Design of Si/poly-Si microrings with complex waveguide cross-sections and minimal non-linearity

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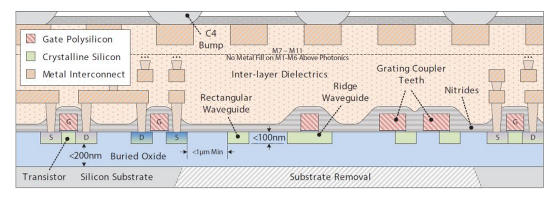
38th Cycle

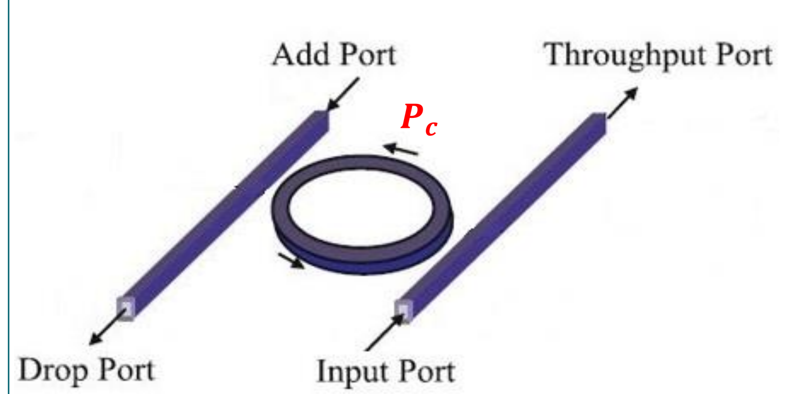
Stefania Cucco
Supervisor: Prof. Mariangela Gioannini

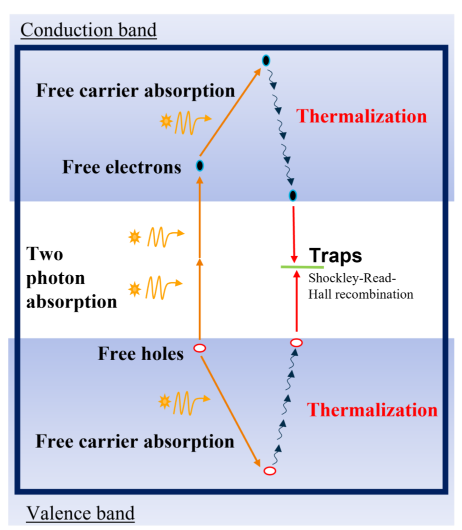
Research context and motivation

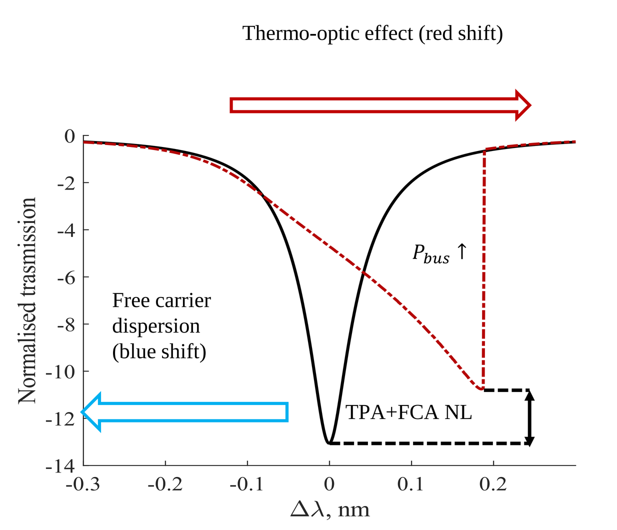
- Silicon Photonic Platform is a technology that allows creating photonic devices that use silicon as an optical medium, with the final goal of integrating photonic and electronic devices on the same silicon chip.



- The microring resonator (MRR) consists of a circular waveguide and two bus waveguides. This device has a four ports where there are two possible frequency responses: pass bass filter from the drop port and notch filter from the throughput port.
- The main parameters are: free spectral range (FSR) and quality factor (Q) that depend on transmission (t), coupling coefficient (k) and bend losses (α_{bend}). Another important parameter is the circulating power (P_c) that refers to the energy of the light stored inside the ring. It depends on bus power and quality factor. We consider a silicon MRR, where there are two mainly type of non linear effect limiting the maximum power entering the waveguide: Two Photon Absorption (TPA) and Free Carrier Absorption (FCA).

