Use of silicon photonic integrated circuits in quantum computing applications

Italian groups

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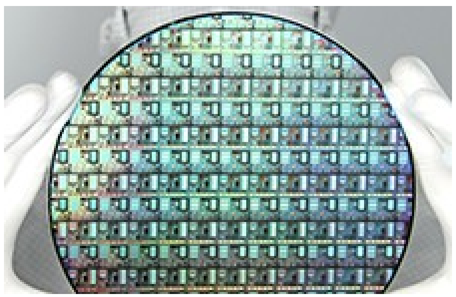
Roma Tor Vergata - INFN, Physics Department, Engineering Department - design, measurements

Milan - INFN, Physics Department, Computer Science Department - design, measurements, computer science

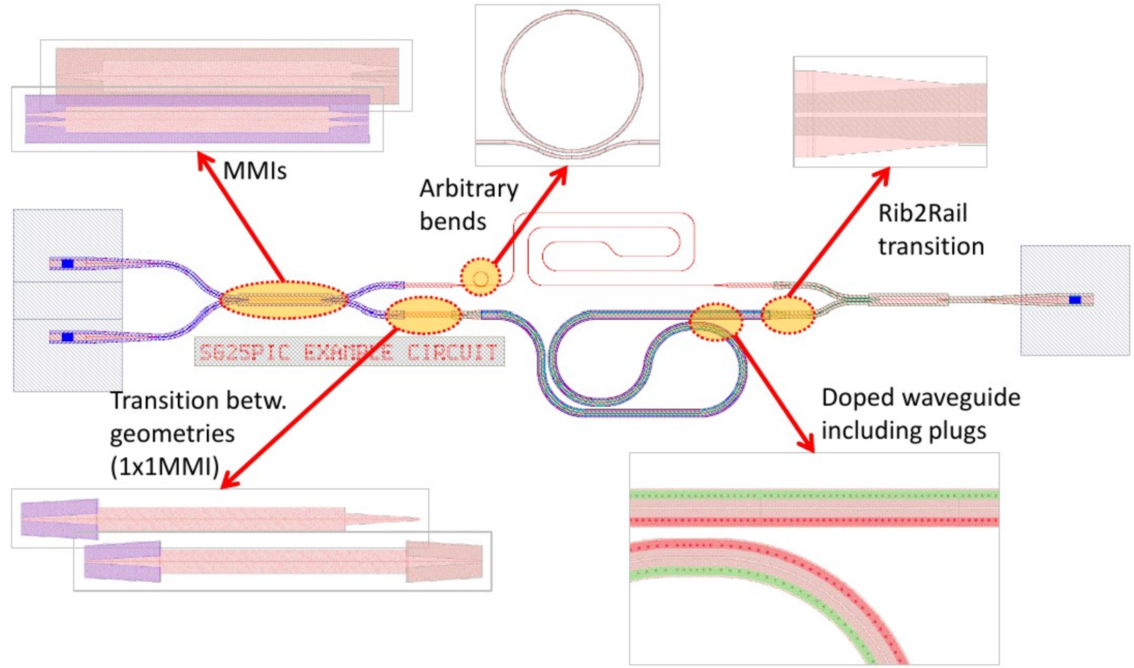
Camerino/Perugia - INFN, Physics Department - theory, measurements

Salerno/Napoli - INFN, Physics Department - measurements

Strong collaboration with IHP and TH Wildau



solutions



- https://www.ihp-microelectronics.com
- Monolithic photonic BiCMOS technology: 0.25 µm CMOS, high-performance npn and full photonic device set (SOI)
- Europractice, Cadence, Luceda, TexEDA, CST
- Joint Master and PhD programme: Tor Vergata - Wildau (www.th-wildau.de/photonik) - IHP
- Silicon photonics summer school https://www.ihp-microelectronics.com/en/jobs-career/students/summer-school-microelectronics/welcome.html

Preliminary contacts with researchers from ...

