Internship proposal (2026-2027)

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" Pulse-Pumped Photon-Pair Generation in Microrings Synchronized to Integrated Mode-Locked Lasers"

Research project description:

Silicon photonics brings CMOS fabrication to optics. After datacom and quantum photonics, a third revolution is under way in integrated nonlinear photonics. Parametric amplification, supercontinuum generation, Kerr combs, solitons and squeezed light were once confined to bulk crystals and tabletop lasers. They now run in dispersion-engineered waveguides and resonators at pJ energies. A flagship application is photon-pair generation by spontaneous four-wave mixing (SFWM, $2\omega_p=\omega_s+\omega_i$). In a straight waveguide, the single-pass interaction is weak and the pairs are broadband, so they need lossy filtering. In silicon, two-photon and free-carrier absorption (TPA/FCA) also limit the usable pump [1]. A microring recirculates the pump. Field enhancement at the pump, signal and idler then boosts the pair rate at low power and emits the pairs into narrow cavity modes suited to interference and entanglement [2].

Continuous-wave (CW) pumping of the ring is nevertheless inefficient, for three reasons: i) the pair rate and the multi-pair noise scale in a way that forces low power to preserve the coincidence-to-accidental ratio (CAR); ii) in silicon, cavity-enhanced TPA/FCA clamp the intracavity intensity; iii) absorbed power heats the ring, causing resonance drift and thermal bistability [3]. SFWM depends on peak power. Pulses synchronized with the ring round trip raise the peak power by the inverse duty cycle. A target pair rate is therefore reached at a much lower average power. Mode-matched pulsed driving is already known to be far more efficient than CW driving for Kerr combs [4]. This matters because integrated lasers are weak: III-V-on-SiN MLLs reached ~2 pJ at 3 GHz [5].

Higher energies require either on-chip amplification, which has reached 800 W peak [6], or new architectures such as the Er:SiN Mamyshev oscillator, whose nJ pulses can be compressed to 147 fs [7]. Typical integrated MLLs, however, remain at 0.05–1 W peak. Resonant enhancement is what lets such a weak source replace a tabletop pump.

THE CORE OPEN PROBLEM IS SYNCHRONIZING THE MLL COMB WITH THE RING COMB. Their spacings, the repetition rate and the free spectral range (FSR), drift independently with temperature.

Solving it requires three things:

- Comb matching: the repetition rate must equal the FSR or a rational fraction of it, set by design, heaters or electro-optic tuning.
- Dispersion matching: the chirped picosecond pulses must fit the ring's integrated dispersion, possibly with on-chip compression.
- Locking: Kerr-induced synchronization lets an injected laser capture or entrain a soliton comb, and self-injection locking relaxes the requirements on the pump laser. Whether a pulsed MLL can entrain, or be entrained by, a ring remains largely unexplored.

A further technological challenge is joining III-V gain material to SiN without degrading SiN's low loss, by bonding, butt-coupling or micro-transfer printing.

