

# Broadband spectroscopic measurement of impurity ions in crystals using the Whispering Gallery Modes technique

Warrick G. Farr<sup>1</sup>, Maxim Goryachev<sup>1</sup>, Natalia C. Carvalho<sup>1</sup>, Daniel L. Creedon<sup>1</sup>, Jean-Michel le Floch<sup>1</sup>, Pavel Bushev<sup>2</sup>, Michael E. Tobar<sup>1</sup>

<sup>1</sup>ARC Centre of Excellence for Engineered Quantum Systems, School of Physics, University of Western Australia, City, Crawley WA, Australia

<sup>2</sup>Experimental Physik, Universitat des Saarlandes, D-66123 Saarbrücken, Germany

Email: Michael.tobar@uwa.edu.au

Crystal resonators with paramagnetic ion impurities are promising devices for hybrid quantum systems. However, a tradeoff exists between cavity coherence time and ion concentration. As a result, it is important to characterize crystals with varying levels of concentration and in the experimental regime where quantum effects occur (millikelvin temperature at microwave frequencies). Here, we describe recent progress in sensitive spectroscopic measurements of paramagnetic impurity ions in crystals. Using hybrid Whispering Gallery (WG) modes and Electron Spin Resonance techniques, interactions between photons and impurity ions in crystalline microwave cavities are studied. Rigorous spectroscopy of single-crystal sapphire and rare earth doped YAG and YSO was performed over the frequency range 8-30 GHz, and external DC magnetic fields of up to 0.9 T. Measurements of a high purity sapphire reveal the presence of Fe<sup>3+</sup>, Cr<sup>3+</sup>, and V<sup>2+</sup> impurities, with quadrupole and hyperfine structure, as well as coupling between spins and photons of up to 6 MHz. Also, new transitions in Erbium and Europium doped YSO crystals are observed in the strong coupling regime and will be presented at the conference.

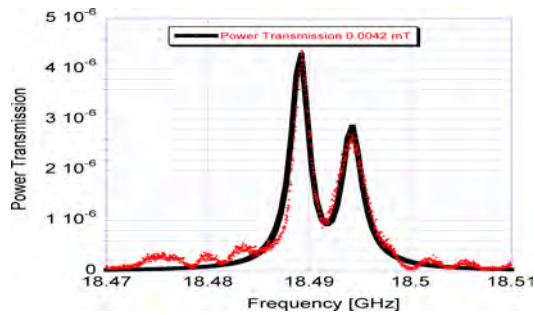


Fig. 1: Example of strong coupling of 2.6 MHz between photons in a WG mode YSO resonator doped with Europium

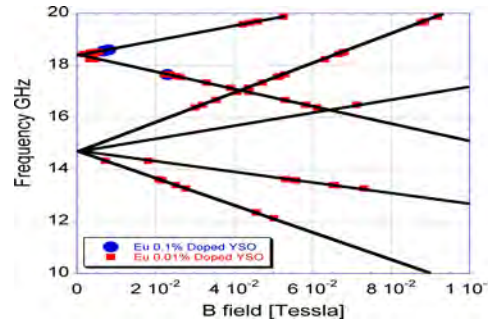


Fig. 2: Example of new transitions discovered in Europium and Erbium doped YSO using the WG mode method.