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CONDENSED-MATTER PHYSICS

Multitasking materials from atomic templates

Two ‘failed’ materials can perform much better when united. Such a combination exhibits magnetization and electric polarization up to room temperature, providing a basis for new magnetoelectric devices. **SEE LETTER P.523**

MANFRED FIEBIG

Materials in which the electric dipoles or magnetic moments associated with atoms, ions or molecules are ordered are of immense technological value. Multiferroic materials unite these two types of order in a single material and are therefore highly desirable. However, because simultaneous electric and magnetic order is difficult to achieve, multiferroics — especially those that function at or approaching room temperature — are extremely rare¹. On page 523, Mundy *et al.*² detail an effort to build such a material.

Remarkably, they achieved this by combining two ‘failed’ multiferroics, forming a new compound with excellent multiferroic properties.

Electrons are subatomic particles that have a magnetic moment and an electric charge. In a crystal, if the electron clouds that surround atomic nuclei orient themselves in the same way, the crystal can develop macroscopic magnetization (ferromagnetism) or electric polarization (ferroelectricity). Ferromagnetism is essential for technologies such as power generators, sensors and computer hard disks. And ferroelectrics are often used in devices that generate or detect a small mechanical

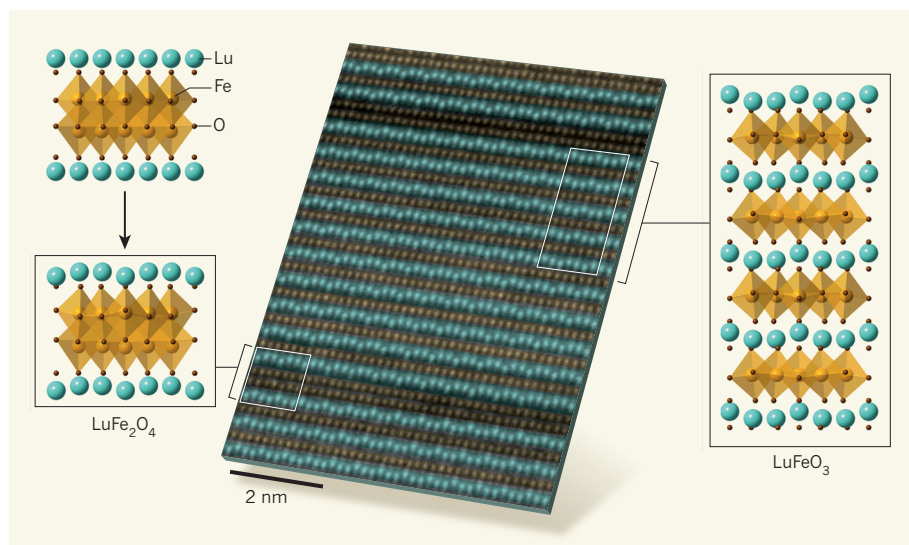


Figure 1 | A new multiferroic material. Mundy *et al.*² have constructed a material that exhibits coupled magnetization and electric polarization at higher temperatures than most existing multiferroics. The authors present a scanning transmission electron microscopy (STEM) image of their multiferroic (centre, shown in false colour). The material is a combination of LuFe_2O_4 and LuFeO_3 , whose crystal structures are shown on the left and right sides of the STEM image, respectively. The corrugated structure of LuFeO_3 modifies the structure of LuFe_2O_4 (indicated by the arrow) and the result is a self-stabilizing multiferroic material.



50 Years Ago

If the ionic pump in the red cell membrane expels three sodium ions and takes up about two potassium ions for each molecule of adenosine triphosphate (ATP) hydrolysed, under physiological conditions the free energy available to drive the reaction forwards must be quite small ... By arranging that the concentration gradients for sodium and potassium are even more adverse, it should be thermodynamically possible to run the pump backwards and synthesize ATP ... Reversal of the sodium pump leading to the formation of ATP is interesting because of its possible relevance to oxidative phosphorylation in mitochondria as well as for the light it may throw on the mechanism of the pump.

