Room-Temperature Silicon Nitride Quantum Emitters for Advancing Quantum Key Distribution

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Abstract: Newly discovered silicon nitride quantum emitters hold great promise for industrial-scale quantum photonic applications. We assess the performance of intrinsic room-temperature SiN single-photon emitters for quantum key distribution, showcasing their exceptional brightness and single-photon purity.

Intrinsic single-photon emitters (SPEs) in silicon nitride (SiN) have recently attracted a substantial interest for integrated quantum photonics due to their room-temperature operation, outstanding single-photon purity, brightness, and compatibility with the mature foundry-friendly SiN photonics platform [1-3]. Our research focuses on incorporating these SiN emitters into industrial-scale quantum photonic applications, spanning communication, simulation, and computing. Our current goal is to adopt SiN SPEs for photonic circuits for Quantum Key Distribution (QKD). We focus on enhancing their brightness and single-photon purity, which are crucial for effective integration into chip-scale photonic circuits and realization of QKD protocols.

QKD protocols for secure communication can be realized using single-photon and entangled-photon states. Single-photon state protocols, such as BB84, leverage single photons prepared in different polarizations as polarization-encoded qubits. Importantly, these protocols relax the need for photon indistinguishability, enabling efficient operation at room temperature. QKD testbeds with polarization-encoded qubits using quantum emitters as single-photon sources were realized with NV and SiV centers in diamond [4], molecule-based single-photon sources [5], and most recently with color centers in hBN [6]. In our previous work [1], we demonstrated that SiN SPEs provide linearly polarized single-photon emission. Here, we aim to implement QKD testbeds with polarization-encoded qubits using SiN quantum emitters by maximizing their brightness, single-photon purity, and stability, all of which is essential both for QKD and for other practical quantum communication applications.

Figure 1 illustrates application of a solid-immersion lens (SIL) for enhanced collection efficiency. Despite an estimated 2.4x increase in collection efficiency from SiN quantum emitters (n = 1.7) using a glass SIL (n = 1.52) and a 0.9 NA objective (Fig. 1a), the observed improvement in SPEs emission rate was marginal, increasing from 10% to 27%. (Fig. 1b). However, the SIL notably enhances single-photon purity, evidenced by improved $g^{(2)}(0)$ values (Fig. 1c). The median $g^{(2)}(0)$ for 166 emitters is 0.13, with some achieving an excellent single-photon purity of 0.05.

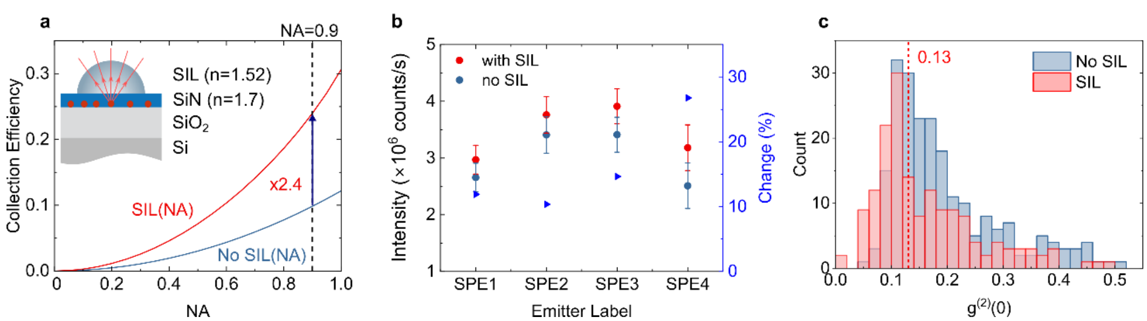

Figure 1. Application of solid-immersion lens (SIL). (a) Calculated collection efficiency with the glass SIL (BK7, n = 1.52). Inset: schematics of the experiment with SIL. (b) Comparison of the saturated intensity from the same SiN SPEs measured with and without the SIL. Right axis: percentage change of the saturated intensity. (c) Histogram of $g^{(2)}(0)$ distribution for SiN SPEs measured with and without the SIL. Bin size: 0.02.

