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XXXV Cycle

Static and Dynamic Nonlinear Effects in Silicon Micro-Rings

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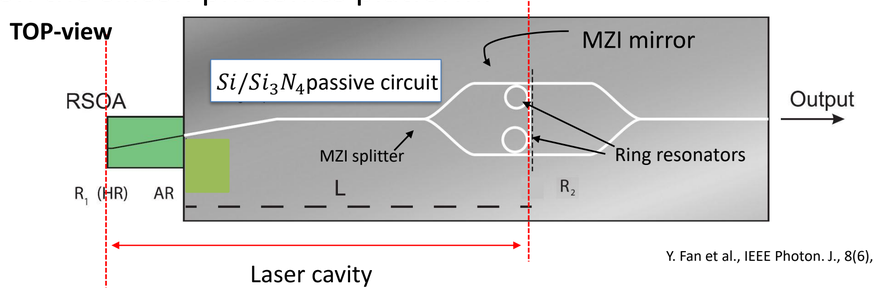
Research context and motivation

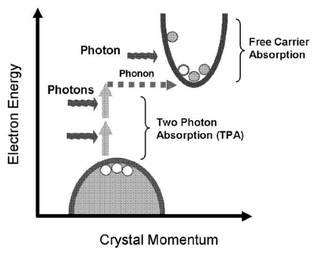
- The design of the passive chip is crucial for improving the performances of hybrid tunable laser built on the silicon photonics platform.



Y. Fan et al., IEEE Photon. J., 8(6), 2016

	Si_3N_4	SOI
Refractive index contrast	≈ 0.55	≈ 2.06
Typical propagation losses	down to 0.0005dB/cm ☺	0.5dB/cm – 2dB/cm ☹
Nonlinear effects (TPA, FCA,FCD, self--heating)	No ☺	Yes ☹
Thermo-optic coefficient (dn/dT)	$2.51 \cdot 10^{-5}\ K^{-1}$ ☹	$1.87 \cdot 10^{-4}\ K^{-1}$ ☺
Minimum ring bend radius	95μm ☹	5μm ☺

- Silicon represents a very good choice for the laser miniaturization, frequency tunability and high field confinement. However, Two-photon-absorption (TPA) and free-carrier-absorption (FCA) are power dependent effects that degradate the propagation of the field inside the ring.

