

Stark Tuning and Resonant Excitation of Hybrid Integrated Telecom Single-Photon Sources

Hugo Larocque,^{1,*} Mustafa Atabey Buyukkaya,² Carlos Errando-Herranz,^{1,3}
Samuel Harper,² Jacques Carolan,¹ Gerald L. Leake,⁴ Daniel J. Coleman,⁴
Michael L. Fanto,⁵ Edo Waks,² Dirk Englund¹

¹ Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

² Department of Electrical and Computer Engineering and Institute for Research in Electronics and Applied Physics, University of Maryland, College Park, MD 20742, USA

³ Institute of Physics, University of Münster, 48149, Münster, Germany

⁴ State University of New York Polytechnic Institute, Albany, NY 12203, USA

⁵ Air Force Research Laboratory, Information Directorate, Rome, NY 13441, USA

*hlarocqu@mit.edu

Abstract: We introduce hybrid integrated telecom single-photon sources on a commercial foundry multilayer silicon photonic chip. We show above-band and resonant waveguide-coupled single-photon emission tunable via the DC Stark shift. © 2023 The Author(s)

Introduction - Scalable quantum photonic systems require a platform that can interface with many optical quantum states. III-V semiconductor quantum dots can notably generate such states, as they have recently enabled photon-spin interfaces [1], photon-photon interactions [2], and on-demand entangled photon emission [3]. Their versatility has motivated recent efforts on their heterogeneous integration with photonic integrated circuits (PICs) [4, 5]. However, to realize programmable systems with a large number of individually addressable emitters, there remains an outstanding need for integration with advanced electronic and photonic control. Here, we address this challenge by heterogeneous integration of InAs/InP chiplets embedded with quantum dot telecom single-photon emitters with a state-of-the-art silicon-on-insulator PIC produced in a 300 mm CMOS foundry enabling on-chip Stark tuning of the chiplet's emitters and efficient photon collection to an optical fiber.

Device design and fabrication - The system relies on hybrid integration of InP/InAs chiplets with a multilayer silicon PIC. The chiplets include a $10\ \mu\text{m} \times 10\ \mu\text{m}$ pad attached to a tapered nanobeam containing multiple quantum dot sources [6]. We then utilize transfer printing to move the chiplets onto the exposed silicon waveguides into the trenches opened up in the PIC. Herein, we align the transferred structures to an adiabatically tapered silicon waveguide enabling optical coupling between the InP nanobeam and the silicon PIC before placing it on

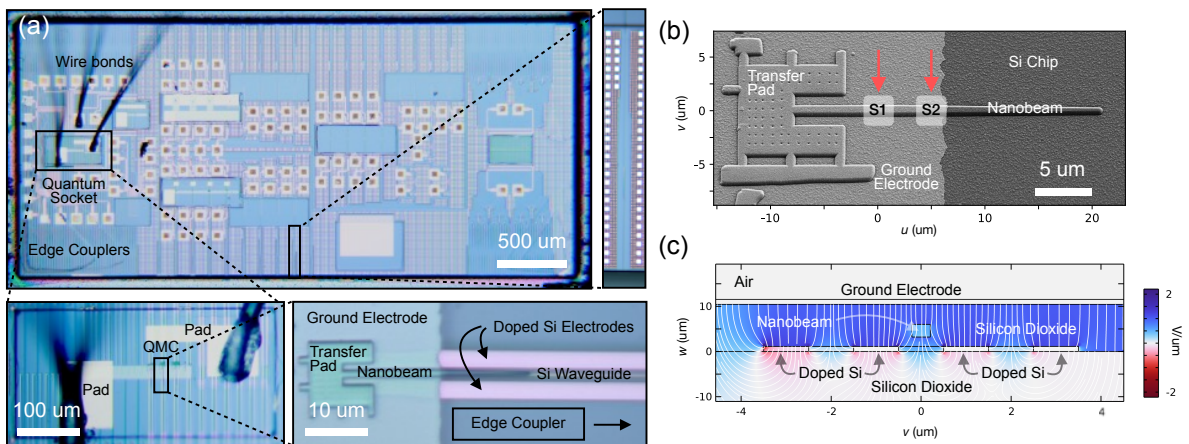


Fig. 1. (a) Optical micrograph of the hybrid chip. Fiber-to-fiber measurements through a 2 mm silicon waveguide with 5 μm mode field diameter lensed fibers indicate a total transmission of $25 \pm 5\%$, highlighting the excellent fiber-to-waveguide facet transmission of better than 50% in this SOI PIC platform. (b) Scanning electron microscope image of the transferred chiplet partially covered with a ground electrode, where two optical excitation sites are labelled. (c) Finite element simulation of the electric field in our tuning capacitor used for Stark tuning.

