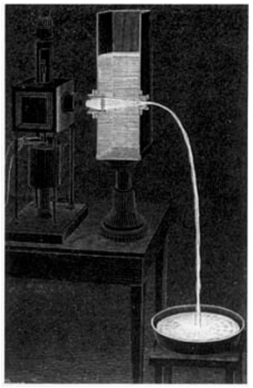
Emerging Nanophotonics; Silicon Nanophotonics (with ALD)

Seppo Honkanen
Helsinki University of Technology

Outline

- **Nanophotonics (?)**
- **Silicon Nanophotonics**
- **Si-slot waveguides filled with ALD**
- **Conclusion**

Photonics/Nanotechnology?



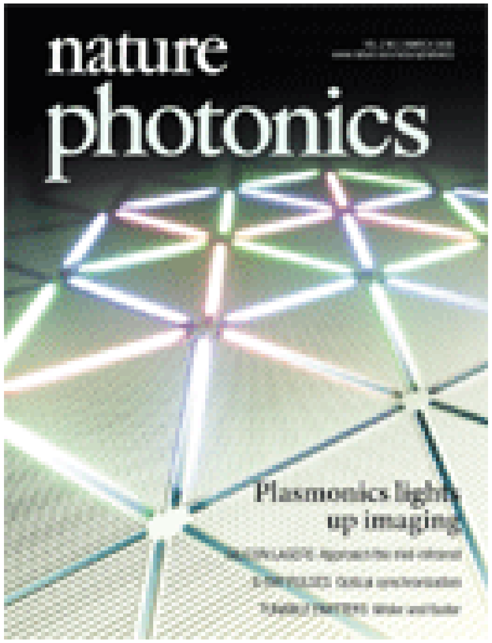
Daniel Colladon
(Swiss physicist), 1841

Wikipedia:

- ***Photonics*** is the science of generating, controlling, and detecting photons, particularly in the ***visible and near infra-red spectrum***
- ***Nanotechnology*** refers broadly to a field of applied science and technology whose unifying theme is the control of matter on the atomic and molecular scale, normally ***1 to 100 nanometers***, and the fabrication of devices with critical dimensions that lie within that size range.

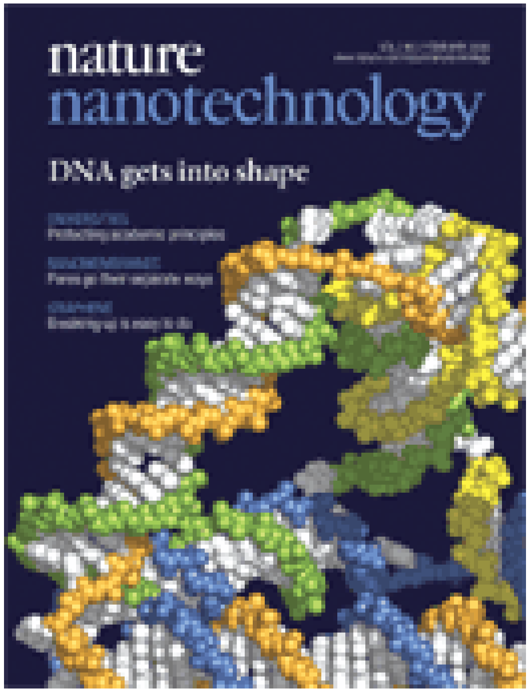
Nature Photonics (topics)

- Lasers, LEDs and other light sources
- Imaging, detectors and sensors
- Optoelectronic devices and components
- Novel materials and engineered structures
- Physics of light propagation, interaction and behaviour
- Quantum optics and cryptography
- Ultrafast photonics
- Biophotonics
- Optical data storage
- Spectroscopy
- **Fibre optics and optical communications**
- Solar energy and photovoltaics
- Displays
- Terahertz technology



Nature Nanotechnology (topics)

Carbon nanotubes and fullerenes, Computational nanotechnology, Electronic properties and devices, Environmental, health and safety issues, Molecular machines and motors, Molecular self-assembly, Nanobiotechnology, Nanofluidics, Nanomagnetism and spintronics, Nanomaterials, Nanomedicine, Nanometrology and instrumentation, Nanoparticles, Nanosensors and other devices, NEMS, Organic–inorganic nanostructures, **Photonic structures and devices**, Quantum information, Structural properties, Surface patterning and imaging, Synthesis and processing

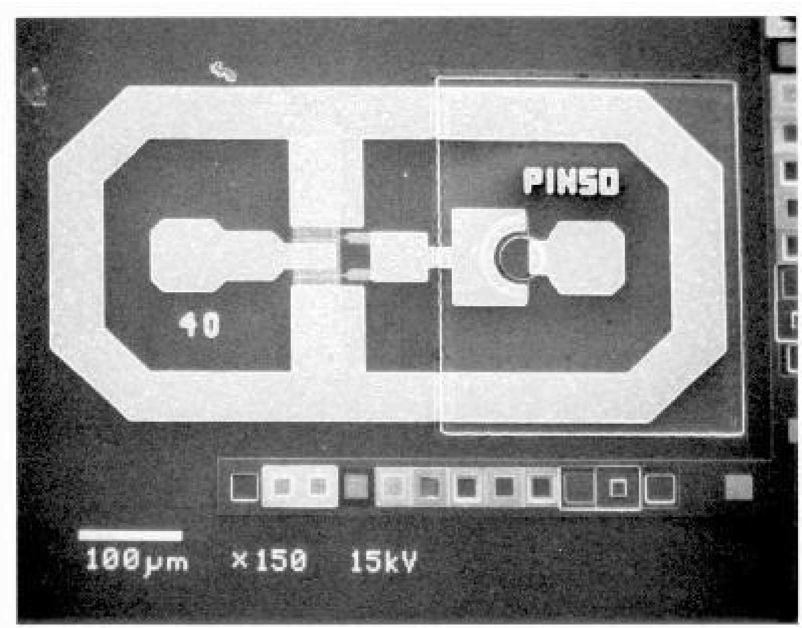


Nanophotonics?