INFN Istituto Nazionale di Fisica Nucleare

CIT CORK INSTITUTE OF TECHNOLOGY
INSTITIÚID TEICNEOLAÍOCHTA CHORCAÍ

CENTRE FOR ADVANCED PHOTONICS & PROCESS ANALYSIS
CAPPA
WWW.CAPPA.IE

Tyndall National Institute

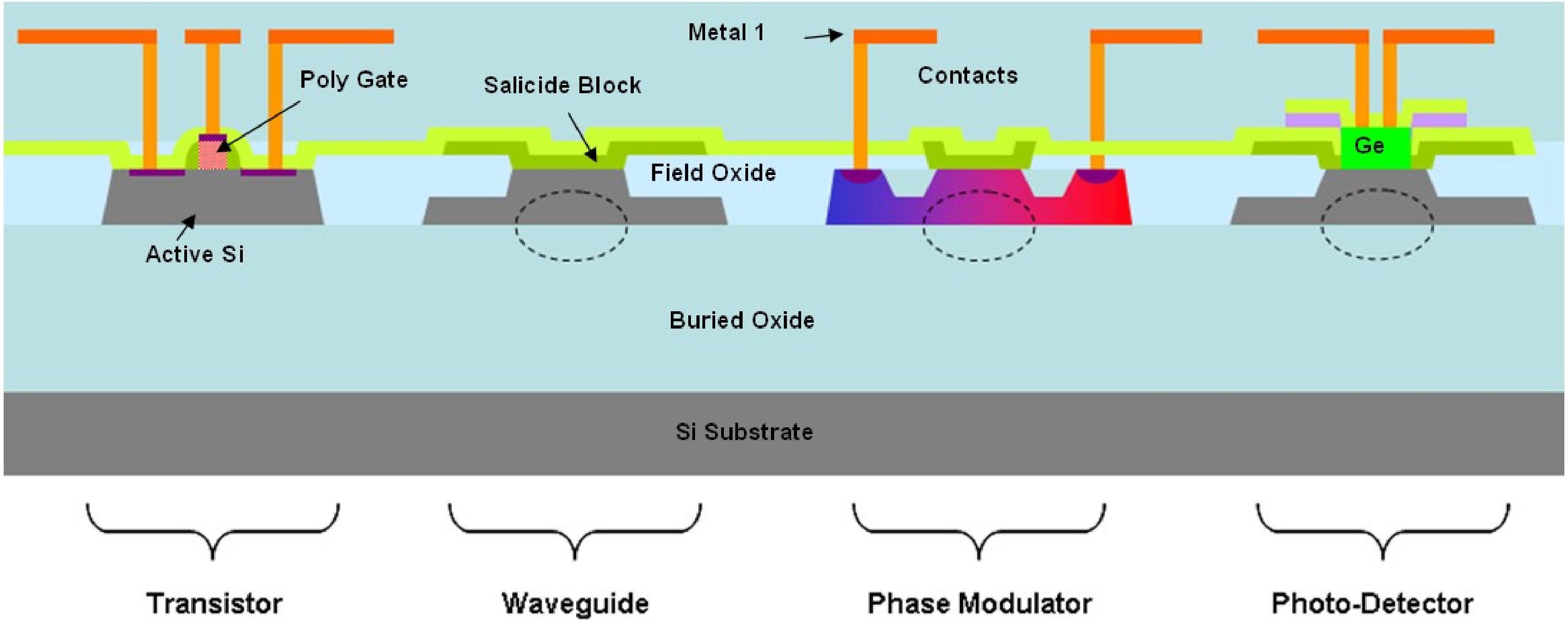
Nanostructures for Silicon Photonics

KTH VETENSKAP OCH KONST

Quantum Nano Photonics group:

→ quantum dots
→ integrated single photon sources

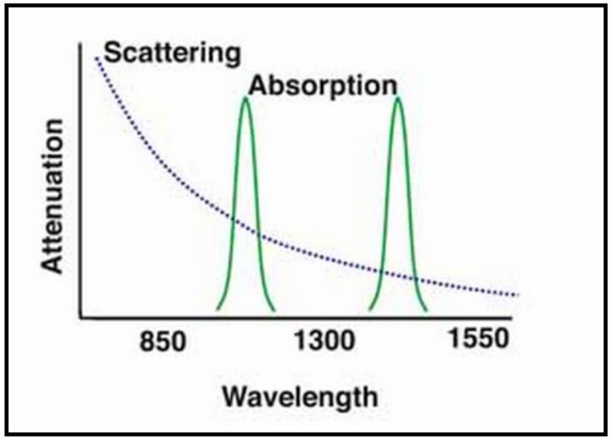
Silicon Photonics



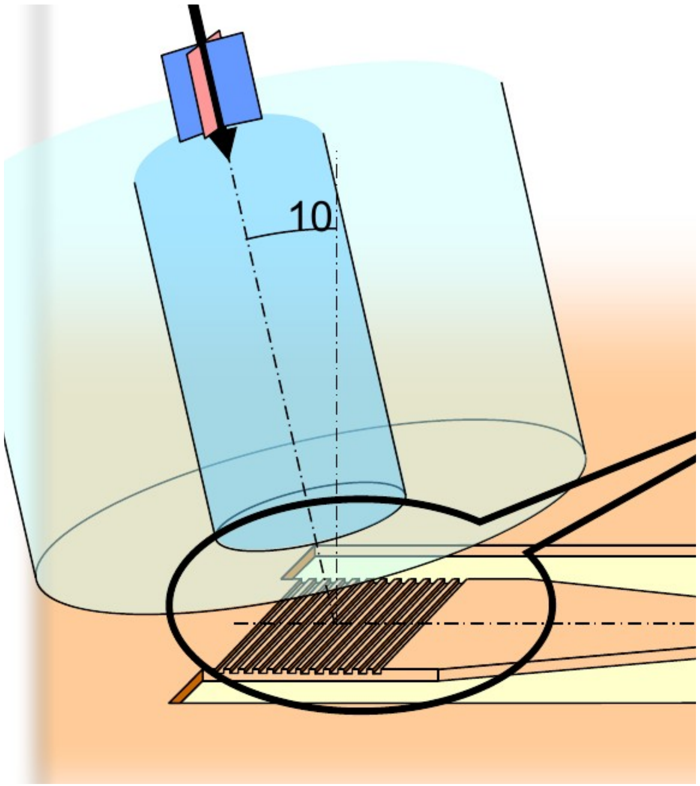
Why Silicon?

- High refractive index (3.5) and low dispersion
- Available in large quantities
- Easily integrable with standard CMOS-processes

Why 1550 nm?

