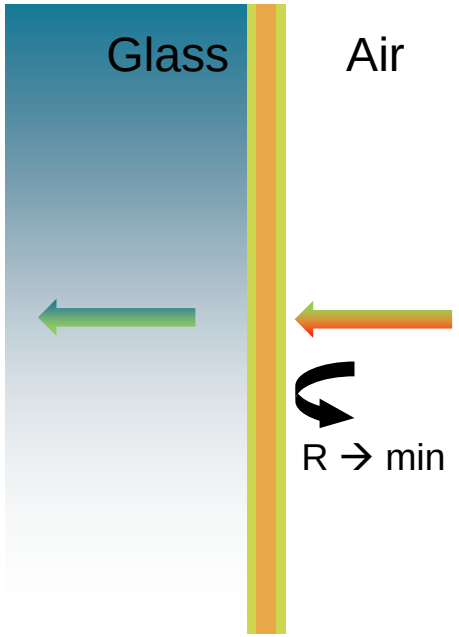
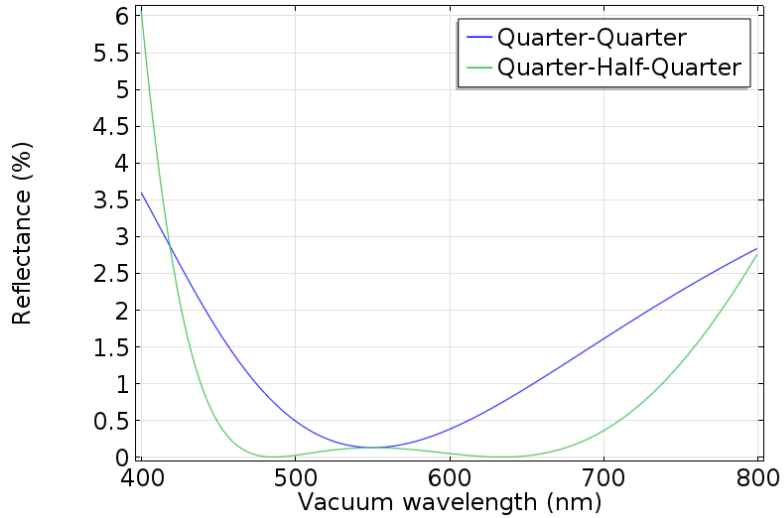
What you will be able to simulate…

- Anti – reflection coating

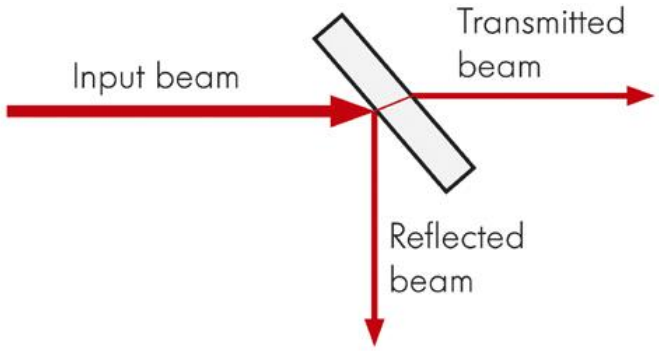




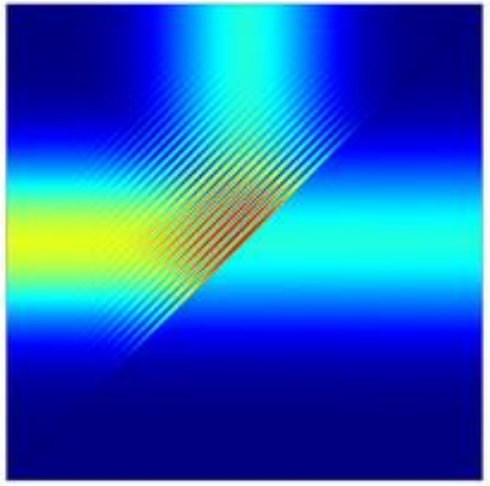
What you will be able to simulate…

- Beam Splitter

1.



2. & 3.



