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GBM Attendance

Silicon Photonics

Jonas Kendra
RPI IEEE/EPS | 20 Feb. 2025

Updates

GlobalFo

We ar

GlobalFoundries Fab 8

- GlobalFoundries Headquarters

- 30 minutes from Troy

- Get to go into fab and see fab equipment in action

- Tour attendees must be IEEE EPS members!

- More details soon!

Interest Form!

Overview

Origins
Physics/how it works
Benefits
Systems that use it
Future State

Origins

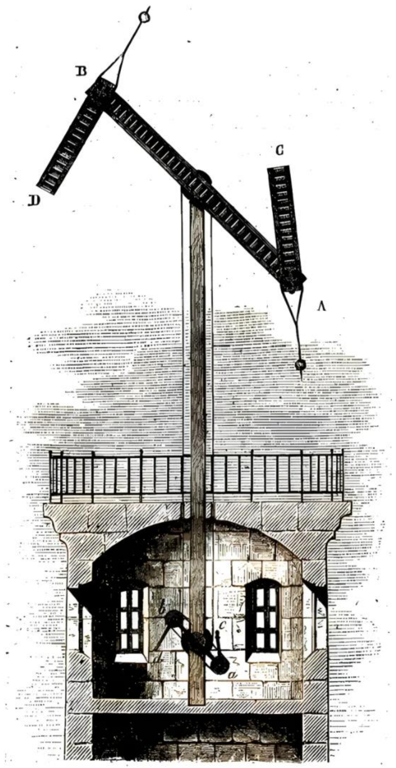
Origins

Optical Telegraph

Claude Chappe, France, 1790

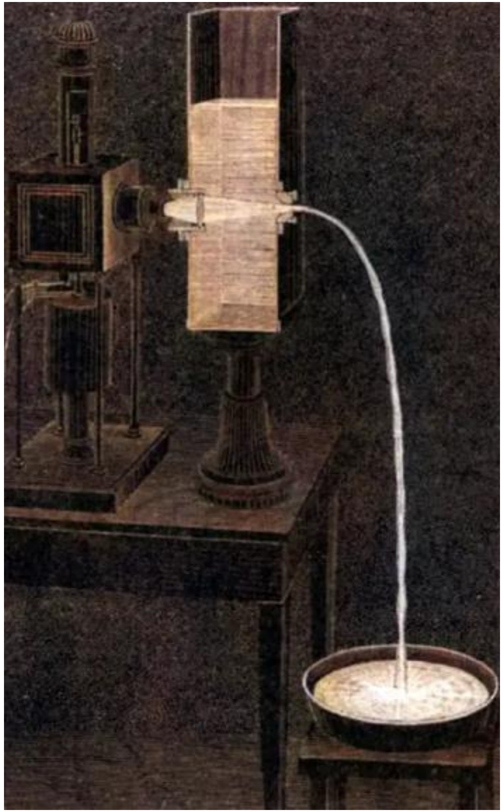
-Encode words/numbers on large towers, 10-30km apart

-2 to 3 words per minute (197km line)

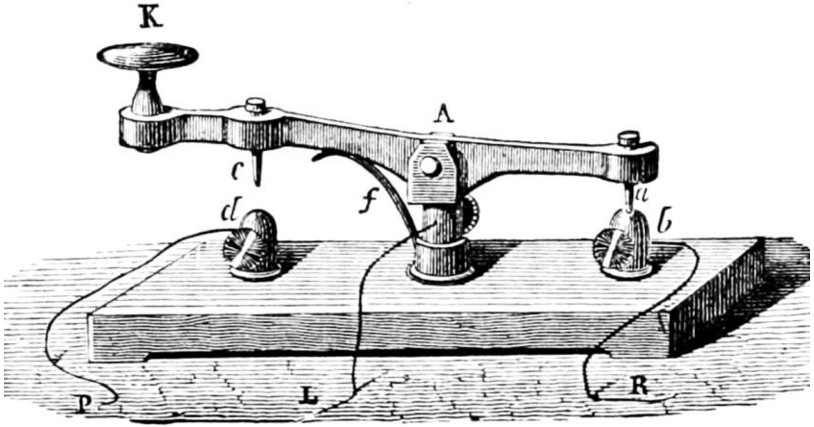


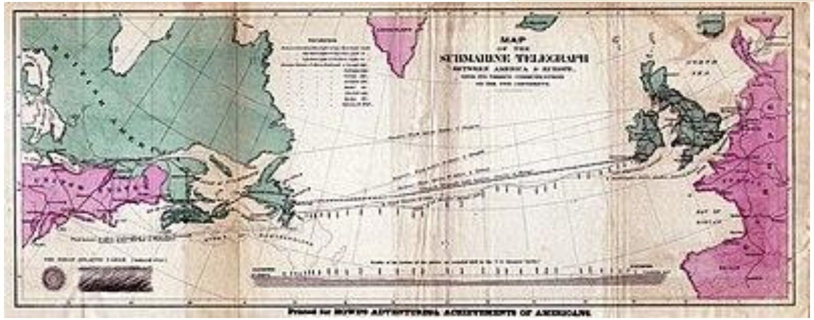
Origins

Total Internal Reflection:
Daniel Colladon, 1841



Origins (1858)

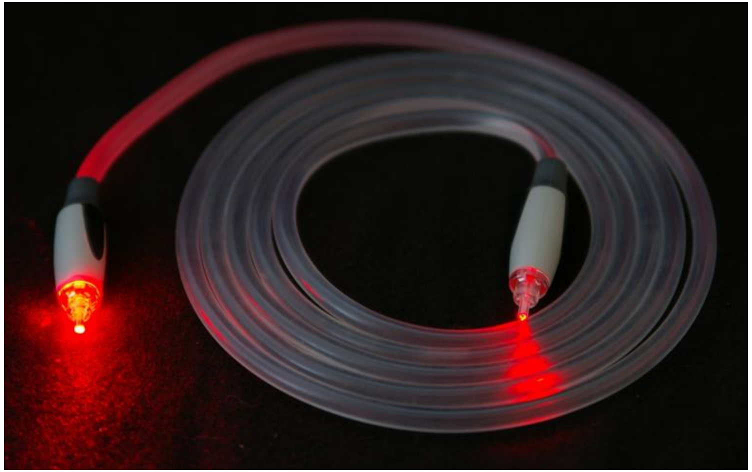


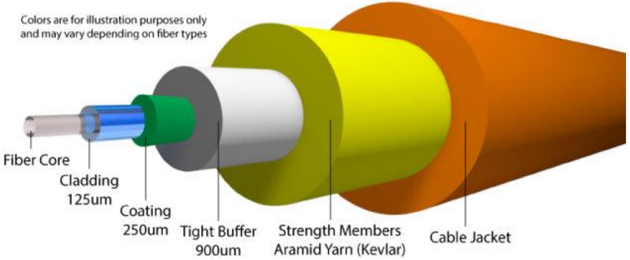


Origins-Cell tower communication - 1977

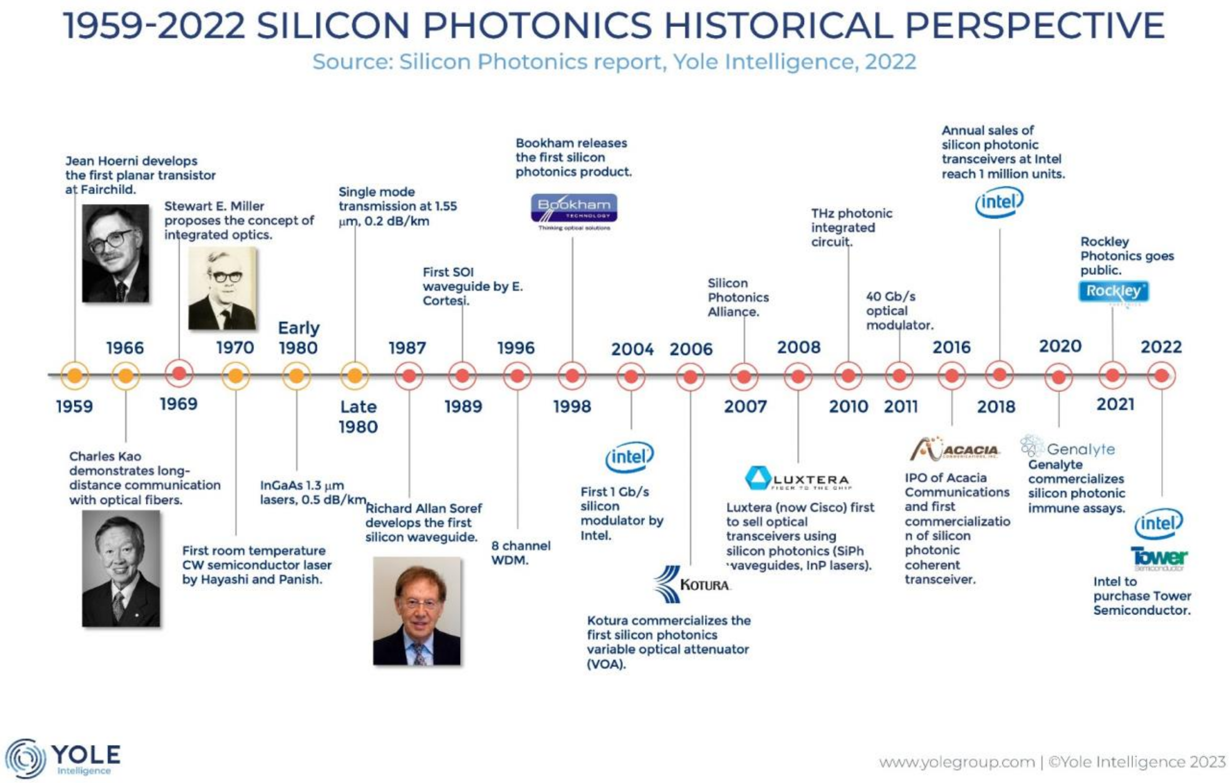
Origins

1952: First fiber optic cable invented
1970: Corning researchers break attenuation barrier, allowing fiber optics for communication
1986: Sprint becomes first US company with nationwide, 100% digital Fiber Optic Network
1996: All-optic fiber cable laid under pacific ocean