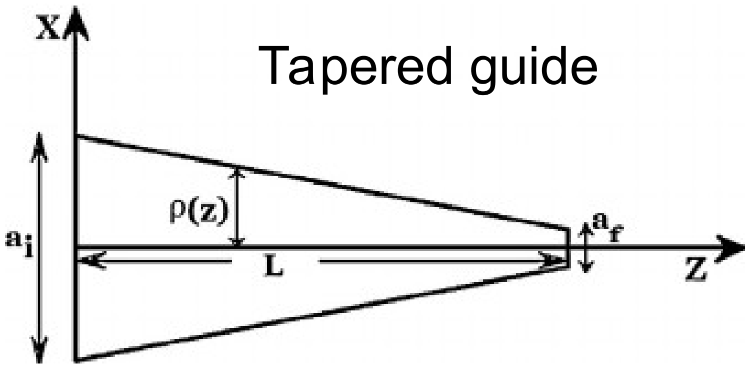


Light coupling and transport

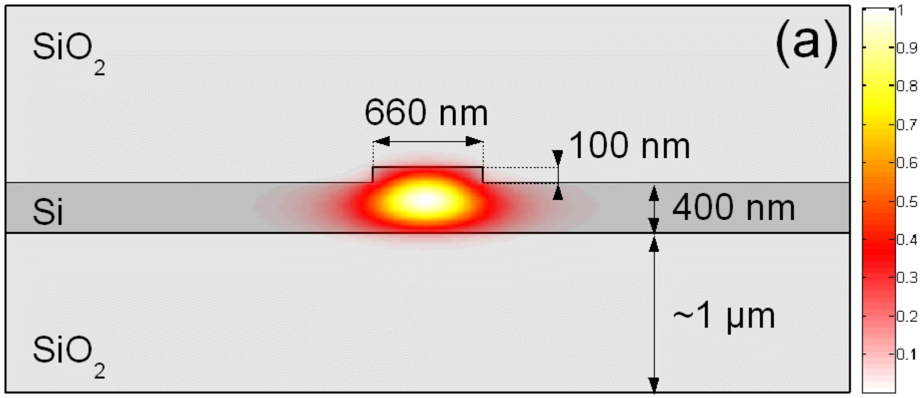


Bragg coupler

Tapered guide



Light guide



Refractive index modulation

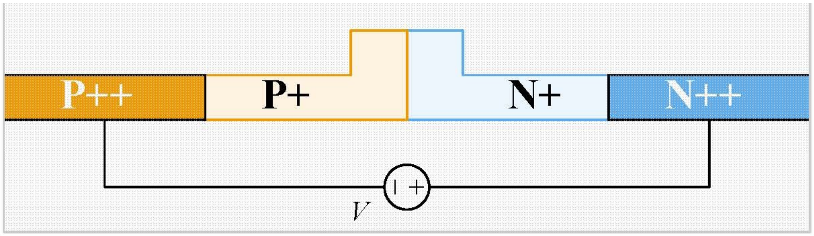
Electro-optical effect:

$$\Delta n = -8{,}8.10^{-22}\Delta N - 8{,}5.10^{-18}\Delta P^{0{,}8}$$

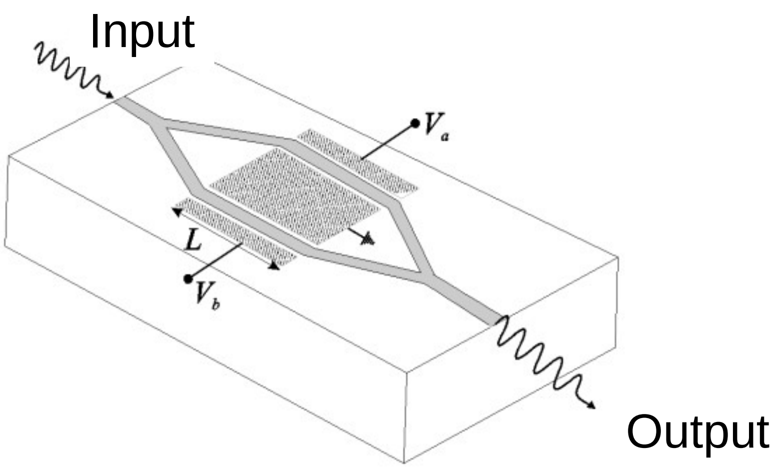
$$\Delta\alpha = 8{,}5.10^{-18}\Delta N + 6{,}0.10^{-18}\Delta P$$

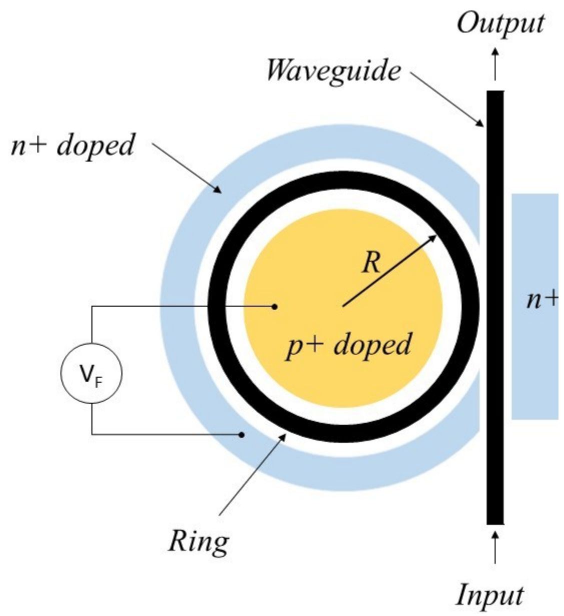
λ = 1550 nm

Soref R. & Bennet B., IEEE J. Sel. Top. Quant. Electron. 23,123-129 (1987)
Reed G.T. et al., NaturePhotonics 4, 518-526 (2010)



