Time-delay reservoir computing with silicon microring resonator

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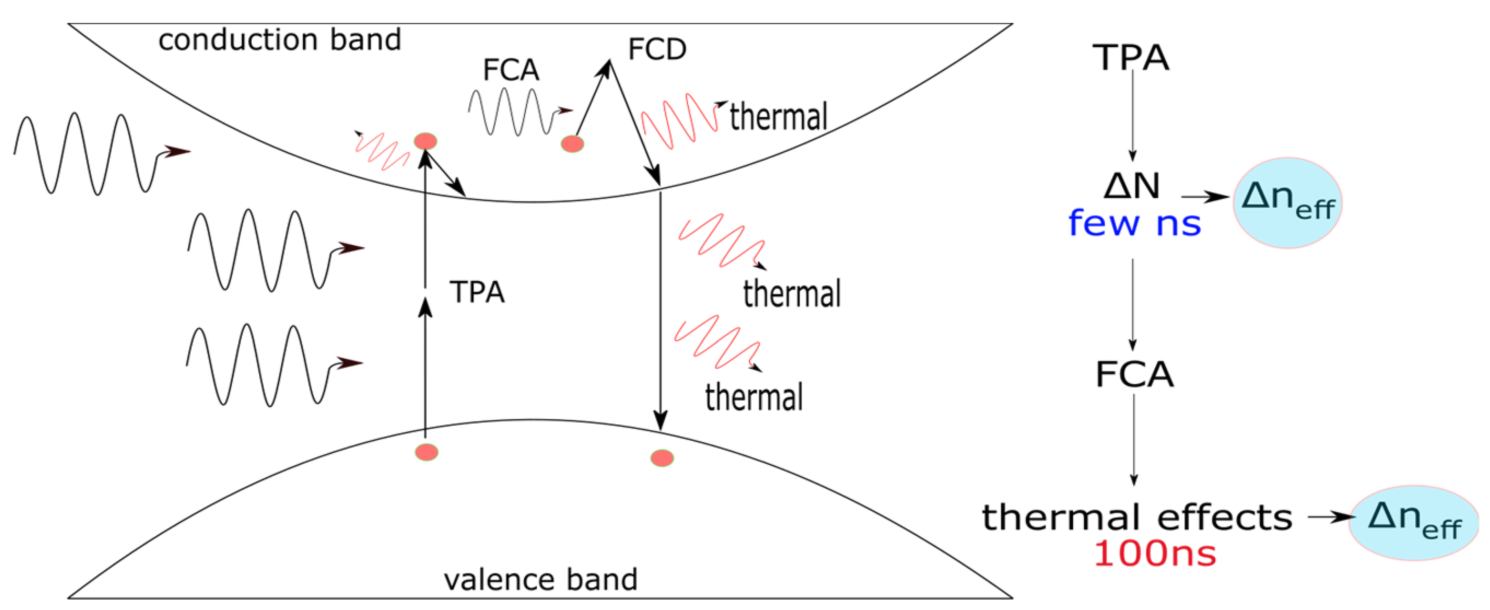
