

Monolithic Integration of Quantum Emitters with Silicon Nitride Photonic Platform

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Abstract: Silicon nitride has great potential for integrated quantum photonics. We demonstrate monolithic integration of intrinsic quantum emitters in SiN with waveguides which show a room-temperature off-chip count rate of $\sim 10^4$ counts/s and clear antibunching behavior. © 2022 The Author(s)

1. Introduction

Integrated photonic technologies are essential for efficient generation, manipulation, and detection of quantum states of light. Integrated quantum photonics can potentially enable the high density of on-chip qubits and the level of performance required for realization of various quantum applications. Silicon nitride stands out as a technologically mature, low propagation loss, CMOS compatible material platform well known for linear and nonlinear integrated optics [1,2] and has recently emerged as a potential platform for integrated quantum photonics [3].

Highly efficient, deterministic, and low-loss generation of single-photon emission is a critical component of future scalable photonic-based quantum devices [4]. The generation of intrinsic single-photon emitters in SiN material was recently demonstrated in our group via a novel growth and annealing processes. Emitters were found to be bright, stable, linearly polarized and high-purity sources of single photons at room temperature [5]. The utilization of quantum emitters natively embedded in SiN has the potential to mitigate the typical low coupling efficiency of emission into photonic components which is common in hybrid systems. Monolithically embedded emitters in quantum photonic circuitry elements such as waveguides and cavities may also improve the scalability of integrated platforms for industrial scale quantum applications.

2. Results

For this study, we grew nominally 250-nm-thick nitrogen-rich SiN film with high density plasma chemical vapor deposition on commercially available silicon oxide (SiO₂) coated silicon substrates suitable for waveguide fabrication. Single-photon emitters were generated by post-growth rapid thermal annealing for 120 seconds at a temperature of 1100°C. Ellipsometry characterization of the samples revealed the refractive index n of the resultant SiN films was ~ 1.7 . The photophysical properties of quantum emitters in the samples were characterized before waveguide fabrication and were in line with previously reported emitters [5]. The waveguides were designed and simulated with a commercial Maxwell solver using the 3D finite-difference time-domain method. Simulation results for a centrally placed emitter shows 33% coupling of the emission from the dipole source to the fundamental waveguide mode (β) and 22% outcoupling efficiency for the grating coupler at 600 nm. Waveguide arrays were patterned via electron beam lithography, hard masked with chrome, and etched using reactive ion etching. The high density of quantum emitters in the SiN layer prior to patterning ensured the integration of a few emitters in each waveguide without special alignment of the waveguide arrays. Fig. 1a shows the electron microscopy image of a representative SiN waveguide. The samples were measured using a decoupled excitation and detection scheme providing direct excitation of quantum emitters and remote collection of photons outcoupled by one of the grating couplers as shown in Fig. 1b. Fig. 1c shows distinct photoluminescence spots corresponding to the photons outcoupled from the waveguide at the excitation spot and from grating couplers upon excitation of an emitter with a 532 nm focused laser beam. Several SiN waveguides were measured to find those containing a quantum emitter which was properly oriented and positioned to efficiently couple to the waveguide mode. The emission outcoupled from one of the grating couplers was then collected to perform the second-order correlation measurement of the emission. The resulted $g^{(2)}(\tau)$ histogram is shown in Fig. 1d. The data was fit with a three-level model yielding a $g^{(2)}(0)$ value of 0.26 without spectral filtering and background correction (Fig. 1d). We also assed the emitter emission count rate and found it to be on the order of 10^4 counts/s.

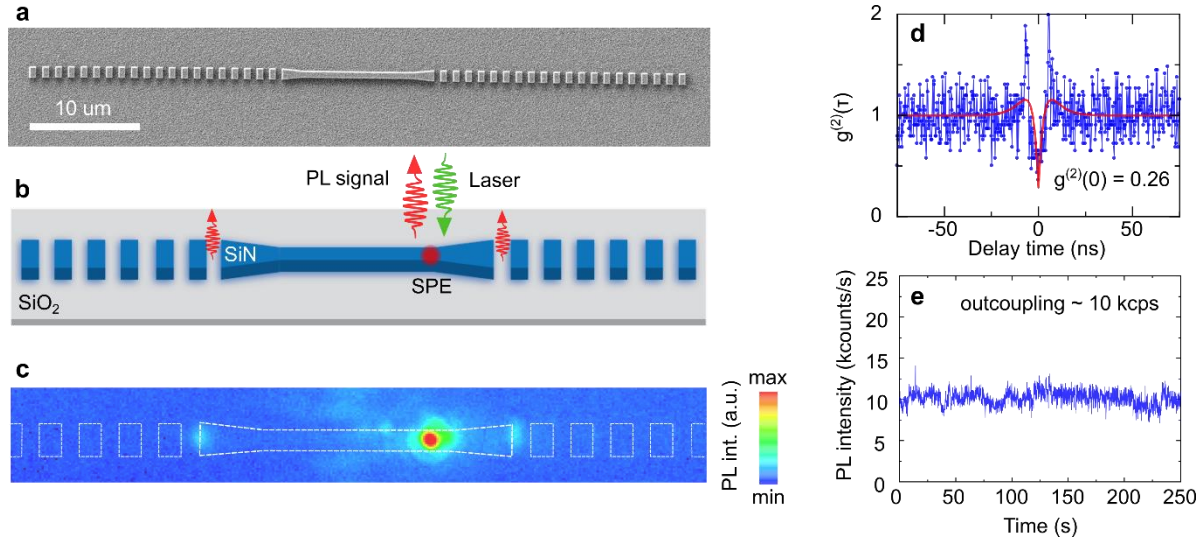


Figure 1. (a) Scanning electron microscopy image of a SiN waveguide. (b) Schematic illustration of a measurement scheme for direct excitation and remote detection of single-photon emission outcoupled from the grating couplers. (c) Photoluminescence image obtained with a CCD camera showing emission intensity from a quantum emitter at the excitation spot and outcoupled by grating couplers. (d) Second-order correlation measurement of the emission yielding the $g^{(2)}(0)$ value of 0.26 without spectral filtering and background correction. (e) Photoluminescence stability measurement.

3. Conclusion

In conclusion, we have demonstrated monolithic integration of intrinsic SiN quantum emitters with waveguides. We measured and characterized single-photon emission coupled to the waveguide and outcoupled off-chip by grating couplers. The count rate of outcoupled photons was found to be on the order of $\sim 10^4$ counts/s. The outcoupled emission preserved single-photon properties as was confirmed by clear antibunching behavior of the second-order autocorrelation histogram. The improvement of the SiN emitter-waveguide system requires further studies of the interplay between growth conditions, auto-fluorescence, and refractive index of SiN. Simulations with higher SiN refractive index (1.9) show improvement of β to $\sim 37\%$. For the next steps of our research on SiN quantum emitters, we will also study the possibility of generating indistinguishable photons by introducing the plasmonic speed-up approach that may enable broader applications in quantum information technology [6]. Monolithically integrated quantum emitters in SiN have a potential to enable a low-loss and scalable quantum photonic platform that is mature in terms of fabrication, quality control, and integration.

4. References

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This work is supported by the U.S. Department of Energy (DOE), Office of Science through the Quantum Science Center (QSC), and the National Science Foundation Award 2015025-ECCS.