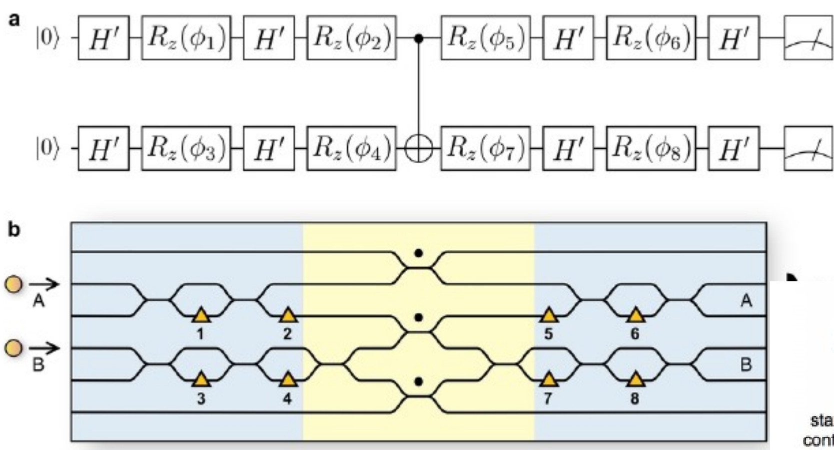
Modulators



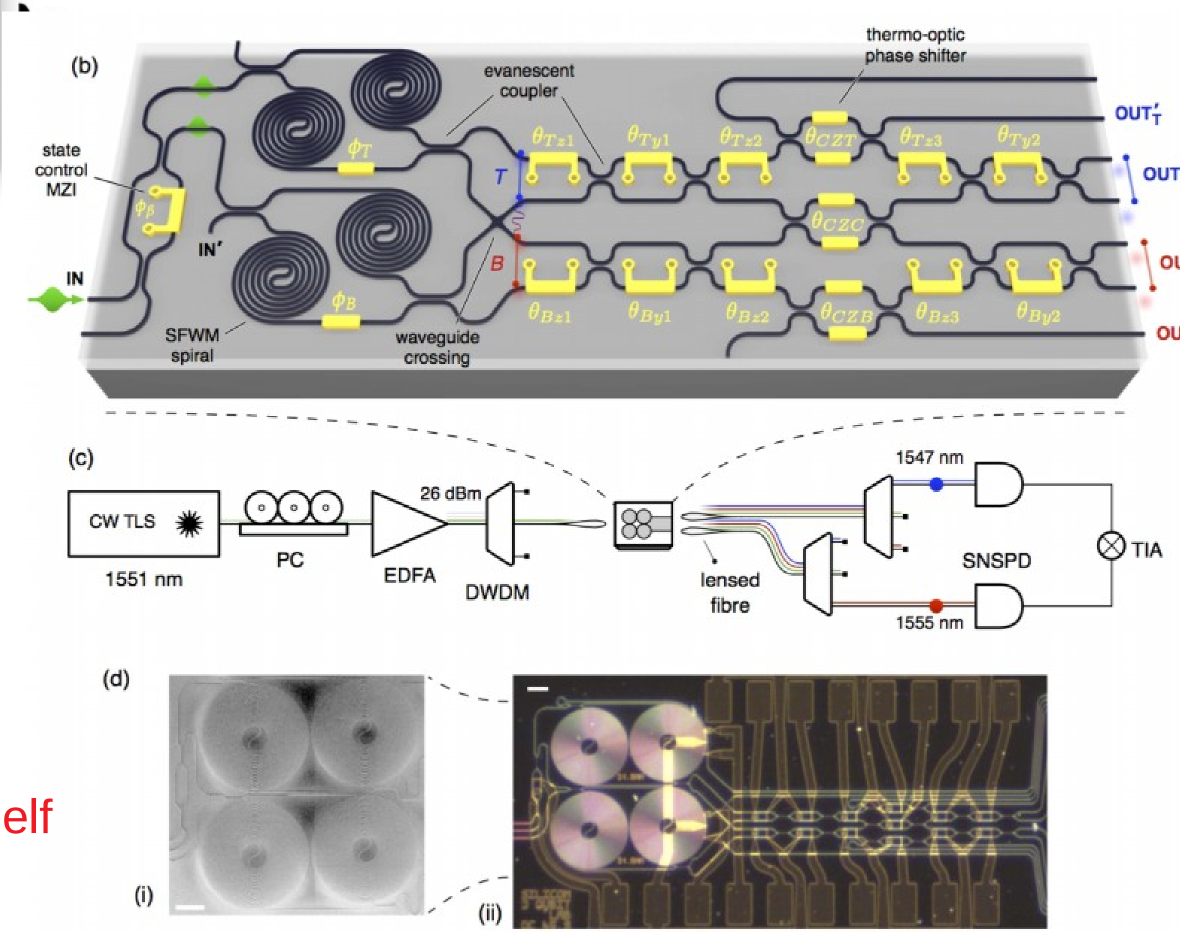


- Mach-Zehnder interferometer
- Ring Resonator: tuning is critical

Linear Optics Quantum Computing



Knill, Laflamme, Milburn (2001)
Quantum computing with linear optics (beam splitter, phase shifter, single photon sources, photon detectors)



