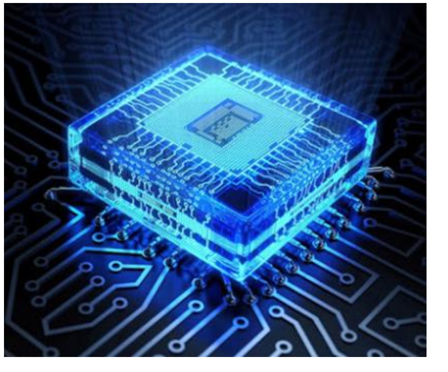
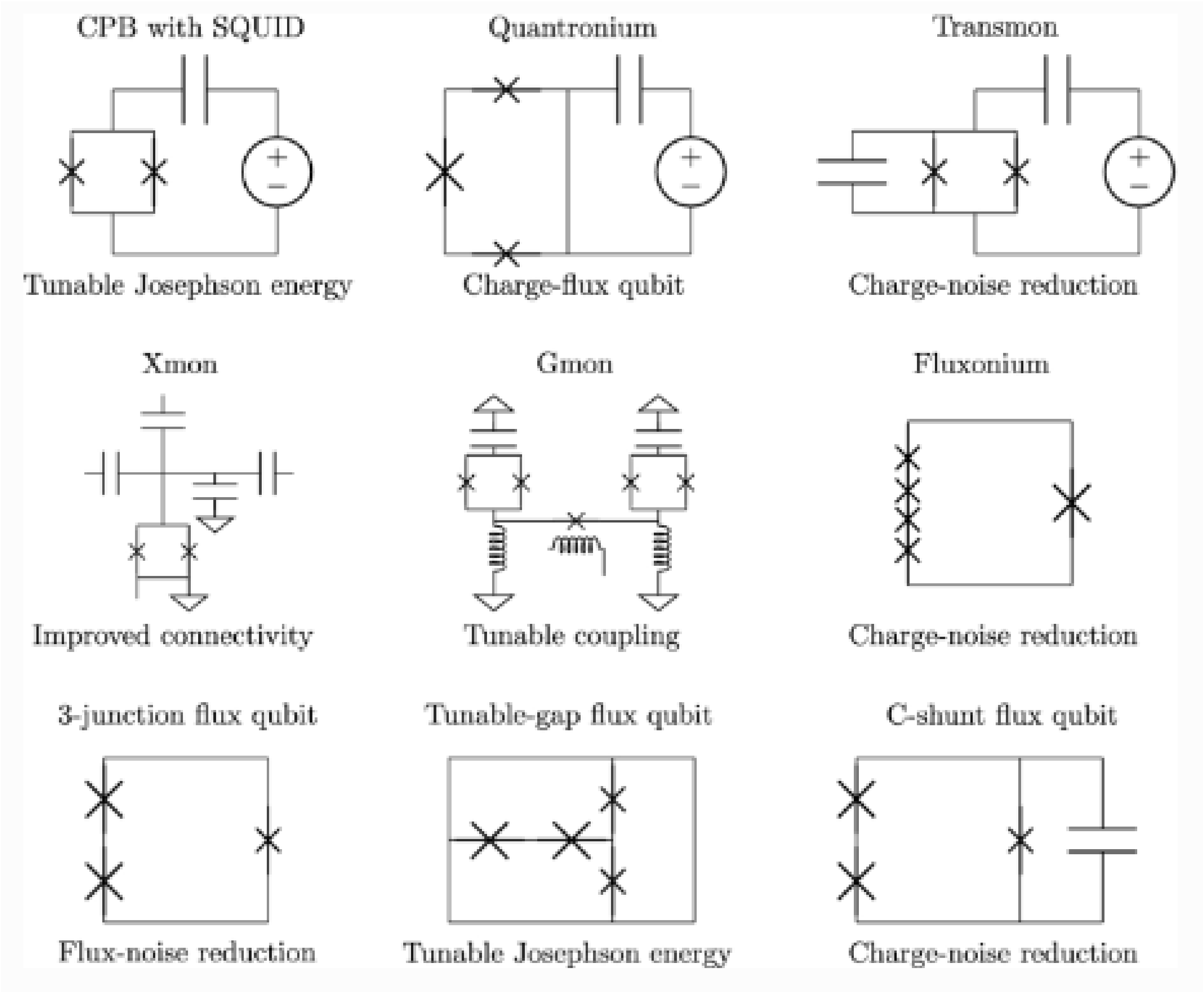
QUANTEP
QUANtum Technologies Experimental Platform

- Call CSN5 “tematica” sulle Tecnologie Quantistiche - R.N. Andrea Salamon
- LNL, MI, Camerino (PG), PI, PV (e UNIMORE), RM2, SA, TO
- Collaborazioni con: LNGS (LUNA-MV), LABEC (DEFEL), UNIPI (Prof Saponara), UNITO, IHP, TYNDALL, Institut Ruđer Bošković (RBI), Micro Photon Devices (MPD), University of Leipzig, Chalmers University of Technology, Physikalisch-Technische Bundesanstalt (PTB).
- 15-17 FTE/anno, fino a ~ 1 MEuro di budget
- 2021-2023 → **chiesto prolungamento al 2024 per completare l’attività**
- Realizzazione di una piattaforma comune basata su **Silicon Photonics** per lo sviluppo e caratterizzazione di:
  - circuiti per il Quantum Computing (MI, PG, PI, PV, RM2)
  - sorgenti di singolo fotone (LNL, TO)
  - rivelatori di singolo fotone (RM2, SA, TO)
  - circuiti per il controllo della polarizzazione (PV, UNIMORE, RM2)