Origins


1959-2022 SILICON PHOTONICS HISTORICAL PERSPECTIVE
Source: Silicon Photonics report, Yole Intelligence, 2022
1959
Jean Hoerni develops the first planar transistor at Fairchild.
1966
Charles Kao demonstrates long-distance communication with optical fibers.
1969
Stewart E. Miller proposes the concept of integrated optics.
1970
First room temperature CW semiconductor laser by Hayashi and Panish.
Early 1980
InGaAs 1.3 μm lasers, 0.5 dB/km
Late 1980
Single mode transmission at 1.55 μm, 0.2 dB/km
1987
Richard Allan Soref develops the first silicon waveguide.
1989
First SOI waveguide by E. Cortesi.
1996
8 channel WDM.
1998
Bookham releases the first silicon photonics product.
Bookham
2004
intel
First 1 Gb/s silicon modulator by Intel.
2006
Kotura
Kotura commercializes the first silicon photonics variable optical attenuator (VOA).
2007
Silicon Photonics Alliance.
2008
Luxtera
Luxtera (now Cisco) first to sell optical transceivers using silicon photonics (SiPh waveguides, InP lasers).
2010
THz photonic integrated circuit.
2011
40 Gb/s optical modulator.
2016
Acacia
IPO of Acacia Communications and first commercialization of silicon photonic coherent transceiver.
2018
Annual sales of silicon photonic transceivers at Intel reach 1 million units.
intel
2020
Genalyte
Genalyte commercializes silicon photonic immune assays.
2021
Rockley Photonics goes public.
Rockley
2022
intel
Tower
Intel to purchase Tower Semiconductor.
YOLE Intelligence
www.yolegroup.com | ©Yole Intelligence 2023

Systems using this

Championed by large volume data companies

-Internal servers for companies like google transport more data at any given time than the entirety of the open internet from east to west coast

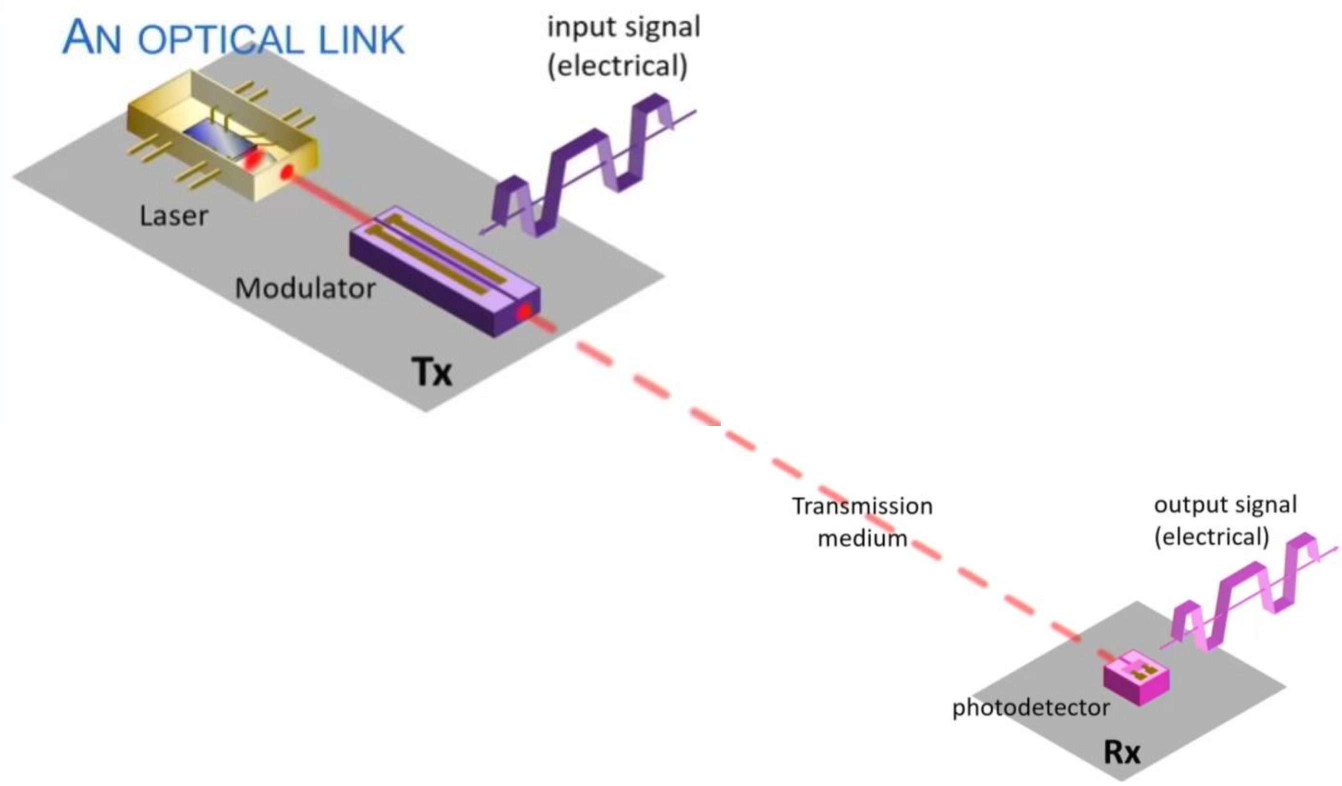
-Desperate need for reduction in communication cost per bit

Adopted by companies to allow faster overseas data transfer (E.g. cross-Atlantic)

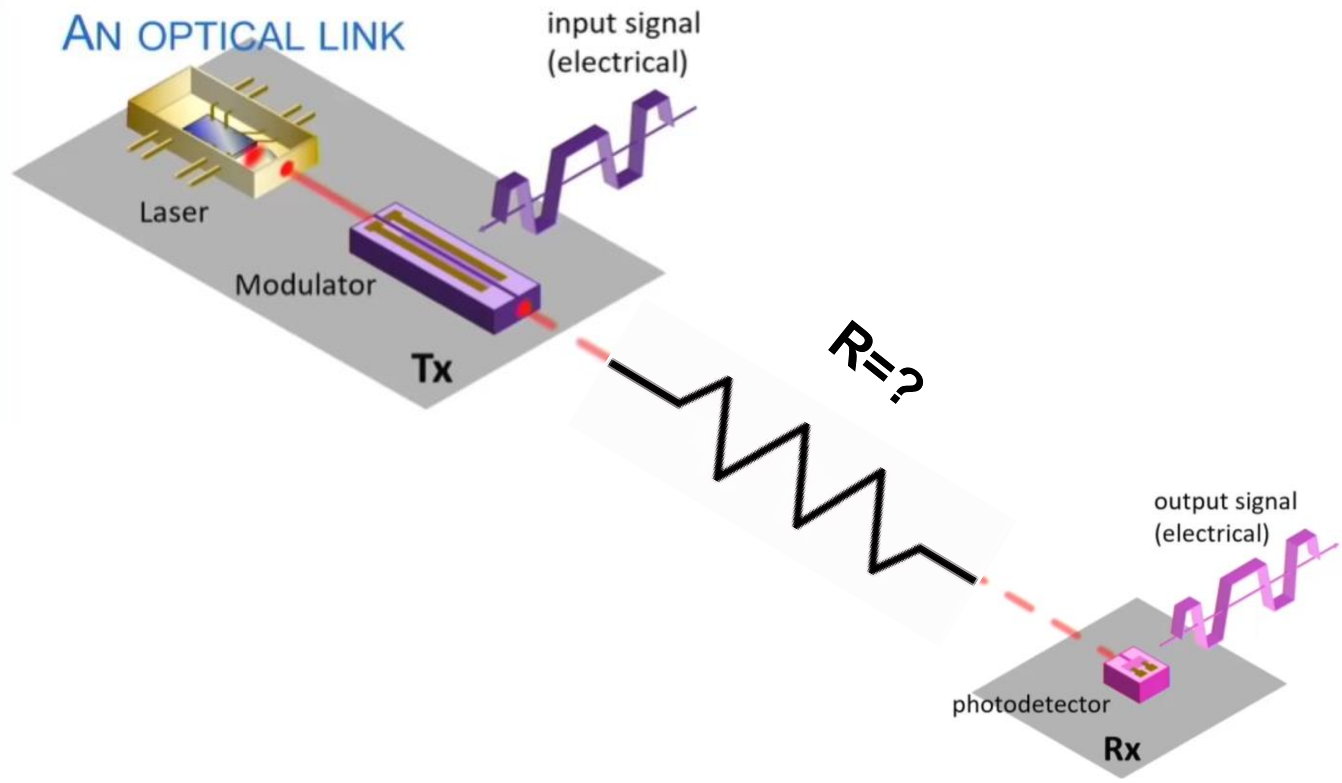
Interest in Silicon Photonics

-Global Foundries industry leader, followed by Intel, Defense companies

Why Photonics?



