



PhD THESIS DEFENSE: Single rare earth ions for quantum computing nodes

EDUARDO BEATTIE EIZAGUIRRE

March 26, 2025

14:00

Elements Room and Online (Teams)

Despite decades of research, practical quantum computing and long-distance quantum communication remain elusive, hindered by significant challenges in current platforms. Single rare earth ions (SREI) in the solid state offer a promising alternative, with potential to form quantum computing nodes containing around 100 highly connected qubits capable of photonic networking. Nanoparticles are ideal for this system, as they enable high doping concentrations for strong interactions while maintaining the required spectral distinguishability. SREI experiments benefit from optical cavities that enhance emission via the Purcell effect. The open-access Fabry-Perot fiber cavity, formed by a fiber-tip micromirror and a planar or fiber mirror, is particularly versatile: a wide range of emitters can be integrated on the mirror surface, optical access is easy via the fiber, and three-dimensional

tunability is possible. This flexibility has enabled studies across various quantum emitters and 2D materials. This thesis presents our work developing the SREI platform using nanoparticles in fiber cavities. It begins with an introduction to quantum computing, quantum communication with quantum repeaters, and rare earth ions as a basis for quantum computers, along with an overview of our experimental design. A review of background knowledge follows, covering optical cavities, the Purcell effect, the optical Bloch equations, and single-photon light statistics. The absence of commercial nanopositioners suitable for controlling our fiber cavity led us to design our own. This positioner enabled the first detection of single ions in nanoparticles. We studied the $4I_{15/2} \rightarrow 4I_{13/2}$ transition at 1535 nm in 20 ppm erbium-doped 150 nm Y₂O₃ nanoparticles, and identified an ion with excellent spectral stability, a linewidth of 3.8(3) MHz, and a $g(2)(0)$ compatible with a perfect single emitter. We then developed a significantly improved second positioner with 2.5 pm RMS stability, 130 μ m $\times$ 130 μ m XY scan range, and MHz-rate cavity modulation, all at 1.65 K in a closed-cycle cryostat. The broad potential of fiber cavities enhances this device's impact, marking it as one of the thesis's main contributions. Equipped with this improved positioner, we proceeded with a new experiment to detect interactions between single ions. We studied the $3H_4 \rightarrow 1D_2$ transition at 619 nm in two sets of praseodymium-doped Y₂O₃ nanoparticles, but were so far unable to observe any praseodymium emission in the cavity. To diagnose why this was happening, we performed additional experiments with a confocal microscope, which confirmed the presence of praseodymium in a majority of objects and found the absorption resonance near where we expected. The thesis ends with conclusions and future directions, including emission shaping and a novel microscopy technique. A closing reflection on this work and recent breakthroughs in the field paints a promising future for quantum information technology.

Wednesday March 26, 14:00 h. Elements Room and online (Teams)

Thesis Director: Prof. Dr. Hugues de Riedmatten

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