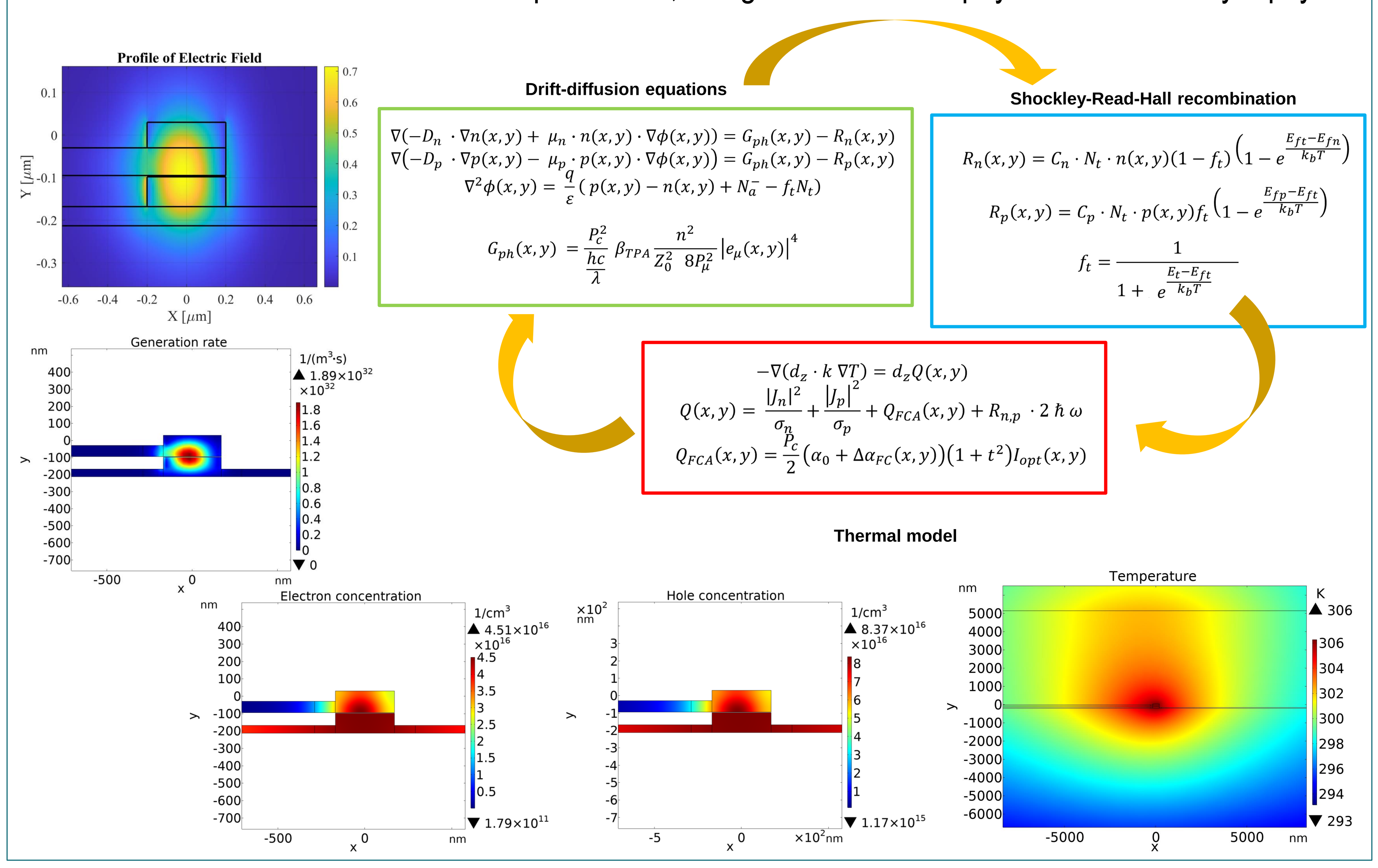






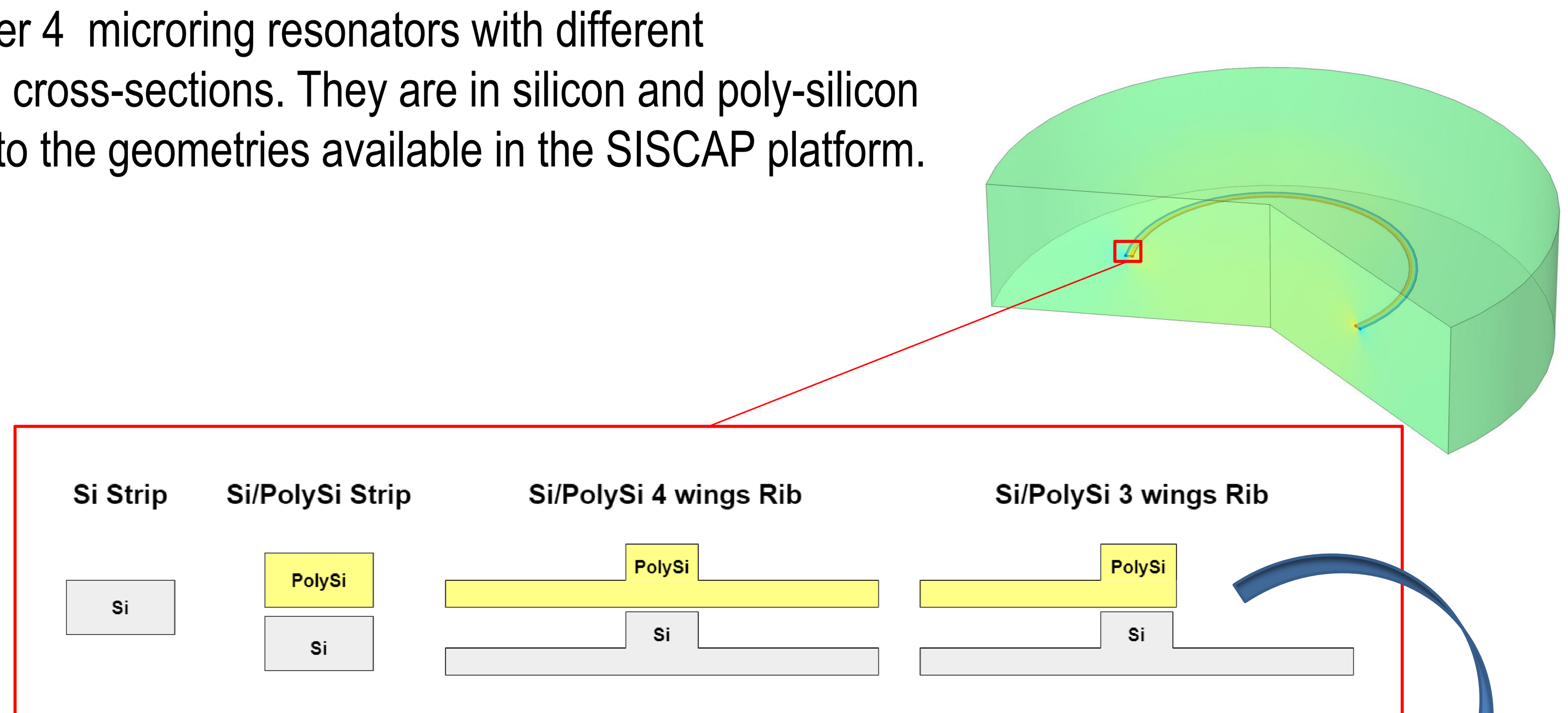
Adopted methodologies

- The self-consistent model that we implemented, using COMSOL Multiphysics and Rsoft Synopsys.

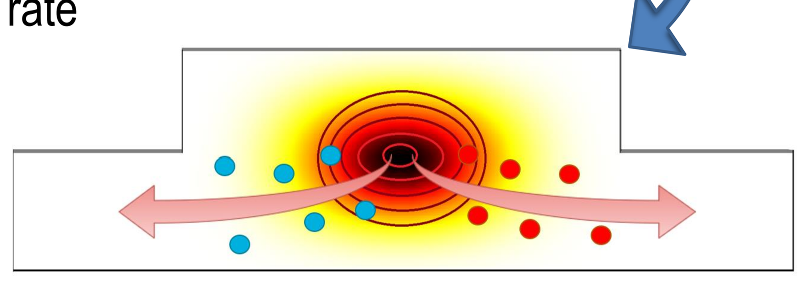


Addressed research questions/problems

- Design a microring resonators with different waveguide cross-sections and material to obtain the minimal non linear loss and self-heating.
- We consider 4 microring resonators with different waveguide cross-sections. They are in silicon and poly-silicon according to the geometries available in the SISCAP platform.