Shadbolt et al. (2012)
Silica on Si @ 808 nm

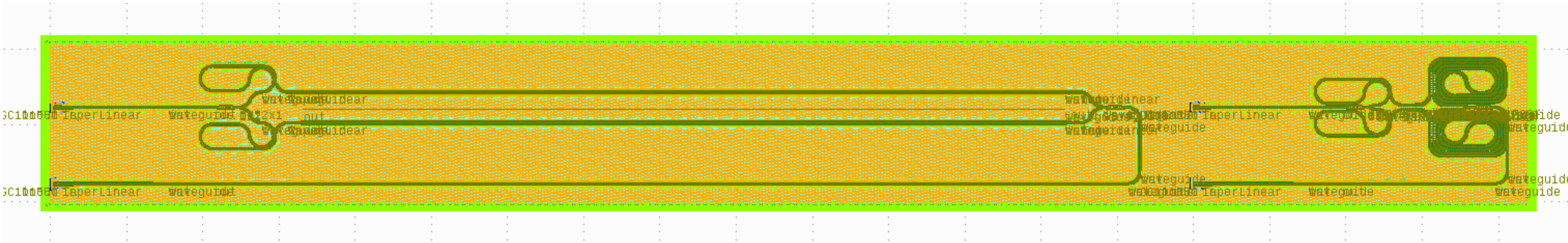
Santagati et al. (2017)
SOI @ 1550 nm

C-band telecom length:
→ Silicon Photonics
→ Components Off The Shelf

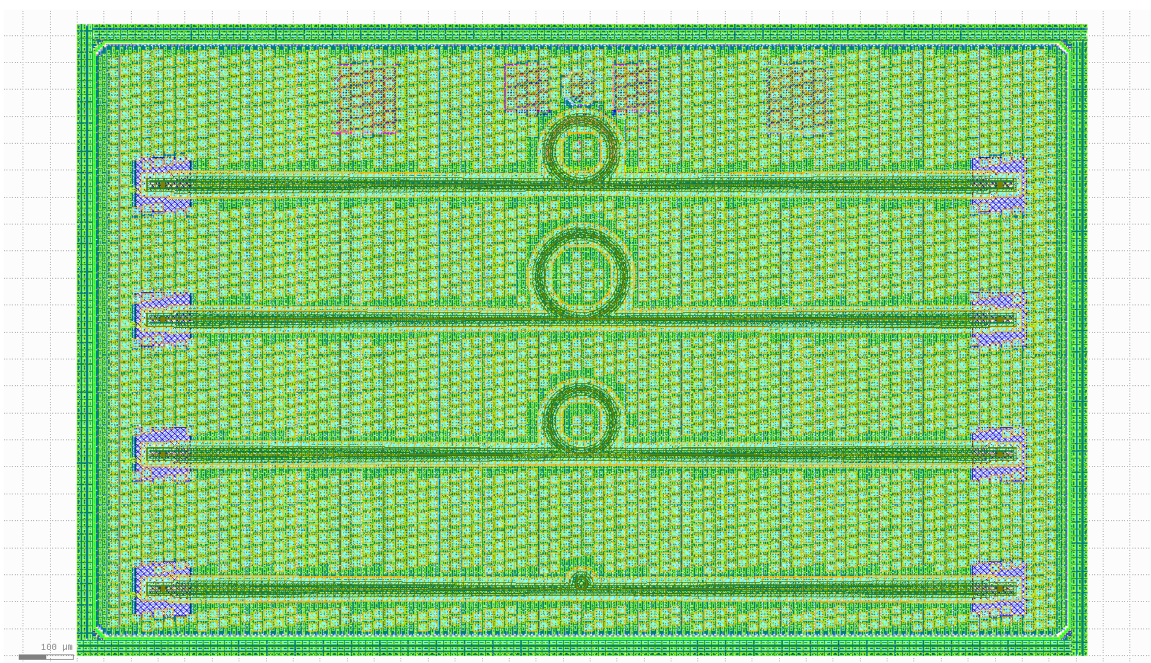
CSN5 funded projects

- SPE - Silicon Photonics Experiment (2017-2019)
  - Silicon Photonics modulator with integrated electronics
- QUICHE - QUantum Integrated CHip Eperiment (2020-)
  - design (without production) of Silicon Photonics basic Linear Optics Quantum Computing elements (Europractice sw: IPKISS, TexEDA, ...)
  - test of “discrete” Linear Optics Quantum Computing elements (at 1550 nm)
  - study of integrated photon detectors at 1550 nm (e.g. heterojunction Si-Bi_2Se_3 avalance photodiode)