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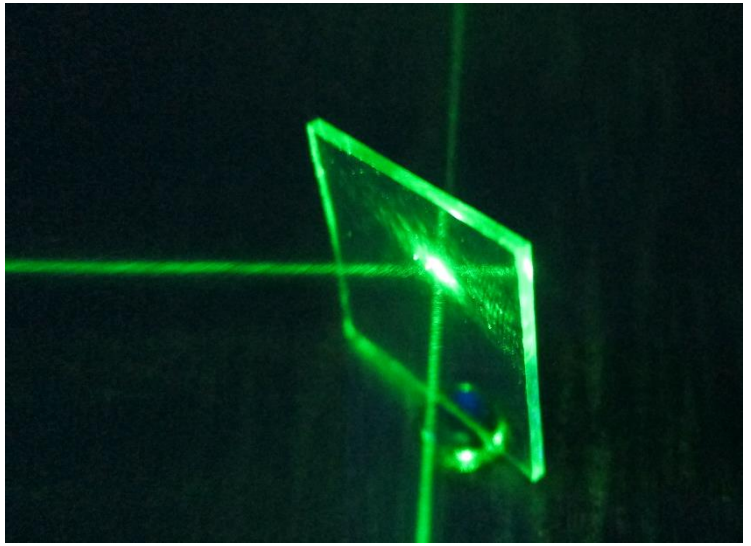

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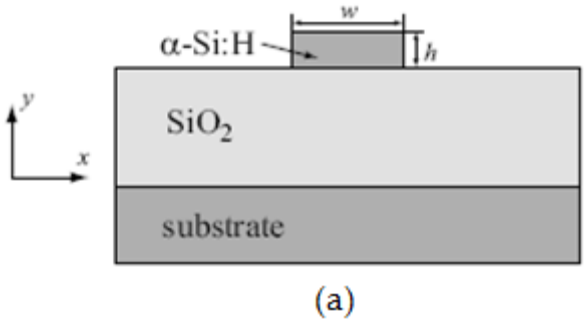
What you will be able to simulate…

- Silicon waveguide

1.



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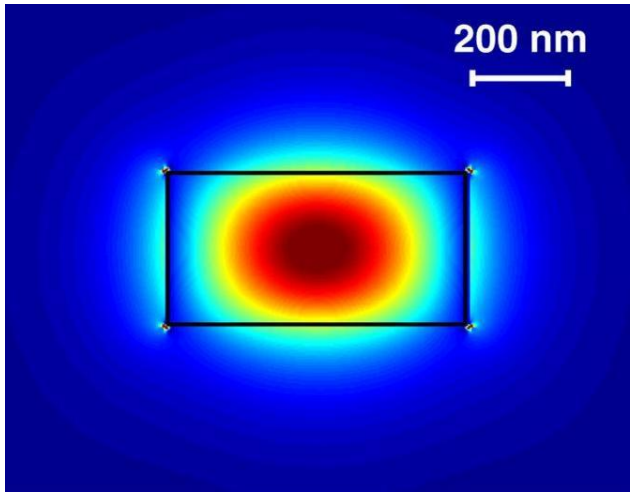

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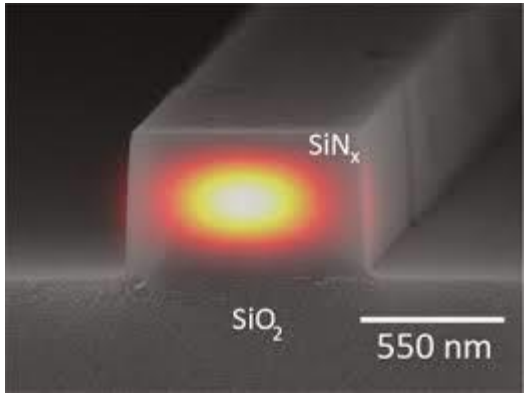

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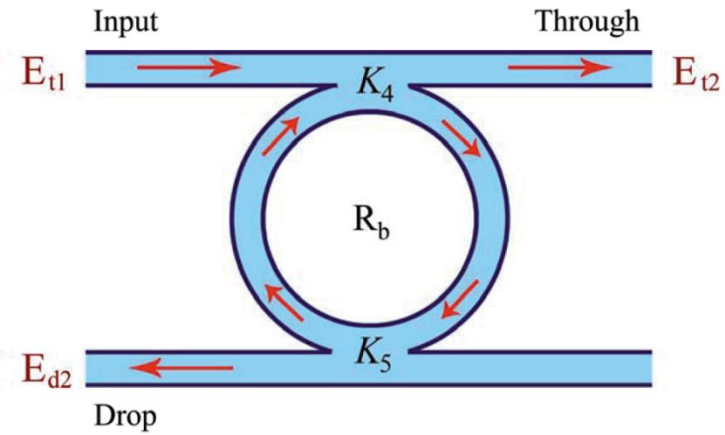
What you will be able to simulate…

- Optical add-drop filters

1.



