Hybridized magnon with orbital and lattice in multiferroics $Ba_2MnGe_2O_7$

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A spin-driven multiferroics has been extensively studied since the discovery of an enhanced magnetoelectric effect in $TbMnO_3$. Among microscopic mechanisms of the multiferroics, a spin-dependent *d-p* hybridization mechanism locally determines the relationship between an electric polarization and spin moment on each magnetic site [1]. In this case, a magnetic anisotropy plays a key role in the characterization of the multiferroicity. A remarkable work in $Ba_2CoGe_2O_7$ demonstrated that the magnetic anisotropy is explained by a spin-nematic interaction which is equivalent to an electric polarization interaction [2]. The interaction may lead to a nontrivial magnon coupled with orbital and lattice.

A multiferroics $Ba_2MnGe_2O_7$ is isostructural to $Ba_2CoGe_2O_7$, where Mn^{2+} ions carrying Heisenberg spin S = 5/2 form square lattice [3]. An antiferromagnetic order with a collinear structure occurs at 4 K, and simultaneously an electric polarization appears [4]. The magnetic susceptibility and the inelastic neutron scattering (INS) spectra were explained by a square-lattice classical Heisenberg model, where the magnetic anisotropy was not considered.

Here we study the temperature variation of the magnetic anisotropy by combination of a magnetization measurement and an ultra-high energy resolution INS experiment. We observed a pair of well-defined magnon modes, T_1 for lower and T_2 for higher energies. The band energies are consistent with the previous report [3]. A temperature evolution of anisotropy-gap energies, E_{g1} for T_1 and E_{g2} for T_2 modes were measured. The energy of E_{g2} at 1.8 K is consistent with a conventional easy-plane anisotropy reported in the previous ESR study [5], which means that T_2 mode is lifted by the easy-plane anisotropy. We found that E_{g1} is scaled by the electric polarization, but it cannot be scaled by any power of the sublattice moment. Since E_{g1} is also scaled by the measured spin flop field, the T_1 mode is lifted by an easy-axis anisotropy. E_{g2} is, in contrast, scaled by the sublattice magnetic moment. Through the analysis of INS spectra using spin wave theory, we found that the T_1 mode is lifted by the spin-nematic interaction, while the T_2 one is lifted by the easy-plane single-ion anisotropy. The anomalous temperature dependence of E_{g1} leads to a conclusion that the T_1 mode is a hybridized magnon with orbital and lattice.

[1] T.-h. Arima, J. Phys. Soc. Jpn **76**, 073702 (2007).
[2] M. Soda *et al*., Phys. Rev. Lett. **112**, 127205 (2014).
[3] T. Masuda *et al*., Phys. Rev. B **81**, 100402(R) (2010).
[4] H. Murakawa *et al*., Phys. Rev. B **85**, 174106 (2012).
[5] Y. Iguchi *et al*., Phys. Rev. B **98**, 064416 (2018).