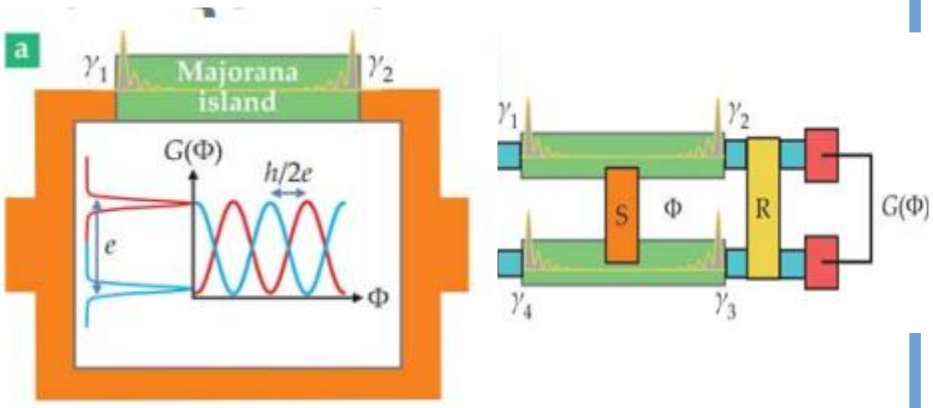


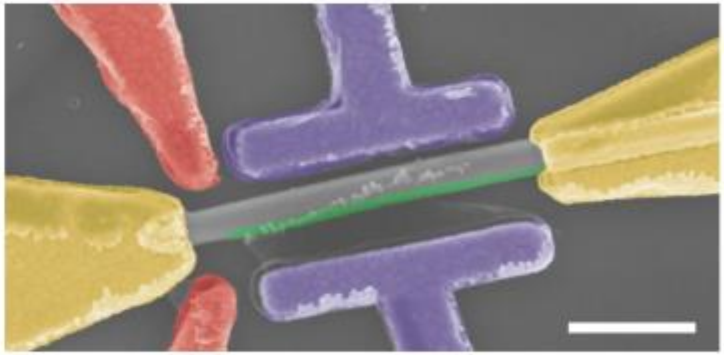
QUANTUM COMPUTING

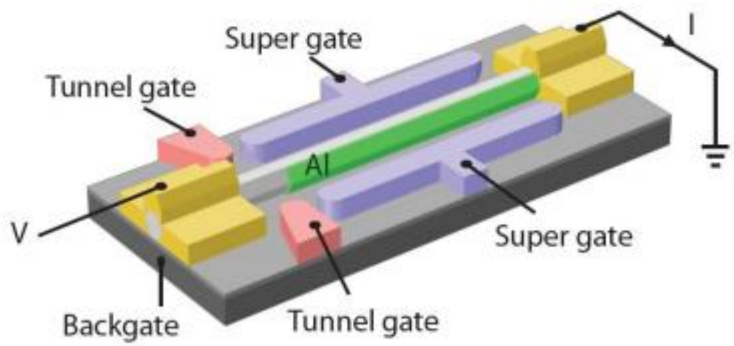


QUANTUM COMPUTING

$$a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle \rightarrow$$
$$\rightarrow a|00\rangle + b|01\rangle + c|11\rangle + d|10\rangle$$







QUANTEP /PG

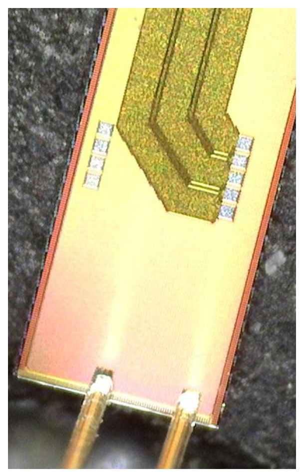
Simulazione, disegno e test (Tor Vergata) di **circuiti per il Quantum Computing** con ottica lineare a 1550 nm

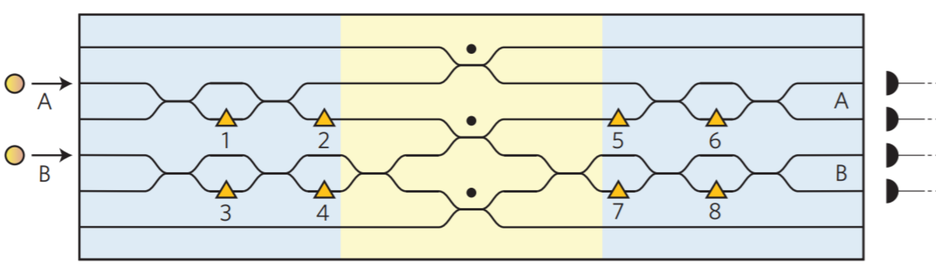
$$a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle \rightarrow$$
$$\rightarrow a|00\rangle + b|01\rangle + c|11\rangle + d|10\rangle$$

control bit

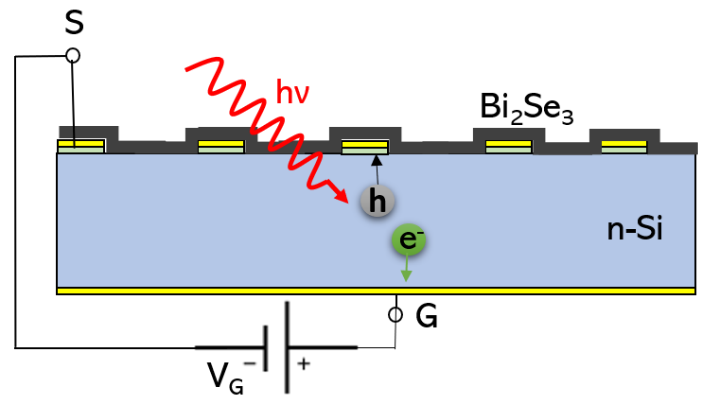
$$\mathrm{CNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

target bit





Rivelatori di singolo fotone a 1550 nm con eterogiunzioni di Bi_2Se_3 ed altri materiali 2D su Si



Circuiti per il Quantum Computing (CNOT gate)

1 qubit: $\alpha_0|0\rangle + \alpha_1|1\rangle, \; |\alpha_0|^2 + |\alpha_1|^2 = 1$

Alcuni gate elementari per 1 qubit

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \quad R_\phi = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\phi} \end{pmatrix} \quad H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

2 qubits: $a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle \qquad |a|^2 + |b|^2 + |c|^2 + |d|^2 = 1$

Il gate prototipo per 2 qubit è il Controlled NOT (CNOT) gate

control bit

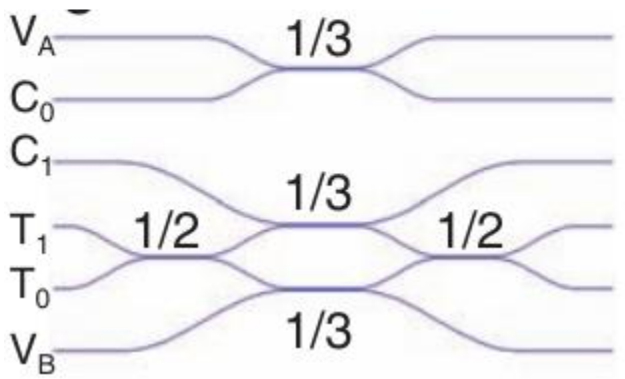
$$\mathrm{CNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

