orders and microscopic mechanisms of magnetoelectric coupling leave plenty of room for further discoveries. In that respect, the work of Kimura and colleagues opens a new hunting ground: high-temperature copper oxide multiferroics.

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PEROVSKITE OXIDES

An atomic force pencil and eraser

A method of writing and erasing conducting nanostructures at the interface between the wide-bandgap insulators $LaAlO_3$ and $SrTiO_3$ is presented. New developments for ultrahigh-density information storage look feasible.

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Perovskite oxides exhibit an exceptional range of properties, including high-temperature superconductivity, colossal magnetoresistance and ferroelectricity. Recently, the remarkable properties of the interfaces between layers of different perovskite oxides have expanded the interest of researchers in this class of materials. Notably, studies on single epitaxial connections between the comparatively wide-bandgap insulators $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) have shown the interfaces to be either high-mobility electron conductors or insulators, depending on the atomic stacking sequence at the interface[1]. Interfaces between these non-magnetic materials also exhibit magnetism[2] and even superconductivity[3]. On page 298 of this issue, Cheng Cen and co-authors show the possibility to 'write' and 'erase' conducting wires at the interface between LAO and STO with the tip of an atomic force micropscope (AFM)[4], taking the first step towards highly dense nanodevices.

Cen *et al.* used a positive-biased conducting AFM tip as their writing tool. The tip was scanned over the surface of three unit cells of LAO grown on a TiO_2-terminated STO substrate, starting from a conducting electrode and moving towards a second one (Fig. 1). The conductance between the two electrodes is very low, but as soon as the AFM tip reaches the second one, the conductance increases, demonstrating the creation of a metallic wire. By applying a negative bias voltage at the AFM tip that scans perpendicularly over the wire, the conductance drops again, indicating that the wire has been cut.

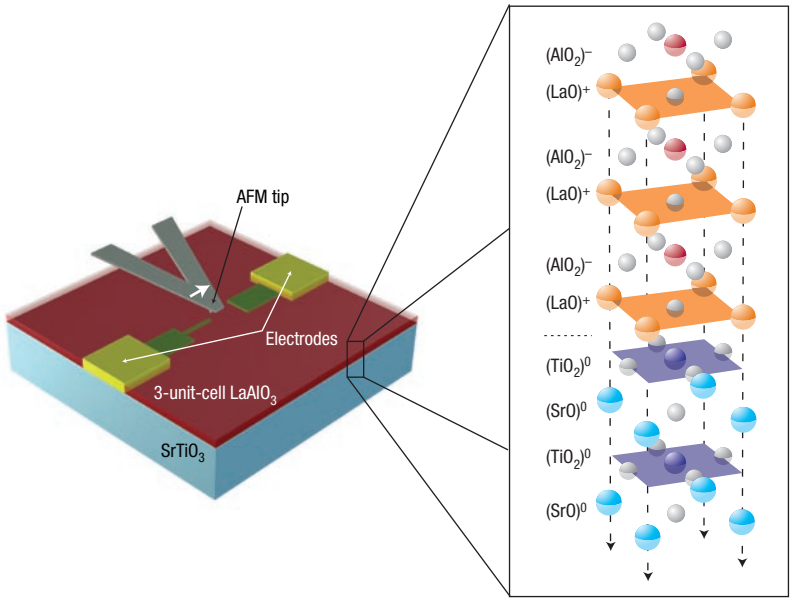

Figure 1 Scheme of the experiment reported by Cen and colleagues[4]. The AFM tip is used almost as a pencil to draw a conducting line between two electrodes on the board represented by the interface between LAO and STO. The white arrow shows the direction of movement of the tip. The right panel shows the layer structure of the device.

The transport properties of the interfaces are closely connected to the number of LAO unit cells grown above the LaO/TiO_2 interface. For example, Huijben *et al.* were able to tune the conductivity by creating the complementary interface with a spacing of less then six unit cells[5]. Thiel *et al.* found that, for the interfaces to be conducting, the number of $LaAlO_3$ unit cells had to reach a critical thickness of four[6]. Just below this critical thickness, Cen *et al.* were able to control the interfacial metal–insulator transition at room temperature using a conducting AFM. Experiments with two or four unit cells did not show the switching effects.

Metal–insulator transitions have been reported earlier in perovskites, such as electrically controlled resistive switching in titanates and manganites[7]. Typically, low-voltage pulses result in a reversible change in resistance, originating from oxygen ion or vacancy incorporation. This effect forms the basis of non-volatile resistance random access memory (ReRAM). Using a conducting AFM as an electrode in a

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metal–insulator–metal (MIM) device, it was recently shown that the electronic properties can be modulated at the nanometre scale. With STO as the insulator, switching between non-metallic and metallic behaviour was observed by application of an electric field, originating from local modulation of the oxygen stoichiometry[8].