Objectives

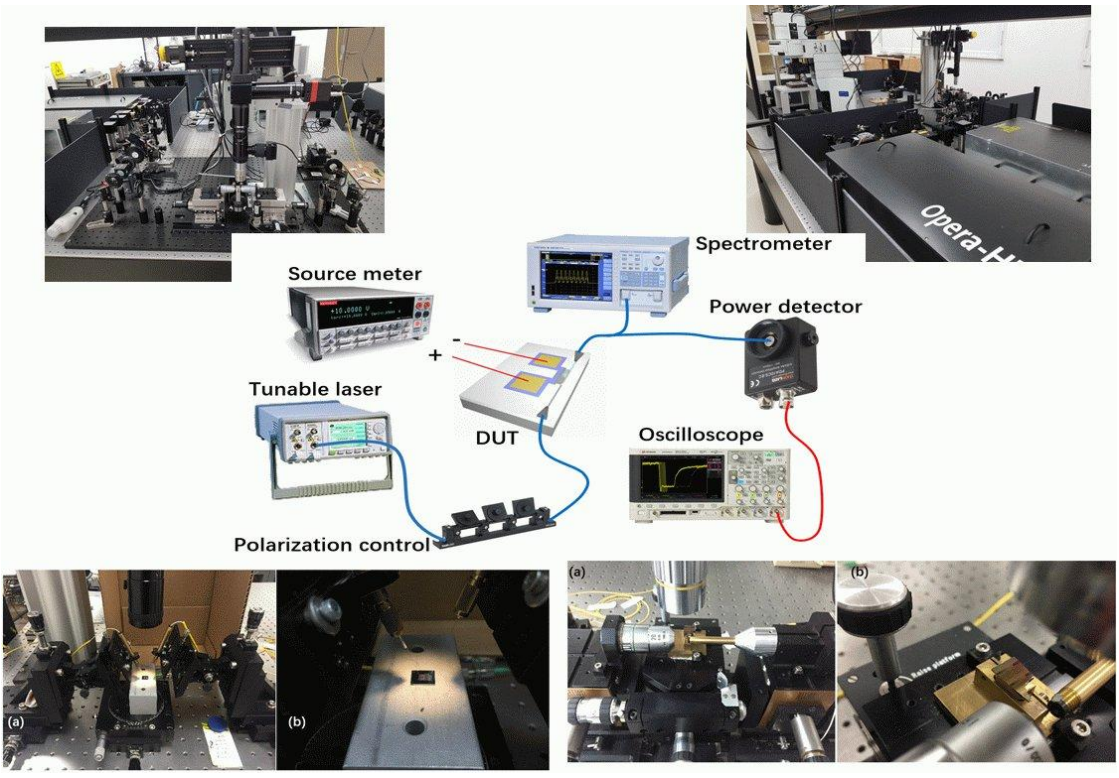
The **INTERNSHIP** aims to contribute to the **DEMONSTRATION OF PULSE-PUMPED SFWM IN SILICON OR SIN MICRORINGS SYNCHRONIZED TO AN MLL, AND TO QUANTIFY THE GAIN OVER CW PUMPING**. Experiments use existing ring chips and an available MLL, so they do not depend on a fabrication run; new designs are prepared in parallel.

Different activities will be carried out alongside the internship period:

Domain	Skills
Modeling and simulation	Coupled-mode and Lugiato–Lefever models; quantum theory of SFWM; TPA/FCA and thermal effects; dispersion engineering with mode solvers
Photonic design	Microring design (FSR, coupling, dispersion, heaters); mask layout for foundry runs
Optical characterization	Swept-laser spectroscopy; extraction of *Q* and dispersion; MLL characterization (autocorrelation, optical and RF spectra)
Transversal	Experimental planning; data analysis; literature review; scientific writing

References

[1]	H. Wang, Q. Zeng, H. Ma, Z. Yuan, "Progress on chip-based spontaneous four-wave mixing quantum light sources," *Adv. Devices Instrum.* **5**, 0032 (2024).
[2]	L. G. Helt, Z. Yang, M. Liscidini, J. E. Sipe, "Spontaneous four-wave mixing in microring resonators," *Opt. Lett.* **35**, 3006–3008 (2010).
[3]	T. Carmon, L. Yang, K. J. Vahala, "Dynamical thermal behavior and thermal self-stability of microcavities," *Opt. Express* **12**, 4742–4750 (2004).
[4]	E. Obrzud, S. Lecomte, T. Herr, "Temporal solitons in microresonators driven by optical pulses," *Nat. Photonics* **11**, 600–607 (2017).
[5]	A. Hermans *et al.*, "High-pulse-energy III-V-on-silicon-nitride mode-locked laser," *APL Photonics* **6**, 096102 (2021).
[6]	M. A. Gaafar *et al.*, "Femtosecond pulse amplification on a chip," *Nat. Commun.* **15**, 8109 (2024).
[7]	Z. Qiu *et al.*, "High-pulse-energy integrated mode-locked laser using a Mamyshev oscillator," *Nature* **654**, 57–63 (2026).



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