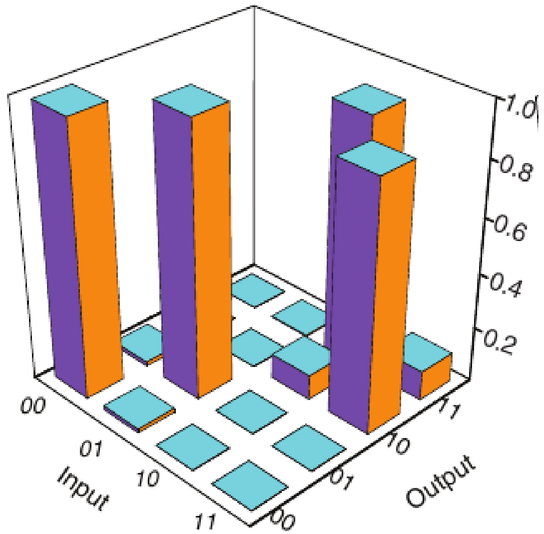
target bit

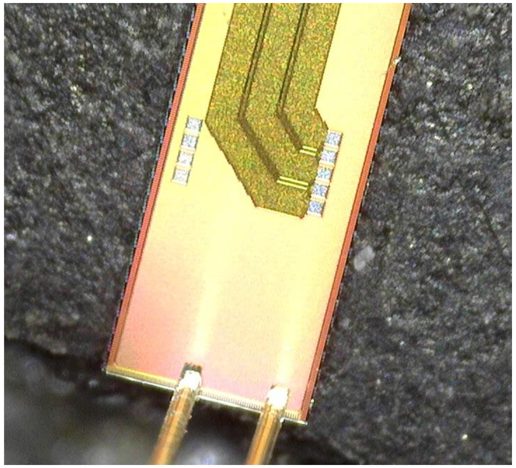
- il control bit non viene modificato
- il target bit in uscita è lo XOR del control e del target bit in ingresso
- … ma ovviamente fa molto di più perchè lavora sulla funzione d'onda

$$a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle \rightarrow a|00\rangle + b|01\rangle + c|11\rangle + d|10\rangle$$

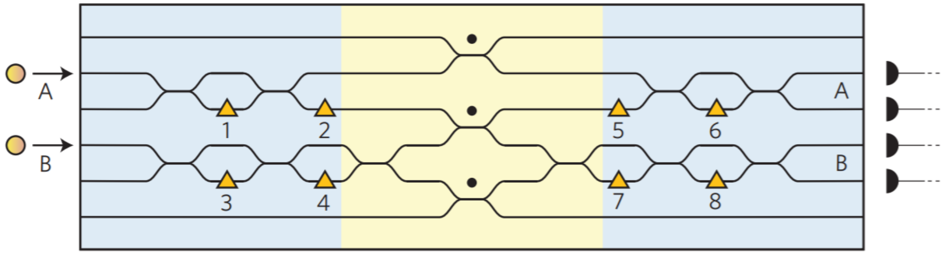
Circuiti per il Quantum Computing (CNOT gate) con ottica lineare a 1550 nm su Silicon Photonics







- Waveguide coupler (con onda evanescente) usati come beam splitter (η=1/2 e η=1/3) → stabilità rispetto a produzione e lunghezza d'onda

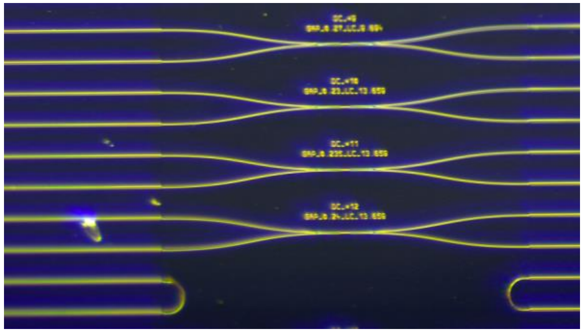


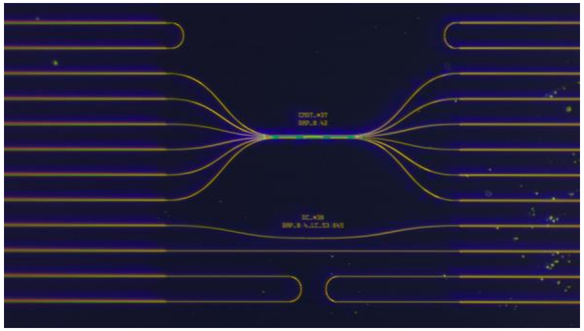
- Coincidence basis (C_0T_0, C_1T_0, C_0T_1, C_1T_1)
- Postselected probabilistic gate (P=1/9)

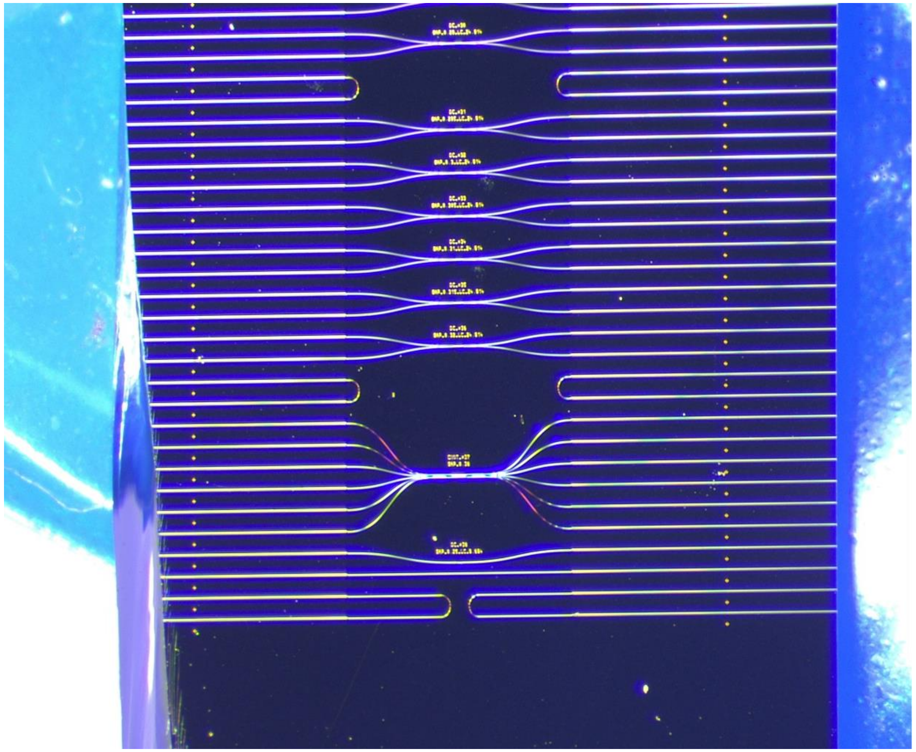
T. C. Ralph et al, Linear optical controlled-NOT gate in the coincidence basis, DOI: 10.1103/PhysRevA.65.062324

