Delft University of Technology

Strain Tuning of a Single Quantum Emitter in Silicon Photonics

Buzzi, Alessandro; Papon, Camille; Pirro, Matteo; Hooybergs, Odiel; Raniwala, Hamza; Saggio, Valeria; Errando-Herranz, Carlos; Englund, Dirk

Publication date
2025

Document Version
Final published version

Published in
2025 Conference on Lasers and Electro-Optics, CLEO 2025

Citation (APA)
Buzzi, A., Papon, C., Pirro, M., Hooybergs, O., Raniwala, H., Saggio, V., Errando-Herranz, C., & Englund, D. (2025). Strain Tuning of a Single Quantum Emitter in Silicon Photonics. In *2025 Conference on Lasers and Electro-Optics, CLEO 2025* (2025 Conference on Lasers and Electro-Optics, CLEO 2025). IEEE.

Strain Tuning of a Single Quantum Emitter in Silicon Photonics

Alessandro Buzzi[1,*], Camille Papon[1], Matteo Pirro[2,3], Odiel Hooybergs[1], Hamza Raniwala[1], Valeria Saggio[1], Carlos Errando-Herranz[2,3], and Dirk Englund[1]

[1] Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA, USA
[2] QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands
[3] Department of Quantum and Computer Engineering, Delft University of Technology, Delft 2628 CJ, Netherlands

[*] abuzzi@mit.edu

Abstract: We demonstrate controllable and reversible spectral tuning of a single quantum emitter in a silicon photonic integrated circuit, achieving up to 400 pm shift at telecom wavelength, paving the way for monolithically integrated quantum technologies. © 2024 The Author(s)

Silicon color centers have emerged as a promising platform for quantum communication and computing [1–3], combining telecom-band emission with the technological maturity and scalability of silicon photonics and CMOS-compatible nanofabrication processes. Driven by these promising characteristics, substantial progress has been made in integrating such emitters into photonic nanostructures [2, 4, 5], achieving deterministic emitter formation [6–8] and enabling the electrical manipulation of emitter ensembles [9]. Quantum information processing relies on the generation of indistinguishable photons, which requires solid-state emitters to have identical emission wavelengths. However, the ability to reversibly tune individual emitters remains an open challenge, limiting both the realization of multiphoton interference and the investigation of the emitter's intrinsic properties.

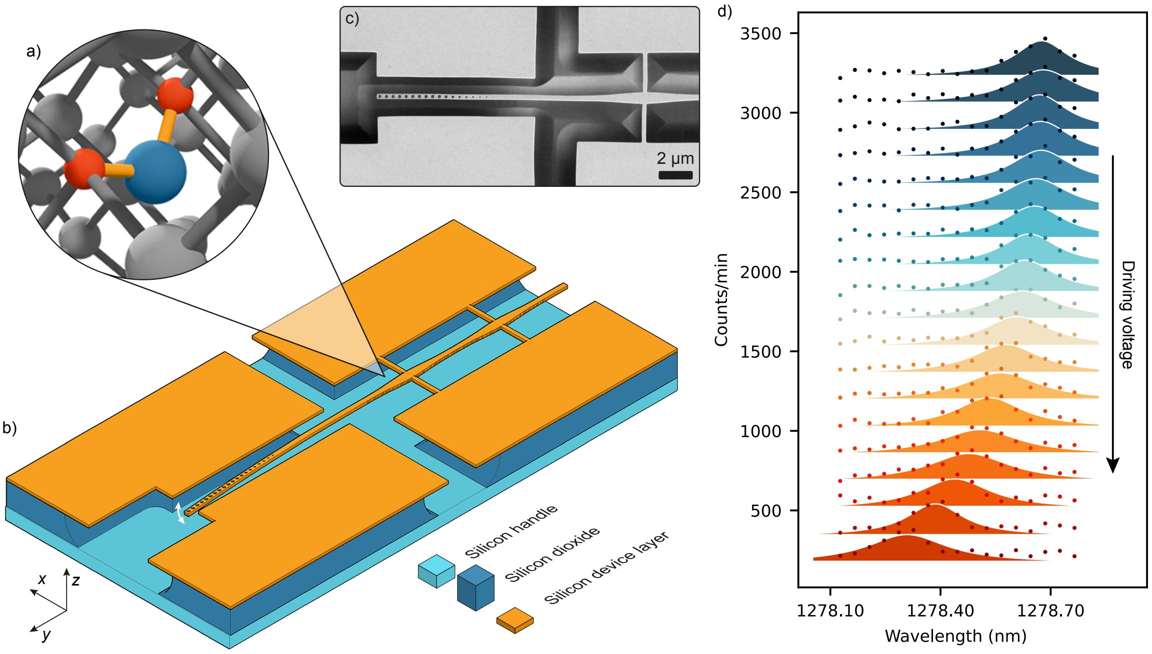

Fig. 1. Suspended cantilever waveguide illustration and emitter spectral tuning. a) Ball-and-stick model of the G center in a silicon lattice, consisting of two substitutional carbon atoms (orange) and an interstitial silicon atom (light blue). b) Diagram of the suspended cantilever waveguide, bent via capacitive actuation for strain control. c) Scanning electron micrograph of the suspended cantilever terminated by a Bragg reflector. d) Spectral tuning of the G center as a function of applied voltage (from 0 to 12 V). Dots represent the data points, and the filled curves are the Lorentzian fits.