- In the case of the rib waveguides, we have non uniform diffusion of free carrier, because the photo-generation rate generates electron-hole pair in the middle of the rib that diffuse along the lateral wings.



- Non linear response model of microring resonator → variation of modal loss and the variation of effective reflactive index for each cross-section of the waveguides to take into account the non uniform diffusion in the numerical solver.

$$T_{thr} = \left| \frac{t\left(1 - k^2 a(P_c) e^{j\theta(P_c)}\right)}{1 - t^2 a(P_c) e^{j\theta(P_c)}} \right|^2$$

Calculation of P_c

$$P_c = P_{bus} \frac{\kappa^2 (1 - \eta^2)}{\left|1 - t^2 a(P_c) e^{j\theta(P_c)}\right|^2}$$

- θ: phase variation in the ring

$$\theta(P_c) = \theta_0 + \frac{n_g}{c}(\omega - \omega_0)L + \Delta\theta(P_c)$$

$$\Delta\theta(P_c) = 2\pi L/\lambda_0 \cdot \Delta n_{eff}(P_c)$$

- a: propagation loss

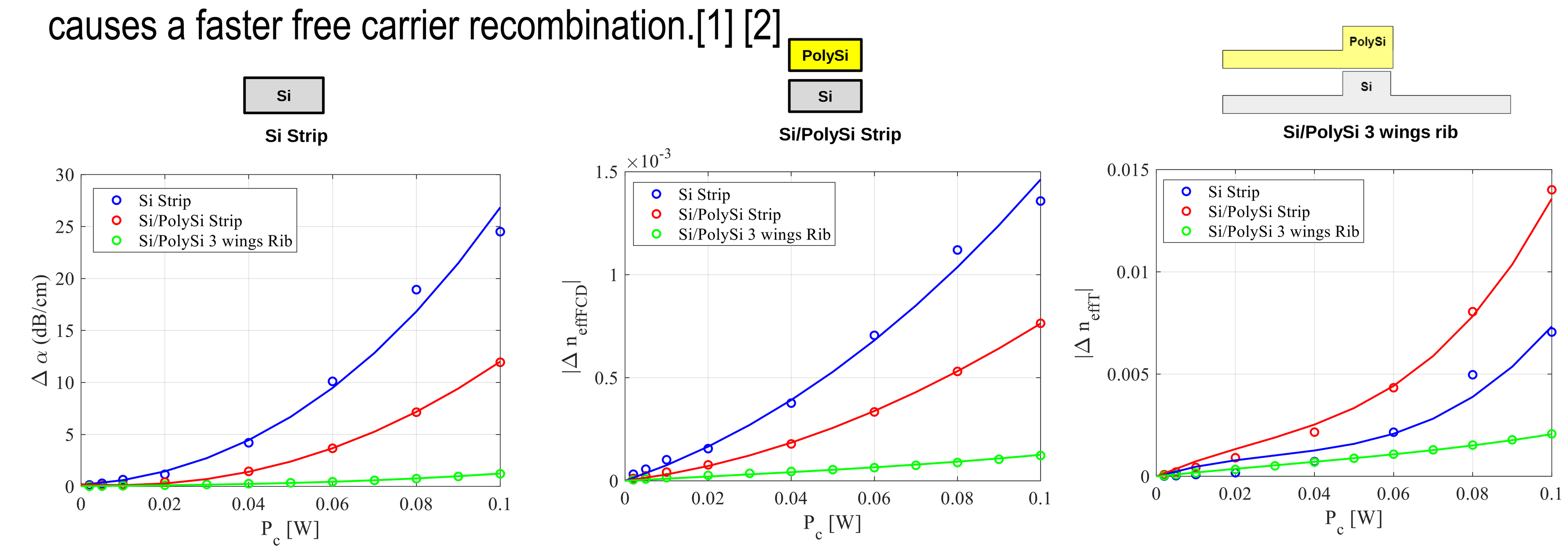
$$a(P_c) = e^{-\alpha_{eff} L/2}$$

$$\alpha_{eff}(P_c) = \alpha_0 + \alpha_{rad} + \Delta\alpha(P_c)$$

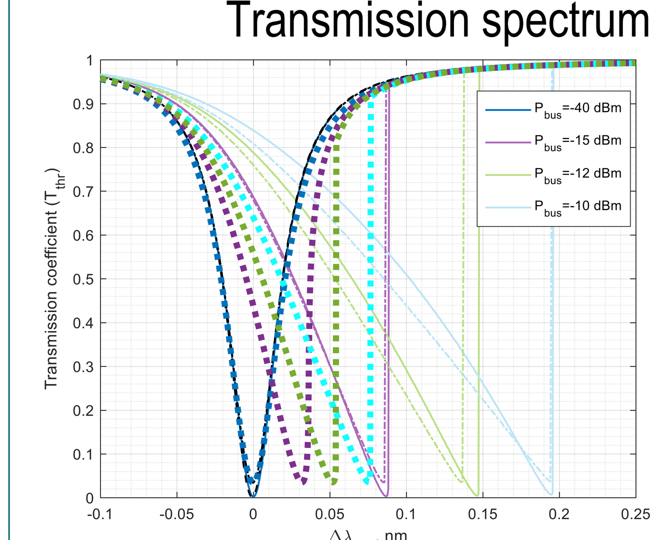
? $\Delta n_{eff}(P_c)$ $\Delta\alpha(P_c)$

Novel contributions

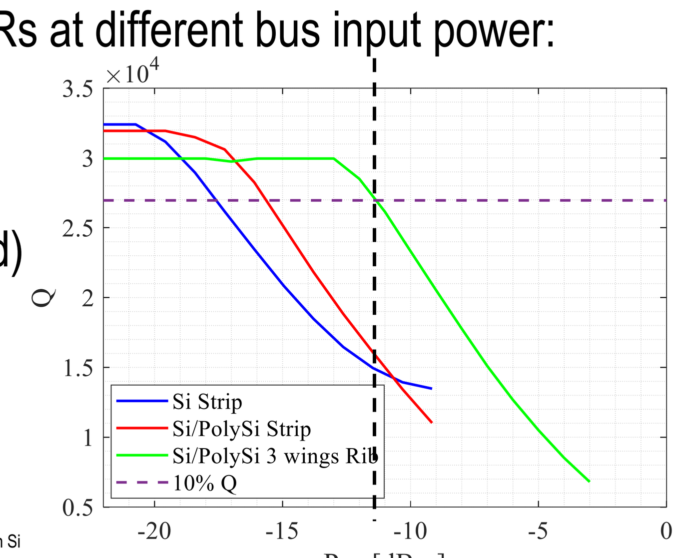