A. Politi et al, Silica-on-Silicon Wavegide Quantum Circuits, DOI: 10.1126/science.1155441

È stata prodotta una prima versione di chip con CNOT e directional coupler







chip caratterizzati in laboratorio a Tor Vergata

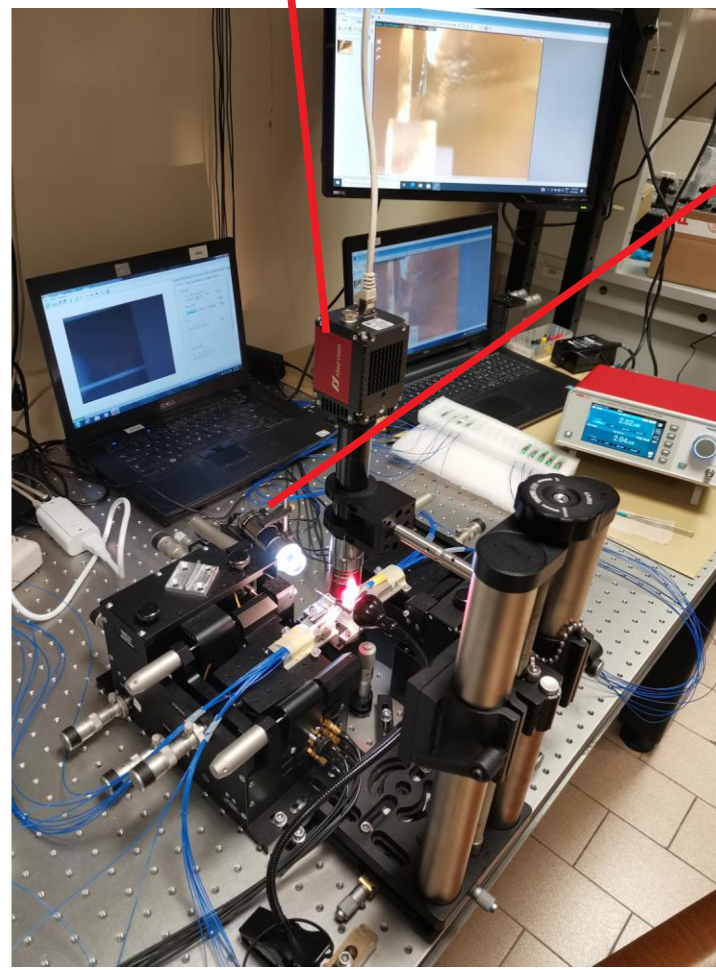
IR source

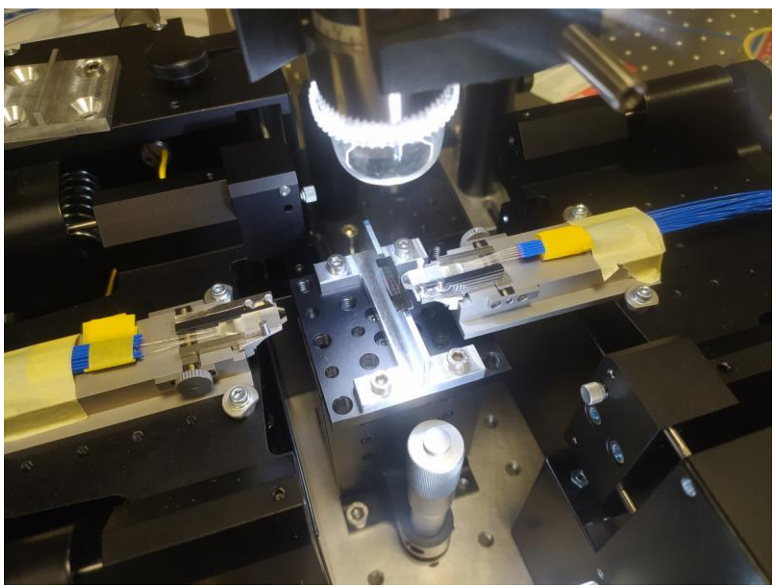
Piezo controllers

IR camera

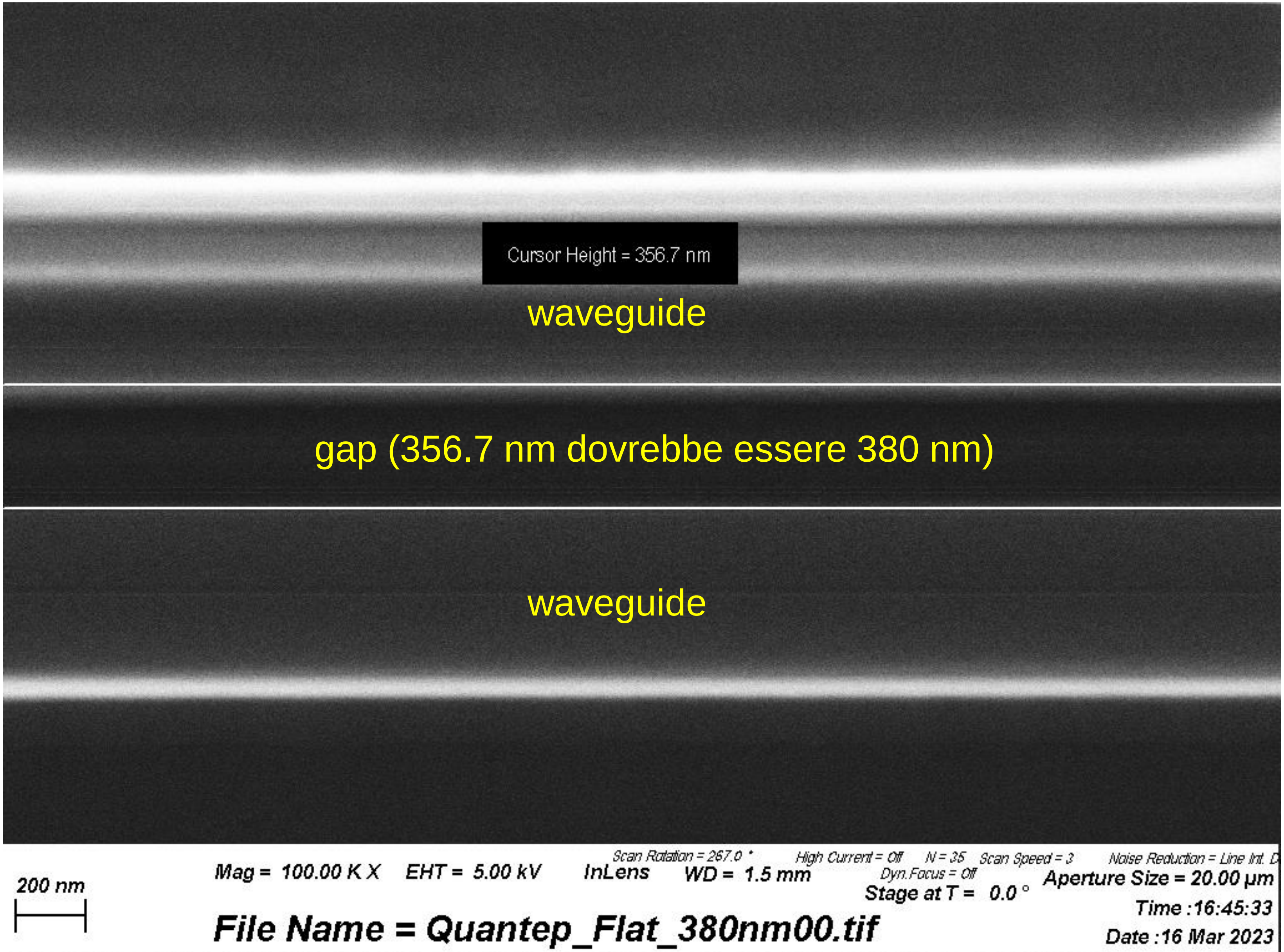
Visible camera

Power meter

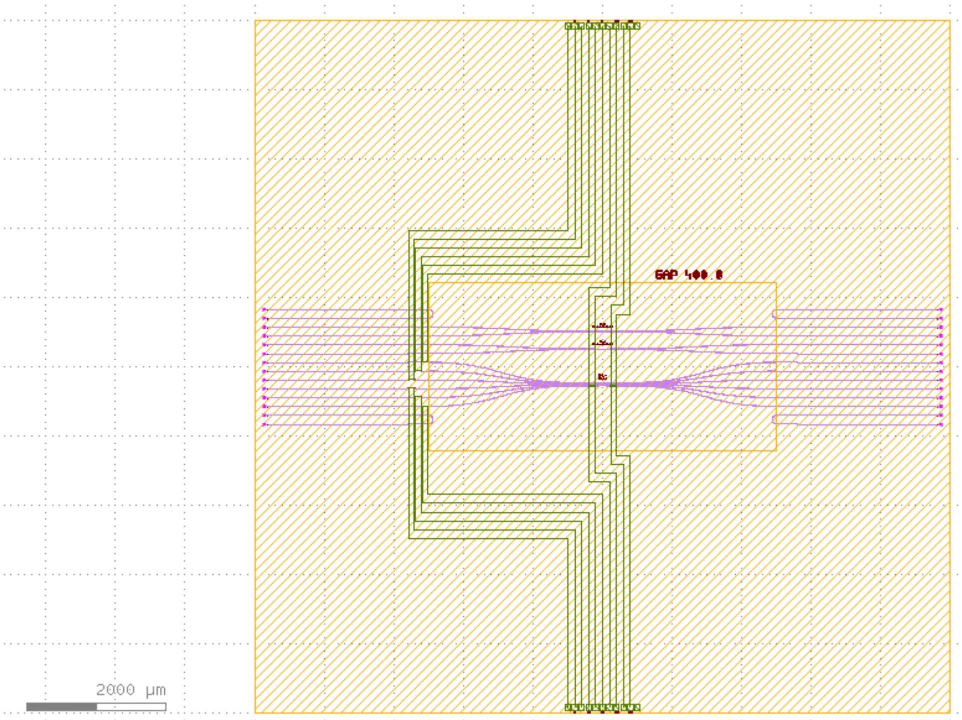


