MAGNETOELECTRIC COUPLING IN $TbMnO_3$

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We have investigated the relationship between magnetism and ferroelectric properties of a magnetic ferroelectric rare-earth manganite, $TbMnO_3$. Magnetoelectric phase diagrams of the orthorhombic rare-earth manganite have been determined from measurements of magnetization, dielectric constant, and electric polarization for magnetic fields along different crystallographic directions.

Using a 14-tesla PPMS at NHMFL-LANL, we measured the magnetic-field effect of the magnetic and ferroelectric properties in single crystals of $TbMnO_3$. Figure shows the isothermal magnetization (M) and electric polarization (P) as a function of magnetic fields (H) at selected temperatures. As displayed in Figs. (a-c), single or double metamagnetic transitions can be seen in M-H curves at 2 or 4 K, depending on the orientation of H relative to the crystallographic axes. With the application of H along the a axis, double metamagnetic transition has been observed. The first transition shows a distinct jump of M at ~1.7 T [the main panel of Fig. (a)], and the second one only exhibits a small change in M at ~10 T [the inset of Fig. (a)]. The application of H along the b axis also gives rise to double transitions around ~1 T and ~4.5 T [Fig. (b)]. With increasing temperature, the steps in the M-H curves become indistinct. Applying H along the c axis causes a single metamagnetic transition above 5 T, as shown in Fig. (c). This metamagnetic transition in H along c is accompanied by a large field hysteresis at low temperatures, and the increase of M at the transition is ~0.2 μ_B/f.u. Comparing the M-H curves with the P-H curves in Figure, it is clear that the metamagnetic transitions give rise to the large changes in P. These results clearly demonstrate the strong interplay between magnetism and ferroelectricity in $TbMnO_3$.

Our systematic investigation shows that several types of metamagnetic transitions [e.g. the reversal of R^{3+} moments, transition from long wavelength antiferromagnetic to layered-type (A-type) antiferromagnetic states on Mn^{3+} moments] produce the magnetic-field-induced changes in dielectric and ferroelectric properties. In $TbMnO_3$, we can suppress ferroelectric order by applying a magnetic field. In addition, we can switch the direction of the ferroelectric polarization vector by using a magnetic field. A variety of magnetic-field induced magnetoelectric phase transitions are realized by fine tuning of the subtle balance of competing magnetic interactions.

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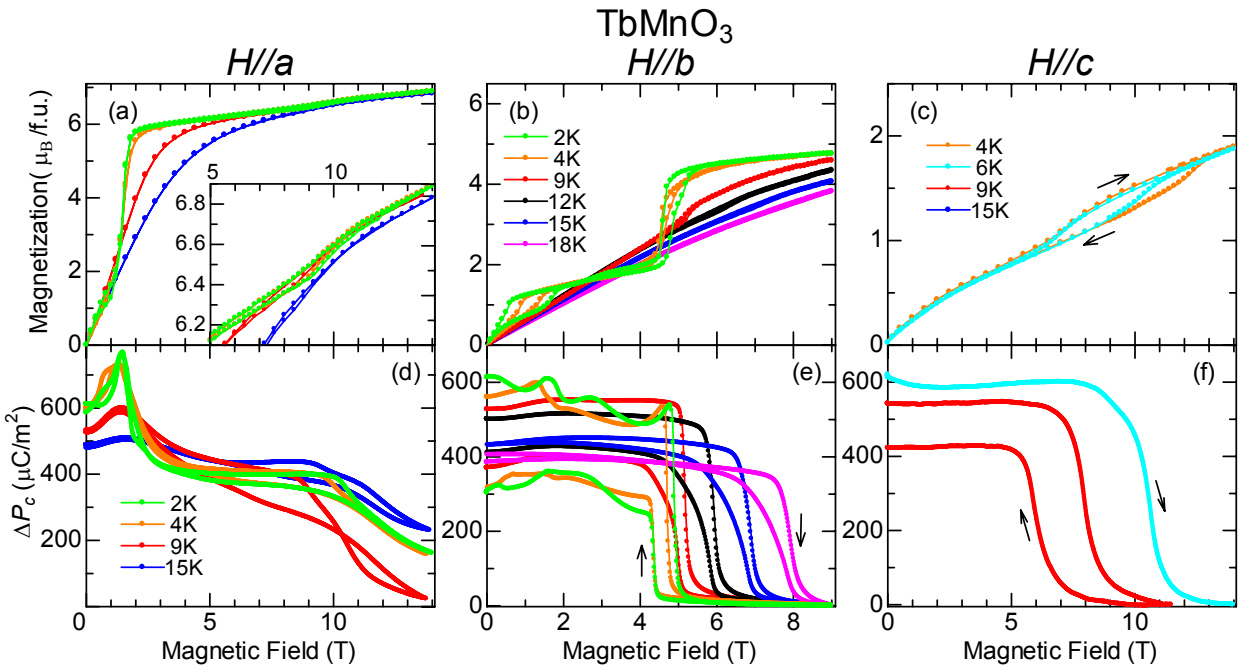

Figure (a-c) magnetization and (d-f) magnetic-field-induced change in electric polarization along the c axis for $TbMnO_3$ crystals as a function of an external magnetic fields parallel to the a, b, and c axes at fixed temperatures.