The SIL furthermore aids in selection of SiN SPEs with both exceptional brightness and single-photon purity. Figure 2 illustrates the photophysical properties of a representative emitter, which shows a remarkable $g^{(2)}(0)$ value of 0.07, comparable to color centers in diamond, hBN, and organic molecules [4-6]. This emitter also exhibits a saturation intensity of 3.6×10^6 counts/s, while a mean value of 1.4×10^6 counts/s was obtained from measuring 166 SPEs (Fig. 2e,f). The wavelength distribution of the most intense photoluminescence peak has an average value 603±47 nm, facilitating preselection of SPEs via narrow bandpass filters. By applying a SIL approach, we were able to identify exceptionally bright SiN quantum emitters with saturated emission rates exceeding 4 MHz and achieving single-photon purities of up to 95% (Fig. 1f).

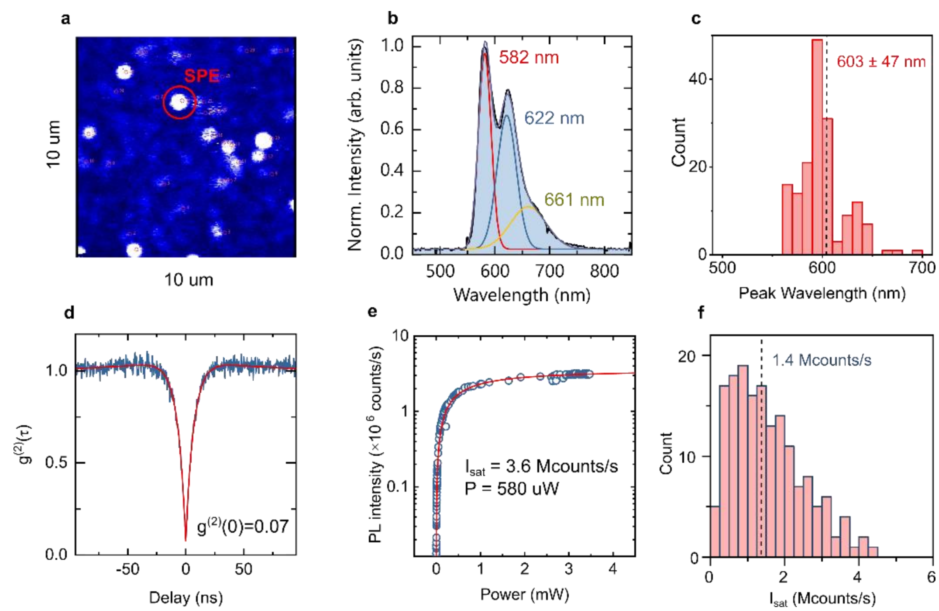

Figure 2. Representative SiN SPE measured with the SIL. (a) Confocal PL map recorded at room-temperature indicating the selected SPE. (b) Room-temperature PL spectrum with the most intense peak at 582 nm. (c) Histogram of wavelengths distribution of the most intense PL peak for 166 SPEs. Bin size: 10 nm. (d) $g^{(2)}(\tau)$ histogram, yielding $g^{(2)}(0)$ of 0.07. (e) Power-dependent emission rate from the SPE showing the saturation intensity of 3.6 Mcounts/s at the saturated power 580 μW. (f) Histogram of saturated intensities obtained from 166 SPEs. Bin size: 250 kcounts/s.

For the next steps, we will explore the potential for quantum frequency conversion using on-chip SiN ring resonators to transform single photons to the telecom range, which is crucial for long-distance communication. Our ultimate goal is to establish an experimental testbed for room temperature QKD with SiN quantum emitters, validating their performance and paving the way for practical applications in secure quantum communication.

This work demonstrates the potential of silicon nitride quantum emitters as robust candidates for room-temperature QKD photon source. The combination of high brightness, single-photon purity, and on-chip integrability positions SiN quantum emitter as promising component for the advancement of quantum photonic technologies.

References

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