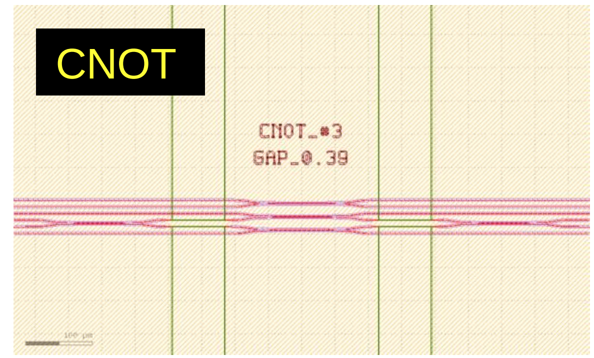


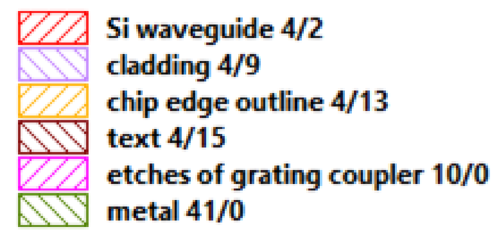
Immagini SEM

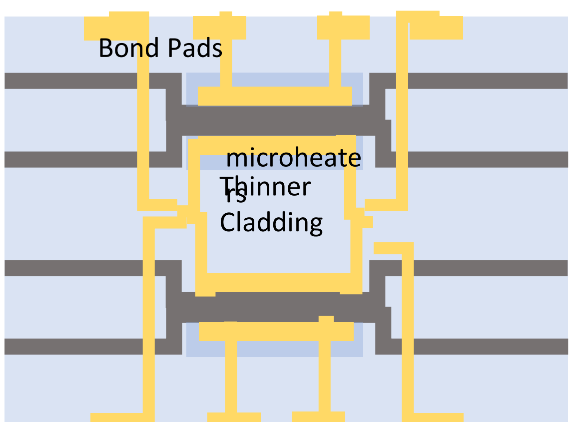


Un secondo chip è in produzione

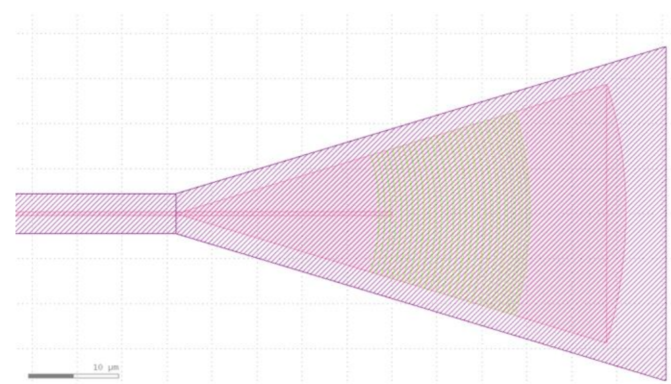








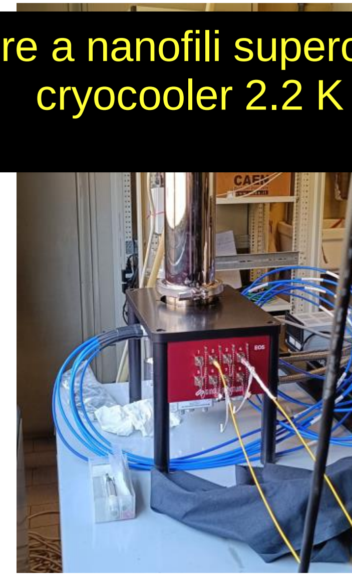
Termal phase shifter



Reticolo di Bragg

Installato il nuovo laboratorio

Tavolo ottico isolato, microscopio VIS+IR, tunable laser,



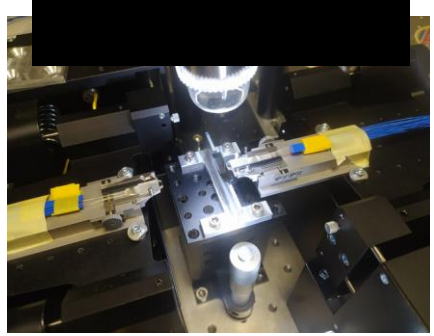
Rivelatore a nanofili superconduttivi:
cryocooler 2.2 K

Rack elettronica

Pompe (rotativa e turbomolecolare)

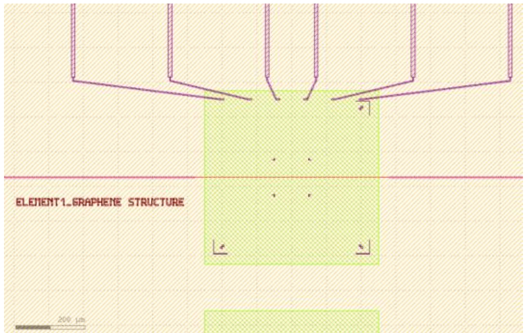
Helium compressor

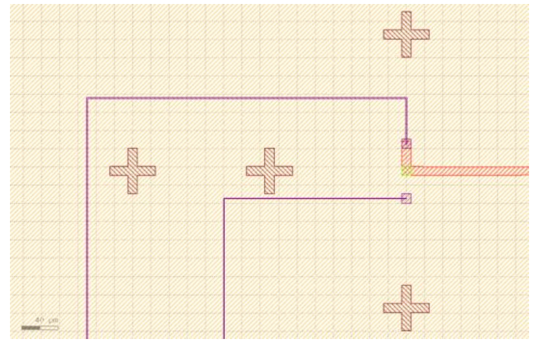
Sorgente di fotoni entangled,
filtro, polarizing beam splitter

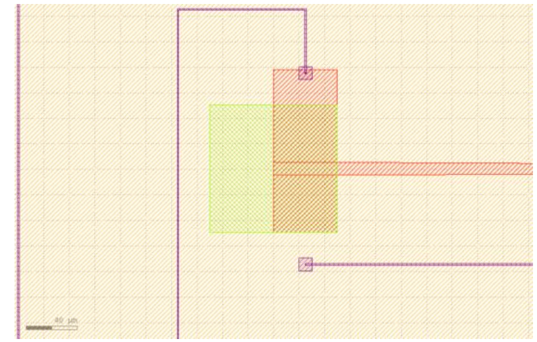


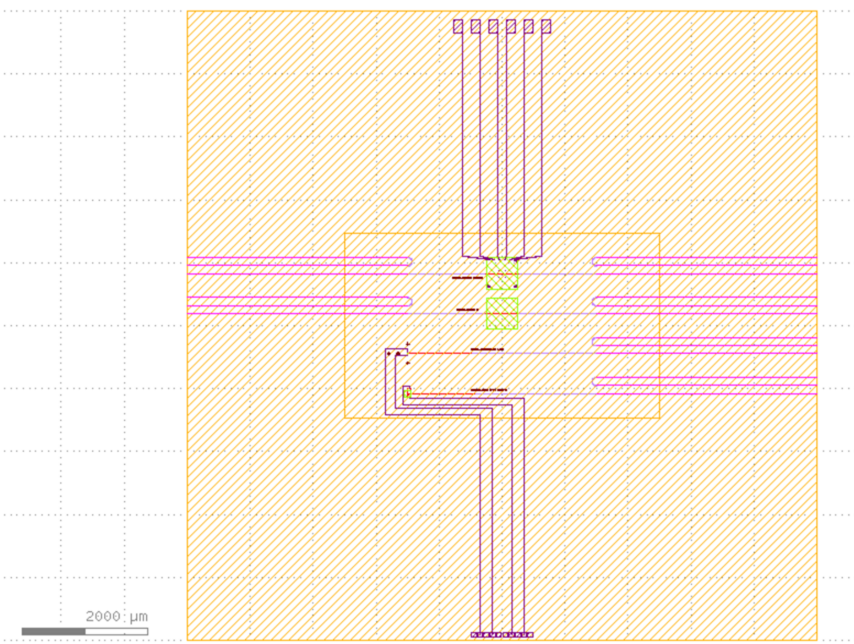
Circuito fotonico in misura

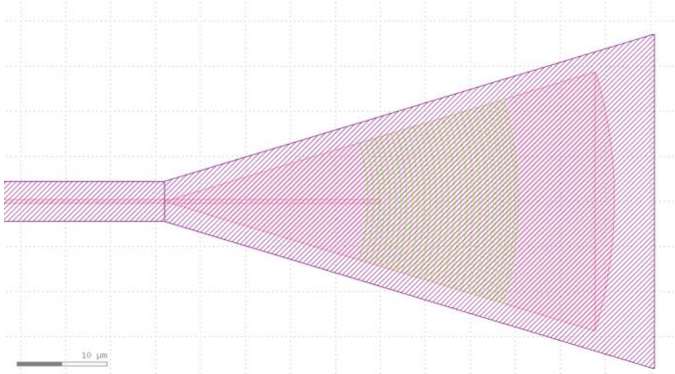
In produzione un altro chip per sorgenti, rivelatori e polarizzatori