the host's surface. Each taper is surrounded by a pair of doped silicon wires used as tuning electrodes. We then deposit PECVD silicon dioxide over the hybrid chip and pattern a ground electrode over the chiplet by electron beam evaporation of chromium followed by lift-off. Figure 1(a) displays an optical micrograph of the resulting hybrid chip. We also provide a scanning electron microscope image of a transferred chiplet partially covered by the ground electrode in Fig. 1(b). We use the resulting structure as a capacitor where the two leads consist of the evaporated ground electrode and the pair of doped silicon wires. As shown in Fig. 1(c), a reasonably high fringing electric field traverses the nanobeam, thereby providing the means to shift the emission wavelength of the embedded emitters through the DC Stark effect.

Measurements - We characterized the hybrid system at 5 K in a closed-cycle cryostat with in-situ fiber positioning and a top-mounted scanning confocal microscope. Figure 2(a) shows the fiber-coupled emitted photoluminescence (PL) spectra while exciting quantum dots at locations $(u, v) = (0, 0); (0, 5) \mu\text{m}$, as indicated in Fig. 1(b). The emission lines used in further experiments are highlighted. Figure 2(b) shows the spectral shift experienced by a quantum dot as we apply a voltage across our on-chip tuning capacitor. We observe shifts of 0.4 nm over an applied voltage range of 200 V. The shift also follows a quadratic trend, as expected from the DC Stark shift.

Photon statistics - We measured the emitted photon stream under resonant excitation using an off-chip Hanbury Brown-Twiss apparatus. Because of excellent pump rejection into the waveguide, these measurements did not require additional spectral filtering. The histogram in Figure 2(c), obtained under continuous-wave illumination, indicates clear anti-bunching at fitted $g^{(2)}(0) = 0.12 \pm 0.02$ based on a three-level model.

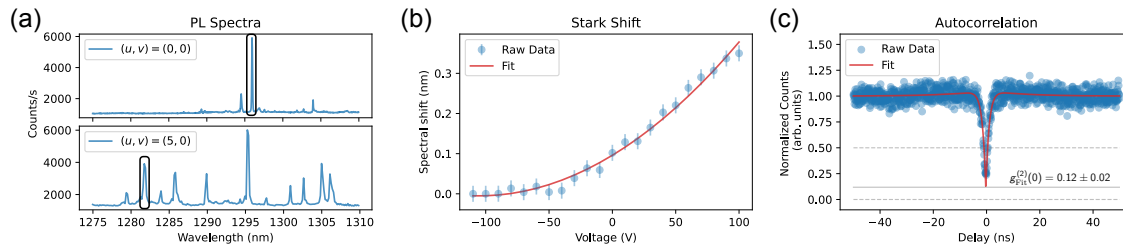


Fig. 2. (a) PL spectrum obtained while exciting different spots along the chiplet's nanobeam. (b) Spectral shifts for various actuation voltages applied across the tuning capacitor, showing a quadratic trend. Error bars correspond to the resolution limit of the spectrometer used in the measurement. (c) Second-order autocorrelation measurement of a quantum dot under resonant excitation.

Summary - We introduced a quantum photonic platform consisting of large-scale silicon PICs embedded with semiconductor single-photon sources emitting directly in telecom bands, a pairing that directly leverages the low losses and integrated components of state-of-the-art silicon photonics along with the high brightness of quantum dot single-photon sources. Our architecture enables electrical tuning and resonant excitation of the dots, thereby providing a promising route towards the generation of many-body quantum systems with individual-particle programmability for quantum information science and technology. Ongoing work focuses on pulsed resonant excitation; large-scale Stark shift control [7]; scaling of optical control by PIC-based modulation; and incorporation into a metropolitan fiber optic network.

References

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