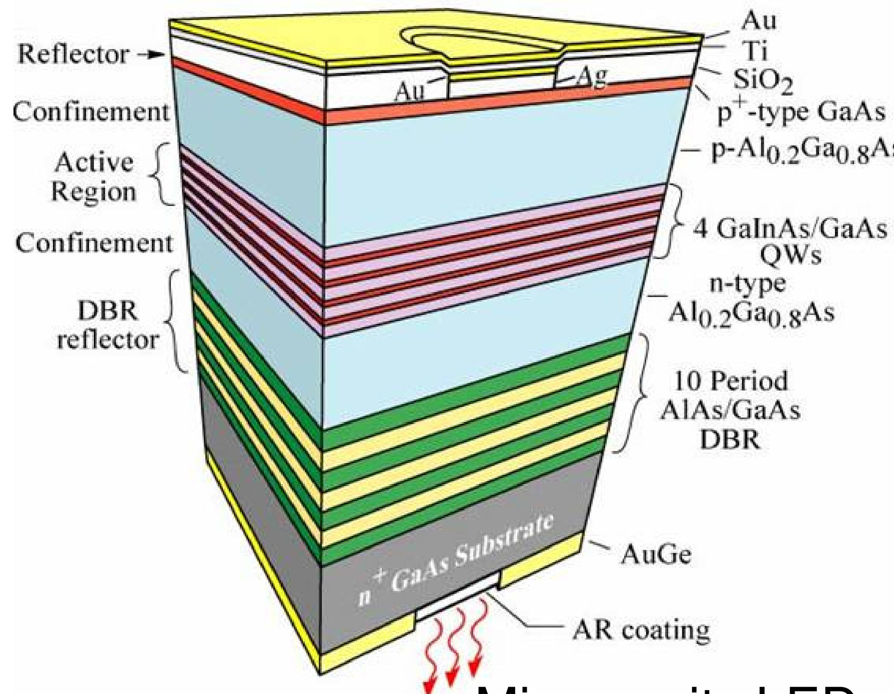
Wikipedia:

- ***Nanophotonics:*** Study of the behavior of light on the nanometer scale
  - Generation and manipulation of light ***using engineered nanoscale structures***
  - Wavelength range: ***UV-visible-near infrared***
  - Device or structure with critical dimensions that lie within ***1 to 100 nanometers***

Currently: Microphotonics

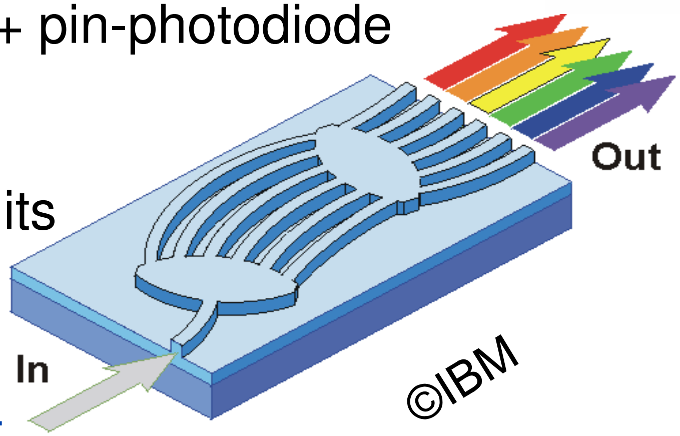


Transistor + pin-photodiode



Microcavity LED

Photonic Integrated Circuits (PICs)

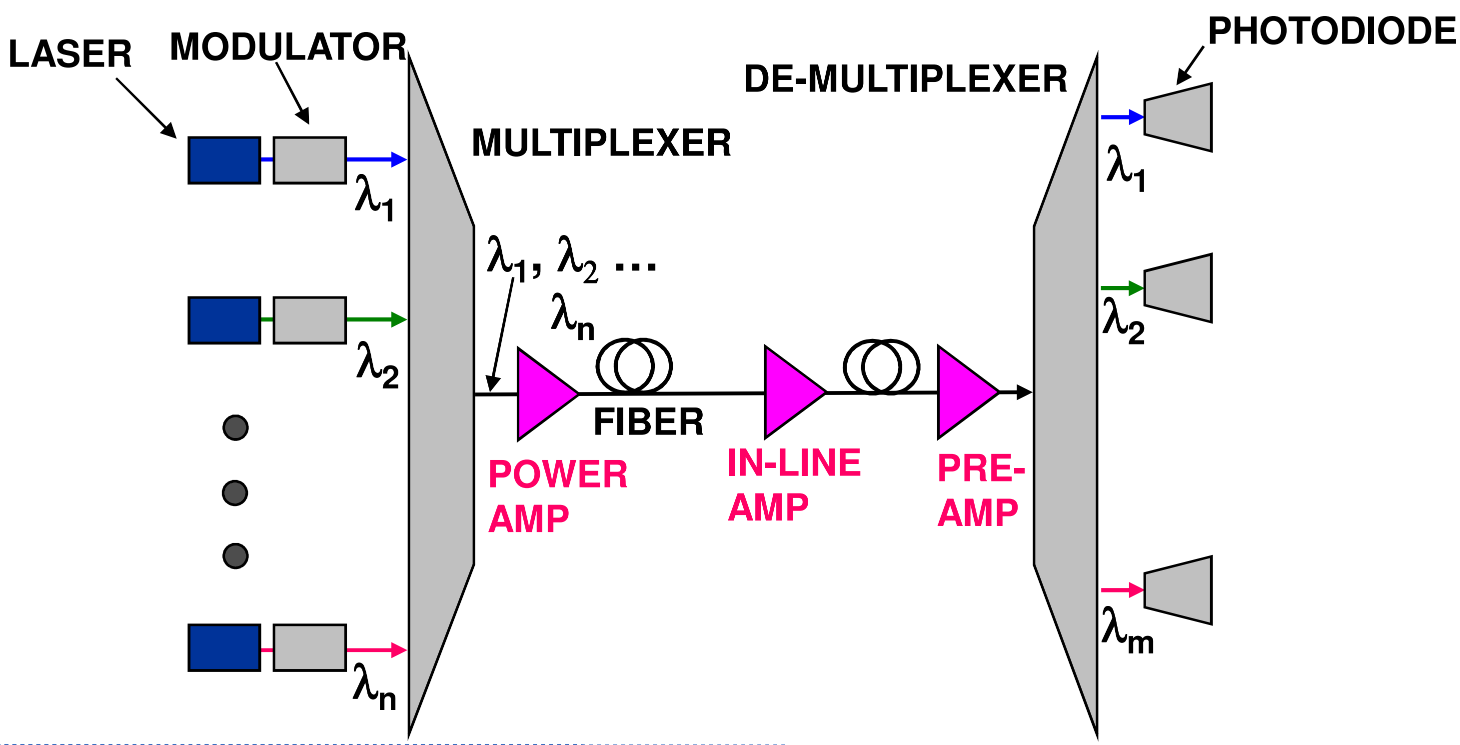


There are already nm-scale layers in present devices.

E.g. the QW's are 2-3 nm thick in some LEDs.