Silicon Photonics designs



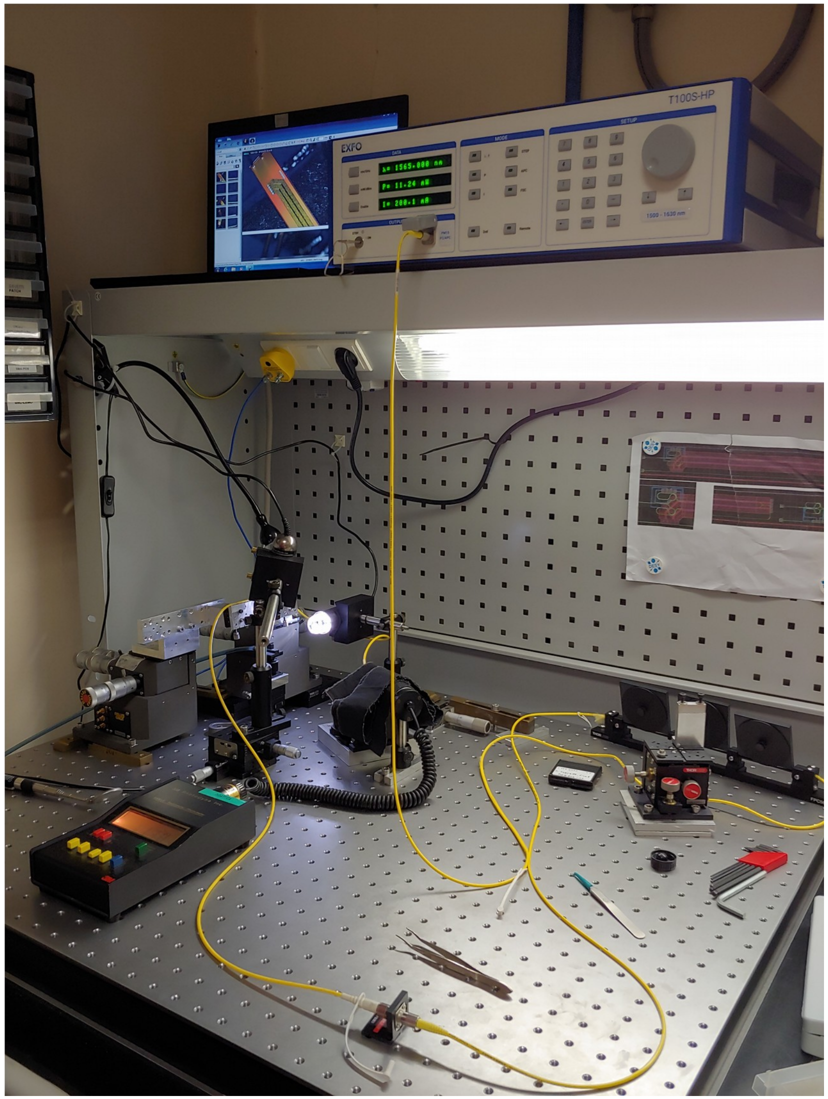
SPE: submitted in april 2017, received on february 2018
10.0 mm x 1.2 mm: two Mach-Zehnder interferometers



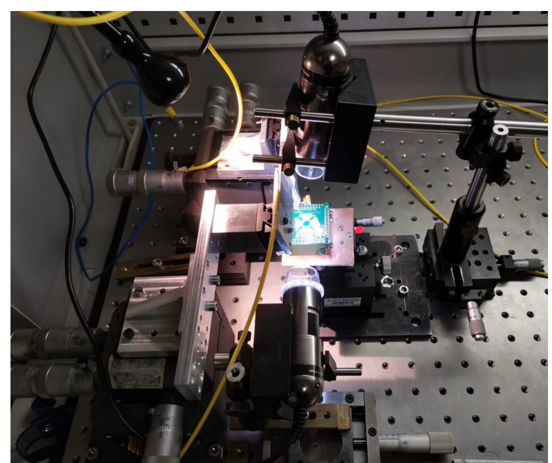
SPE: submitted in october 2019, expected on april 2020
1.9 mm x 1.2 mm: four ring resonators

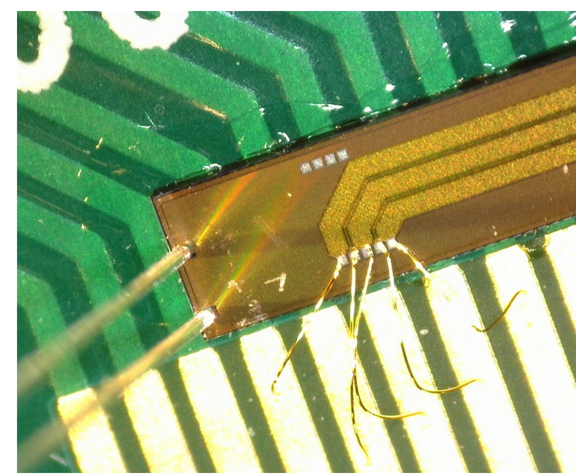
MZI → Cadence
RR → Luceda IPKISS, TexEDA

Silicon Photonics lab

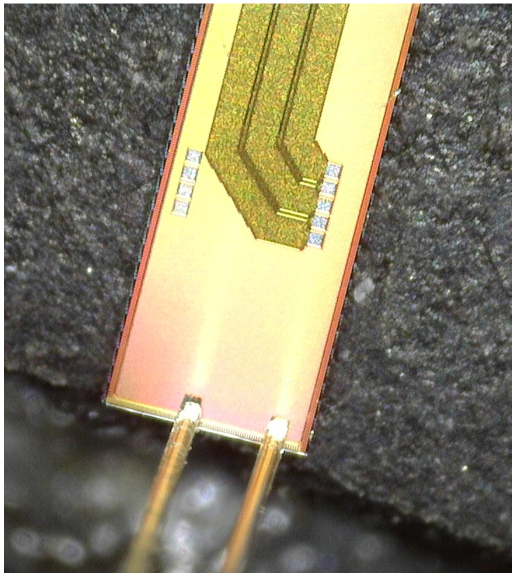


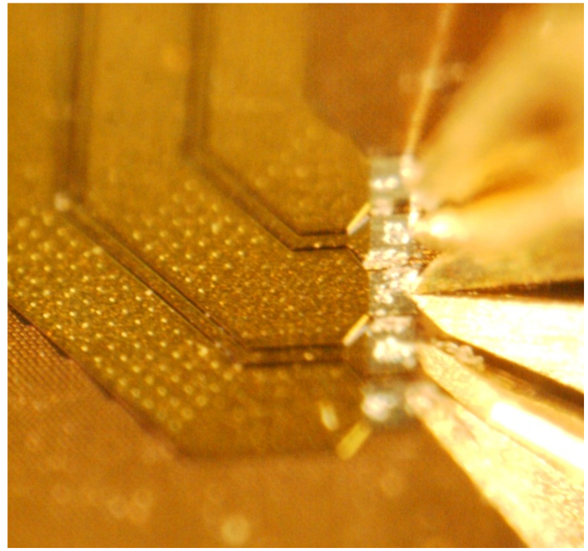
- 20 mW 1550 nm tunable-wavelength laser
- Optical bench, microscopes, micropositioning
- 100-150 um pitch microprobes
- 6 ps risetime photodiode
- 40 GHz BW amplifier and bias tee
- 1550 nm EDFA and filter
- Superconductive Nanowire Single Photon Detector