Why Photonics?



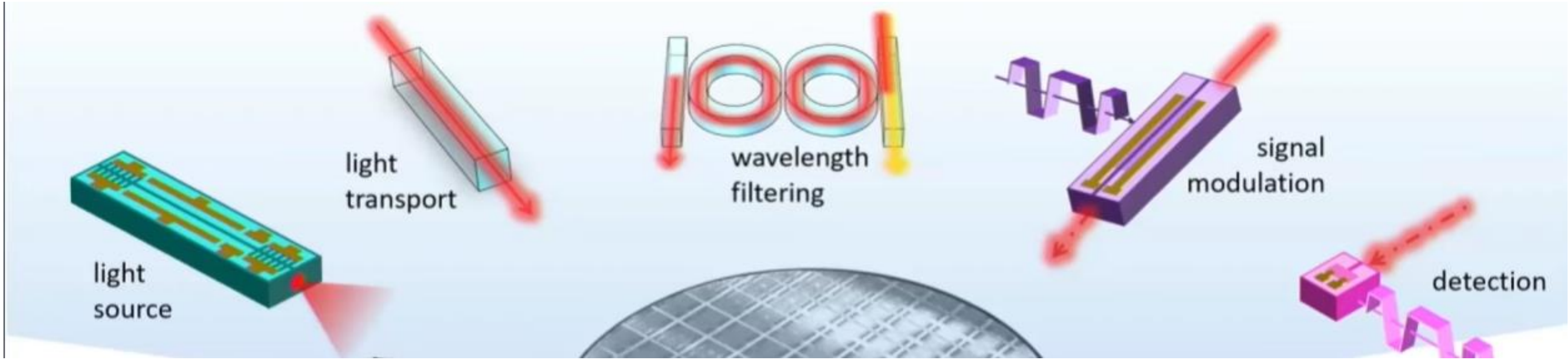
Why Photonics?

Data cost goes down (J/bit)
Low losses
Reliability goes up
Performance goes up

Why Photonics?

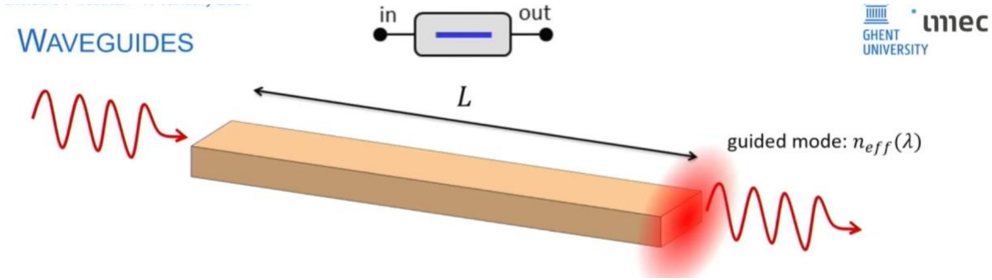
Building complexity goes up
Yield (May) go down
Production cost goes up

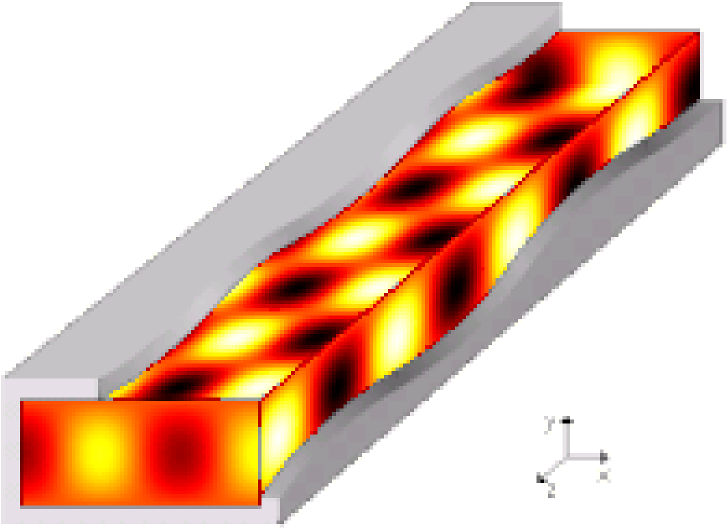
HOW Photonics?



Devices- Waveguides

High Performance: Glass/Complex Polymers
Mid Performance: III/V Semiconductors
Low Performance: Silicon





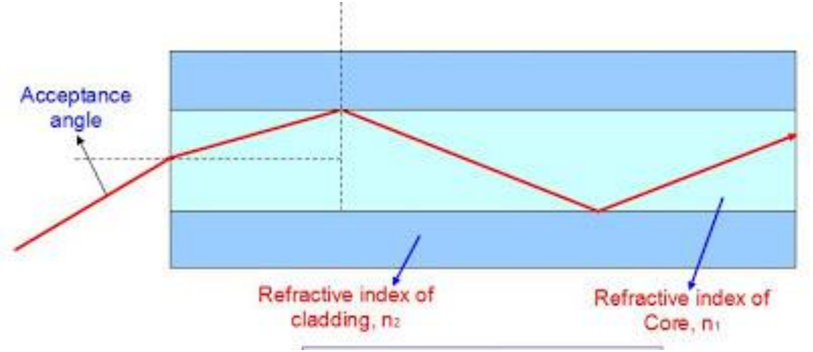
Physics-Reflection & Cladding

Critical for design: Refractive index (Acceptance Angles)

Value in core: ~1.5

Value in cladding: ~1.4

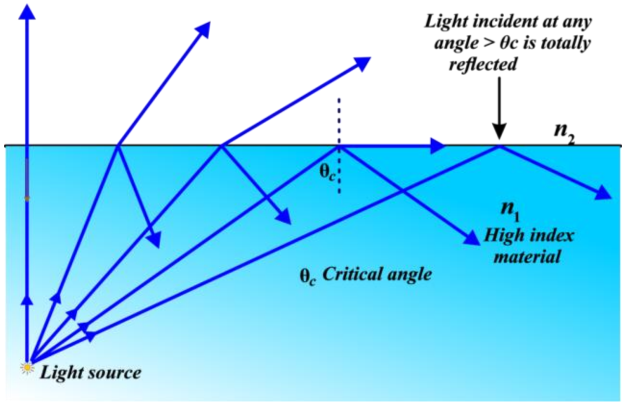
$$NA = \sqrt{n_1^2 - n_2^2}$$



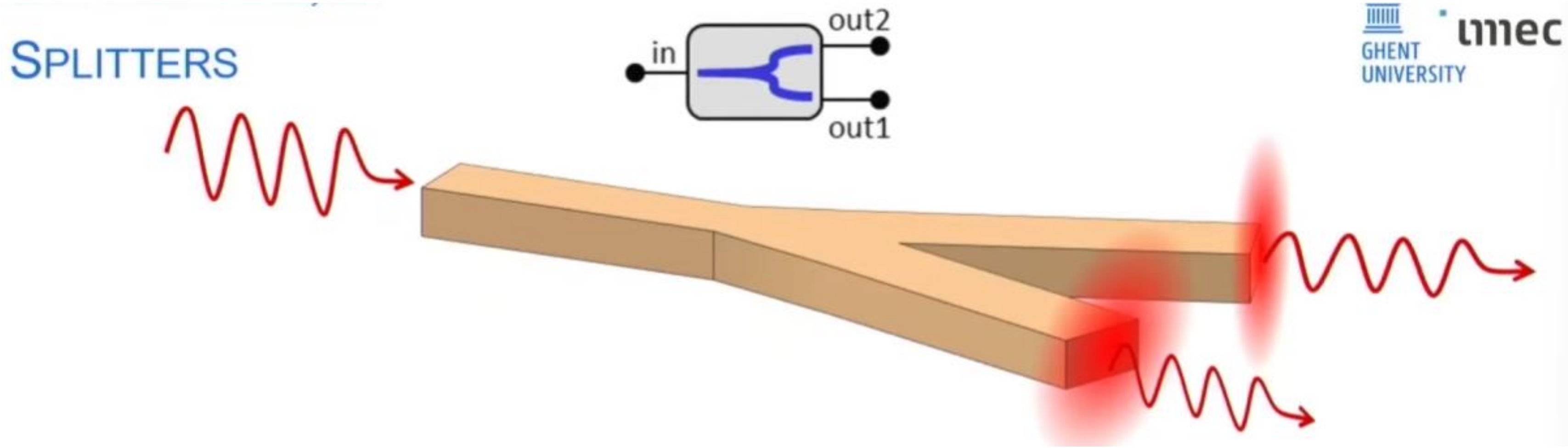
Critical angle (Total Internal Reflection)

