Imaging electrically-induced changes of magnetic order and orientation at room temperature and above

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The control of magnetism by electric fields is an important research goal [1,2] with possible applications in spintronic storage and logic architectures with low power consumption [2,3]. To these ends, recent efforts have delivered electric field control of the magnetic anisotropy [4], domain structure [5], spin polarization [6] and critical temperature [7] of various magnetic phases. Until recently, on-off switching of robust ferromagnetic order at room temperature remained elusive.

Here we show electrically-induced changes of magnetic order in two magnetic thin film systems. We grow each onto ferroelectric and ferroelastic $BaTiO_3$ (BTO) substrates, which apply simultaneous strain and charge stimuli in response to small electric fields applied through their thickness. We use spatially-and chemically-resolved information from photoemission electron microscopy (PEEM) with x-ray magnetic circular dichroism (XMCD) to study large local magnetic changes, and understand the mechanisms that underpin them.

In the FeRh system, we recently achieved large magnetoelectric effects by driving the metamagnetic transition between antiferromagnetic (AF) and ferromagnetic (F) states [8]. XMCD-PEEM images reveal sub-micron-scale AF-F phase coexistence, and the large effects of underlying ferroelastic domains on the F phase fraction and magnetization direction.

In ultrathin Fe, in addition to the expected changes of magnetic anisotropy, we find evidence that ferroelectric domain wall motion alters the critical thickness for room-temperature ferromagnetism, and thus changes the magnetic order at some thicknesses. Unexpected non-volatile changes are interpreted in terms of dynamic strain relaxation mechanisms.

Our work suggests new avenues for spintronics at the nanoscale combining ferroelectric and magnetic materials.

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