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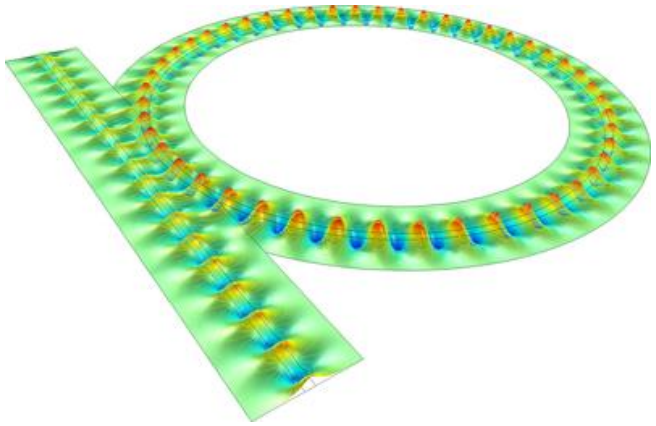

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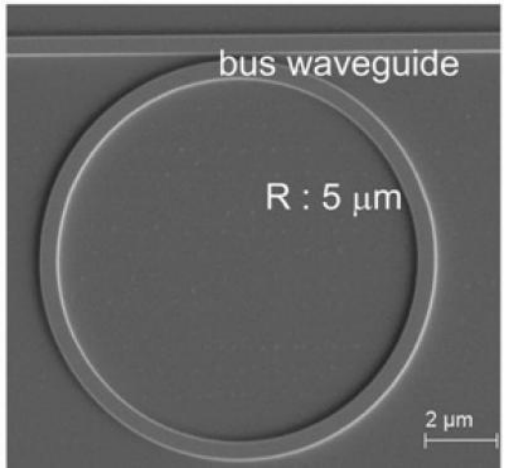

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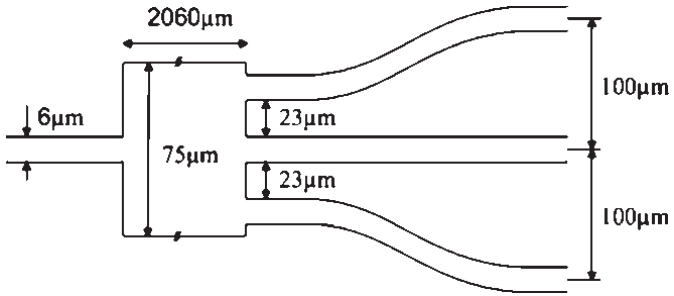
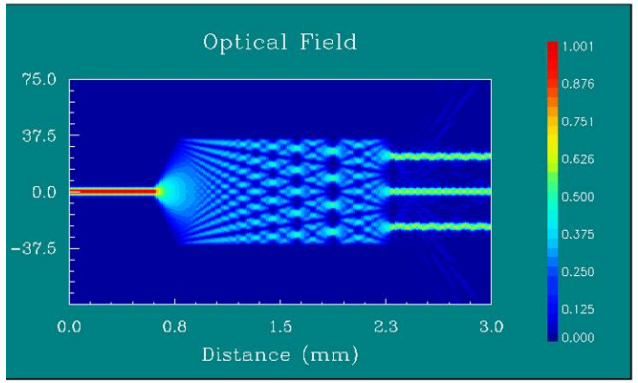
What you will be able to simulate…

- Multi-mode interferometer

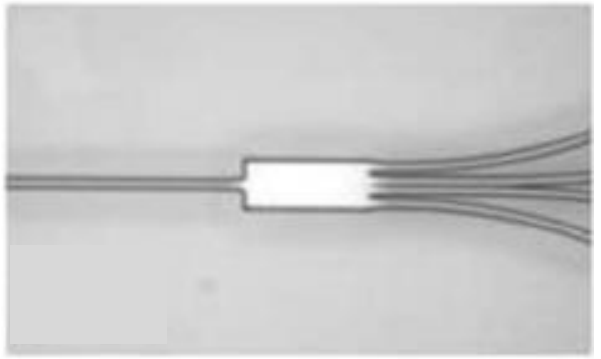
1.



2. & 3.



4.