$$\theta_c = \arcsin(\frac{n_2}{n_1})$$

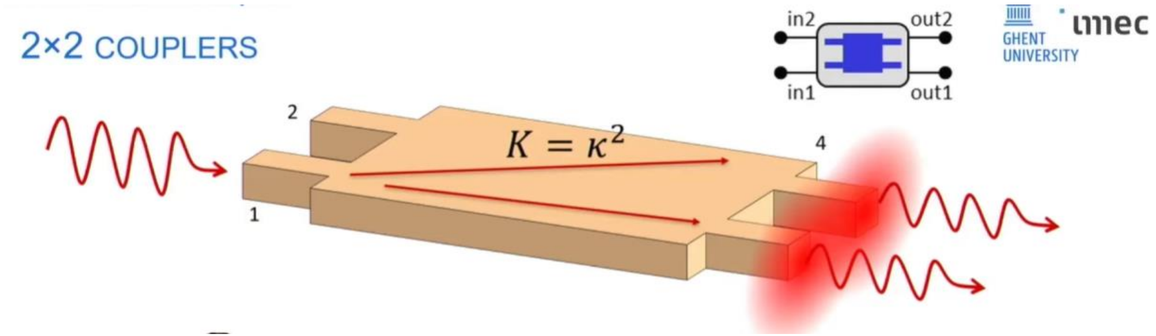
Note: This corresponds with maximum bend angle!

