Rare Earth Doped Oxide Thin Films on Silicon for Chip Scale Quantum Emitters and Memories

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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 μm 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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