Si-Nanophotonics

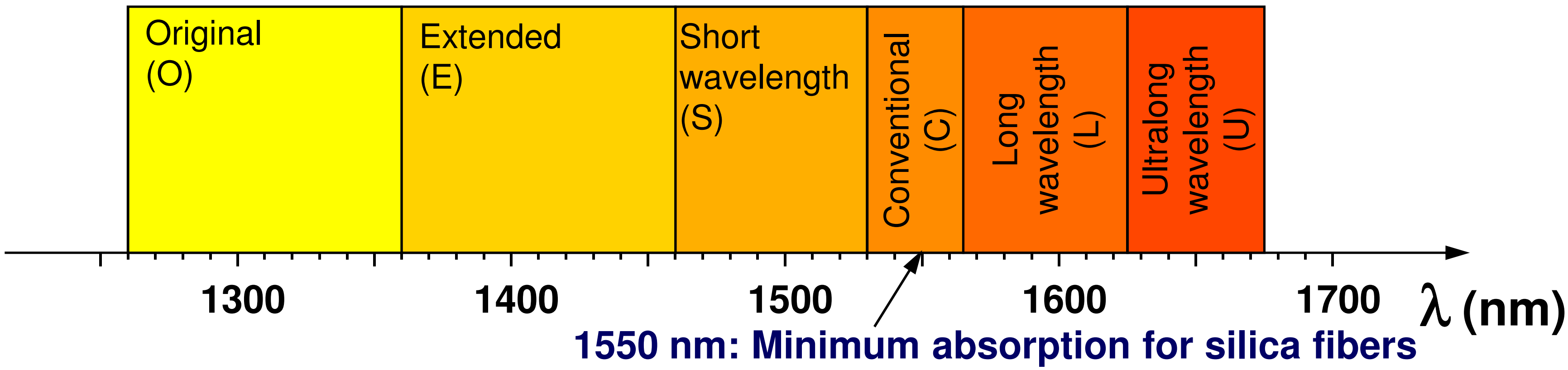
- ***Main Driver:*** **Optical Communications**
  - Dense Wavelength Division Multiplexing (DWDM)
  - Multiple wavelength channels (~ 1.55 μm) in a single optical fiber
  - Data rate today: 10 Gbit/s; soon: 40 and 100 Gbit/s



Photonics Group TKK

Si-Nanophotonics

Optical telecommunication windows defined by ITU (International Telecommunications Union):



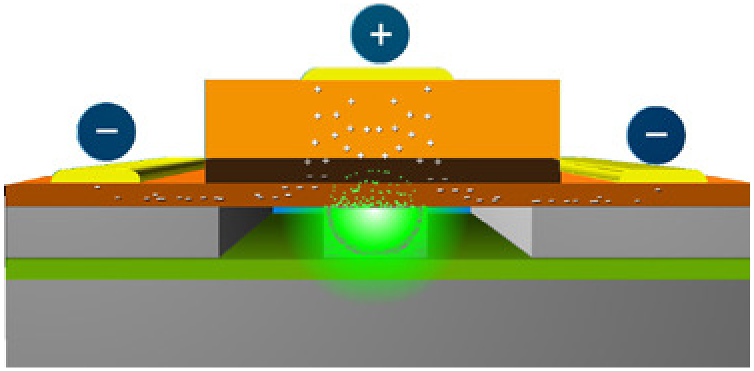
- Silicon is ***the material of choice*** for Photonic Integrated Circuits (PICs):
  - Si is transparent and has low loss over the 6 telecom windows
  - Si can combine ***optical*** and ***eletrical*** components on the same chip
  - Si technology is ***mature***

BUT poor efficiency as a light emitter (LEDs and lasers) !!

Si-Nanophotonics

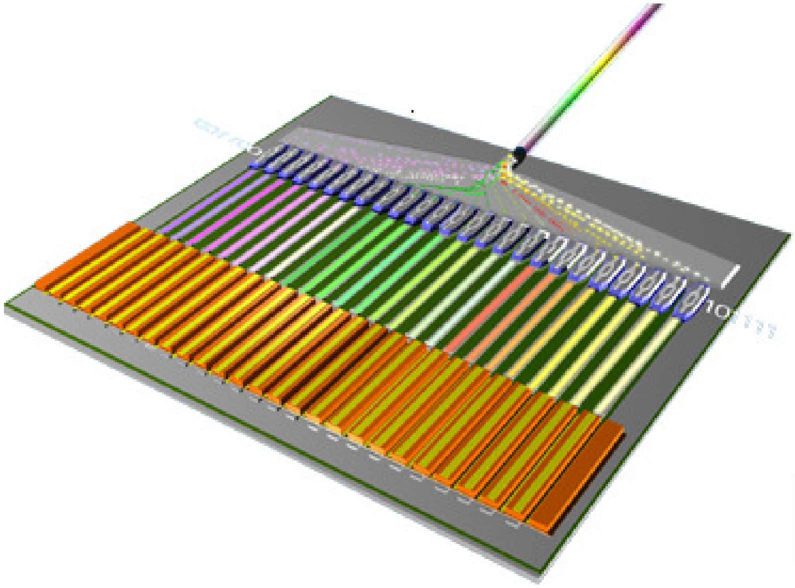
- Hybrid laser on Silicon (Intel / UC Santa Barbara)
- Electrically pumped (September 2006)

Schematics

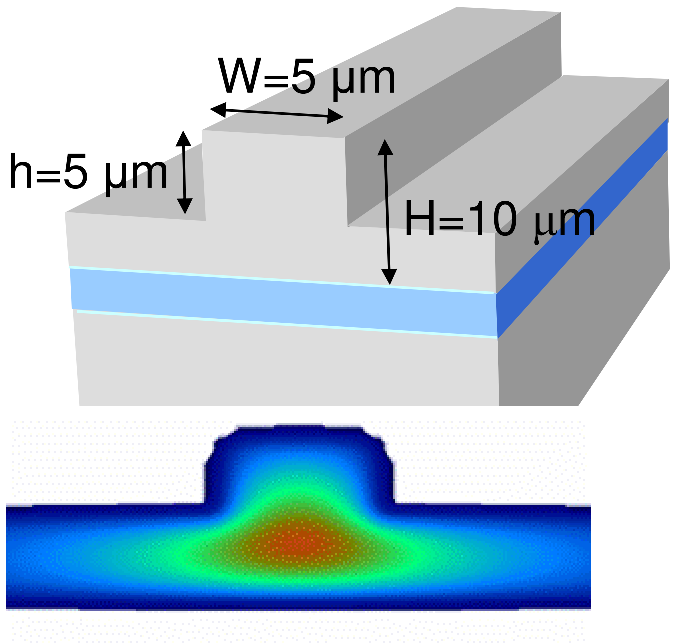


Future goal:

- 1 Tbit/s source on a Si-chip!

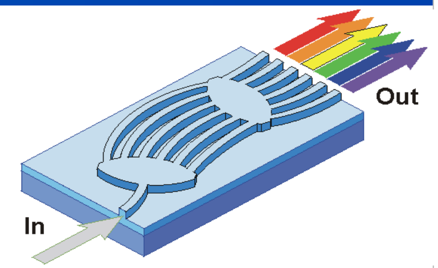


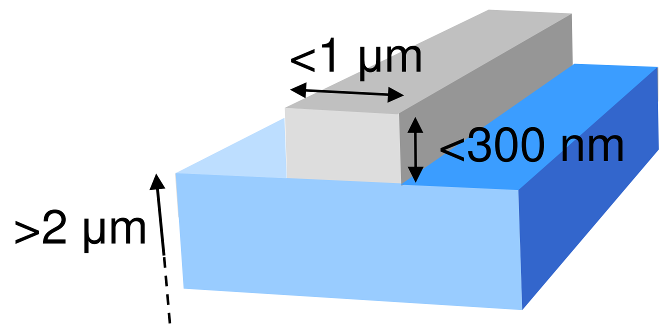
Si-on-Insulator (SOI) Waveguides



Ridge waveguide

- Singlemode
- Low loss (< 0.2 dB/cm)