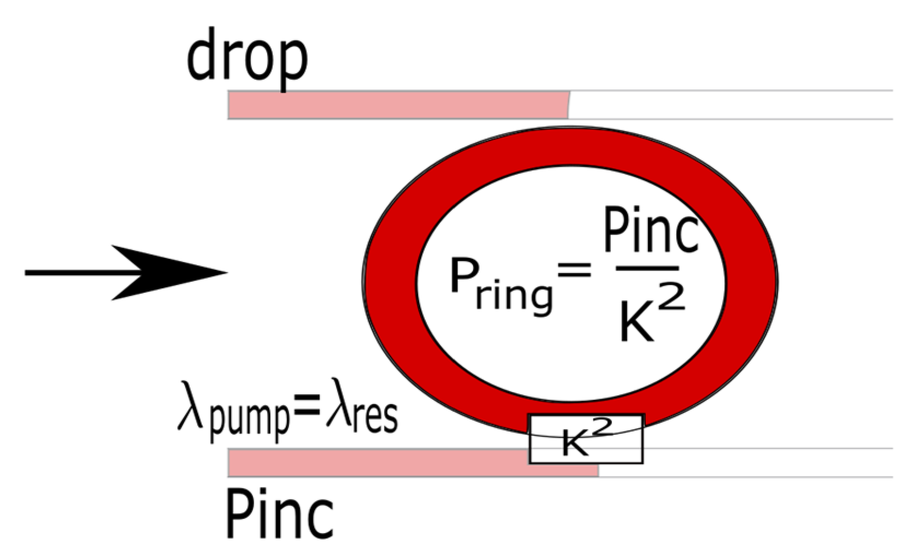
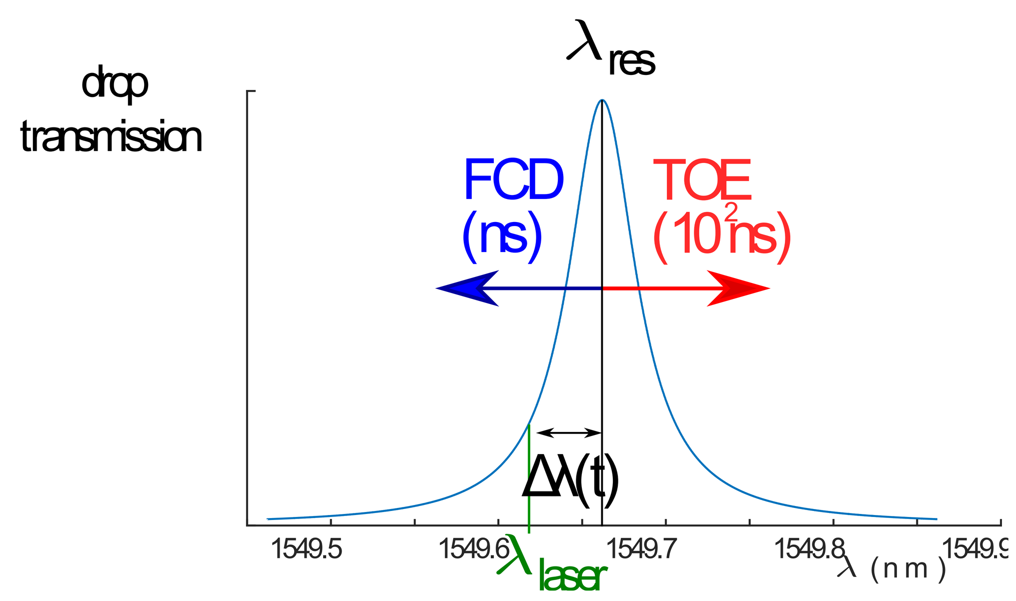
Nonlinear silicon microring resonator