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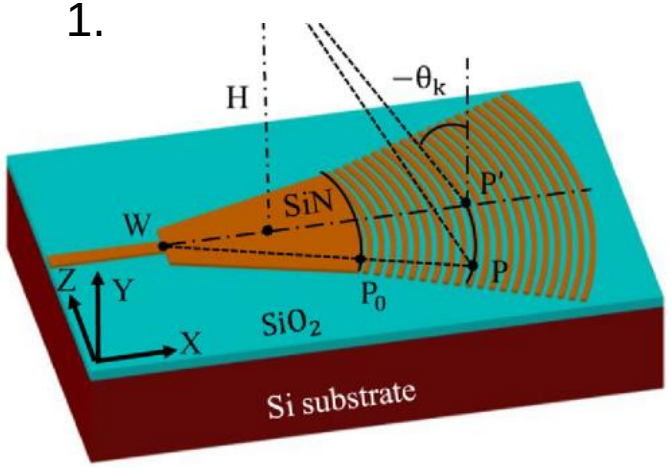
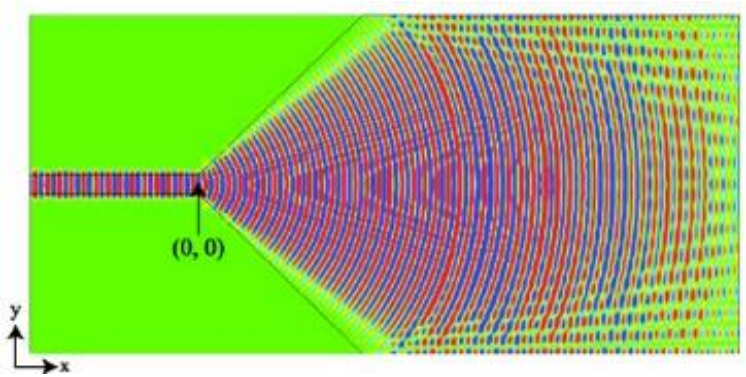
What you will be able to simulate…

- Grating coupler

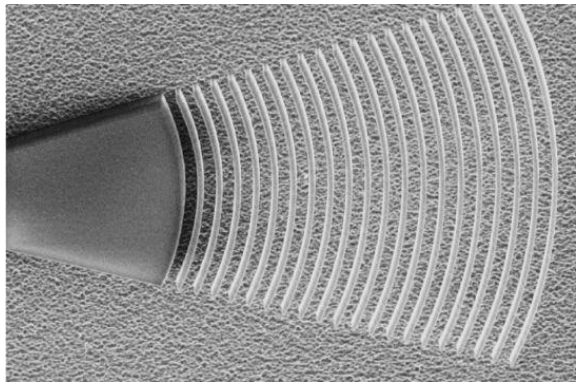
1.



2. & 3.



4.



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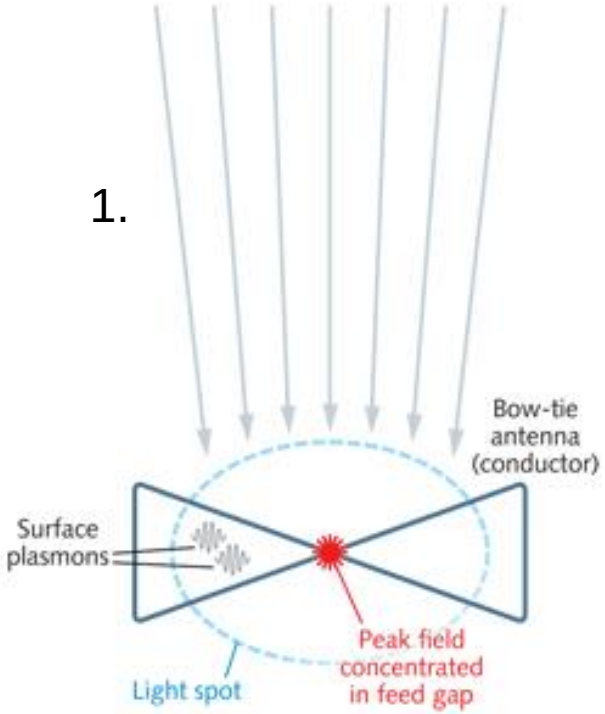
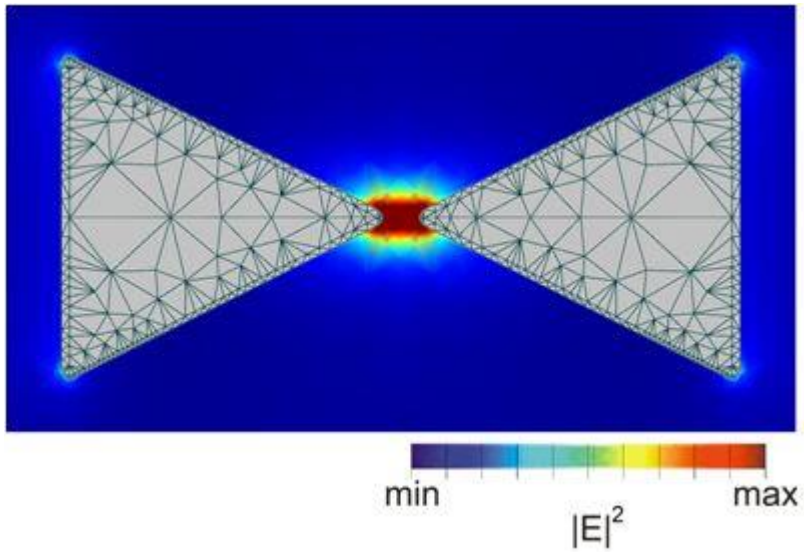
What you will be able to simulate…

