Erbium ions in silicon for quantum networks

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Entangling remote quantum nodes based on photonic links enables us to establish secure communication channels and to overcome current limitations in quantum technologies via distributed quantum computing or sensing [1]. A crucial part of such a network is the interface between static quantum nodes and the flying photonic qubits. Erbium ions 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 the erbium ions 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].
By incorporating the ions into nanobeam photonic crystal cavities, we are able to resolve single ions spectroscopically with Purcell enhancements of up to 177-fold [5]. Using external magnetic fields, we lift the spin-degeneracy of the ground state and find electronic spin lifetimes above one second for temperatures accessible by conventional ^{4}He cryocoolers. We initialize and read out the electronic spin state by optical means with fidelities approaching 90% [6].

Besides quantum information processing, we can also use the integrated erbium as a sensor for nanophotonic silicon devices. The temperature-dependent spectral response of an ensemble of erbium ions within a waveguide is used to demonstrate a broad-range nanoscopic temperature sensing with relative sensitivities ranging from 0.22(4) %/K at room temperature increasing to 420(50) %/K at 2 K.

References

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Figures

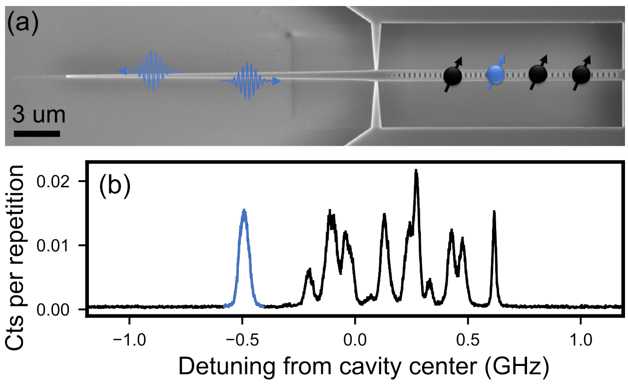

Figure 1: (a) Single erbium ions (spin symbols) integrated into a silicon nanobeam photonic crystal cavity (SEM image) are optically controlled and read out. (b) Spectroscopically resolving single ions (blue) within the cavity linewidth for quantum information processing.