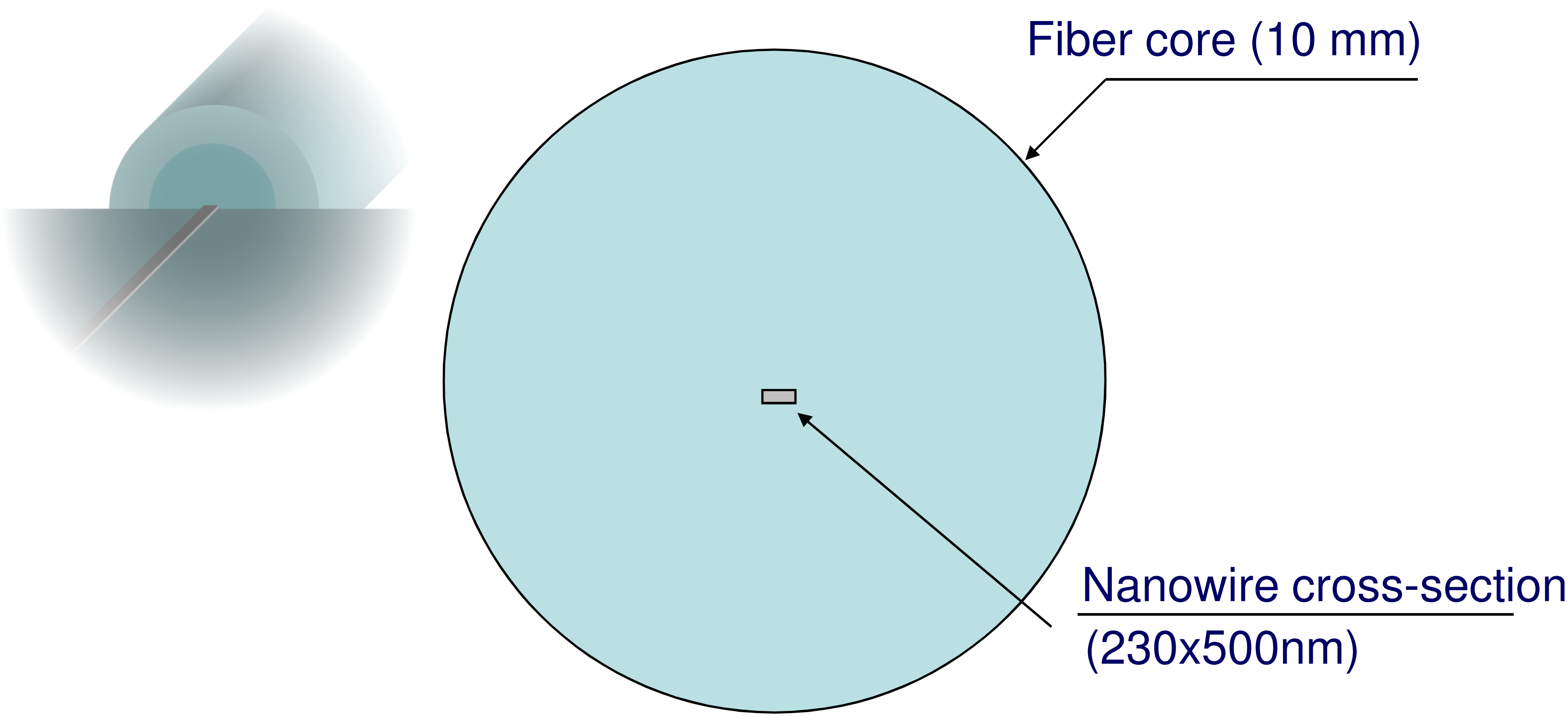
Nanowaveguides

- Singlemode if small enough
- Low loss if sidewalls are smooth (< 3 dB/cm)
- Faster refractive index tuning
- Very tight mode cofinement

