Multiscale coexistence of magnetic order and ferroelectricity

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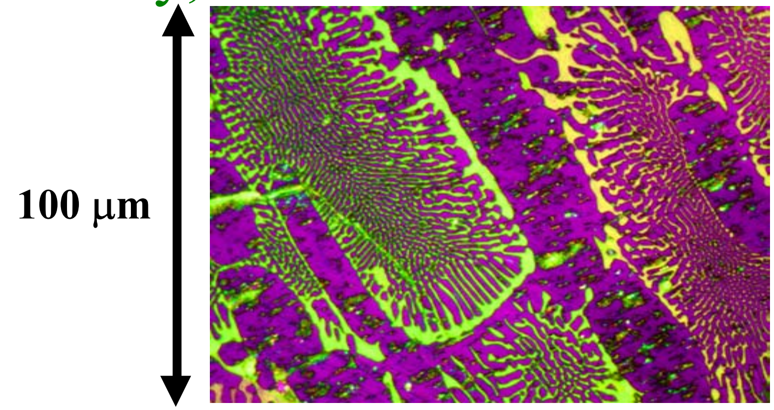
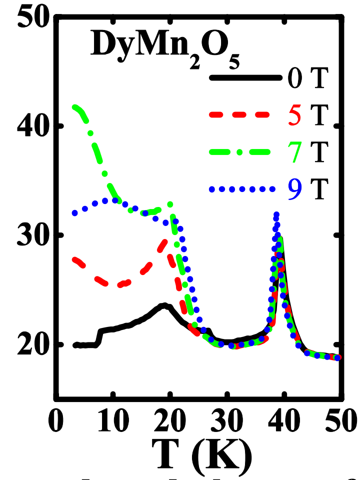
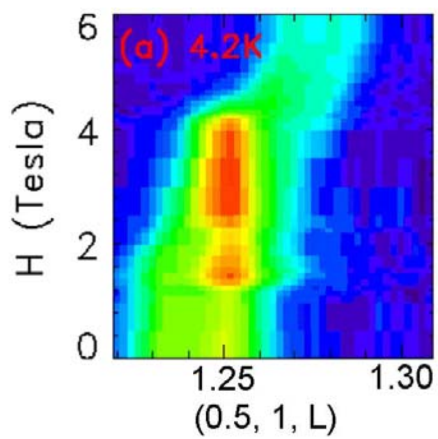


Polarized optical microscope image of (La,Sr)MnO_3-$LuMnO_3$ shows the coexistence of ferroelectric regions (bright) and ferromagnetic regions (purple)

Ferrroelectric and magnetic materials have lead to the most important technological advances to date, but there scarcely exist materials (multiferroics) exhibiting both properties. We discovered that in a multiferroic, these two properties are strongly coupled in the way that electric polarization can be controlled by external magnetic field, and dielectric constant can be changed by more than 100 % in magnetic field.





Unprecedented change of dielectric constant in magnetic field in $DyMn_2O_5$, which is closely related with the appearance of incommensurate magnetic modulations.

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

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

Hur *et al*., Phys. Rev. Lett., in print.

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.

Despite the possible coexistence of ferroelectricity and magnetism, any profound interplay between them has been rarely observed. This fact has largely prevented the realization of devices with a previously unavailable functionality, which these multiferroics could make possible. We have discovered an astonishing interplay between ferroelectricity and magnetism in the multiferroic $TbMn_2O_5$, demonstrated by a highly-reproducible electric polarization reversal and permanent polarization imprint that are both actuated by an applied magnetic field. Another fundamental discovery is the unprecedented large change of the dielectric constant with magnetic field, particularly in $DyMn_2O_5$, associated with an unusual commensurate-incommensurate magnetic transition. This extraordinary effect appears to originate from the high sensitivity of the incommensurate state to external perturbation.

Our discoveries have been published in Park *et al*. Phys. Rev. Lett. *92*, 167206 (2004) and Hur *et al*., Nature *429*, 27 (2004). In addition, one paper by Hur *et al*. is recently accepted in Phys. Rev. Lett..

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Education:
Five graduate students (W. Ratcliff, Namjung Hur, Peter Sharma, Soonyong Park, and Yew San Hor) and one undergraduate student (Derya Yinanc) have been involved in the multifferroics and related projects. Yinanc is currently a senior at Rutgers. Ratcliff and Hor received Ph.D. late 2003 and are presently postdocs, working for NIST and Argonne National Laboratory, respectively. Sharma and Hur are finising up Ph. D. in the summer of 2004.

Societal Impact:
The extraordinary coupling between spin and lattice degrees of freedom in multiferroics can lead to the ability to inter-control magnetic parameters and dielectric/ferroelectric parameters, which point to new device concepts such as magnetically (electrically) recorded ferroelectric (magnetic) memory and reflective index changed by applied external magnetic field.