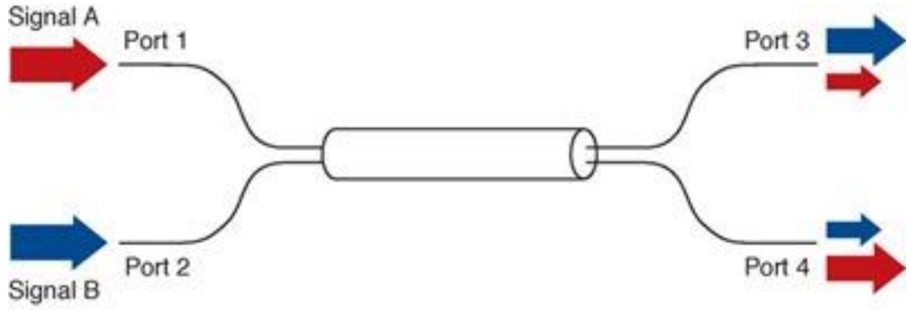


Devices- Splitters



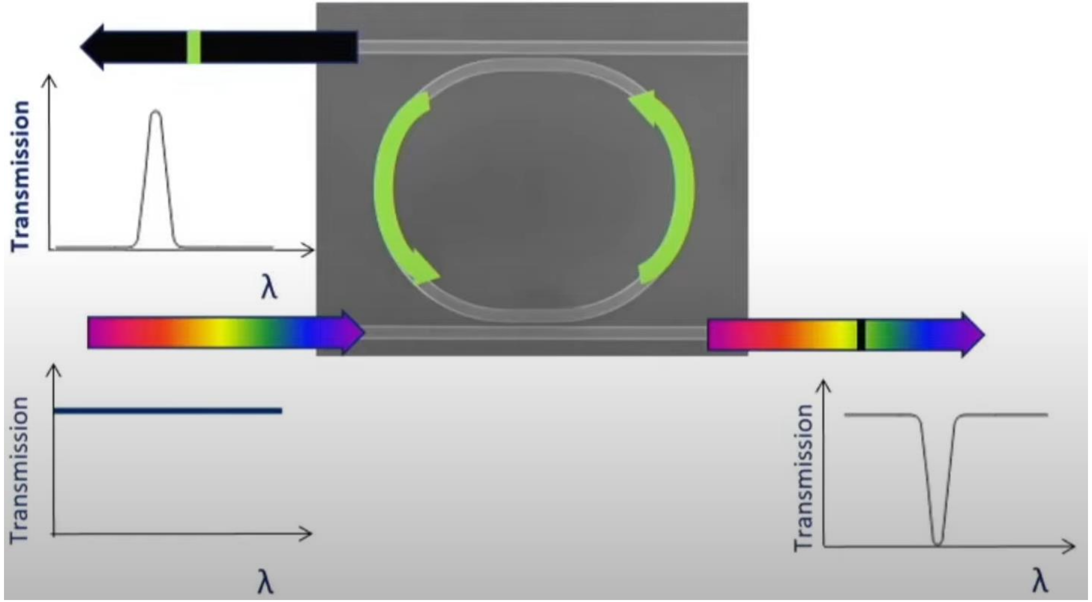
Devices- Couplers





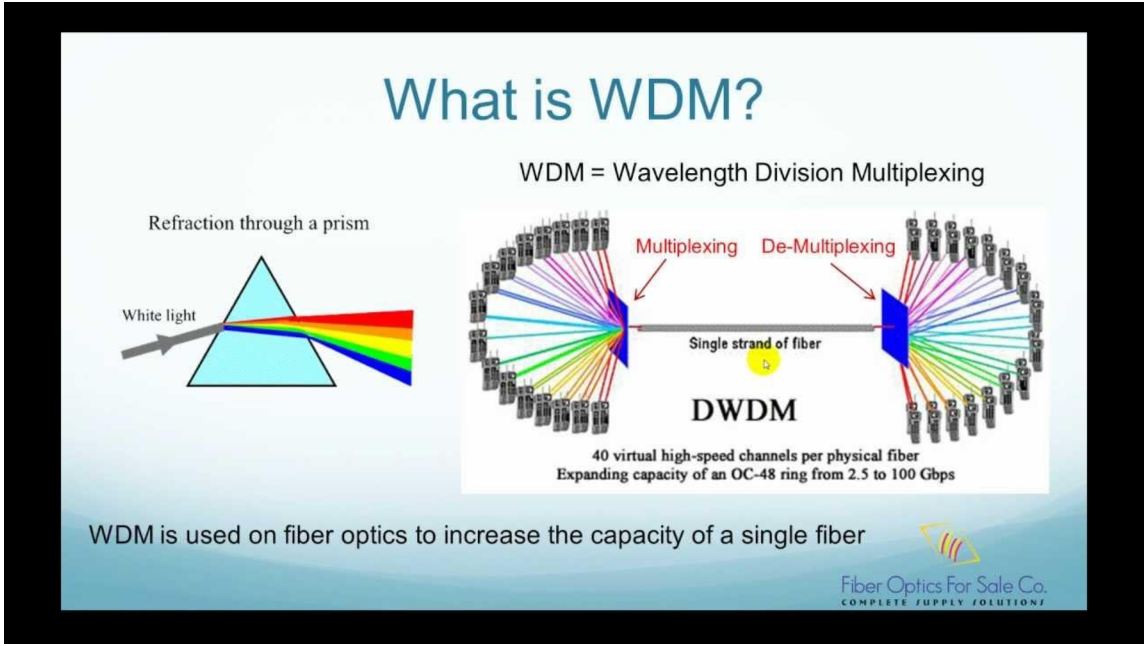
Devices- Resonators

NOTE: Wire length/size MUST be multiple of wavelength of desired light



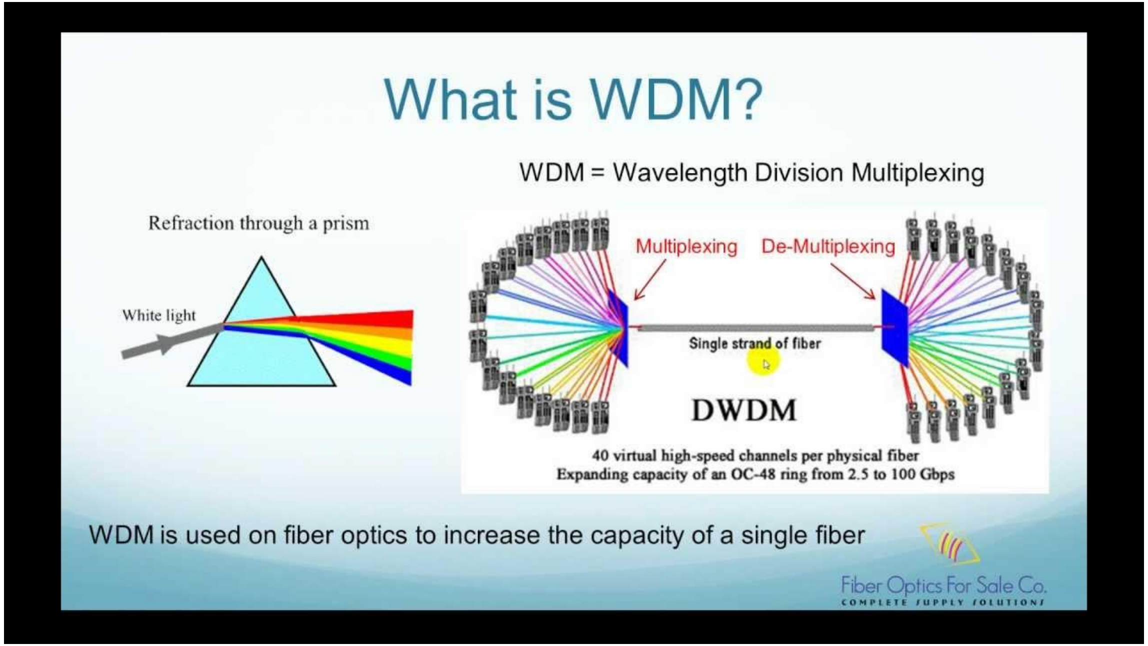
Physics- Optical Multiplexing

https://youtu.be/spUNpyF58BY?t=15



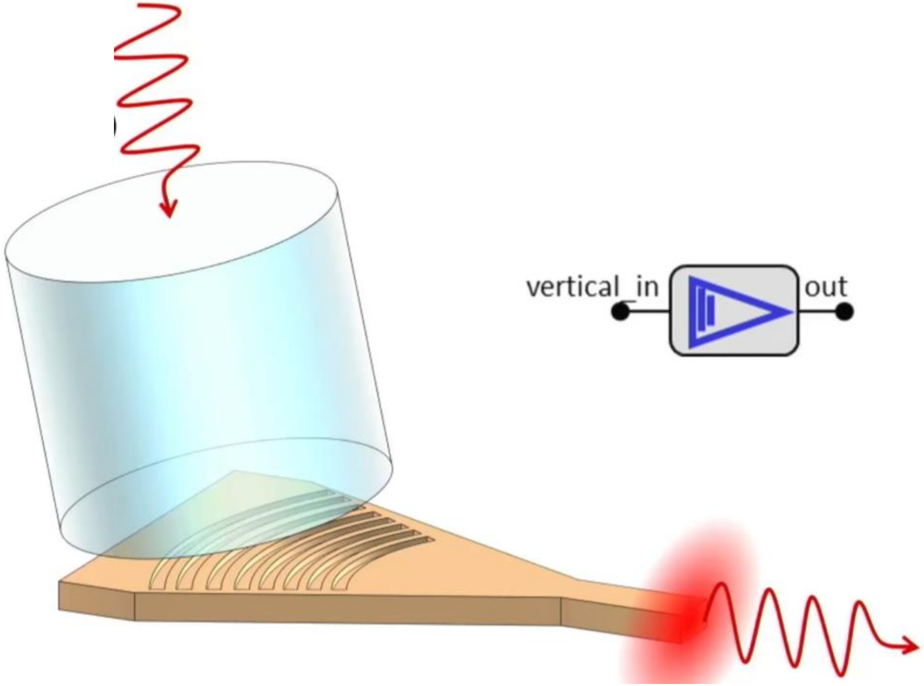
How do we “De-multiplex” in real life?

https://youtu.be/spUNpyF58BY?t=15



Devices- Vertical Fiber Interface

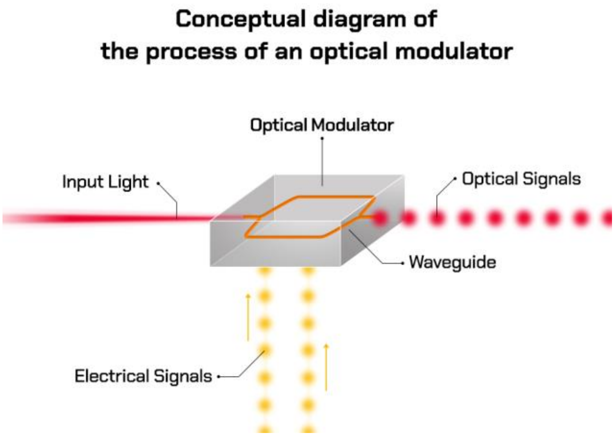
Allows fiber to interact with Silicon-end waveguide

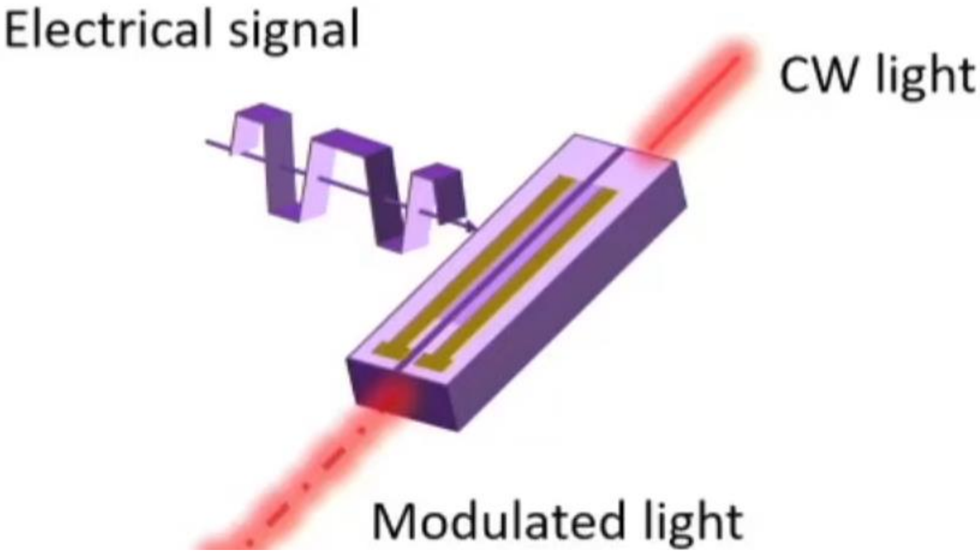


Devices- Electrical Modulator

VERY exotic materials!

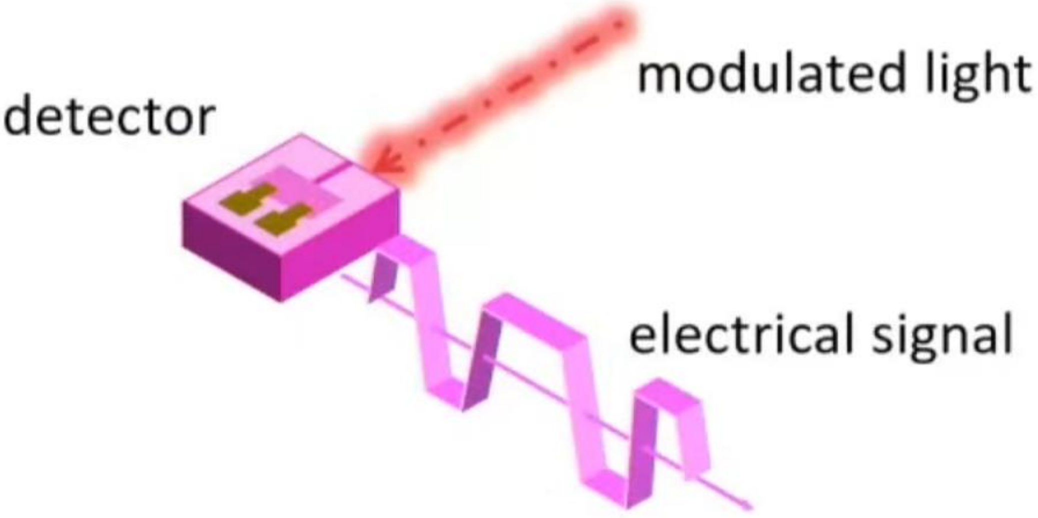
Lithium Niobate
Complex Polymers
III/V Semiconductors



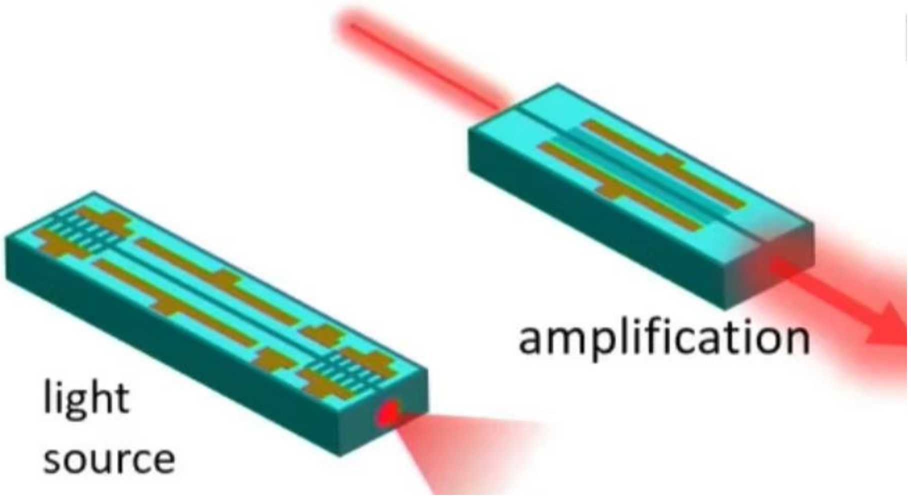


Devices- Photodetector

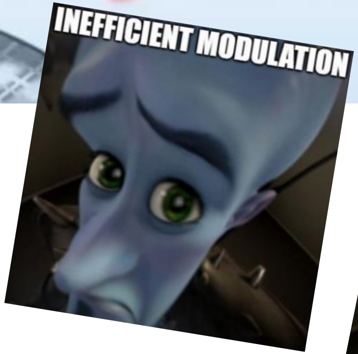
Typically III/V Semiconductors



Typically III-V Semiconductors
GaAs, InP



Why does Silicon suck at this?