→ **Compact, densily packed circuits !!**

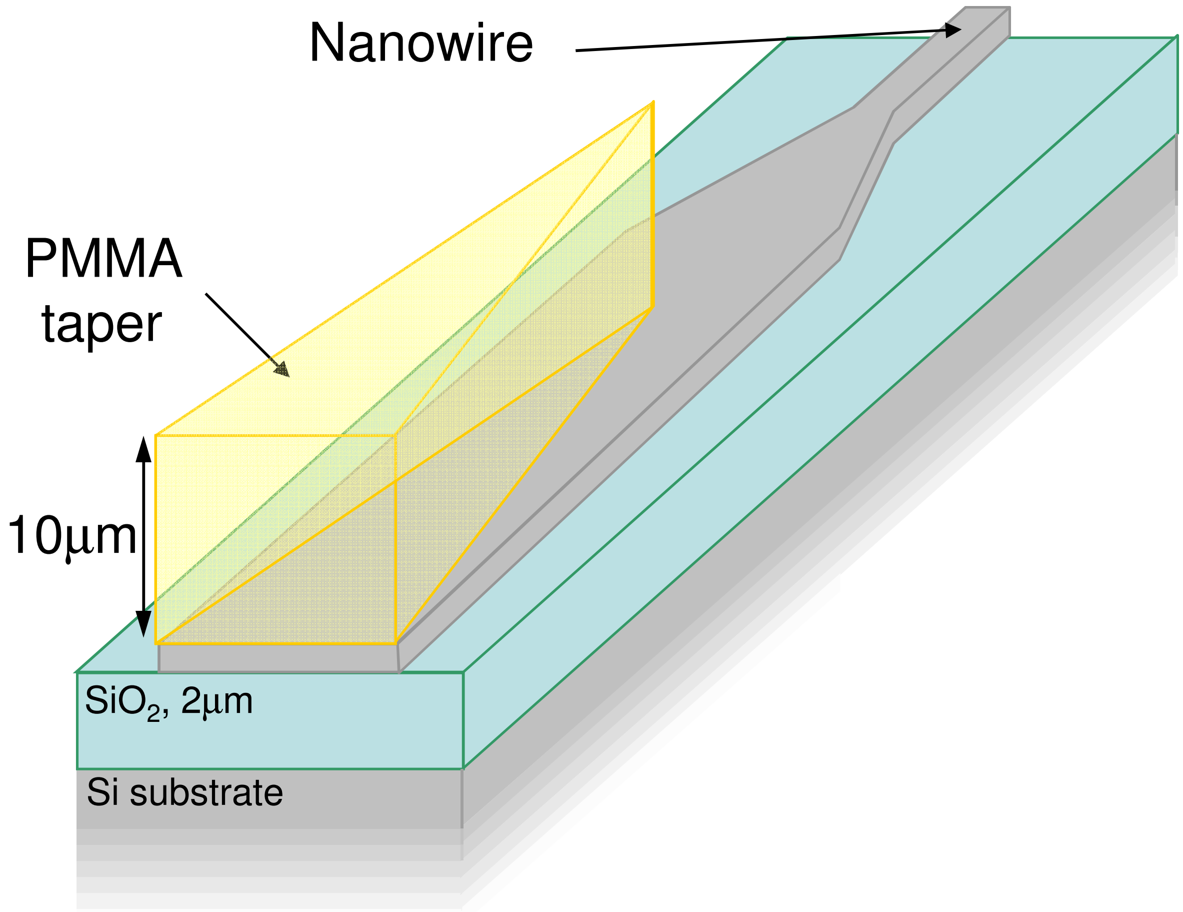
Photonics Group TKK

Coupling light into Si-nanowaveguides



Huge size mismatch between fiber and nanowire! → large coupling losses

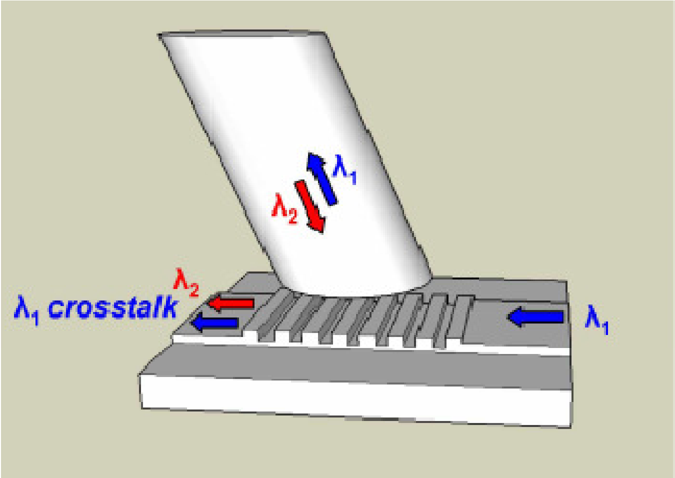
Coupling light into Si-nanowaveguides

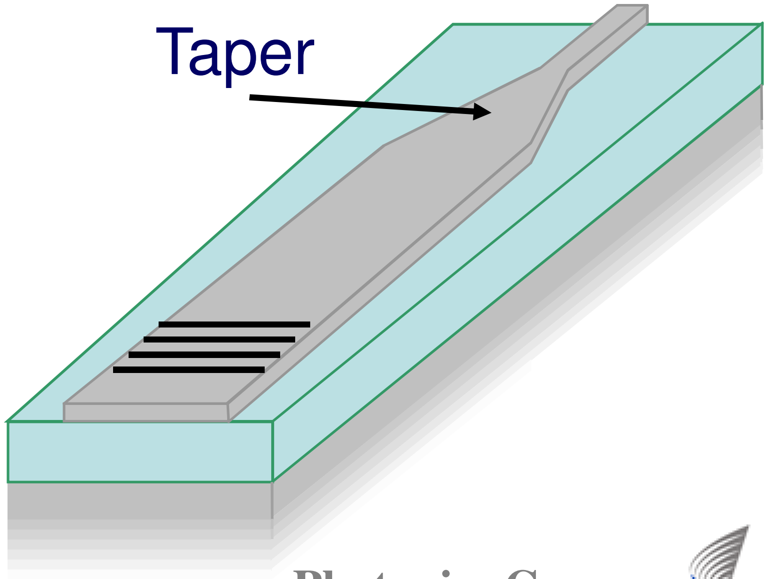


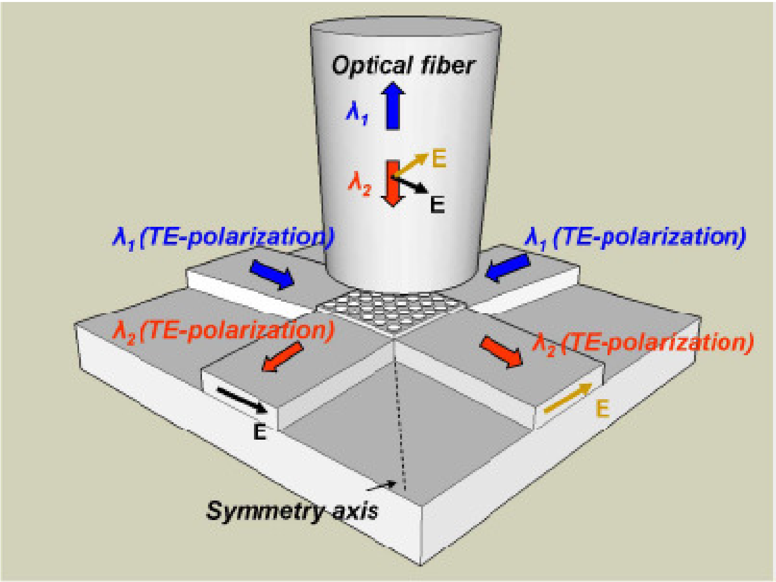
Coupling efficiency close to 100% with optical fiber

