Terahertz Magnetospectroscopy Mapping of the Low-Temperature Phase Transition of $Er_xY_{1-x}FeO_3$

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1. Introduction

The celebrated Dicke Hamiltonian, one of the most fundamental models in quantum optics, describes the interaction between a collection of N two-level atoms and a single mode of electromagnetic radiation in a cavity of volume V [1,2]. Extensive research has been carried out over the years to understand some of its far-reaching consequences, particularly the existence of a second-order phase transition known as the superradiant phase transition (SRPT) in the thermodynamic limit $N,V \to +\infty$ [3,4]. To date, a SRPT in thermal equilibrium has not been attained experimentally, and it has been proven that, if the atoms are coupled with cavity photons through their electric dipole moments, they will remain stable against its occurrence [5].

In this work, we have studied the low temperature properties of the rare-earth orthoferrite $Er_xY_{1-x}FeO_3$ using terahertz (THz) time-domain magnetospectroscopy. Comparison of the theoretical predictions with actual observations revealed that the phase transition this material exhibits can be modeled using an extended Dicke Hamiltonian that incorporates short-range Er-Er exchange interactions, broadening our understanding of the role of cooperative effects in the SRPT.

2. Experimental Methods

Time-domain THz magnetotransmission spectroscopy measurements were carried out in the Faraday geometry with the sample placed in a liquid-helium-cooled magneto-optical cryostat (Oxford Instruments Spectromag-10-T) with variable temperatures (T) between 1.4 K to 300 K and static magnetic fields (B) up to 10 T. THz pulses were generated via optical rectification using a Ti:Sapphire regenerative amplifier laser (1 kHz, 0.8 mJ, 775 nm, 150 fs, Clark-MXR, Inc., CPA2001) as a laser source that pumped a (110) ZnTe crystal, while detection was accomplished through electro-optical sampling in another ZnTe crystal. Single crystals of $Er_xY_{1-x}FeO_3$ were grown according to the procedure detailed in [2].

3. Results

Figure 1a (b) shows THz absorption coefficient spectra at T = 1.4 K (T = 5.0 K) for a c-cut $ErFeO_3$ crystal. Each one of the curves corresponds to a different value of B. As shown in Fig. 1, two distinct features (appearing as peaks in the absorption spectra and labeled "q_{FM}" and "q_{AFM}", respectively) can be observed. These features correspond to the excitation of two optically active resonances in this material – the quasi-antiferromagnetic (q_{AFM}) and quasi-ferromagnetic (q_{FM}) magnon modes. Above ~4.5 K and at B = 0 T, the Er spins are paramagnetic and follow the weak magnetization vector of the Fe spins. However, below the critical temperature T_c ~ 4.5 K, the Er spins order antiferromagnetically, and a magnon-mediated long-range interaction causes a rotation of the AFM vector of the Fe spins, affecting its magnetic configuration. This can be observed, for example, in the redshift of the q_{AFM} mode at 0 T when the T is decreased below T_c (compare black curves in Fig. 1a and Fig 1b, respectively). Moreover, an applied magnetic field can critically destroy the rare-earth ion ordering (seen at B larger than 1.00 T in Fig. 1a for example) and bring the system back to the magnetic configuration existing at high temperatures.

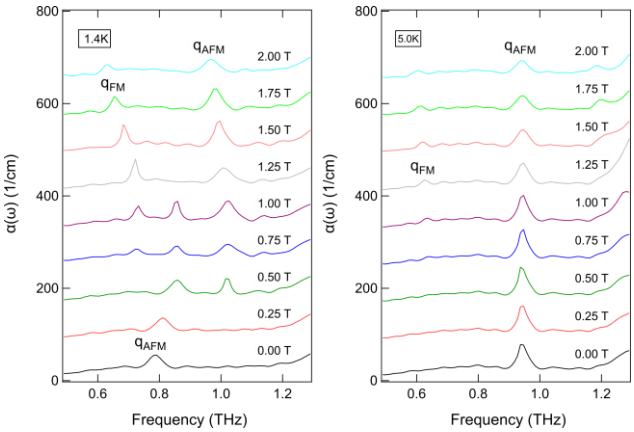

Fig. 1. THz absorption coefficient spectra for $ErFeO_3$ at (a) 1.4 K and (b) 5.0 K at various magnetic fields. Curves are vertically offset for clarity.

References

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