Electric Control of Spin Helicity in $TbMnO_3$

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In a magnetoelectric compound $TbMnO_3$, a sinusoidal incommensurate antiferromagnetic ordering of the Mn^{3+} moments takes place at $T_N = 42$ K with a magnetic wave vector with $q \sim 0.27$. The ferroelectric polarization along the c axis (P_c) emerges upon the magnetic phase transition from collinear to cycloid spin structure at $T_C = 27$ K. We report here the quantitative elucidation of such magnetically induced ferroelectricity in terms of the spin ellipticity as the order parameter and show the successful electric control between the clockwise (CW) and counter-clockwise (CCW) spin helixes.

Spin polarized neutron diffraction measurements were performed with a triple-axis spectrometer PONTA at JRR-3. A single crystal was mounted on a sapphire plate in a closed-cycle helium refrigerator and irradiated with a spin-polarized neutron beam with a kinetic energy of 36.0 meV. A Heusler monochromator was utilized to obtain the spin-polarized neutron beam. The spin of the neutron beam could be flipped by a spin-flipper, so as to be parallel or anti-parallel to the scattering vector Q_s with a guide-field of about 10 gauss applied by a Helmholtz coil.

All the neutron diffraction measurements were performed without application of electric field after cooling the sample from 50 K in a poling field. Peak profiles of magnetic satellite reflections ($4\ {+q}\ 1$) and ($4\ {-q}\ 1$) with $q \sim 0.27$ were obtained by rotating the sample around the vertical axis, which approximately corresponded to the L scan in the reciprocal space.

Figure 1(a) shows the profiles of magnetic satellites at Q_s = ($4\ {\pm q}\ 1$) for the ferroelectric state at 9 K after cooling in an electric field of $E = \pm 160$ kV/m. In the case of $P_c > 0$, the intensity of the satellite ($4\ {+q}\ 1$) is approximately 9 times as high with neutron spin (S_n) anti-parallel to the scattering vector Q_s as that with parallel S_n. As for the satellite ($4\ {-q}\ 1$), the opposite relation is observed. These behaviors are typical of a spiral magnet with a single helicity, where the spiral plane is almost perpendicular to the scattering vector. Here, it is to be noted that the spiral plane of $TbMnO_3$ is perpendicular to the a axis. When the direction of the cooling electric field is reversed, it is clearly shown that the opposite helicity domain becomes dominant. In other words, that the spin helicity can be successfully controlled by a poling electric field. The revealed relation between the spin helicity and electric polarization is depicted in Fig. 1(b).

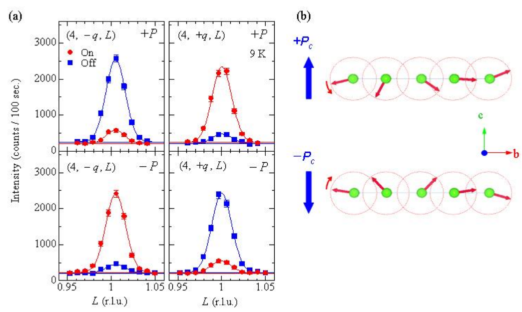

Fig. 1. (a) Profiles of magnetic satellites ($4\ {\pm q}\ 1$) with $P_c > 0$ and $P_c < 0$ at 9 K. (b) Relation between the spin helicity and the direction of electric polarization in $TbMnO_3$.