Grating Couplers

Approach used by:
- IMEC
- Luxtera





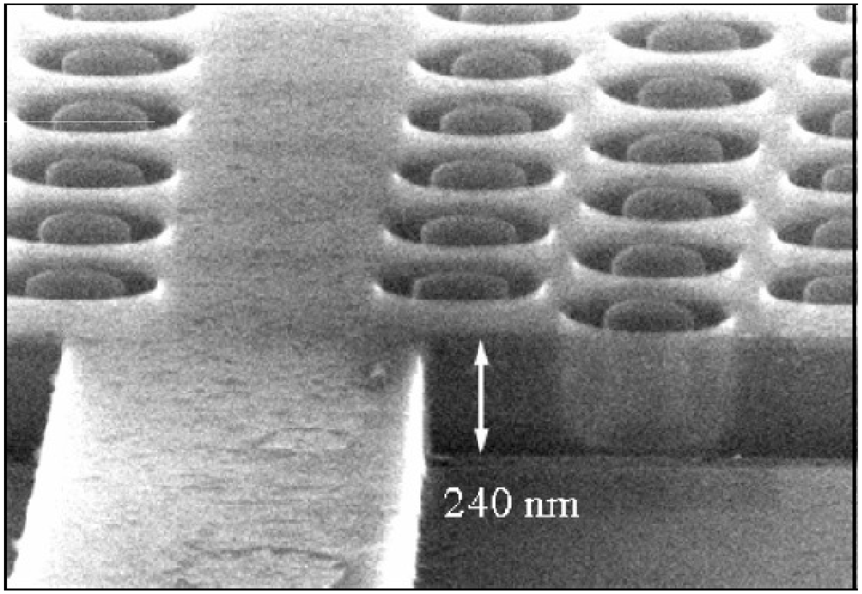


Si-Nanophotonics at TKK

Examples

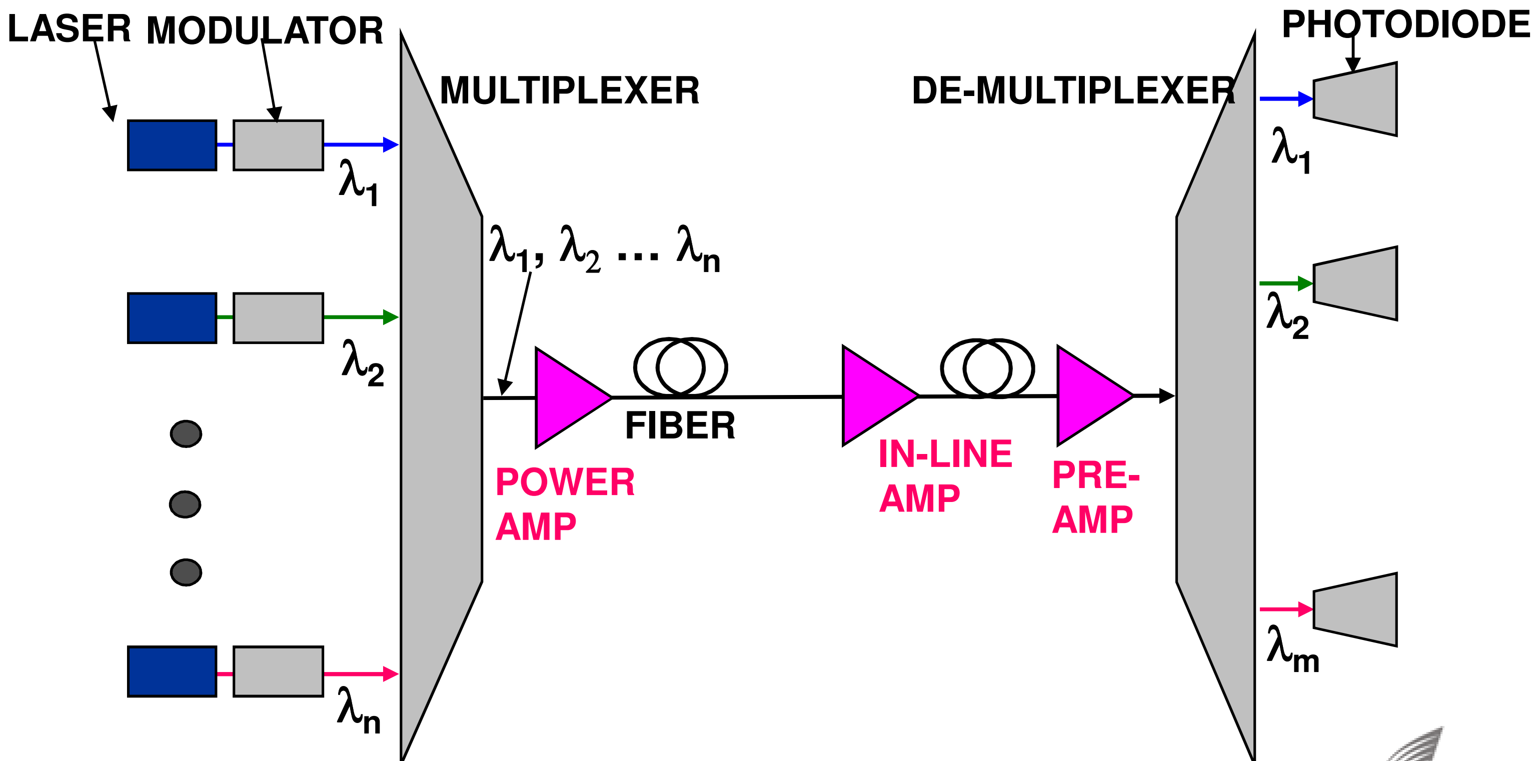
Waveguide bridge

Photonic Crystal waveguide



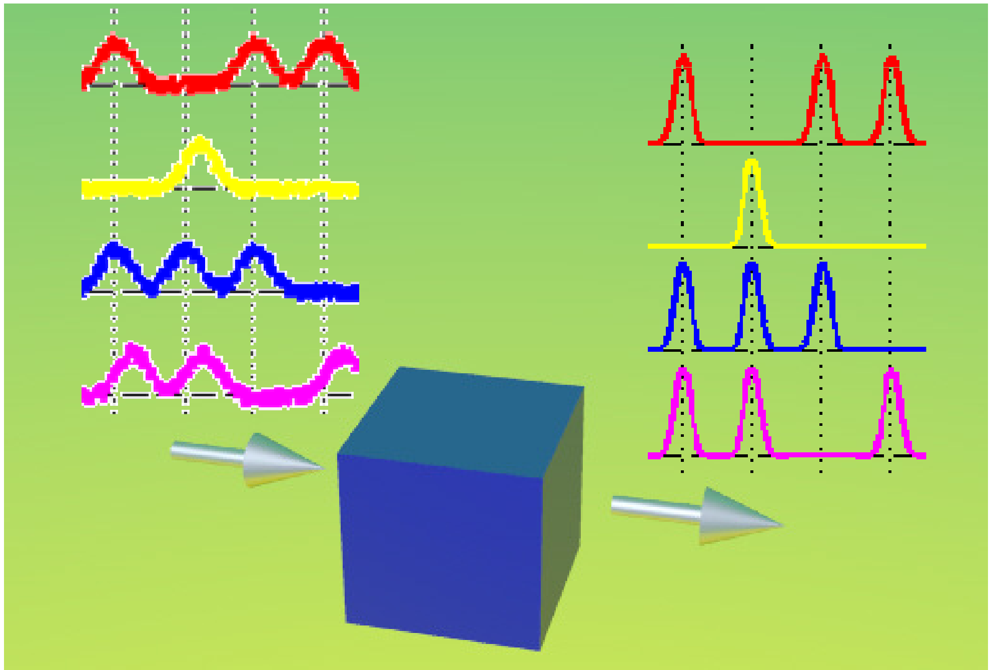
Si-Nanophotonics

- **Main Driver: Optical Communications**
  - Dense Wavelength Division Multiplexing (DWDM)
  - Multiple wavelength channels (~ 1.55 *μ*m) in a single optical fiber
  - Data rate today: 10 Gbit/s; soon: 40 and 100 Gbit/s



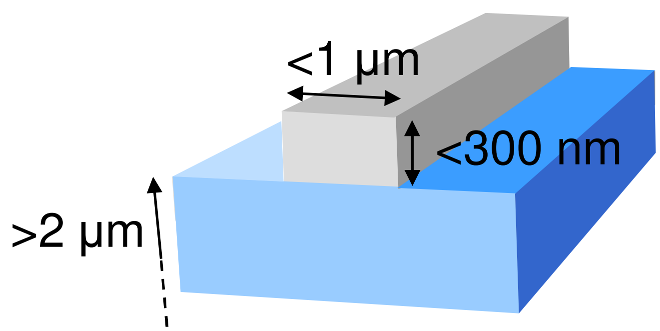
All-Optical Signal Processing

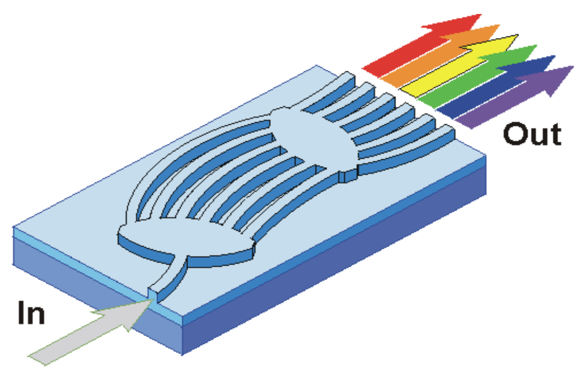
- **For example: All-optical 3R** (re-timing, re-shaping, re-amplification)
  - Dense Wavelength Division Multiplexing (DWDM)
  - Eliminates the need for Optical-to-Electronic-to-Optical (O-E-O) conversion, the so-called “electronic bottleneck”
  - Expected to become important at 40 Gbit/s and beyond