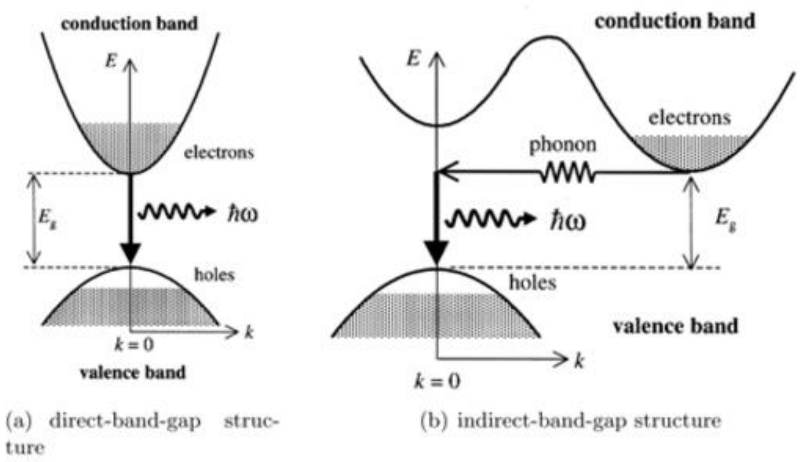


Why Photonics- Direct Bandgap Challenge

To lase or not to lase…
Band gap: An energy gap that an electron must traverse to change from valence to conduction band…

Direct: Energy release in form of photon
E.g. GaAs, InP (Typically III-V)

Indirect: Offset between states leads to release of photon (and phonon, to conserve momentum)
-Inefficient
-Most semiconductors do this
E.g. Si* (Typically IV)

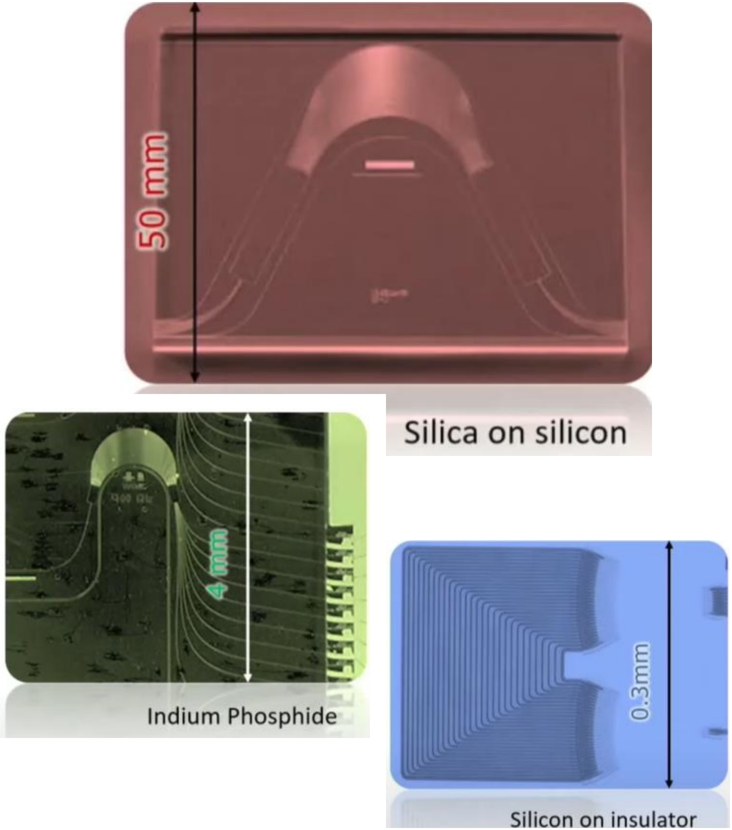


Why does Silicon GREAT at this?

CMOS technology is extremely mature/highly repeatable

New technologies enable smaller waveguides.

- -Silica on Silicon
  - Low contrast
  - Mode Diameter: 8um
  - Bend radius: 5mm
  - Size: 10cm^2
- -Indium Phosphide
  - Medium Contrast
  - Mode diameter: 2um
  - Bend radius: 0.5mm
  - Size: 10mm^2
- -Silicon on Insulator
  - High contrast
  - Mode diameter: 0.4um
  - Bend Radius: 5um
  - Size: 0.1mm^2



Why is precision important?

Yield/size precision issues?

- -Let's look at a Silicon waveguide…
- -Height & Width vs. Resonant wavelength (Filters)

How do we fix this???

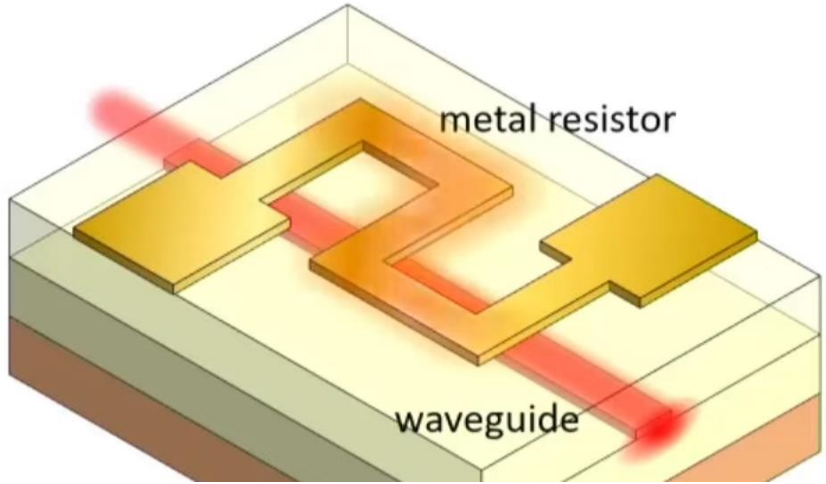
- -Statistical Process Control
- -Redundant/Tolerant Design
- -Tunable Circuits

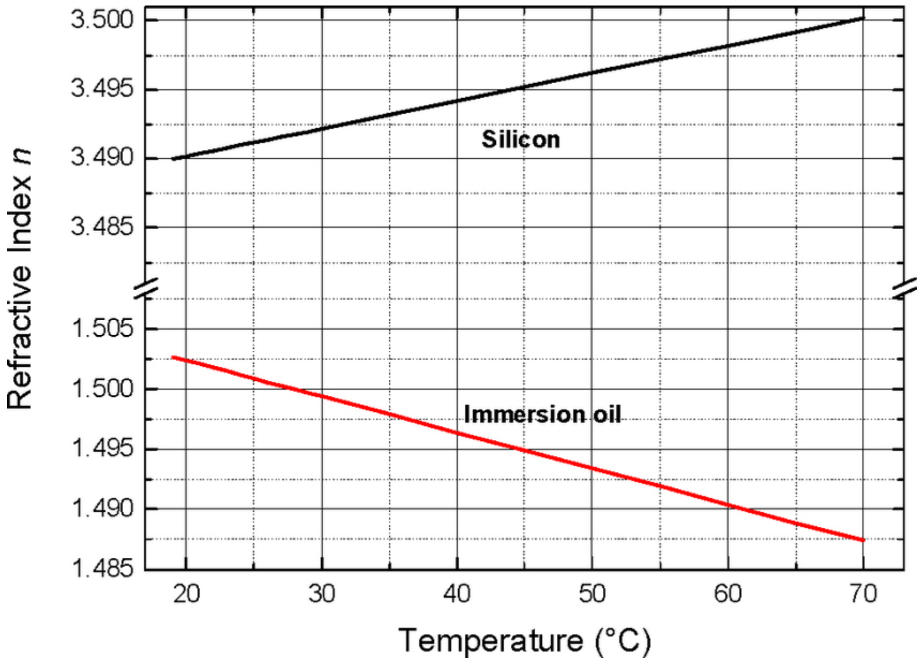
$$\frac{\partial\lambda}{\partial w} \approx 1\, {}^{nm}/_{nm}$$