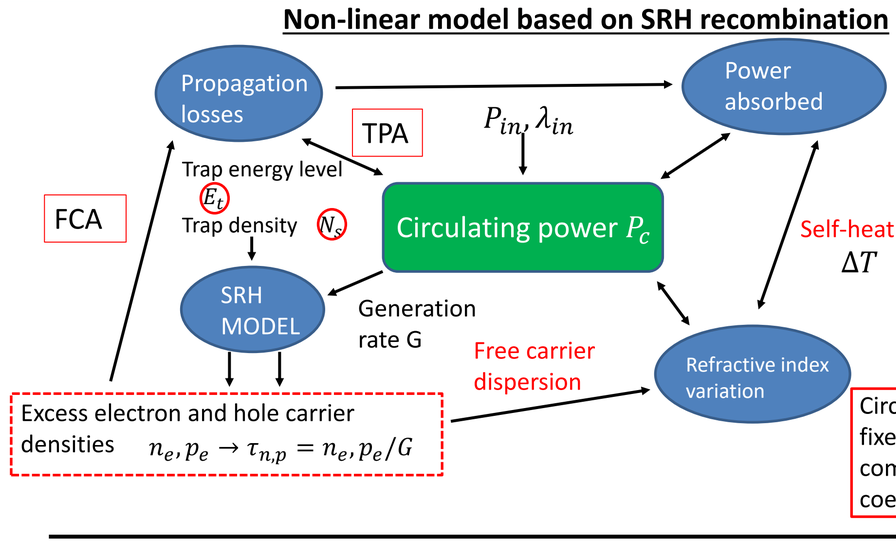


D. Dimitropoulos et al., Journal of Lightwave Technology, 26 (7), 847-852, 2008

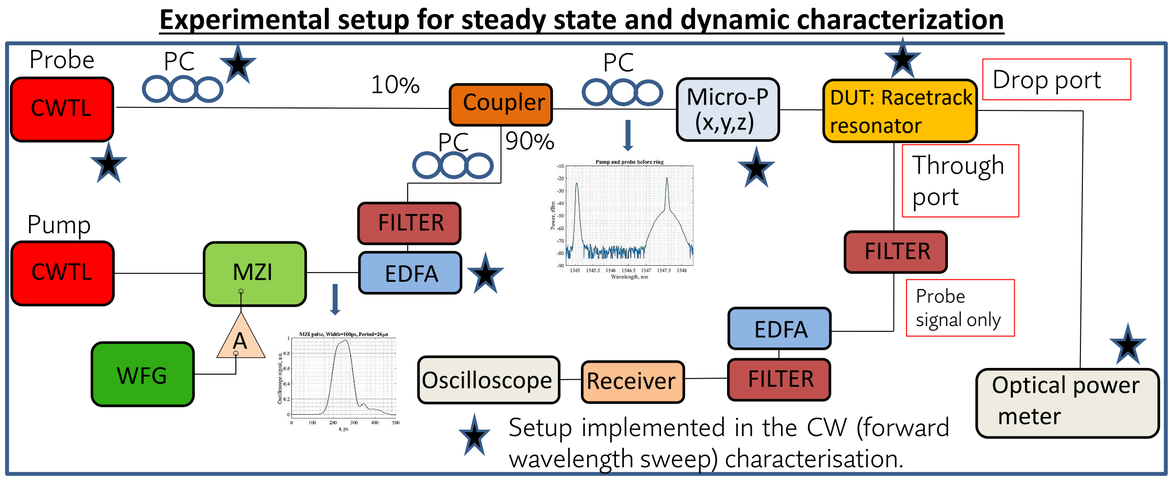
- A detailed description of the non-linear effects in silicon is therefore needed when designing ring resonators in the silicon platform.

Adopted methodologies

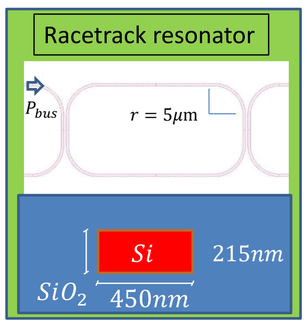
Non-linear model based on SRH recombination

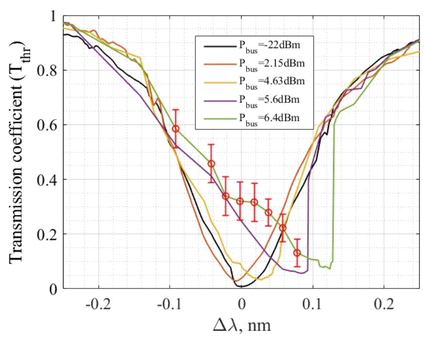


Experimental setup for steady state and dynamic characterization



Addressed research questions/problems





- The power dependent deformation of the ring transmission causes a shift in the ring resonant frequency and also self-oscillations in the ring output power

- The main objective is then to study these non-linear behaviors in steady state and through pump and probe measurements with the aim of:

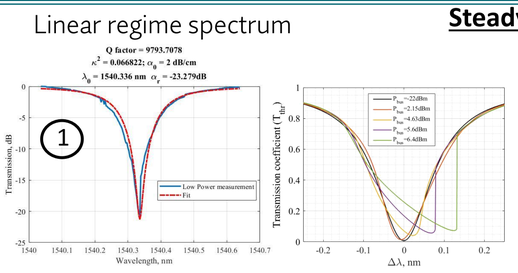
❑ Understanding the impact of non-linear effects on the ring spectral response.
❑ Developing a model that does not rely on empirical expression for the carrier lifetime[1,2,3].

Reference

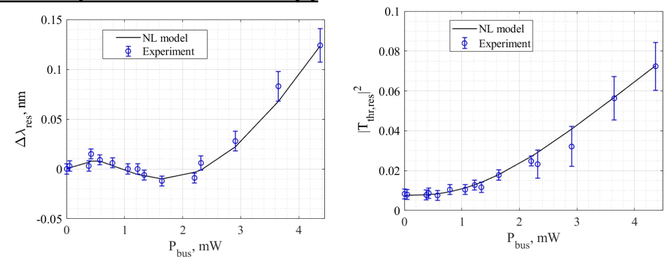
[1] G. Priem et al., Opt. Expr., *13 (23), 2005*
[2] M. Borghi et al., Opt. Expr., 29 (3), 2021
[3] A. G. Aberle et al., J. Appl. Phys., 71(9), 1992

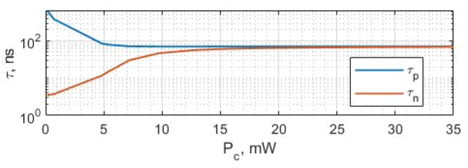
Novel contribution

Linear regime spectrum



Steady state (CW forward sweep)





