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

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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 4I15/2 ? 4I13/2 transition at 1535 nm in 20 ppm erbium-doped 150 nm Y2O3 nanoparti[1]cles, 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 m×130 m XY scan range, and MHz-rate cavity modulation, all at 1.65 K i
a closed-cycle cryostat. The broad potential of fiber cavities enhances this device's impa
t, marking it as one of the thesis's main contributions. Equipped with this improved position
r, we proceeded with a newexperiment to detect interactions between single ions. We stud
ed the 3H4 ? 1D2 transition at 619 nm in two sets of praseodymium-doped Y2O3 nanoparticl
s, but were so far unable to observe any praseodymium emission in the cavity. To diagnose
hy this was happening, we performed additional experiments with a confocal microsco
e, which confirmed the presence of praseodymium in a majority of objects and found
he absorption resonance near where we expected. The thesis ends with conclusions and fut
re directions, including emission shaping and a novel microscopy technique. A clos
ng reflection on this work and recent breakthroughs in the field paints a promising future
or quantum information technologi

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Thesis Director: Prof. Dr. Hugues de Riedmatten

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