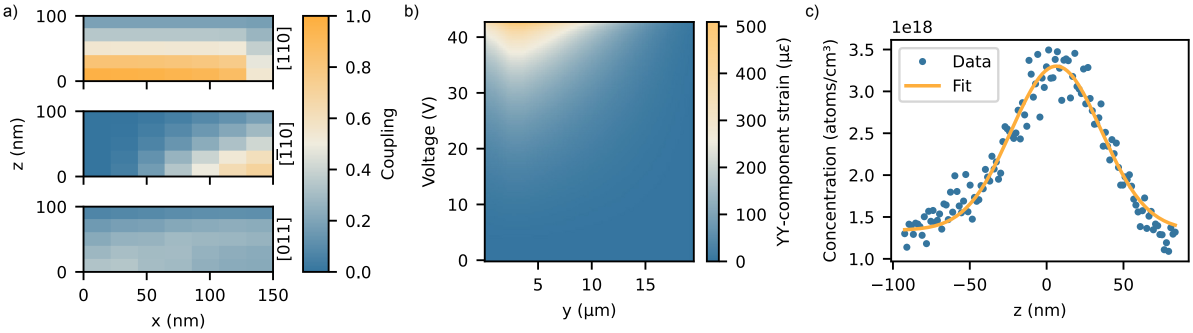

Fig. 2. Simulations and experimental data used in the model to determine the emitter's position in the waveguide. (a) Coupling efficiency of dipoles at different waveguide positions. (b) Heatmap of maximum strain in the cantilever as a function of voltage and position along y ([-110] direction). (c) Fitted SIMS data of carbon distribution in the waveguide, used to estimate G center generation likelihood. The origin of the coordinate system is defined at the center of the waveguide cross-section for x and z and at the center of the last tether along the cantilever's y-axis.

In this work, we experimentally demonstrate the controllable and reversible spectral tuning of a single G center embedded in an integrated photonic circuit (Fig. 1a). To control the local strain applied to the emitter, we employ a MEMS suspended cantilever waveguide (shown in Fig. 1b-c) that is capacitively actuated by applying a voltage between the device layer, through a deposited metal electrode, and the silicon handle ground plane. We drive the device up to 35 V and observe a maximum wavelength shift of over 100 pm in a reproducible, reversible, and low-power fashion while maintaining the emission intensity.

By combining the piezospectroscopic model for G centers, dipole orientation coupling to the waveguide (Fig. 2a), electromechanical finite element method simulations (Fig. 2b), and secondary ion mass spectroscopy (SIMS) measured carbon distribution (Fig. 2c), we model emitter positions and orientations. Maximum likelihood estimation is used to analyze potential scenarios for four individual emitters inside the waveguide.

The methods demonstrated here can be readily applied to other color centers in silicon, such as the T center, enabling broader quantum technology applications. Future work will focus on demonstrating the spectral tuning of two emitters at the same wavelength, which is essential for achieving the multiphoton interference required for quantum networking and computing.

This work represents a significant milestone in the physical understanding of these emitters and a crucial step toward developing large-scale quantum communication and computing systems based on silicon color centers.

References

1. D. B. Higginbottom, A. T. K. Kurkjian, C. Chartrand, M. Kazemi, N. A. Brunelle, E. R. MacQuarrie, J. R. Klein, N. R. Lee-Hone *et al.*, "Optical observation of single spins in silicon," *Nature* **607**, 266–270 (2022).
2. V. Saggio, C. Errando-Herranz, S. Gyger, C. Panuski, M. Prabhu, L. De Santis, I. Christen, D. Ornelas-Huerta *et al.*, "Cavity-enhanced single artificial atoms in silicon," *Nature Commun.* **15**, 5296 (2024).
3. Photonic Inc., "Distributed Quantum Computing in Silicon," *arXiv preprint* arXiv:2406.01704 (2024).
4. M. Prabhu, C. Errando-Herranz, L. De Santis, I. Christen, C. Chen, C. Gerlach, and D. Englund, "Individually addressable and spectrally programmable artificial atoms in silicon photonics," *Nature Commun.* **14**, 2380 (2023).
5. L. Komza, P. Samutpraphoot, M. Odeh, Y.-L. Tang, M. Mathew, J. Chang, H. Song, M.-K. Kim *et al.*, "Indistinguishable photons from an artificial atom in silicon photonics," *Nature Commun.* **15**, 6920 (2024).
6. K. Jhuria, V. Ivanov, D. Polley, Y. Zhiyenbayev, W. Liu, A. Persaud, W. Redjem, W. Qarony *et al.*, "Programmable quantum emitter formation in silicon," *Nature Commun.* **15**, 4497 (2024).
7. G. Andrini, G. Zanelli, S. D. Tchernij, E. Corte, E. N. Hernández, A. Verna, M. Cocuzza, E. Bernardi *et al.*, "Activation of telecom emitters in silicon upon ion implantation and ns pulsed laser annealing," *Commun. Mater.* **5**, 47 (2024).
8. M. Hollenbach, N. Klingner, N. S. Jagtap, L. Bischoff, C. Fowley, U. Kentsch, G. Hlawacek, A. Erbe *et al.*, "Wafer-scale nanofabrication of telecom single-photon emitters in silicon," *Nature Commun.* **13**, 7683 (2022).
9. A. M. Day, M. Sutula, J. R. Dietz, A. Raun, D. D. Sukachev, M. K. Bhaskar, and E. L. Hu, "Electrical manipulation of telecom color centers in silicon," *Nature Commun.* **15**, 4722 (2024).