Si-Nanowaveguides for non-linear devices

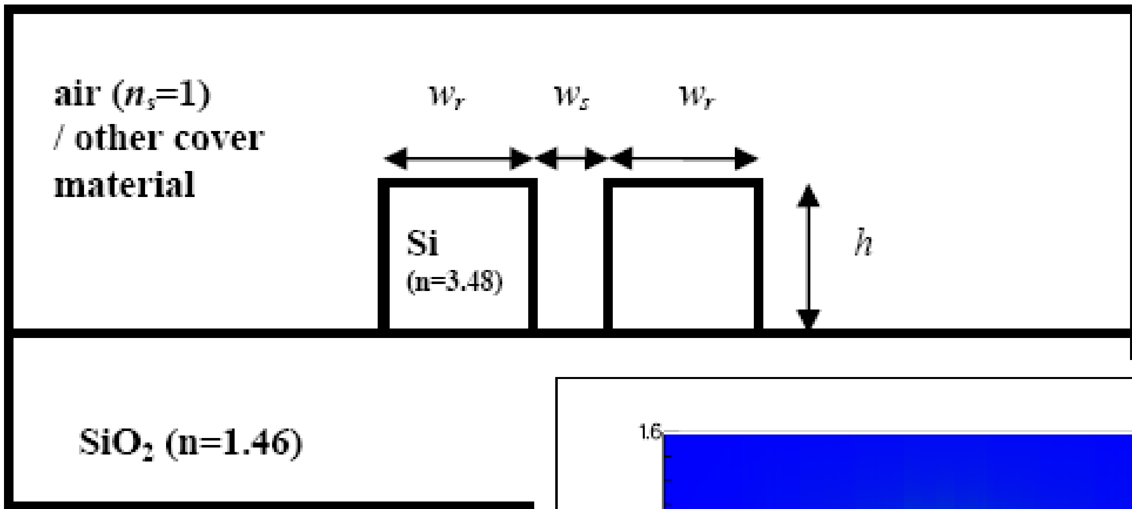
- Large nonlinearity
- Very tight mode confinement
  - High intensity
- Several all-optical devices demonstrated
- Better materials are still required !!



