Evolution of Ferroelectricity in $CuCrO_2$ up to 100 T

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Introduction

$CuCrO_2$ offers insights into the different types of spiral magnetic orderings that can form spontaneously due to frustration in triangular-lattice antiferromagnets. Previously, we explored the magnetic phase diagram up to 65 T along all the principle axes by using electric polarization to probe changes in the spiral order at high magnetic fields [1]. It is known that at zero magnetic field a proper-screw spiral of the Cr **S** = 3/2 spins forms that in turn induces electric polarization with six possible orientations **ab**-plane [2]. Applied magnetic fields in the **ab**-plane have been shown to induce a transition to cycloidal spiral magnetic order above ~5.3 T in those domains that have spins perpendicular to the applied magnetic field. On the other hand for magnetic fields along the **c**-axis, we observe a transition in the electric polarization near ~45 T at T = 4 K, and it is followed by a series of steps and/or oscillations in the electric polarization. Since the magnetization value at 60 T reaches ~0.7 μB/Cr, which is far below the expected saturation value of 3 μ_B, a rich variety of magnetic and ferroelectric phase and the coupling between these are expected beyond studied magnetic field range of 65 T.

Experimental Results and Discussion

Electrical polarization measurements were performed up to 92 T in the 100 Tesla multi-shot magnet. The measured magneto-electric current and its integral are plotted in the left and right figure, respectively, at selected temperatures. In multi-shot magnet, the measured magneto-electric current shows no field dependence up to ~ 38 T due to the low sweep rate of magnetic field driven by generator, whereas the induced current due to the sample polarization change clearly reveals peak structures and slope changes for H > 38 T with ~4000 times faster sweep rate of magnetic field driven by capacitor-bank. For **H** || [001] we observe additional anomalies in electric polarization with extraordinarily hysteresis (not shown for the down sweep curve in the figure) beyond 65 T. By contrast to the magnetization measurements which reveal a quasi-linear isotropic magnetic field dependence up to 60 T, the electric polarization is very sensitive to the magnetic phase transitions in $CuCrO_2$. Therefore, the evolution of complex magnetic orders can be probed by the magnetically-induced electric polarization in the regime of phase space that is not accessible to neutron diffraction.

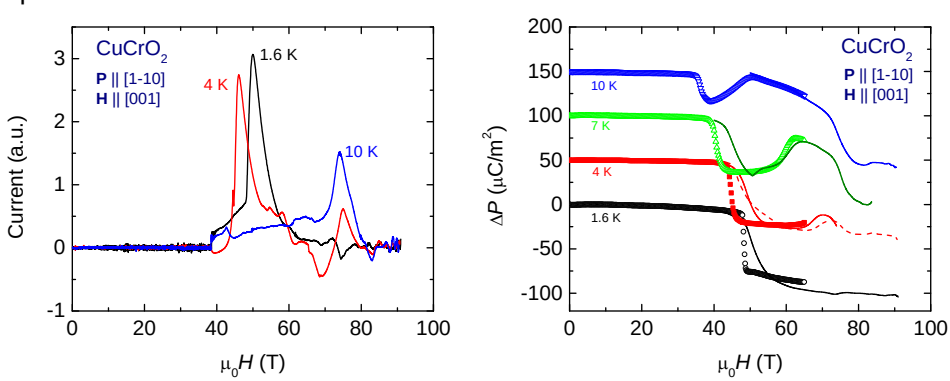

Fig. 1 (Left) the measured magneto-electric current for [1-10] along H || [001], plotted as a function of H and T. (Right) the electric polarization P(H) curves for up-sweep of magnetic field at selected temperatures. For comparison, P(H) curves taken in 65 T short pulse magnet are plotted (symbols) [1].

Conclusions

New oscillations or phase transitions are observed in the electric polarization of $CuCrO_2$ between 65 and 92 T. These may be related to interactions between the wave vectors of the incommensurate spiral magnetic order and the lattice. By a simple linear extrapolation of magnetization isotherms, complete saturation of magnetization (and suppression of the electric polarization) is expected by ~270 T.

Acknowledgements

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References

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[2] Mun, E. D., *et al*., arXiv:1312.2548.