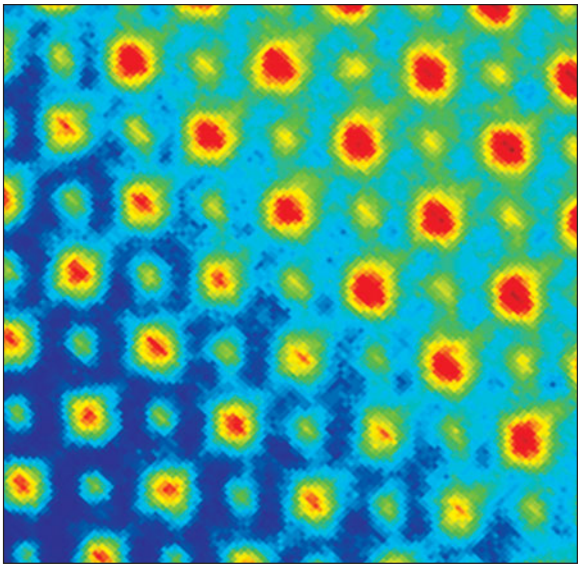
Ferroelectric polarization changes local structure at complex oxide interfaces

By coupling an electron's charge and spin, spintronic memories could transport information at a much faster rate than conventional computer memories. A unique way of making a spintronic memory is by using a magnetoelectric material—a material with magnetic properties that can be controlled by an electric field. One way to make this type of materials system is by alternating layers of ferromagnetic and ferroelectric materials. However, any variations in the electronic and magnetic phases at the layer interface could affect the transport process. A recent report in *Nature Communications* (DOI:10.1038/ncomms7735) explores such local variations at the atomic scale in order to understand asymmetries at such interfaces. Interestingly, the team, led by Mitra Taheri of Drexel University, found that the polarization is not uniform throughout the film, but instead has unique local structure.

Controlling a material's magnetic properties "is the key for new spintronic devices," says Evgeny Tsymbal, George Holmes University Distinguished Professor of Physics and Astronomy at the University of Nebraska–Lincoln, who was not involved in this work. "There are a number of industrial companies that are interested in controlling magnetism by electric fields. It's a big deal now, but there aren't yet any spintronic devices based on this." Further understanding of the mechanism driving spin transport is needed before researchers can consider industrial applications. "The science is important, because if we understand the underlying mechanism then we can fabricate relevant structures, explore different kinds of materials, and improve their properties so that eventually we will come to the devices."

The first layer of the materials system in the present work consisted of a manganese perovskite oxide, specifically $La_{0.7}Sr_{0.3}MnO_3$ (LSMO). In this material, valence electrons from the 3*d* orbital of the Mn atoms are delocalized and can be used to transmit spin information. Layering LSMO with a ferroelectric material, specifically $PbZr_{0.2}Ti_{0.8}O_3$ (PZT), polarizes the electron spin when an electric current is passed through the nanoscale composite. A final layer of LSMO completes the circuit, so that the bottom layer is in a hole accumulation state while the top layer is in a hole depletion state.

An interesting aspect of this system is that the magnetic properties may be controlled by an external electric field. Because manganese valence electrons are used in spin transport, changing the valence will alter the material's magnetoelectric properties. Typically, a chemical change is used to alter the valence structure; for example, by changing the ratio of lanthanum to strontium in the LSMO layer. However, although the structure of LSMO was fixed in this report, the researchers found the valence structure of manganese could be altered solely through interactions with the ferroelectric PZT layer. As it turns out, the charge state of manganese is highly sensitive to the polarization of the PZT layer. Therefore, polarization of the PZT layer induces a change in the local structure of LSMO near the interface.



High-angle annular dark-field scanning transmission electron microscope image of the transition from LSMO to PZT (bottom left to top right). Localized polarization occurs at the LSMO/PZT interface due to the ferroelectric properties of the PZT layer. Credit: James Rondinelli.

"There's a subtlety we pointed out in this report: namely, that one can use changes in valence to predict critical structure distortions," says James Rondinelli, professor of Materials Science and Engineering at Northwestern University, who contributed theoretical work for this report. "That had always been hypothesized and people inferred it from prior studies, but in this paper we show that that link is actually possible. It's a nice balance between having experiments with exquisite structural chemistry information and using theory to piece together some of the nuances of the experimental data and draw broader conclusions."

At the interface of LSMO and PZT, researchers observed a gradient in the local magnetic moment. The gradient was different for the top and bottom LSMO/PZT interfaces. The bottom interface had a much less pronounced drop in manganese doping that extended only a single nanometer into the LSMO layer. On the other hand, the top interface showed a magnetic phase transition from metal to insulator that extended deeper into the material. Using a combination of experiment and theory, the researchers were able to show that this transition was caused by a change in the valence state of the manganese atoms.

"To get to the next stage where we really start thinking about commercialization, we need to think more about the local interface structure, because that's ultimately going to influence the performance of these materials," says Rondinelli. "What we're challenging now is that, when going forward, one needs to control structure at this local atomic scale level, which is shorter than a few nanometers. If we can achieve that control then it's possible to really get these materials into devices."

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