

PCSI

Room Ballroom - Session PCSI-SuE2

Quantum Networks & Rare-Earth Emitters

Moderator: Gregory Fuchs, Cornell University

8:15pm PCSI-SuE2-10 Engineering Erbium-Doped Rare-Earth Oxide Thin Films For Quantum Networks, *Jiefei Zhang*, Argonne National Laboratory

INVITED

Telecom spin qubits in semiconductors are of considerable interest for quantum memories and repeaters for quantum communication networks. Among the candidate systems, erbium ions (Er^{3+}) are especially promising because they provide a telecom C-band optical transition together with long-lived spin states, making them attractive for spin-photon interfaces. The development of CMOS-compatible erbium doped thin films is therefore an important step towards scalable Er^{3+} -based quantum devices. In this talk, we present a comparative study of two complementary approaches to this goal: (1) molecular beam epitaxy (MBE) of Er^{3+} doped oxide thin film on silicon [1-4] and (2) controlled spalling [5] of thin film from high-quality bulk Er^{3+} -doped crystal onto CMOS-compatible platforms. Specifically, we compare Er^{3+} doped CeO_2 thin film and spalled Er^{3+} doped CaWO_4 film to elucidate competing spin decoherence dynamics and the influence of surfaces/interfaces. The MBE grown Er^{3+} : CeO_2 exhibits a promising narrow optical homogeneous linewidth (~ 440 kHz) [2], a spin relaxation time of ~ 120 ms and a spin coherence of $38.8 \mu\text{s}$ at 77mK [3]. We identify spectral diffusion driven by Er-Er spin flips as the dominant decoherence mechanism, with the large and symmetric g -tensor of this host playing a critical role in inducing strong Er-Er magnetic dipolar interactions. For comparison, we further explore an asymmetric host, CaWO_4 . By optimizing the spalling conditions for this medium-hard material, we obtain Er^{3+} : CaWO_4 films with thicknesses of ~ 1 microns. The spalled film shows a spin coherence of $347 \mu\text{s}$, only 20% lower than that of bulk crystal ($438 \mu\text{s}$) [6]. In this host, the Er-Er interaction is governed by the much weaker $g \sim 1.2$ tensor component, significantly suppressing Er bath spin flip induced spectral diffusion. The modest reduction in coherence between spalled and bulk samples may be attributed to additional decoherence from dangling bonds and charges at the spalled surface. Finally, we discuss the trade-offs between epitaxial growth and crystal spalling as routes to scalable erbium-based quantum-network platforms, and outline mitigation strategies for reaching millisecond-scale spin coherence in integrated devices.

[1] G. Grant, et al. *APL Mater.* 12, 021121 (2024).

[2] J. Zhang, et al. *npj Quantum Information* 10,119 (2024)

[3] S. Seth, et al. *Phys. Rev. Lett.* 135, 266901 (2025)

[4] I. Masiulionis, et al. *APL Mater.* 13, 101116 (2025)

[5] C. P. Horn, et al., *ACS Nano* 18, 31381–31389 (2024).

[6] S. Seth, et al., manuscript under preparation

8:45pm PCSI-SuE2-16 UPGRADED: A Fibre-Coupled Single-Erbium-Ion Source in Silicon Nanophotonics, *Sven Rogge*, University of New South Wales, Australia

Erbium in silicon combines telecommunications C-band transitions with long optical and electron-spin coherence [1], but its millisecond lifetime constrains photon generation. Here, we demonstrate a fibre-coupled single-photon source from individual Er ions in silicon photonic-crystal cavities. Each device integrates 40 cavities (mode volume approximately $0.04 \mu\text{m}^3$; quality factor near 100,000) on a common bus waveguide, with approximately 50% measured waveguide-to-tapered-fibre outcoupling. Magnetic-field tuning brings individual Er transitions into resonance with the cavity modes. For the most strongly coupled ion, the excited-state lifetime is reduced from 1.68 ms to $1.5 \mu\text{s}$, directly enhancing the total emission rate by more than a factor of 1000; correcting for the optical branching ratio implies a transition Purcell factor of approximately 5000. Pulsed Hanbury Brown and Twiss measurements give $g^2(0) = 0.001$, corresponding to a single-photon purity of approximately 0.999. A detected rate of approximately 3700 counts/s corresponds to an estimated in-fibre photon flux of approximately 60 kHz after accounting for excitation, spin shelving, optical transmission and detector efficiency. Similar lifetime reductions across cavities, and coupling of the same Er site in separate devices and fibre channels, demonstrate a reproducible fibre-addressed silicon architecture for telecom-band single-photon generation.

[1] I. R. Berkman et al., *npj Quantum Information* 11, 66 (2025).

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