Richieste Finanziarie

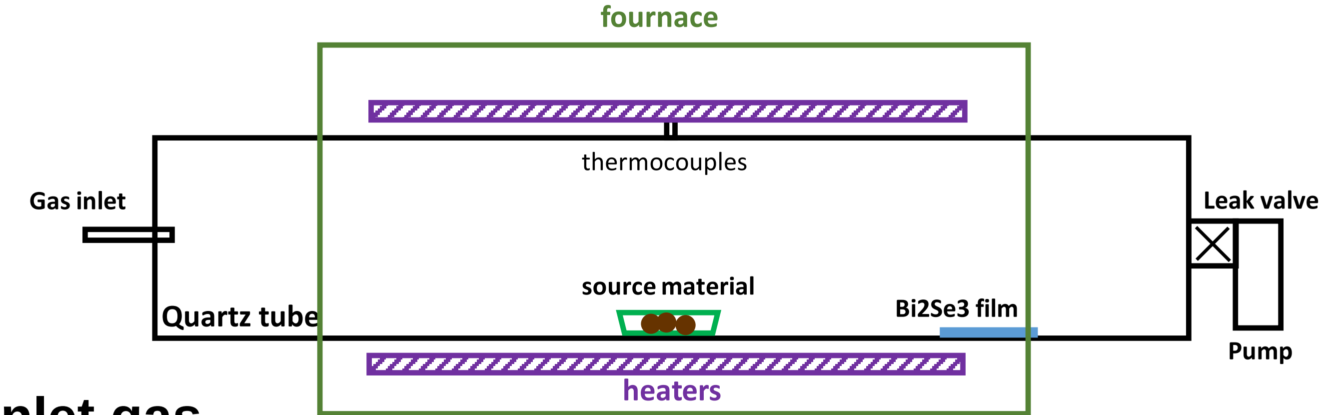
Anagrafica

2.3 FTE

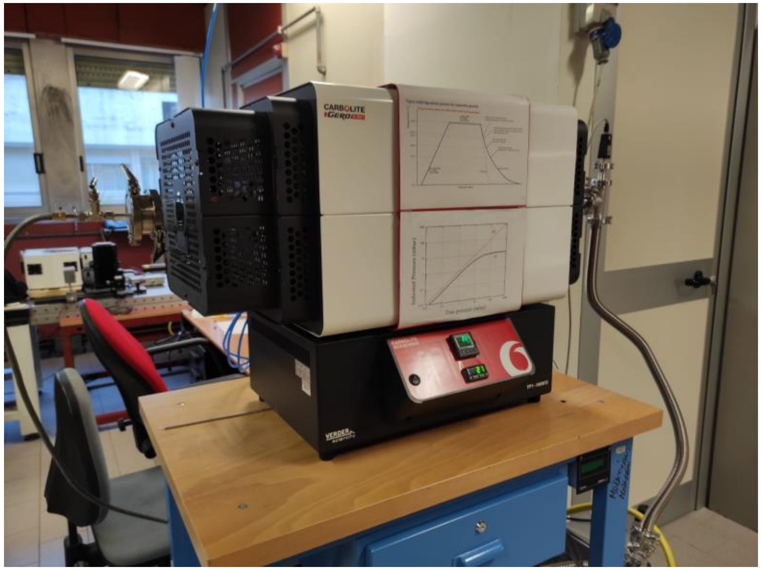
Ricercatori						
	Nome	Età	Contratto	Qualifica	Aff.	%
1	Di Giuseppe Giovanni		Associato	Prof. Associato		**20**
2	Gunnella Roberto		Associato	Prof. Associato		**70**
3	Natali Riccardo		Associato	Tecnico E.P.		**20**
4	Piergentili Paolo		Associato	Dottorando		**100**
5	Vitali David		Associato	Prof. Ordinario		**20**
			Numero Totale Ricercatori	5	FTE: 2.30	

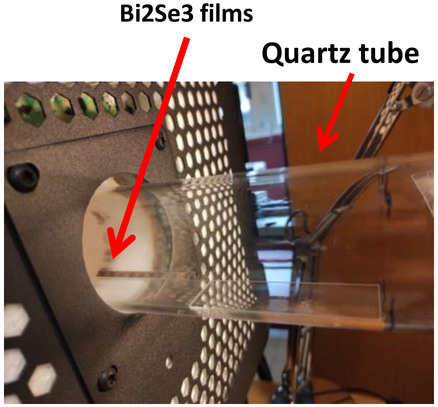
2 dottorandi 38 e 37mo ciclo.

Bi2Se3 thin film growth by Vapor-Solid Deposition method



Fournace Carbolite 1600 °C
Quartz tube
Leybold pumping system
Stainless steel pipeline for Ar inlet gas
Leak valve for gas flow rate regulation



