Tuesday Evening, January 16, 2024

PCSI
Room Ballroom South - Session PCSI-TuE
Point Defects for Quantum Information Applications
Moderator: Roland Kawakami, The Ohio State University

7:00pm **PCSI-TuE-1 Rare Earth Doped Oxide Thin Films on Silicon for Chip Scale Quantum Emitters and Memories*, Supratik Guha*, *D. Awschalom,* University of Chicago, Argonne National Laboratory*; C. Ji, G. Grant, S. Seth, I. Masiulionis,* University of Chicago*; A. Dibos, J. Zjang,* Argonne National Laboratory*; S. Chattaraj,* University of Chicago*; M. Singh,* University of Chicago, memQ*; J. Wen,* Argonne National Laboratory **INVITED**

Quantum memories are an enabling technology for long distance repeater based quantum communications via optical fibers. Embedded within a host dielectric, the Er ion, with its 1.5 mm 4f-4f optical transition and its expected long spin coherence times, presents a convenient solid-state spin-optical interface that is telecom wavelength compatible for such quantum memory applications. Furthermore, it is desirable that such memories be scalable and compatible with silicon electronics for large scale deployment. Consequently, we have been exploring the properties of Er doped (few to ~100 ppm) dielectric oxide thin films grown on silicon substrates through detailed microstructural, growth and optical studies. Those oxides are also judiciously chosen to have low nuclear spin noise in the host to foster long Er electron spin coherence for memory applications. In these studies, using Er doped TiO_2, Y_2O_3, and CeO_2 as epitaxial and polycrystalline thin film hosts, and careful correlations of electron microscopy and X-ray diffraction based microstructural studies with optical properties, we find that while extended defect densities do not appear to have a significant effect upon the inhomogeneous linewidths, the Er doping levels, proximity of surfaces, the substrate interface, and film thickness have strong effects upon the optical properties including spectral diffusion and optical lifetime besides inhomogeneous linewidth, all critical for memory applications. We will discuss these results and the models of interaction that arise from these results. For the case of epitaxial CeO_2 on Si(111) we measure a narrow homogeneouslinewidth of 440 kHz with an optical coherence time of 0.72 µs at 3.6 K when studying the Z_1-Y_1 optical transition near 1530 nm at ~3.5K, along with an inhomogeneous linewidth of 10 GHz, an optical excited state lifetime of 3.5 ms. Using Er doped TiO_2 films on silicon grown via both molecular beam deposition as well as atomic layer deposition (where we had to develop mechanisms of ppm level doping of Er), we further show that such structures can be processed into good quality factor Si nanophotonic cavity devices and demonstrate a large Purcell enhancement (~ 300) of their optical lifetime leading to higher emission rates. These results indicate the significant promise of Er doped thin films as silicon compatible qubit devices for optical quantum memory and emitter applications. We will discuss these results with a focus on the materials science engineering aspects of this work.

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7:40pm **PCSI-TuE-9 Erbium sites in Silicon for Quantum Information Processing*, Sven Rogge*,** University of New South Wales, Australia **INVITED**

Rare-earth ions incorporated in several solid-state hosts were shown to exhibit low homogeneous broadening and long spin coherence at cryogenic temperatures making them a promising candidate for quantum applications, such as optical quantum memories, optical-microwave transductions, and quantum communication. However, long electron spin coherence has not been demonstrated in Si, a leading material platform for electronic and photonic applications. Here, we present the first demonstration of Er sites in semiconductor (Si) with a millisecond electron spin coherence time, optical homogeneous linewidths below 100 kHz, spin and optical inhomogeneous broadening approaching 100 kHz and 100 MHz, correspondingly. Er properties were measured using photoluminescence excitation spectroscopy within a nuclear spin-free silicon crystal (<0.01% ^{29}Si) doped at 10^{16} cm^{-3} Er level. Er homogeneous linewidth and spin coherence were addressed using optical comb-based spectral hole burning and optically detected magnetic resonance. To enhance Er emission collection efficiency, samples were directly positioned on top of dedicatedly fabricated superconducting single photon detectors and resonantly excited using fiber optics. Measurements in naturally abundant Si revealed that the Er electron spin coupling to ^{29}Si nuclear spins significantly shortens Er spin coherence times. Long spin coherence time and narrow optical linewidth show that Er in ^{28}Si is an excellent candidate for future quantum information and communication applications.

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