Spectral Properties of Photons Pairs Generated in a Si_3N_4 Microresonator

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Nonlinear media are attractive platforms for generating entangled photon pairs and, additionally, are heralded sources of single photons, making them essential resources for quantum communication, quantum computing, and advanced information processing [1–2]. Several approaches to single-photon and entanglement generation have been explored, including solid-state emitters such as nitrogen-vacancy centers in diamond and nonlinear processes based on parametric down-conversion in bulk crystals [3]. While successful, these platforms can face challenges related to scalability, integration, and precise control of the emitted photon bandwidth. Photonic integrated circuits (PICs) provide a promising alternative due to their reduced size, power consumption, and potential for large-scale integration [4]. In this context, microresonators exploiting spontaneous four-wave mixing offer an efficient and scalable route to heralded single-photon generation, while resonant enhancement naturally enables spectrally narrow emission compatible with narrowband quantum systems and telecommunication technologies [5].

Here, we investigate photon-pair generation via cavity-enhanced spontaneous four-wave mixing in a high-Q silicon nitride microresonator. The ring resonator, with an intrinsic quality factor $Q \sim 5 \times 10^6$, is evanescently coupled to a straight waveguide, yielding a loaded quality factor $Q_L \sim 2.5 \times 10^6$under critical coupling. Pumping a resonance in the center of the telecommunications C-band generates photon pairs in symmetric signal and idler modes. Considering one branch of the pair, the device operates as a heralded single-photon source, as confirmed by measurements of the heralded second-order correlation $g^{(2)}$.

We then focus on the spectral and coherence properties of the generated photons. By tuning the laser wavelength relative to the thermally shifted cavity resonances, the intracavity pump power is varied, allowing continuous access to regimes ranging from spontaneous four-wave mixing to the onset of optical parametric oscillation. Across this transition, we observe that the photon linewidth evolves from being determined by the cavity lifetime in the spontaneous regime to approaching the pump laser linewidth in the stimulated regime. This theoretically predicted spectral narrowing is experimentally observed and characterized here for the first time. The effect is investigated through complementary measurements of second-order correlations (auto- and cross-correlation) and first-order coherence, using heterodyne detection and delayed self-interferometry, and is supported by theoretical modeling and numerical simulations including dispersion effects neglected in previous works.

These results highlight the potential of high-Q silicon nitride microresonators as compact and efficient sources of heralded narrowband single photons/photon pairs, suitable for applications such as entanglement-based quantum key distribution over standard telecommunication fibers.

References

[1] Zhong H-S., *et al.*, Science 370,1460-1463 (2020).
[2] Kimble H., Nature 453, 1023–1030 (2008).
[3] Lounis B., and Orrit, M., Rep. On Prog. In Phys. 68(5), 1129-1179(2005).
[4] Pelucchi E., *et al.*, Rev Phys 4, 194–208 (2022).
[5] Wang Y., *et al.*, Appl. Phys. Rev. 1, 011314 (2021).