- Optical Antennas

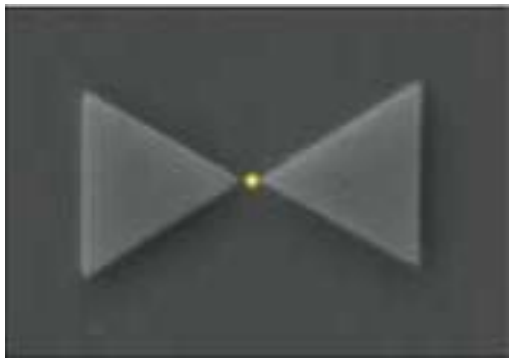
1.



2. & 3.



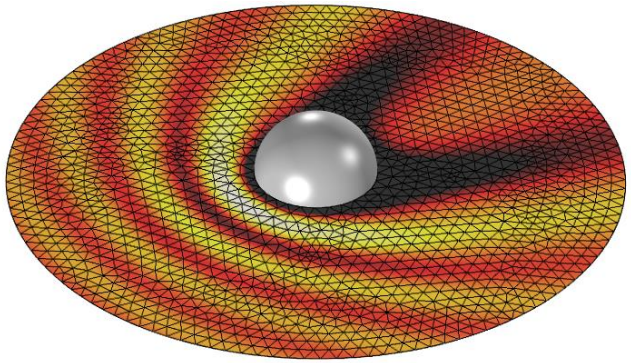
4.



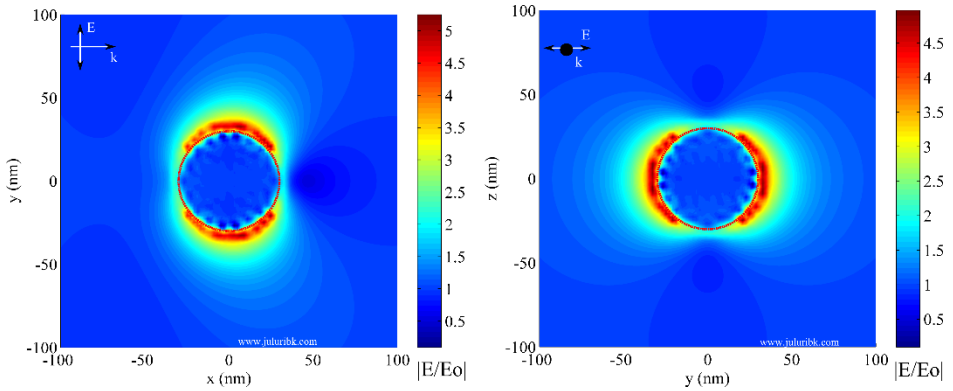
What you will be able to simulate…

- Scattering from metallic nanoparticle

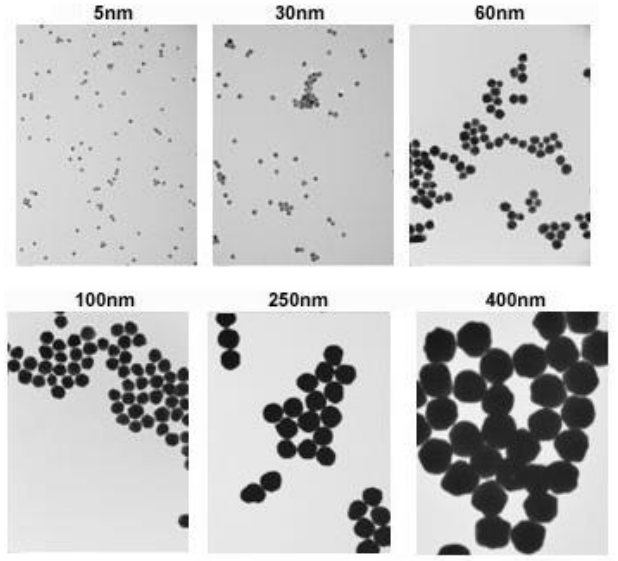
1.



2. & 3.



4.



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Questions?

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