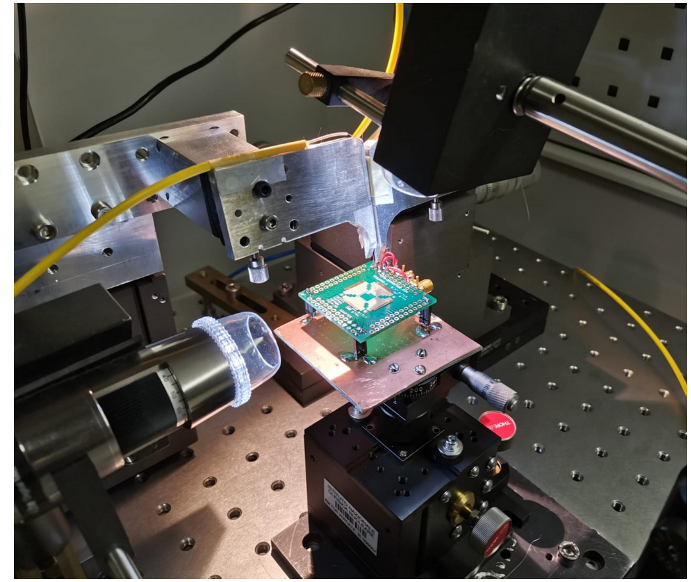


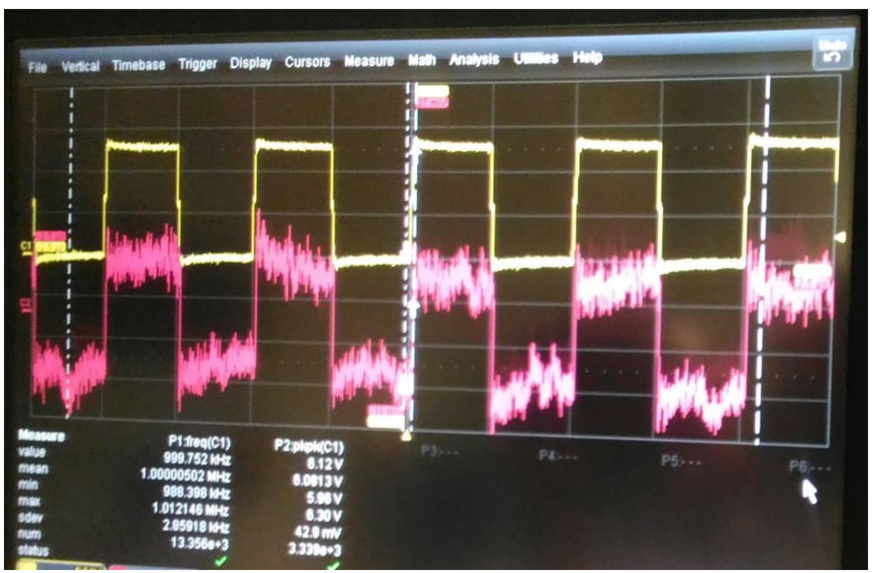


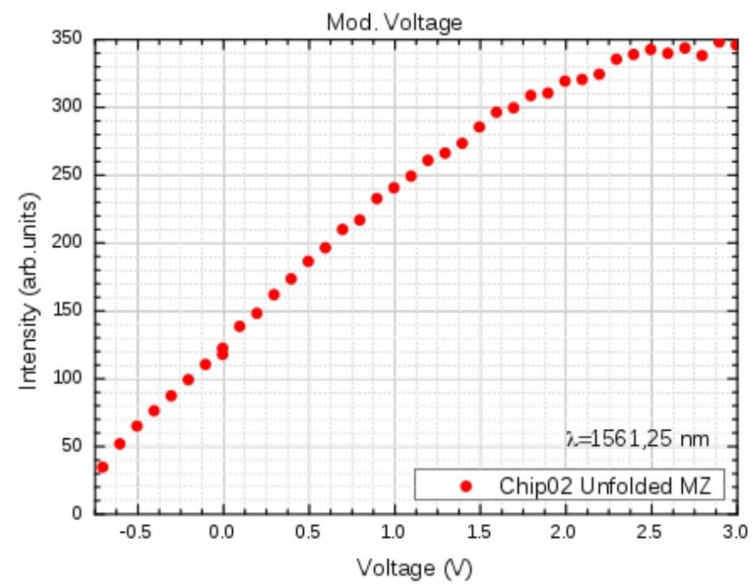
Silicon Photonics lab





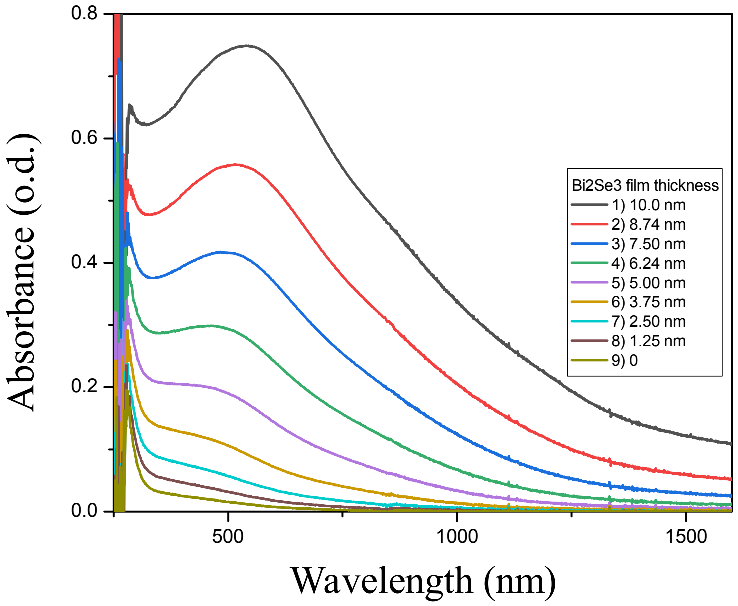


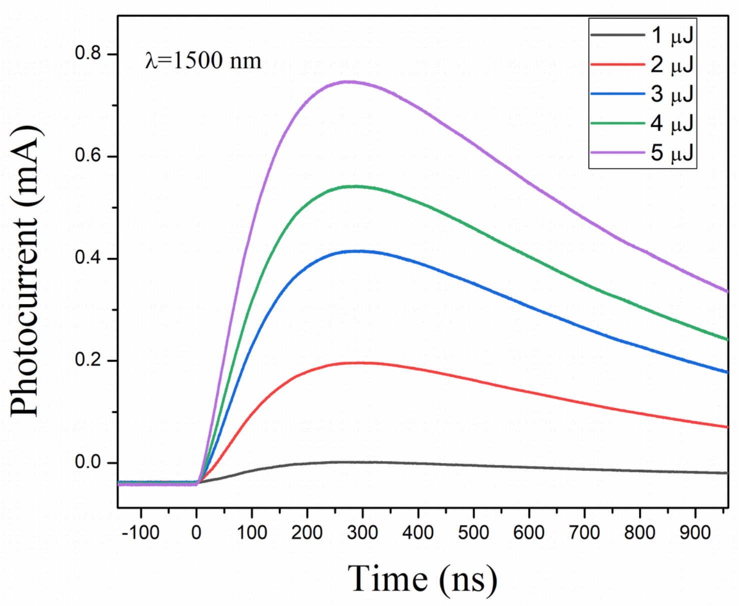




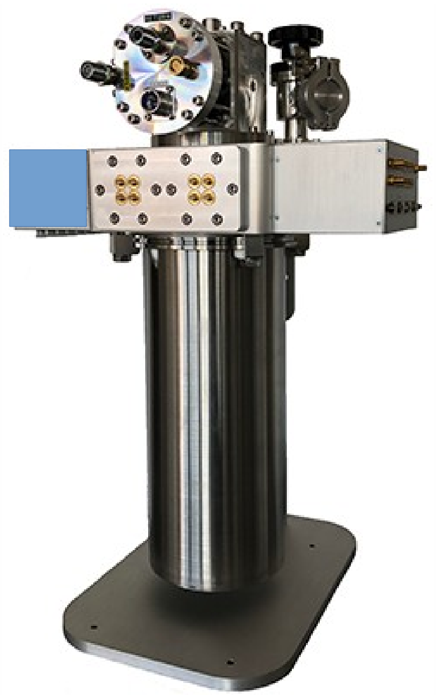
Study of integrated photon detectors

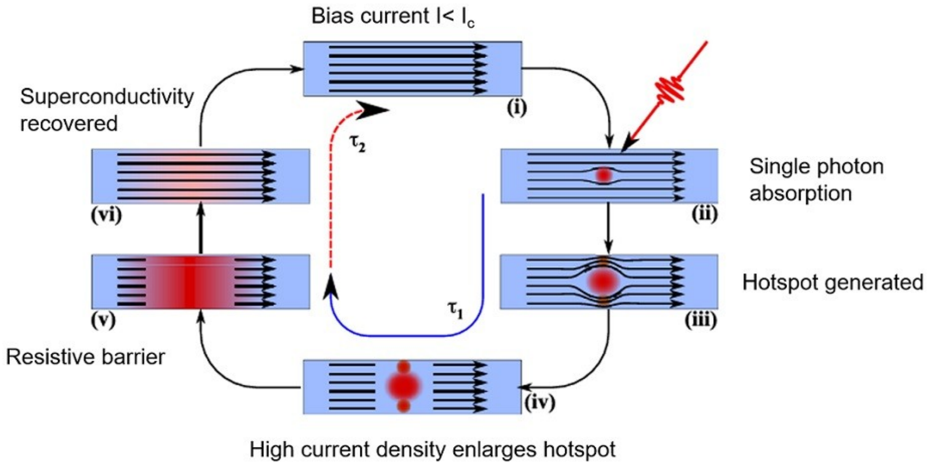
- E.g. Si-Bi_2Se_3 heterojunction
- Deposition: Chalmers Institute Goteborg
- Characterization: Tor Vergata and Salerno





Superconducting Nanowire Single Photon Detector





- The superconducting nanowire single photon detector (SNSPD) is constituted by a thin film of superconducting material (niobium nitride, NbN) shaped into a meandering nanowire.
- The detectors are operated at 2.5 Kelvin and a constant current below the critical current of the superconductor is applied to the device.
- Once a single photon is absorbed in the meandering nanowire, superconductivity is locally broken. As a result, the current is directed towards the amplification electronics and creates a voltage pulse.

Thanks a lot for your attention!