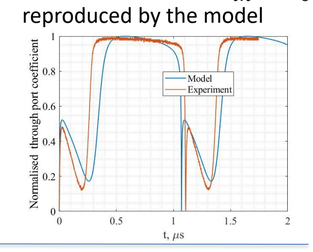
$E_t = 0.65eV$

$N_s = 5.7 \cdot 10^{10} cm^{-2}$

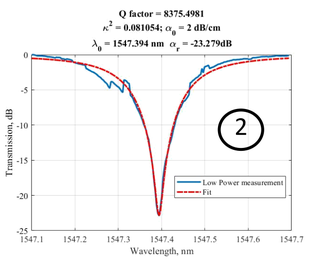
- Within experimental measurements on Si/SiO_2 interfaces [3]

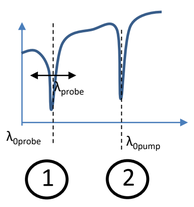
➢ Non-linear electron and hole carrier lifetime are obtained with SRH treatment avoiding any empirical carrier lifetime.

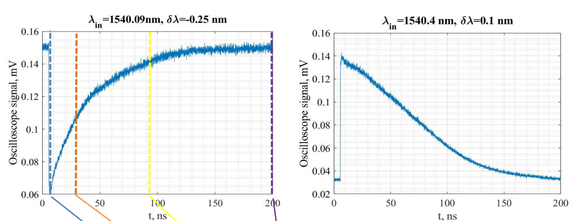
➢ Ring self-oscillation $\lambda_{in} \approx \lambda_0$ reproduced by the model

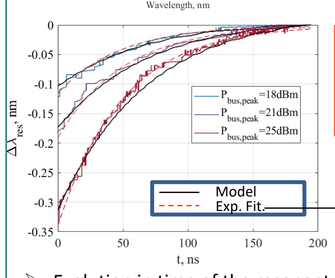


Pump-probe measurements





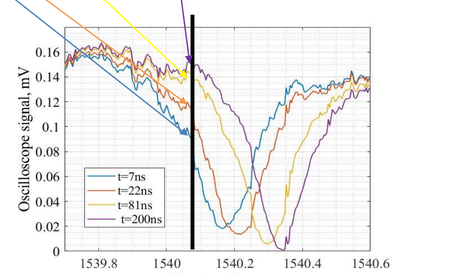




$a \cdot e^{\left(-\frac{t}{\tau}\right)}$

$\tau \approx 50ns$

Figure of merit that can be used to compare different ring structures and get information on carrier lifetime: non-linear effect minimization



➢ Evolution in time of the resonant wavelength shift well reproduced by the model by applying the same experimental method.

Ring spectral response reconstructed at different time instants

Future work

❑ Apply the model on different ring resonator structure and compound waveguide
❑ Designing ring resonator with different cross-section and material composition to reduce NL effects.
❑ Test the designed hybrid laser in the laboratory.

External training activities

- Photon design Training Course, Online (28/05/2020, 10 hours)
- 7th ePIXfab Silicon Photonics Summer School, France (20/06/2022-24/06/2022, 33 hours)

Submitted and published works

- M. Gioannini, L. Columbo, A. Bologna, M. Novarese, et al., "*Design of hybrid lasers for silicon photonics: efficiency, optical feedback tolerance and laser dynamics*", European Conference on Integrated Optics ECIO 2020, Paris,2020
- M. Novarese, S.R. Garcia,S. Cucco et al.,"*Study of nonlinear effects and self-heating in a silicon microring resonator including a Shockley-Read-Hall model for carrier recombination*", Opt. Express, vol. 30, no 9, 2022, pp. 14341-14357
- M. Novarese, M. Gioannini, C., "*Study of nonlinear effects and self-heating in silicon microring resonator including SRH model for carrier recombination*", SPIE OPTO, 2022, San Francisco, California, 2022, pp. 16-29
- M. Novarese, S. Cucco, R. Hui et al., "*Static and Dynamic Nonlinear Effects in Silicon Micro-Rings: Impact of Trap Assisted Shockley Read Hall Carrier Recombination*", European Conference on Integrated Optics ECIO 2022, Milan, 2022, Poster

List of attended classes

- 02MXBOQ – Passive Optical Components (6/7/2020, CFU 8)
- 01SIHRV- Bio-Nano Electronics and BioMolecular Computing (29/5/2020, CFU 4)
- 01SFURV -Advanced scientific programming in Matlab (25/5/2020, CFU 4)
- 01QCEIW- Advanced topics in the finite element method (1/6/2020, CFU 4)
- 01UOIRS -Big data applications in transportation (DE) (12/3/2020, CFU 4)
- 01DNYRV- Semiconductor light sources for engineers (1/7/2020, CFU 4)

PhD program in
Electrical, Electronics and Communications Engineering