Magnetization and Electric Polarization Measurements on Multiferroic $CuCrO_2$ in Pulsed Magnetic Field

Eundeok Mun, Vivien Zapf (LANL), A. Podlesnyak, G. Ehlers (Neutron Scattering Science Division, ORNL), S. Barilo, S. Shiryaev (Institute of Solid State and Semiconductor Physics, Belarus), M. Frontzek* (Oakridge National Lab) * now at Laboratory for Neutron Scattering, PSI, Switzerland

Introduction

The triangular lattice antiferromagnet $CuCrO_2$ show ferroelectricity induced by a proper-screw spiral magnetic structure, where spins in form 120° angles with neighboring spins due to frustration [1]. In zero magnetic field, a spontaneous electric polarization is coupled to antiferromagnetic ordering below 23.6 K. The $CuCrO_2$ compound is thought to be a rare example of the Arima mechanism for multiferroic behavior [2]. It has been shown that the magnetoelectric coupling can be tuned by both an electric and a magnetic field along **ab**-plane [3]. We investigate the magnetic field-evolution of the physical properties of $CuCrO_2$ via magnetization and electric polarization measurements up to 65 T in short-pulsed magnet. We explore the complicated *H-T* phase diagram along **c**-axis.

Results and Discussion

The magnetization isotherms *M*(*H*) taken up to 60 T along **H** || [110], [1-10], and [001] at T = 1.6 K are depicted in **Figure 1** (a). Essentially no magnetic anisotropy is observed along three different orientations of magnetic field. As magnetic field increases, the *M*(*H*) curves show a steady linear increase up to 60 T, reaching ~ 0.7 μ_B/Cr^{3+} far below the saturation magnetization value of 3 μ_B/Cr^{3+} expected to be due to the magnetic frustration. The observed electric polarization change $\Delta P(H)$, however, is quite anisotropic between the longitudinal (**P** || **H**) and the transverse (**P** ⊥ **H**) configuration as shown in Fig. 1 (b). When the magnetic field is applied in plane, the $\Delta P(H)$ curves indicate a polarization flop around 5.3 T, which is consistent with earlier reports [3]. On the other hand, when the magnetic field is applied along [001] direction, we found that the $\Delta P(H)$ shows an abrupt change around 45 T with large hysteresis loop. Based on the electric polarization measurements at various temperatures, we construct the *H-T* phase diagram (Fig. (c)). In contrast to the in-plane magnetic fields, the assembled *H-T* phase diagram is complex, showing multiple ferroelectric phases. The electric polarization in $CuCrO_2$ can be suppressed for H > 85 T along [001].

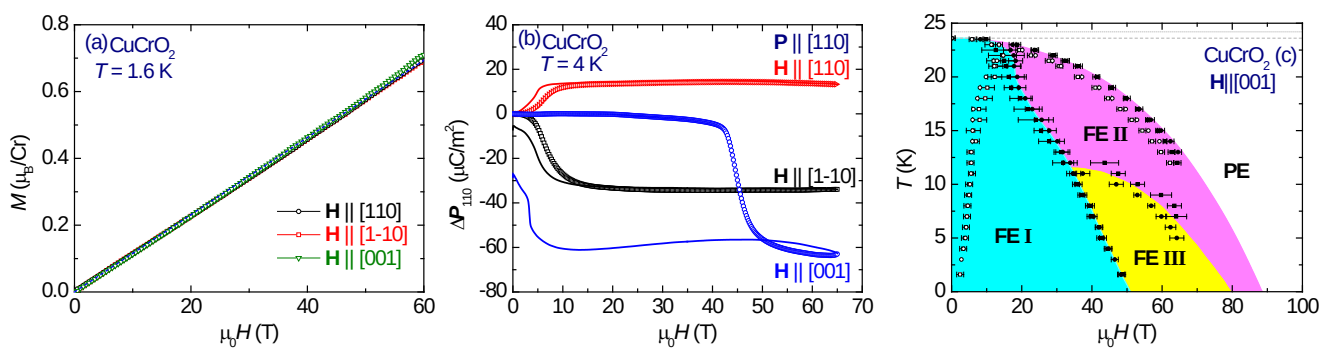

Figure 1: (a) Magnetization isotherms at T = 1.6 K for **H** || [110], [1-10], and [001]. (b) Electric polarization for **P** || [110] along **H** || [110], [1-10], and [001], taken at T = 4 K. Symbols and lines indicate up- and down-sweep of magnetic field. (c) *H-T* phase diagram of $CuCrO_2$ along **H** || [001], constructed from electric polarization measurements. Closed and open symbols are based on the up- and down-sweep of magnetic field.

Conclusions

We observe electric polarization flops for magnetic field along the **ab**-plane and the suppression of electric polarization along **c**-axis. By contrast no noticeable anomaly is detected in magnetization isotherms, which are liner in magnetic fields up to 60 T. The electric polarization is highly sensitive to the external magnetic field for both **ab**-plane and **c**-axis due to a 3-dimensional proper-screw spiral magnetic structure as found by an inelastic neutron diffraction study [4]. We suggest that in addition to the in-plane exchange interaction, the ferromagnetic inter-chain coupling [4] may be necessary to explain our observed results.

Acknowledgements

Work at the NHMFL is supported by the NSF, the DOE, and the State of Florida.

References

[1] Kimura, K., *et al.*, Phys. Rev. B **78**, 140401(R) (2008).
[2] Arima, T., J. Phys. Soc. Jpn **76**, 073702 (2007).
[3] Kimura, K., *et al.*, Phys. Rev. Lett. **103**, 107201 (2009).
[4] Frontzek, M., *et al.*, Phys. Rev. B **84**, 094448 (2011).