Erbium Doped Silicon Nanophotonics for Scalable Quantum Networks

Kilian Sandholzer, Florian Burger, Justus Edelmann, Johannes Früh, Andreas Gritsch, Adrian Holzäpfel, Jakob Pforr, Stephan Rinner, Jonas Schmitt, Alexander Ulanowski, and Andreas Reiserer
TUM School of Natural Sciences
Department of Physics and Munich Center for Quantum Science and Technology (MCQST)
Technical University of Munich, James-Franck-Straße 1, Garching, Germany

Abstract— The connection of remote quantum nodes via quantum links enables us to establish secure communication channels and to overcome current limitations in quantum technologies via distributed quantum computing or sensing [1]. The basic building block of such a network is the interface between the static quantum nodes and the flying qubits. Erbium dopants integrated into solid-state materials are a prime candidate for this interface as their electronic and nuclear spin degrees of freedom show long coherence times and can be interfaced to photons in the telecommunication range via the 4f-shell transitions [2].

We directly implant erbium into nanophotonic silicon devices to increase light-matter coupling and realize on-chip integrated quantum devices. The reliable integration of erbium in the silicon crystal at newly discovered sites with narrow inhomogeneous linewidths [3] is also demonstrated in commercially fabricated samples [4].

We apply resonant fluorescence spectroscopy of ensembles in silicon nanophotonic waveguides under a varying magnetic field orientation to determine the symmetry and spin Hamiltonian of our sites [5]. Furthermore, the temperature dependence of the spectra is investigated to evaluate the performance as a nanoscopic optical thermometer in silicon, demonstrating a broad-range (2–300 K) with relative sensitivities ranging from 0.22(4)%/K at room temperature increasing to 420(50)%/K at 2 K [6].

By incorporating the dopants into nanobeam photonic crystal cavities, we are able to resolve single ions spectroscopically and measure Purcell enhancements of up to 177-fold [7]. We further achieve spin-resolved excitation of individual emitters with a narrow spectral diffusion linewidth, down to 20 MHz, approaching the 1 MHz lifetime-limit of the best-coupled emitters. At larger magnetic fields, we initialize and read out the electronic spin state by optical means with fidelities approaching 90% [8]. By directly driving the spin transition with a microwave field, we measure the spin-coherence time with a Hahn-Echo sequence to be 40 µs that can be further enhanced using dynamical decoupling.

Overall, these results establish erbium-doped silicon nanostructures as a promising platform for spin-photon interfaces that can be used as the basis for scalable quantum networks.

REFERENCES

1. Wehner, S., D. Elkouss, and R. Hanson, *Science*, Vol. 362, eaam9288, 2018.
2. Rančić, M., et al., *Nat. Phys.*, Vol. 14, 50, 2018.
3. Gritsch, A., et al., *Phys. Rev. X*, Vol. 12, 041009, 2022.
4. Rinner, S., et al., *Nanophotonics*, Vol. 12, 3455, 2023.
5. Holzäpfel, A., et al., *Adv. Quantum Technol.*, Vol. n/a, 2400342, n.d..
6. Sandholzer, K., et al., *Nanophotonics*, Vol. 14, 2005, 2025.
7. Gritsch, A., A. Ulanowski, and A. Reiserer, *Optica*, Vol. 10, 783, 2023.
8. Gritsch, A., et al., *Nat. Commun.*, Vol. 16, 64, 2025.