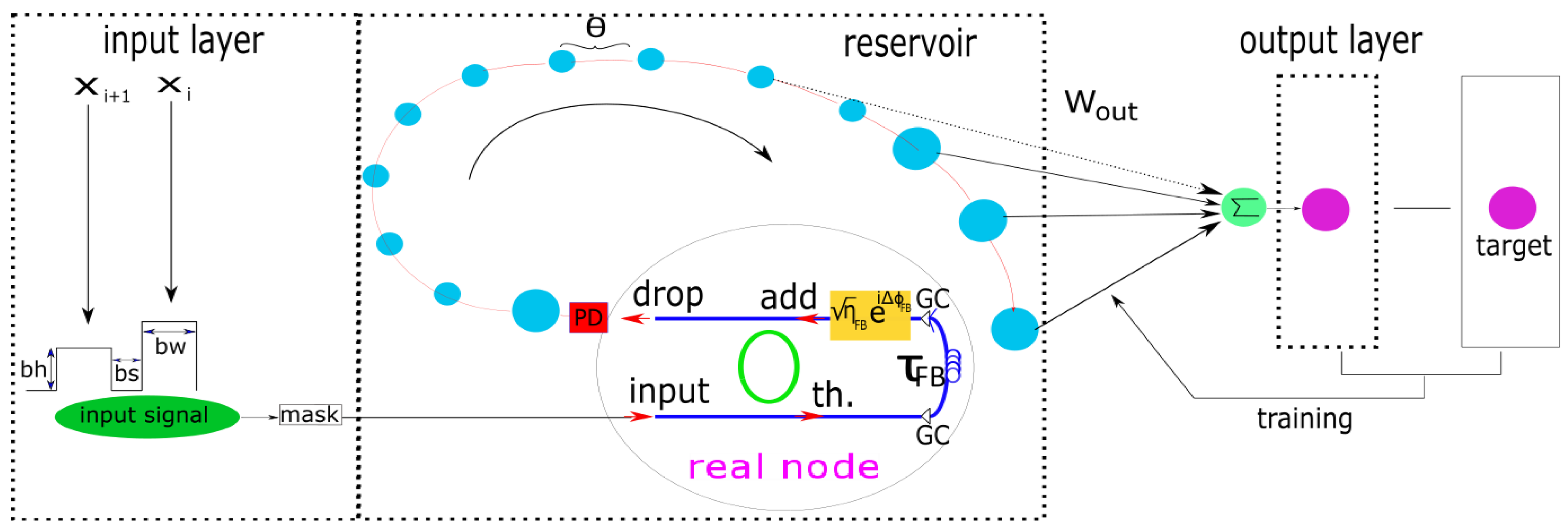
- Silicon nonlinearities originate from two photon absorption (TPA) which produces extra free carriers and phonons, and change of the refrective index of silicon.
- High quality factor silicon microring resonators make possible TPA at telecom wavelengths. Variation of its refrective index can be seen as a shift of the resonance.
- The microring presents three characteristic timescales:

τ_{photon} : Decay time of the ring internal field, related to K^2

$\tau_{\Delta N}$: Decay time of the excited free carrier from conduction band to valence band, responsible of the free carrier dispersion (FCD) effect on the resonance shift

τ_{TOE} : Thermal relaxation time of the ring cavity, responsible of the thermal optical effects (TOE) on the resonance shift

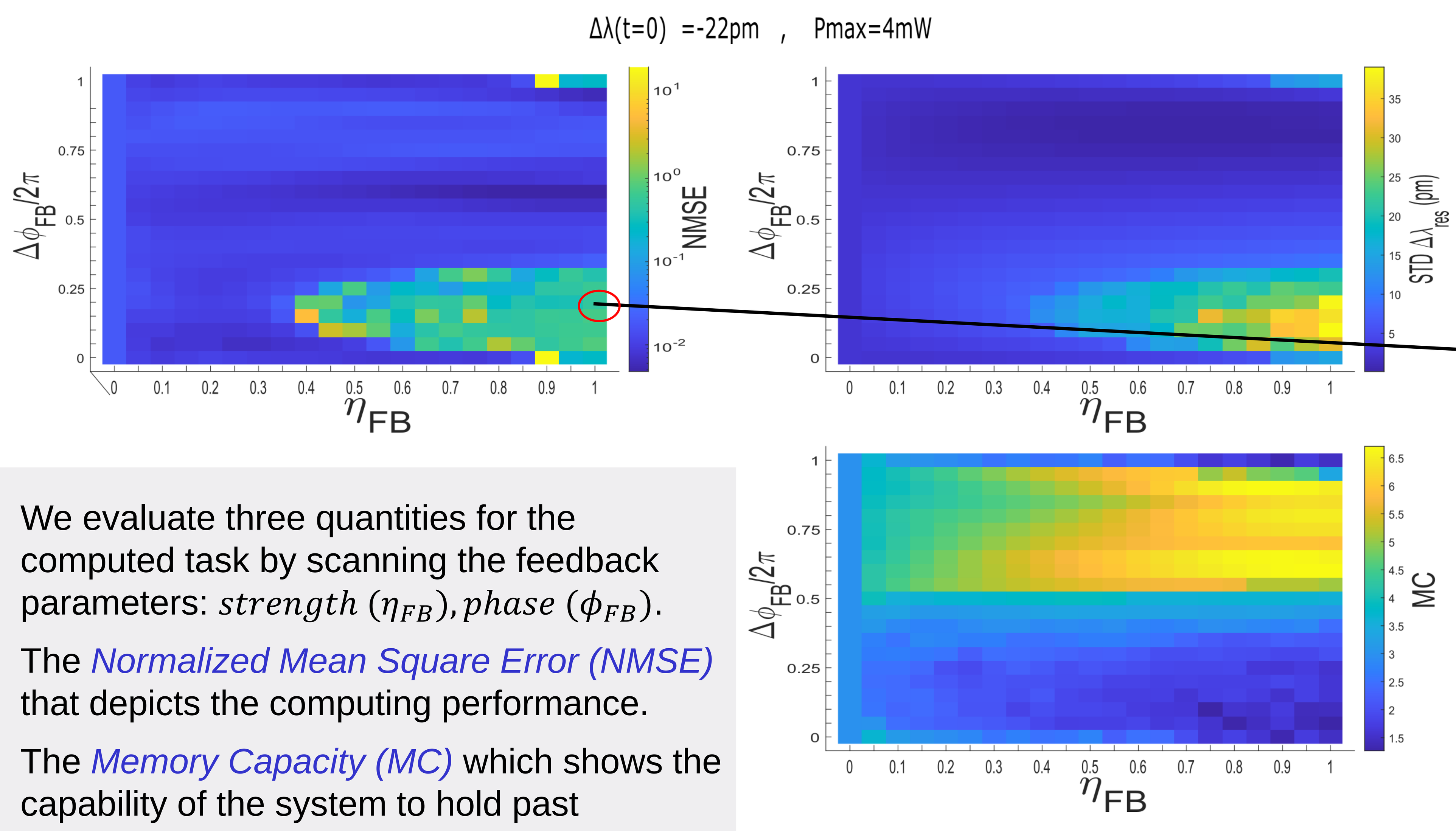
Microring nonlinearities exploited in time-delay reservoir computing



Numerical modeling of the microring resonator system in presence of feedback, in a reservoir computing topology and evaluation of its computational properties in various benchmark tasks

- Input information as discrete time-multiplexed series
- Sample and hold operation for every element to process.
- Periodic mask signal: to keep the real node in a transient state and enrich its reponse ($\theta = 40ps$).
- Physical nonlinear node: silicon microring resonator (MR) exploiting the free carrier timescale (3ns) and the delayed information provided by the optical feedback (FB) via connecting the through and add ports.
- Definition of virtual nodes (VNs), by sampling the photodetected drop signal
- Output of the network: $\sum(VNs(i)\, W_{out}(i))$
- Supervised learning: training of W_{out}

MackeyGlass benchmark task



We evaluate three quantities for the computed task by scanning the feedback parameters: $strength\ (\eta_{FB}), phase\ (\phi_{FB})$.