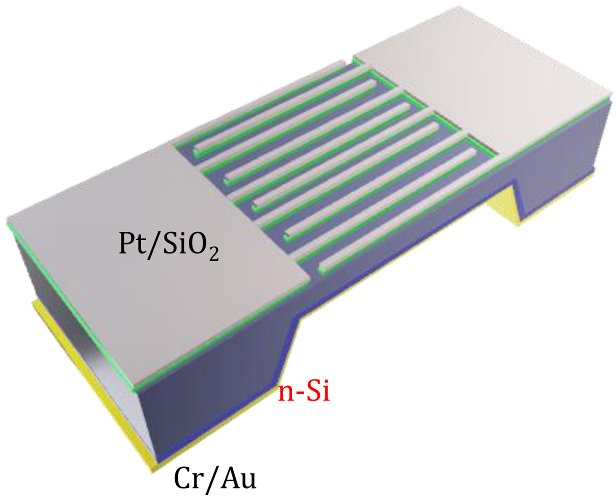


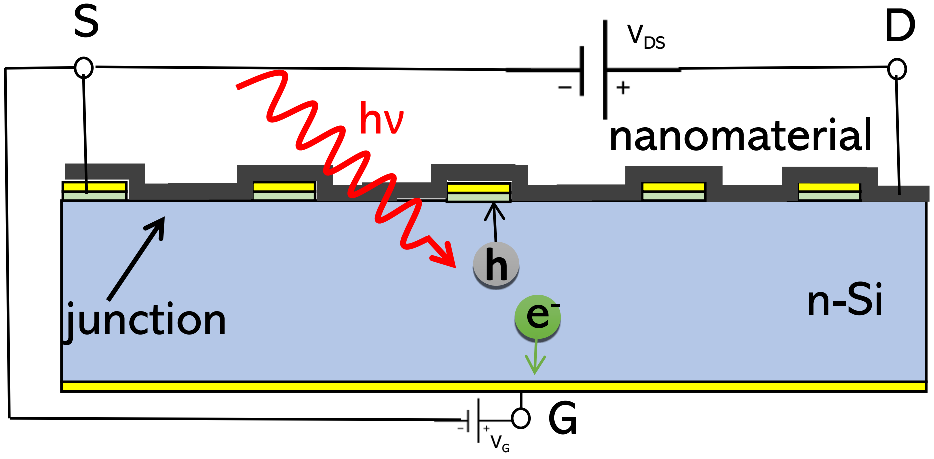
Operating conditions:
Evaporation Temperature 590 °C
Substrate temperature: <100 °C
Pressure: 10^-2 mbar

Optical properties

Optical absorbance measurements in the wavelength range 200 nm-3000 nm show good absorption of Bi_2Se_3 films at l=1550 nm. The optical absorbance increases with the film thickness. Optical gap of about 300 meV is measured in agreement with the expected value for Bi_2Se_3

Bi2Se3/n-Si junctions

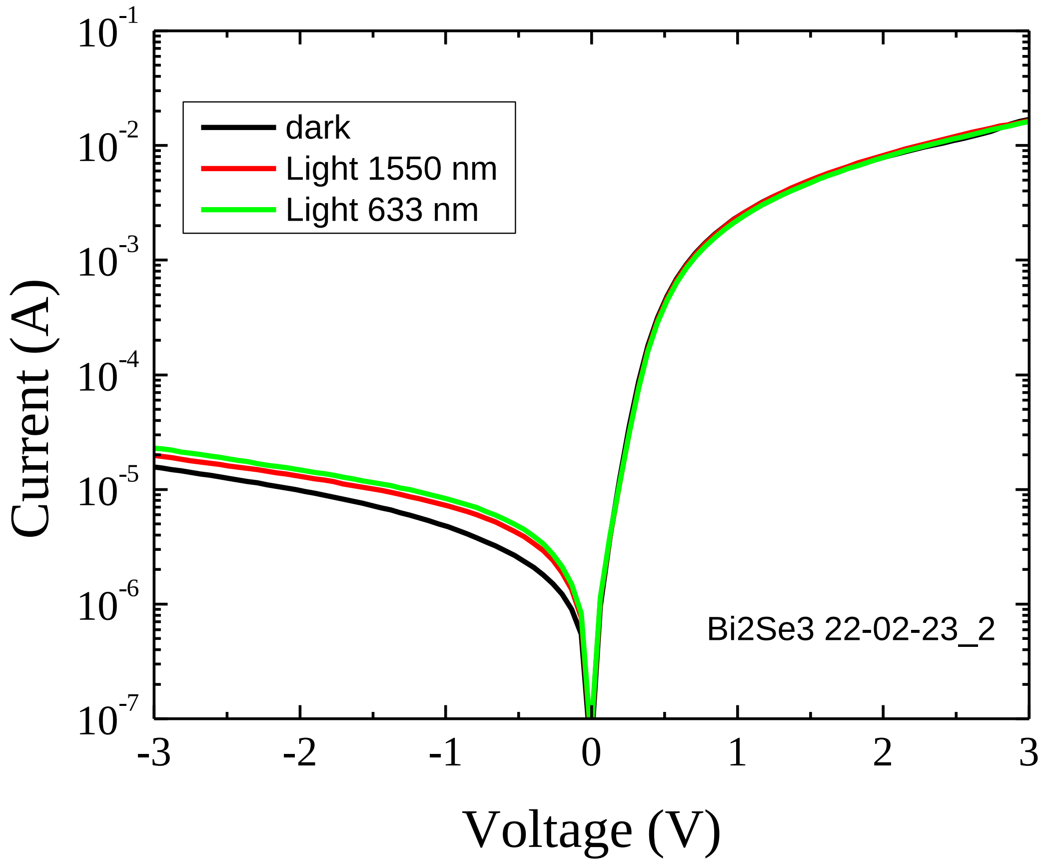


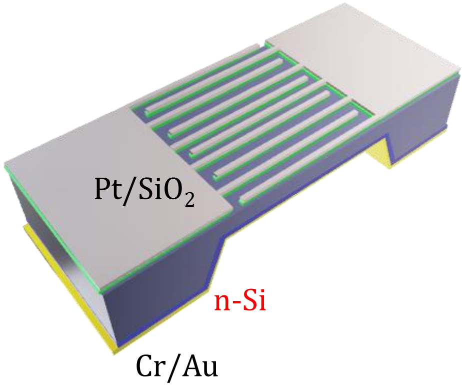


The substrates used for Bi2Se3/n-Si photodetectors are n-Si with metallic electrodes on the bottom and interdigitated metallic electrodes on the top. Different n-Si active area (n-doping 10^16 cm-3) are available with area in the range of 0.1x0.1 mm^2 up to 3x3 mm^2. The Bi2Se3 is deposited on the substrate surface and when in contact with n-Si give rise to the Bi2Se3/n-Si heterojunction. Different number of fingers are available to improve the photocharge collection.

Electro-optical characterization

At communication wavelength





Preliminary results on Bi2Se3/n-Si heterojunctions on interdigitated FBK substrates show response at λ=1550 nm. Increasing the Bi2Se3 thickness a better photoresponse is expected.