Multiscale Coexistence of Magnetic Order and Ferroelectricity

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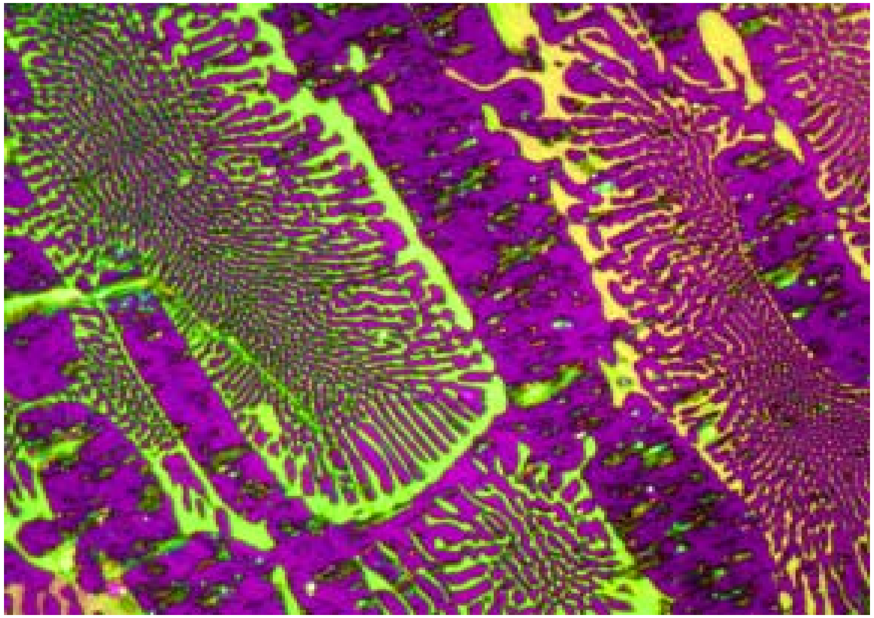
Ferroelectric and magnetic materials have been a time-honored subject of study and have lead to some of the most important technological advances to date. Magnetism and ferroelectricity are involved with local spins and off-center structural distortions, respectively. These two seemingly unrelated phenomena can actually coexist in certain unusual materials, termed multiferroics. The understanding of this remarkable occurrence remains a scientific challenge. We found that the *immiscibility* between rhombohedral $La_{5/8}Sr_{3/8}MnO_3$ and hexagonal $LuMnO_3$ leads to a mm-scale heterogeneous mixture of half-metallic-ferromagnetic and insulating-ferroelectric phases. Thus, this system is a new kind of multiferroics with the large sacle coexistance of ferromagnetism/ferroelectricity.

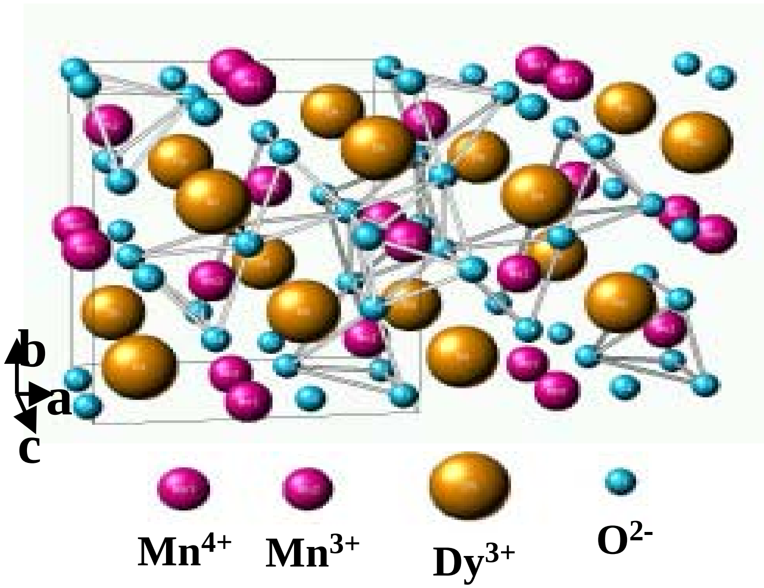
Hur *et al*., Nature *429*, 27 (2004).