$$\frac{\partial\lambda}{\partial h} \approx 2\, {}^{nm}/_{nm}$$

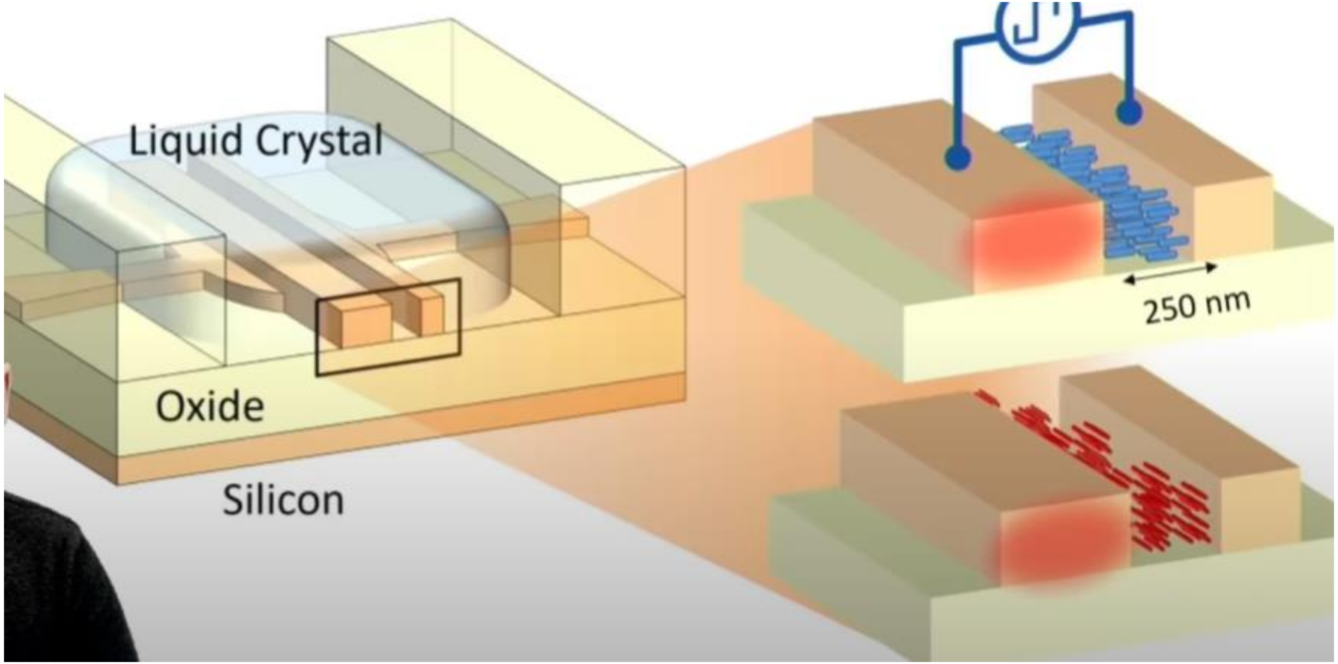
$$\frac{\partial\lambda}{\partial T} \approx 0.08\, {}^{nm}/_{K}$$

Precision- Thermal Tuning



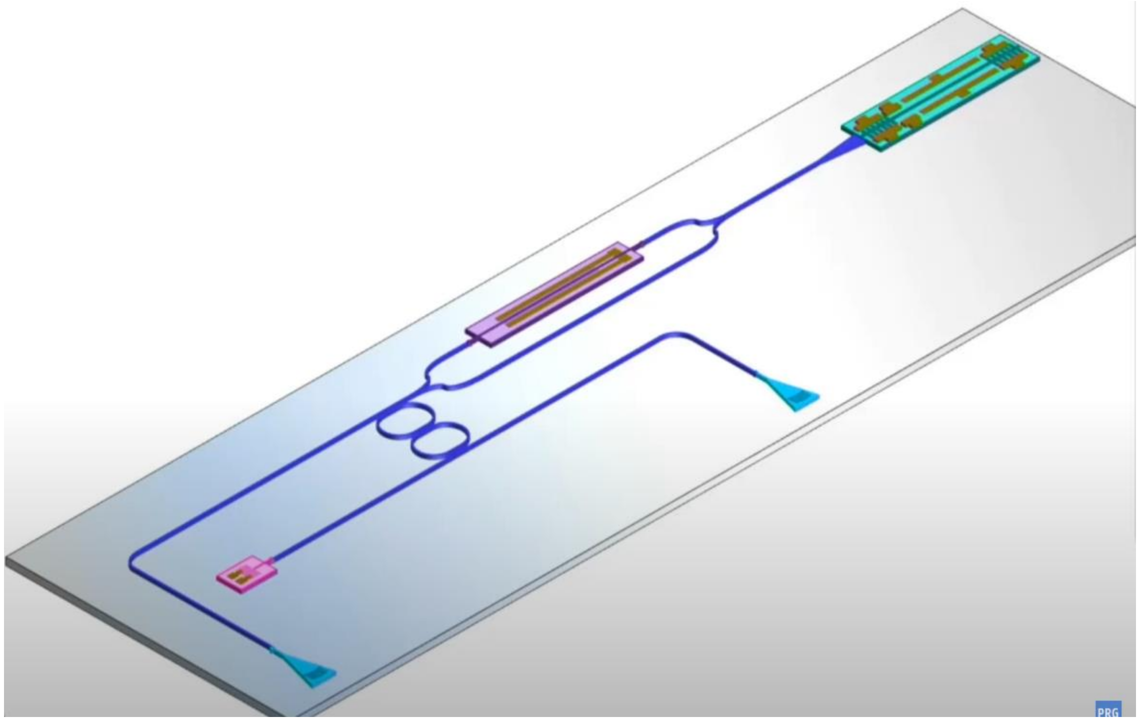


Precision-Liquid Crystal Tuning



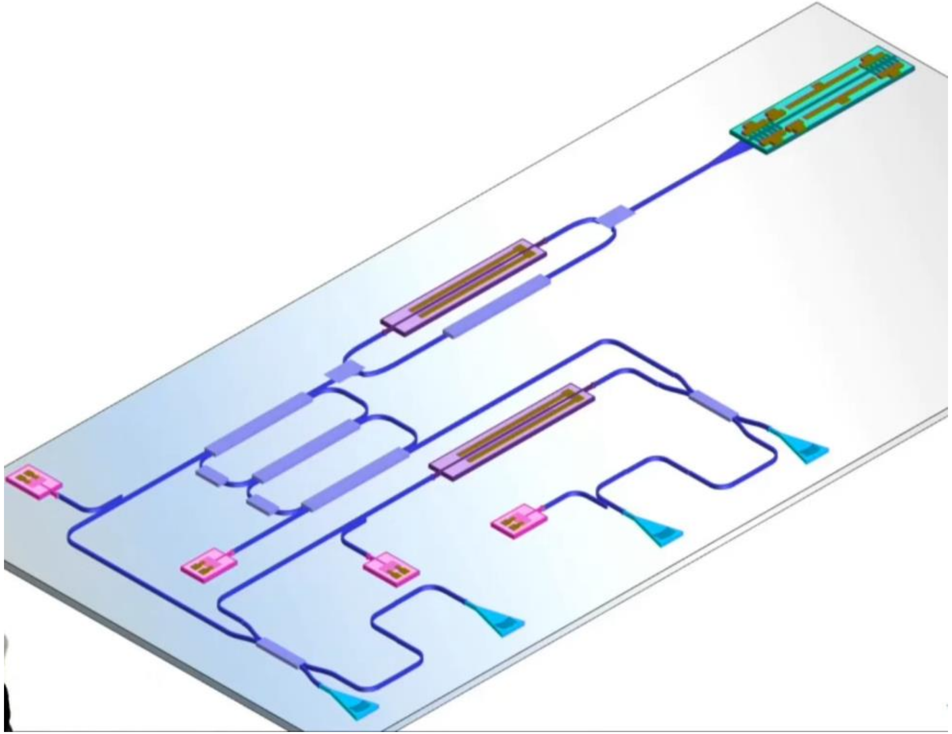
Designing a SIMPLE optical circuit

-Laser source
-Filter (Resonance)
-Photodetector
-Fiber Interfaces



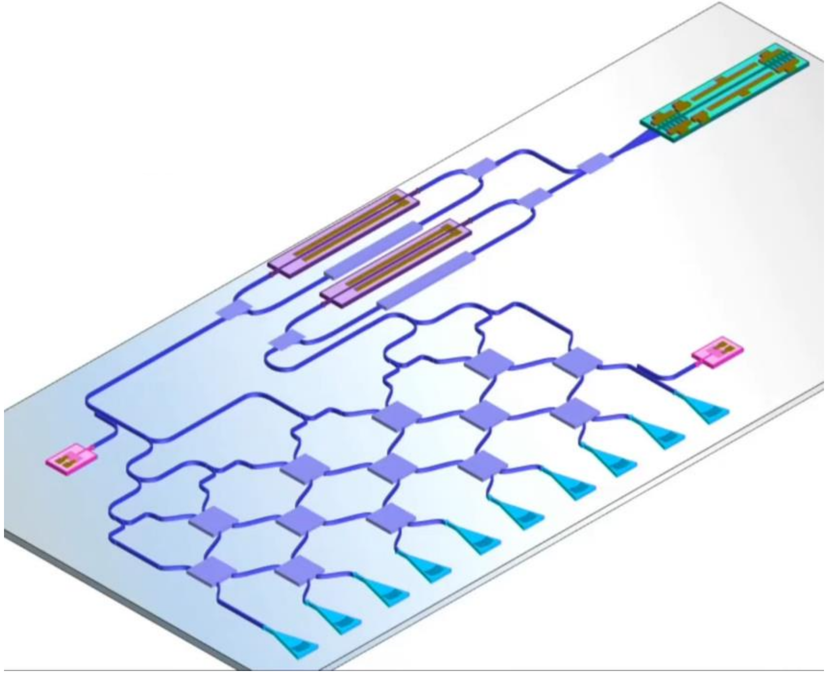
Designing a ROBUST, multifunctional optical circuit

-Why is this more robust?