- We can observe that the Si/PolySi 3 wing rib has the lowest variation of modal loss and effective refractive index with respect to the others two, because free carriers diffusion reduces the impact of NL effects on the electric field propagating in the ring, moreover the high trap density in polysilicon causes a faster free carrier recombination.[1] [2]



- We analyze the three MMRs with R = 3.5μm and $k^2 = 0.0055$.
  Transmission spectrum and quality factor of the 3 MRRs at different bus input power:



- Si strip (continuos)
- Si/PolySi strip (dash-dotted)
- Si/PolySi 3 wings Rib (dotted)



[1] Nedeljkovic, M., Soref, R., and Mashanovich, G. Z., *IEEE Photonics Journal*, 3(6):1171–1180,2011.
[2] M. Novarese , S. Romero-Garcia , J. Bovington and M. Gioannini. "Dynamics of Free Carrier Absorption and RefractiveIndex Dispersion in Si and Si/PolySi Microrings". EEE Photonics Technology Letters,

Future work

- Compare these results with experimental measurements taken in laboratory on microring resonator.
- Use these tools to test complex structures, for example pn or pin based devices to reduce free carriers.

Publications

- Published works: S. Cucco, et al. , 23rd International conference on NUmerical Simulation of Optoelectronic Device (NUSOD 2023), Turin, Design of Si/poly-Si microrings with complex waveguide cross-sections and minimal non-linearity.
- In preparation a paper to be submitted to JLT.