Park *et al*. Phys. Rev. Lett. *92*, 167206 (2004).

Polarized optical microscope image of (La,Sr)MnO_3-$LuMnO_3$ shows the co-existence of ferroelectric regions (bright) and ferromagnetic regions (purple)

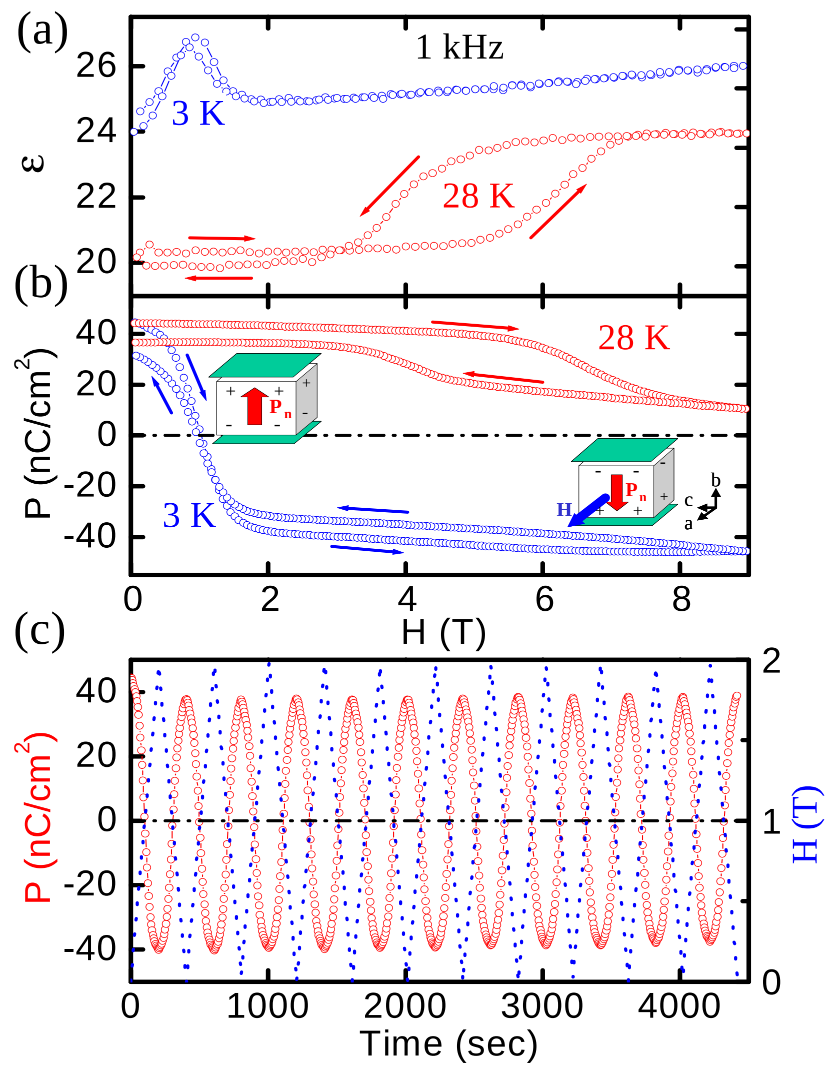
100 μm





Orthorhombic structure of $TbMn_2O_5$

Hur *et al.*, Nature *429*, 27 (2004).



Despite the coexistence of ferroelectricity and magnetism in some materials, a significant interplay between them has been rarely observed. This fact has prevented the realization of devices with previously unavailable functionalities, which these multiferroics could make possible. We have discovered an astonishing interplay between ferroelectricity and magnetism in the multi-ferroic $TbMn_2O_5$, demonstrated by a highly-reproducible electric polarization reversal and permanent polarization imprint that are both actuated by an applied magnetic field. These functionalities are closely associated with an unusual commensurate-incommensurate magnetic phase transition. The high sensitivity of the incommensurate state to external perturbation appears to be responsible for the unprecedented effects.