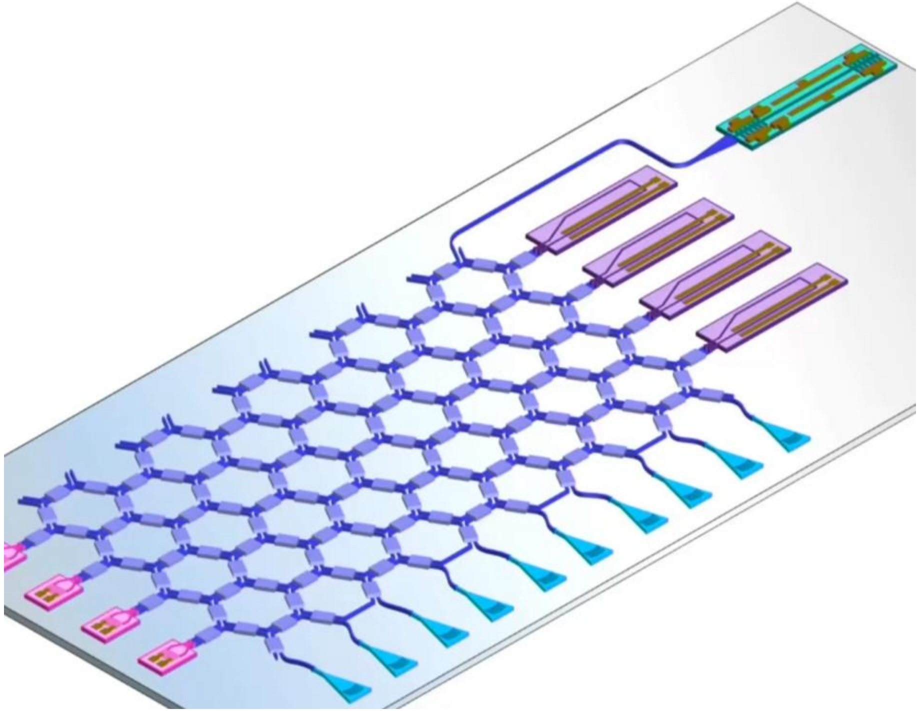
Building an application-specific PROGRAMMABLE optical circuit

-Why is this more robust?



Building a GENERAL-PURPOSE PROGRAMMABLE optical circuit

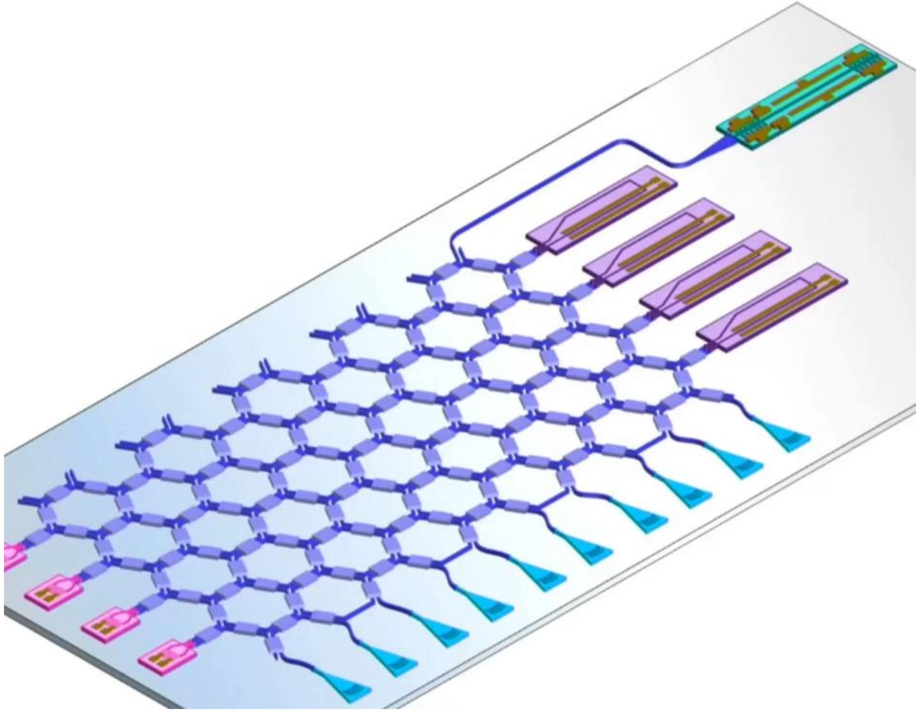
-How???



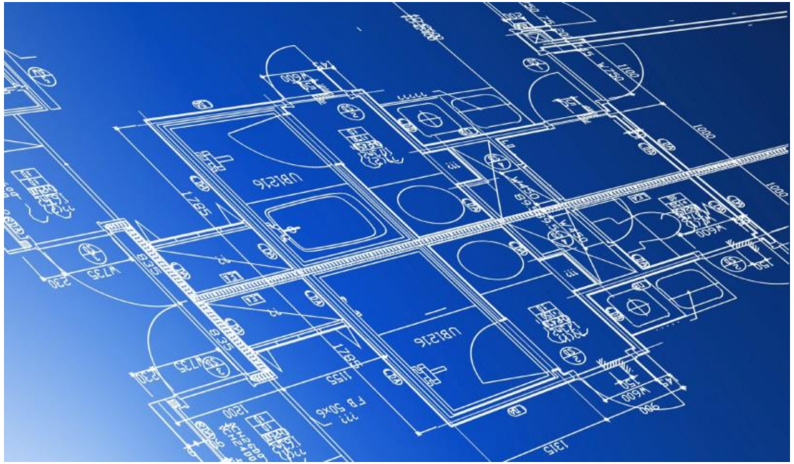
Building a GENERAL-PURPOSE PROGRAMMABLE optical circuit

-How???

https://youtu.be/CBhdLTTbYoM?t=2825



ESSENTIAL in IC industry- Why?
CHALLENGING in SiPh industry

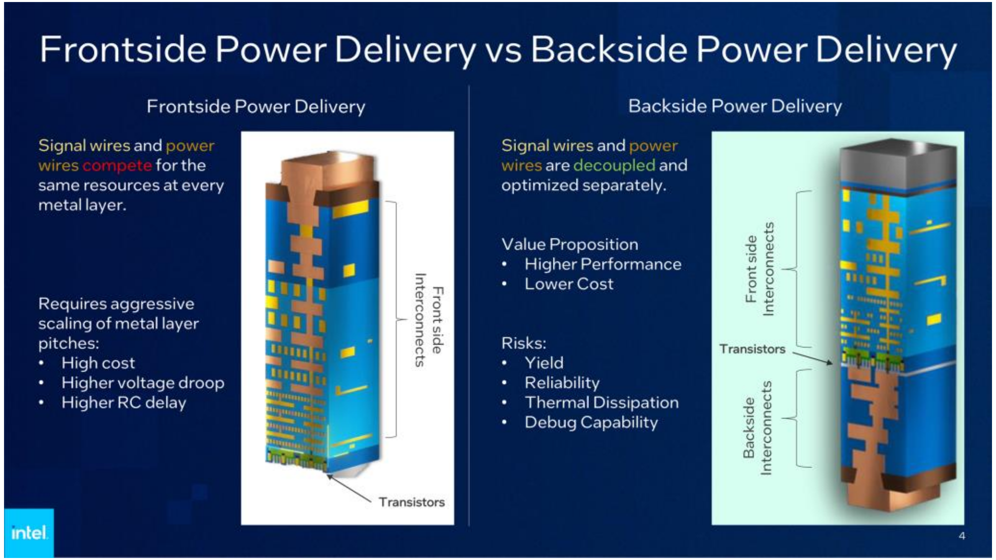


Future state- My thoughts

Possibility for signal wires do be further decoupled, using waveguides instead of traditional wires

Solves some electrical, power issues

Even faster signals (Near instant transmission)



Summary

-Silicon Photonics poses many challenges- particularly the “silicon” part

-Fabrication isn’t very different from a typical fab’s process-just requires precision

-Photonics enable long range communication at low cost, but becomes challenging at small scale

-Minimum signal size & supporting devices pose challenges when scaling

-This is an extremely young, fast developing industry. Now is a good time to get into this

Thanks ☺

Asianometry- “Casual watch”, not as deep (15 min)
https://www.youtube.com/watch?v=29aTqLvRia8

U. Ghent Silicon Photonics Research Group- More technical/longer (50 min)
https://www.youtube.com/watch?v=CBhdLTTbYoM&t

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