Nanoscale Ferroelectrics

P. Paruch, N. Stucki, C. Lichtensteiger, M. Dawber, S. Kumar*, S. Gariglio, D. Matthey, K. Takahashi and J.-M. Triscone
DPMC, University of Geneva, Switzerland,
*Now at NTNU Trondheim, Norway,
http://dpmc.unige.ch/gr_triscone/

UNIVERSITÉ DE GENÈVE

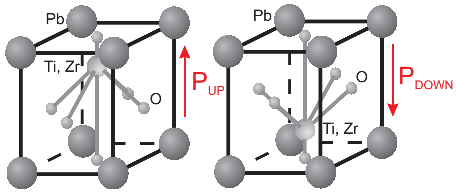
The research interests of the group of **Prof. J.-M. Triscone** at the University of Geneva are focused on the growth and study of epitaxial oxide films and heterostructures with unconventional electronic properties. The materials are primarily oxides, in particular superconductors and dielectrics / ferroelectrics.

Continued from page 1

Recently, ferroelectricity in ultra-thin films and superlattice structures has been found far below originally expected length scales, opening up a whole new regime of device characteristics. Concurrently, the integration of ferroelectric oxides in epitaxial heterostructures with magnetic, superconducting or metallic oxides, as well as on silicon, has created the possibility of oxide based electronics. Finally, atomic force microscopy (AFM) allows control of individual ferroelectric domains, providing a practical tool both for fundamental studies and novel applications of nanoscale ferroelectricity. Below, we briefly touch on the main questions in the field today.

How thin can a ferroelectric be?

Although ultra-thin ferroelectric films can be advantageous for many applications, the evolution of ferroelectric polarization with thickness remains an open question. In MaNEP, we are studying the ferroelectric properties of films only a few unit cells thick, using high resolution x-ray diffraction and x-ray photoelectron diffraction in collaboration with the group of Ph. Aebi at the University of Neuchâtel. Our experiments, showing a decrease in ferroelectric polarization in thinner films [2], are in agreement with recent ab-initio studies by J. Junquera and Ph. Ghosez (University of Liège). Our results show that films as thin as 2 nm (5 unit cells) remain ferroelectric. Further polarization control can be achieved by alternating epitaxial layers of different materials, also investigated in MaNEP, raising the possibility of novel artificial ferroelectrics tailored to specific applications.



Tetragonal PZT has two possible polarization states, P_{UP} and P_{DOWN}, due to the relative displacement of positive and negative charges in the unit cell.

Can ferroelectric oxides be epitaxially grown on silicon?

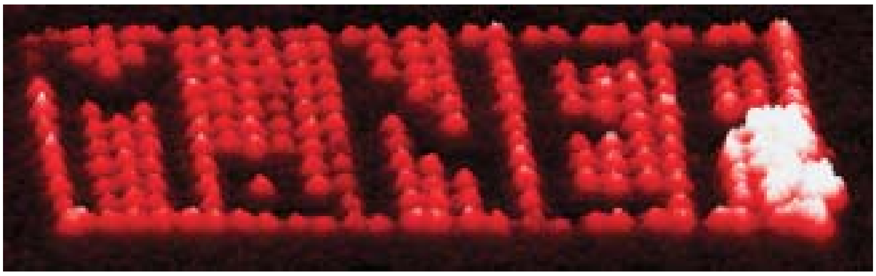
A key target on the way to high quality epitaxial oxide film applications is the ability to integrate these materials, in thin-film form, with the existing mainstream Si-based technology. The development of an epitaxial $SrTiO_3$ buffer layer [3] has now made this integration possible. In MaNEP the pursuit of this research is being implemented in collaboration with the HES, Genève, promising numerous opportunities for scientific and technological applications.

Can ferroelectric polarization be controlled with nanoscale precision?

The remanence (stability) of ferroelectric polarization combined with the high resolution and localized focus of AFM have made these systems very interesting both for fundamental studies of ferroelectricity and for non-volatile memory applications. By applying voltage pulses to a metallic AFM tip scanning a uniformly pre-polarized area, we can create arrays of individually addressable, non-volatile, fully reversible domains with densities up to 30 Gbit/cm^2, at least an order of magnitude higher than current hard-drive capacity [4] (see Figure). We have also investigated AFM written ferroelectric domain structures for a prototype high GHz range surface acoustic wave device [5]. Nanoscale studies in collaboration with T. Giamarchi have identified the mechanism for domain wall motion as a disorder-controlled creep process [4], implying high stability of the ferroelectric domains, useful for devices requiring long retention times. We have confirmed this by following a variety of ferroelectric domain structures for up to 4 months, with no change in size, random nucleation, or backswitching observed.

Can electronic nanofeatures be realized using ferroelectric field effect?

The screening of the ferroelectric field can be used as a mechanism to control the charge carrier density in very thin oxide films used as underlying electrodes, modulating for instance, the superconducting transition temperature or the nature of the electronic behaviour (superconducting/ normal/insulating). Combined with local polarization switching, this could allow nanoscale electronic features to be fabricated in oxide heterostructures. ■



An 11x28 array of ferroelectric domains at 6 Gbit/cm^2 density, written to spell out MaNEP with 12V pulses applied for 200 ms. The domains have radii of ~50 nm. A surface particle is visible in the lower right corner.

References:

[1] C. H. Ahn, K. M. Rabe and J.-M. Triscone, Science 303, 488 (2004).
[2] C. Lichtensteiger et al., cond-mat/0404228 (2004).
[3] A. Lin et al., Appl. Phys. Lett. 78, 2034 (2001).
[4] T. Tybell et al., Phys. Rev. Lett. 89, 097601 (2002).
[5] A.K.S. Kumar et al., to appear in Ferroelectrics .