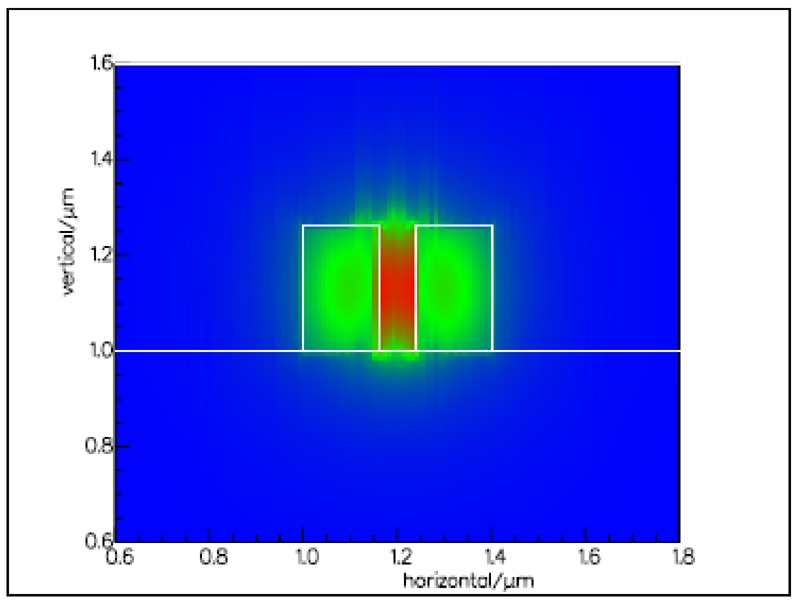


Si Nanowaveguides

Slot waveguides

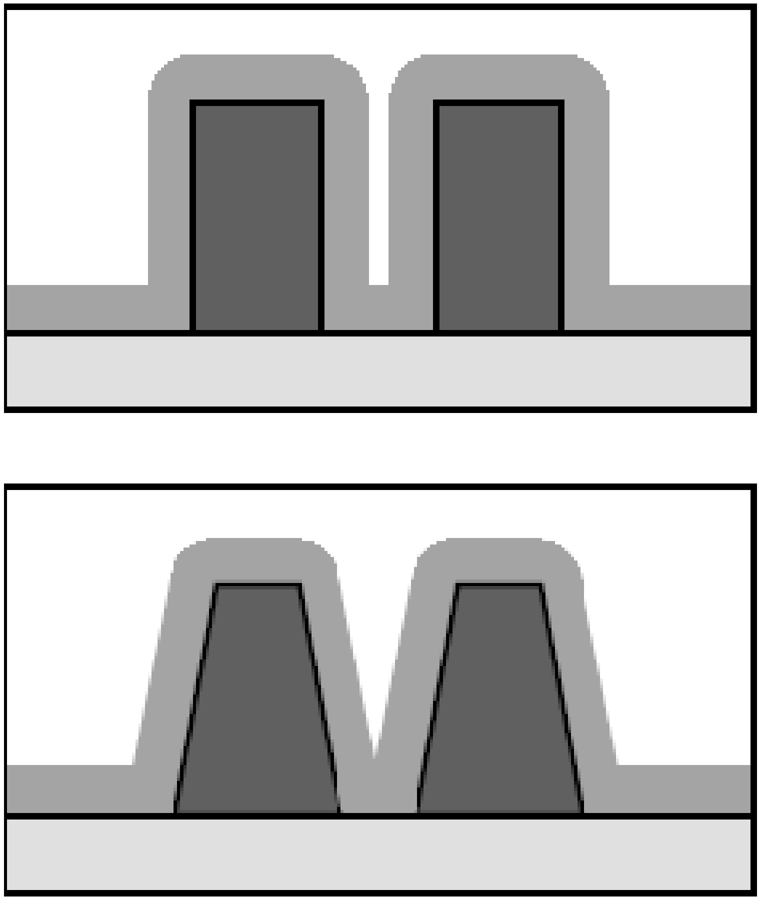


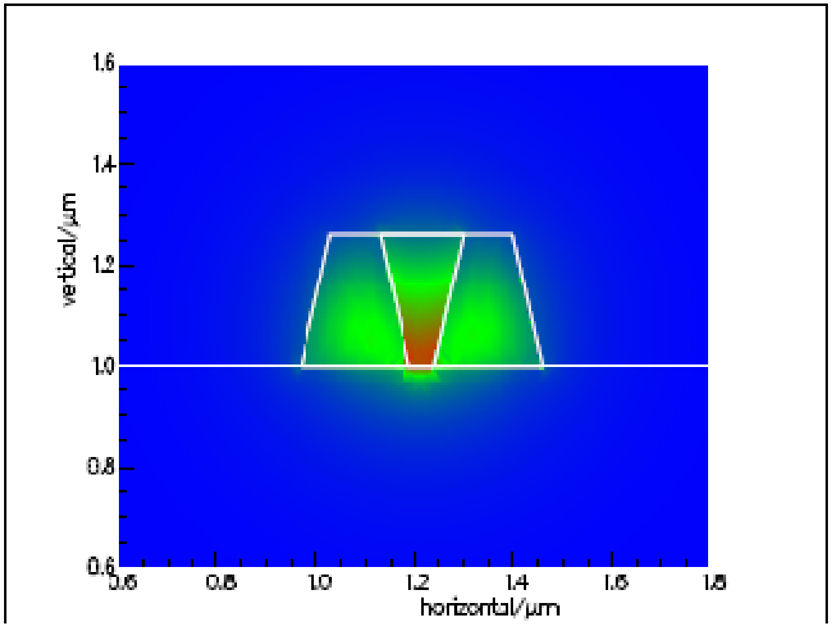
Slot width w_s = 80 nm



Si Nanowaveguides

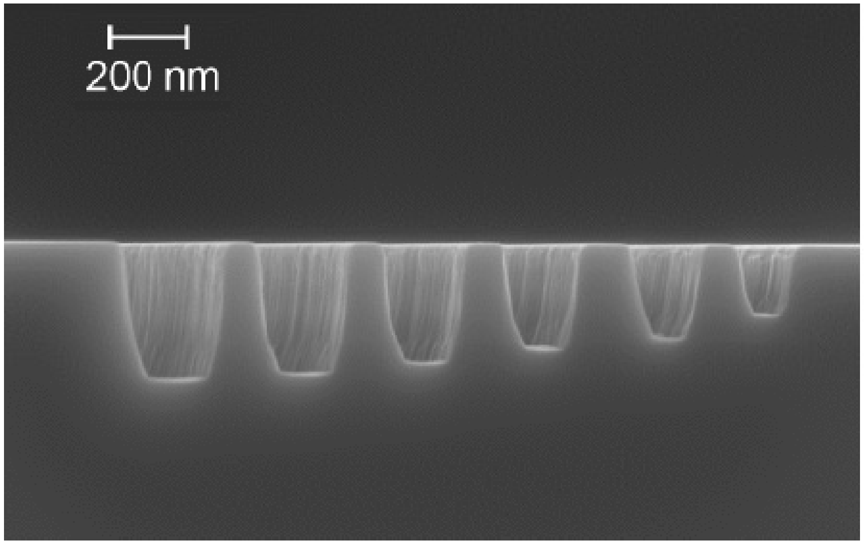
Slot filling with non-linear material

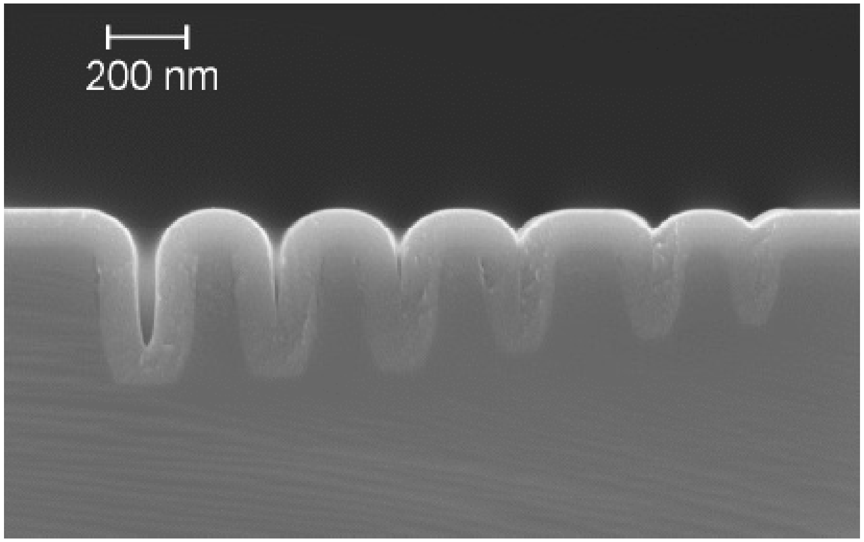




Si Nanowaveguides

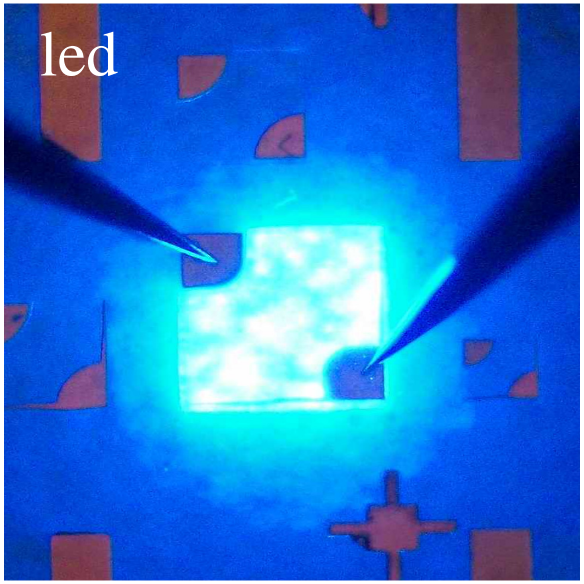
Slot filling using ALD!

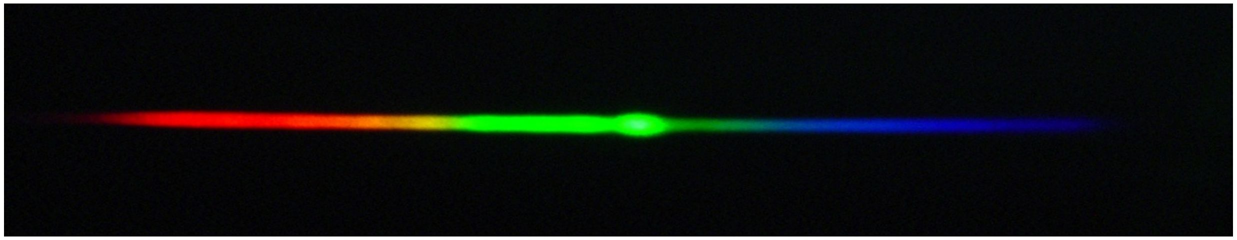




Conclusion

Nanophotonics has a bright future !!





Thank you!