Investigating Degenerate Optical Parametric Oscillation Stability within SiN Microrings

E S Gonçalves[1], N B Tomazio[2], L F Santos[3], L O Trinchão[1], P F Jarschel[4], F S Santos[1], T Alegre[4], and G S Wiederhecker[1]

[1] *Department of Quantum Electronics, Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Campinas, Brazil*

[2] *Institute of Physics, Universidade de São Paulo, São Paulo, Brazil*

[3] *School of Electrical Engineerig and Computer Science, University of Ottawa, Ottawa, Canada*

[4] *Department of Applied physics, Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Campinas, Brazil*

Contact Email: esg@unicamp.br

Photonic processors have been explored to address the increase demand for efficient solutions to non-deterministic polynomial-time problems with exponential time and energy scaling. Recent studies have utilized a network of coupled degenerate optical parametric oscillators (DOPOs) based on the $\chi^{(2)}$ nonlinearity to create a time-multiplexed coherent Ising machine. These studies take advantage of the phase transition at the parametric oscillation threshold that results in a binary phase state offset by π, mimicking the binary spin system. In silicon nitride (SiN) microresonators, third-order nonlinearities have been explored for dual-pumped DOPO in various configurations, including normal group velocity dispersion (GVD) and in a system of coupled microcavities, for true random number generation.

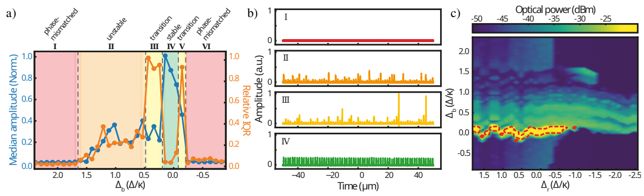

Figure 1: (**a**) Median amplitudes and relative interquartile range of filtered DOPO for a fixed red pump detuning (Δ_r) as function of blue pump detuning (Δ_b). $\kappa = 86.5$ MHz is the central resonance linewidth. (**b**) Temporal trace for the different conditions presented in (**a**). (**c**) Optical power at the DOPO frequency, the stable region is highlighted with red dashed lines.

This research examines the temporal stability of degenerate signal/idler pair oscillation in SiN microrings with anomalous GVD. Our calculations reveal that higher-order cavity modes are involved: the geometry of the bus waveguide implies a better effective index coupling between its fundamental mode and the first two higher-order modes of the cavity. The experimental setup features dual-pump tones from tunable continuous-wave lasers, pulsed by synchronized electro-optic modulators (EOMs). Pumps are tuned to TE modes from the same family separated by 2×FSRs (relative mode numbers $= \pm 1$). Independent detuning of each pump was carried out systematically. For each detuning step of the red pump, the entire spectral region near the resonance was scanned by the blue pump, considering thermal and nonlinear phase-shift effects like cross-phase modulation in the scanning region. Fig 1(a) shows the DOPO median amplitude (blue, left axis), as well as its interquartile range (IQR) (orange, right axis). Stability is characterized by high amplitude and low IQR. No DOPO is seen when the blue pump is far from resonance (I). As it nears resonance, DOPO emerges, but significant amplitude fluctuations are observed (II), as seen in Fig 1(b). Further reducing the pump-cavity detuning intensifies these fluctuations (III). When the blue pump is finely tuned to resonance, a stable DOPO condition with minimal amplitude variation is achieved (IV), persisting in a narrow detuning region. This is indicative of a controlled and sustained oscillatory state. As the blue pump undergoes additional detuning beyond this stable region, the photothermal pump dragging of the resonance reaches its maximum and terminates the DOPO. This behavior was examined across various red-pump laser detunings (Fig 1(c)), The highlighted region corresponds to the region of the parameter space where the system achieves sustained DOPO. The narrowness of this stability region suggests a specific set of detuning conditions for maintaining stability in the oscillatory state. Further investigation regarding the dependence of DOPO with the microring dispersion regime should allow broader stability conditions.