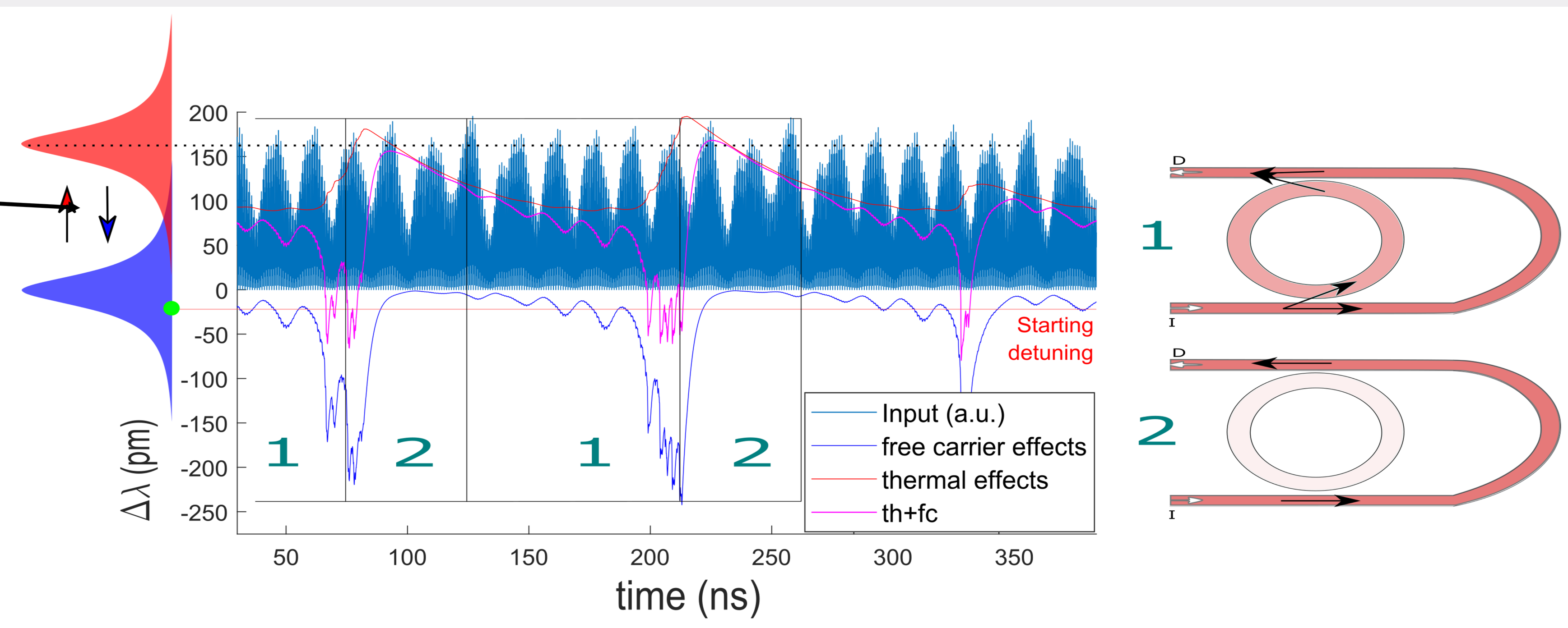
The *Normalized Mean Square Error (NMSE)* that depicts the computing performance.

The *Memory Capacity (MC)* which shows the capability of the system to hold past information.

The *Standard Deviation of the resonance shift (STD $\Delta\lambda_{res}$)* which gives an estimate of the nonlinearity of the system.

Thermal inconsistency

Example of resonance shift dynamic while processing a MackeyGlass task



Due to the high optical power the ring enters in a self pulsing dynamic: large thermal effects periodically drive the resonance far away from the pumping wavelength (starting detuning)

Two ways of processing the input are induced during the task:
1. includes the ring path (pumping wavelength coupled to the resonance peak)
2. bypass the ring (pumping wavelength out of resonance) -> inconsisntency!

Discussion

- When working at the faster free carrier timescales, microring thermal nonlinearities induce inconsistencies that do not allow efficient computing.
- Feedback strength and feedback phase are important parameters to optimize towards the best computing performance.
- Together with the maximum power and the starting frequency detuning, these parameters allow to tune the compromise between memory capacity and degree of free carrier nonlinearities specific of the task at hand.
- By testing Mackey Glass, SantaFe and Narma10 benchmark tasks, we have idenitfied different optimal parameters that correspond to a different balance between memory capability and nonlinearity of the system.