The resistive switching in MIM systems is usually a combination of chemical and physical effects: electronic, ionic or thermal effects. Because of this mixture of effects in combination with the different preparation routes, applied voltages and measurement set-ups, a clear answer to the origin of resistive switching is still under debate[9].

The conductive switching observed by Cen *et al.* could be characterized as electronic charge injection and/or charge displacement, which is different from the typical MIM devices reported so far. The proposed strategy to control the interfacial metal–insulator transition offers new possibilities for nanoscale devices, for instance, one could write conducting electrodes that can be used in, for instance, MIM devices.

Cen *et al.* ascribe the observed mechanism of conductive switching to the adsorption of oxygen or other anions. Although certainly plausible, this is only one possible explanation. The fact of the matter is, more generally, that the origin of the conductivity at the LAO/STO interfaces has generated considerable debate. From simple consideration of the charge distribution in a discrete number of layers, it can be seen that when the LAO is grown on a TiO_2-terminated STO, a polarity discontinuity arises, which creates charge accumulation at the interfaces, leading to the formation of a conducting interface[10]. But other effects should be taken into account. It is clear that the deposition pressure during growth has a very strong effect on the transport properties (as can be seen in Fig. 2). Although in all three regimes conductivity is observed due to the LaO/TiO_2 interface, in the low-pressure regime the oxygen vacancies dominate the conduction properties[11]. Remarkably, at high pressures the interface becomes magnetic[2], whereas in the intermediate regime the interface becomes superconducting[3].

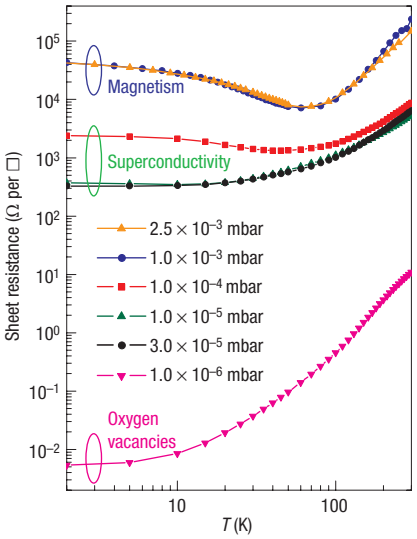

Figure 2 Sheet resistance of n-type $SrTiO_3$–$LaAlO_3$ interfaces. Temperature dependence of the sheet resistance, R_{sheet} for n-type LAO/STO conducting interfaces, grown at various partial oxygen pressures (data from ref. 2). Three regimes can be distinguished: low pressures leads to oxygen vacancies[1], samples grown at high pressures show magnetism[2], whereas samples grown in the intermediate regime show superconductivity[3].

Regardless of the precise origin of their observations, Cen *et al.* show that electronic applications of perovskite interfaces are coming closer. However, several practical issues remain to be solved. In the writing experiments of Cen *et al.* the sample is exposed to air, which could lead to contamination. Because of the sensitivity of the number of unit-cell layers, three in their case, contamination could have an underestimated effect. This work is yet another example of the rapid development of materials science of functional oxides. To fully use the possibilities, integration with silicon technology is desirable. Because switching is only observed at the $LaO–TiO_2$ interface, with a top layer of only three unit cells of $LaAlO_3$, epitaxial single-crystal growth on silicon is urgently needed.

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HYDROGELS

Structure starts to gel

The new generation of hydrogels moves away from the bulk materials of old, to those with multilayered, complex internal structures and controllable physical properties.

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Hydrogels are formed by crosslinking polymer chains — through physical, ionic or covalent interactions — and are well known for their ability to absorb water. In most cases, they are homogeneous materials, and their bulk properties are characterized and considered with regard to applications. From a biomedical perspective, they show promise in a number of areas including devices, drug delivery and regenerative medicine[1]. Hydrogels are already widely used as three-dimensional cell and tissue culture environments, as they are excellent mimics of the *in vivo* state.

For these bio-related applications, the ability to control the synthesis of hydrogels to make structures with specific internal forms and shapes is an attractive prospect. For example, internal spaces created in hydrogels could be used to store cells or drugs and the three-dimensional structure of actual tissues and other *in vivo* components could be mirrored in the gel. So far there has been little control over gel formation, and the creation of

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