From *Nature* 24 September 1966

100 Years Ago

In ‘La Pileta’ a further considerable contribution is made to our knowledge of the Jurassic caves of South-West Europe ... The cave ... is, with its various corridors, recesses and ‘galleries’, more than usually complicated ... Wherever the cave opens out to form a chamber, wall paintings are to be seen ... The paintings comprise examples of four separate pictorial phases. The earliest ... consist largely of serpentine forms with an occasional realistic figure of a goat, ox, or horse. The second series ... is red in colour, and here ... are to be found various signs or symbols ... These are followed by a series drawn with charcoal ... among these last figures ... the authors believe they can recognise figures intended for human beings. The fourth and last series is purely schematic ... In the opinion of the authors the four phases represented extended over a long period, from the Aurignacian to Neolithic times.

From *Nature* 21 September 1916

deformation, such as loudspeakers and pressure sensors³.

The idea of creating multiferroic materials that simultaneously exhibit magnetic and electric order was first suggested in the late 1950s, and they began to be constructed a few years later⁴. In these materials, the magnetic and ferroelectric properties are manifested together and, more importantly, the two types of order are often coupled to each other.

Why would such a coupling be useful? As an example, many computer memory elements are operated by electric currents. These currents limit the computer's processing speed, and produce so much heat that energy consumption and the need for cooling become serious problems. However, in a multiferroic memory element, a voltage pulse could be used to control the ferroelectric state and, through an internal magnetoelectric coupling, activate the ferromagnetic state that represents the memory bit. Voltage pulses can be transmitted more quickly than electric currents and consume less power⁵.

Unfortunately, building a multiferroic material is difficult because the conditions that favour magnetic and electric order tend to be mutually exclusive¹. As a result, the use of known multiferroics is technologically infeasible for various reasons — for example, the magnetization and electric polarization are too small to be used in devices, occur far below room temperature or are too weakly coupled. Even the most promising room-temperature multiferroic, bismuth ferrite (BiFeO₃), is intrinsically not ferromagnetic⁶.

Mundy and collaborators' work introduces a way to engineer materials that have coupled magnetization and electric polarization. Early attempts to produce such multiferroics focused on bulk synthesis — magnetic and electric moments were brought together in the same unit cell (the smallest periodically repeating structure in a crystal), usually resulting in weak manifestations of multiferroic order⁴. However, spiral-like arrangements of magnetic moments across many unit cells provided a new and general source of such order⁷. A later development was to apply small changes to multiferroics at inter-atomic distances (for example, using external pressure⁸), which could modify the materials' magnetization, polarization or ordering temperature. Finally, moving from bulk materials to thin films of multiferroics had advantageous effects resulting from the limited thickness of the material and the presence of surfaces or interfaces⁴.

Building on this earlier work, Mundy and colleagues create a multiferroic that has large magnetization and electric polarization at room temperature, and a strong coupling between the two up to at least 200 kelvin. They achieve this by combining two 'failed' multiferroics — LuFeO₃ and LuFe₂O₄ — unit cell by unit cell, such that the deficiency of each material is compensated for by the desirable

property of the other. LuFeO₃ is multiferroic but lacks pronounced magnetization⁹, whereas LuFe₂O₄ has magnetization but no ferroelectric order¹⁰.

Using a technique called molecular-beam epitaxy, the authors build a film of repeating units that consist of a single layer of LuFe₂O₄ and nine layers of LuFeO₃ (Fig. 1). The LuFeO₃ has a corrugated structure, which acts as a template for the atomic arrangement of LuFe₂O₄, allowing the latter material to become ferroelectric. In turn, the multiferroic order of the entire structure is reinforced. The authors show that when an electric field is used to reverse the direction of the polarization, the magnetization direction is also reversed, which suggests that the multiferroic has a strong magnetoelectric coupling.

Such a coupling at the atomic level is reflected in the macroscopic properties of the authors' material. A sharp tip, to which a positive or negative voltage is applied, can be used to draw an electric polarization pattern in the material. The authors show that this pattern is complemented by an identical magnetization pattern, even though a magnetic field was not applied. The magnetization is determined entirely by the sign of the electric voltage, which is exactly the functionality that is required for magnetoelectric devices.

It remains to be seen whether Mundy and colleagues' atomic-template approach can

be used to create multiferroics in general. However, their work seems to show that the box of tricks for improving such materials is not yet empty. Multiferroics are now migrating to a wide variety of research disciplines, such as electronics, photonics and even high-energy physics, in which they are studied for properties that are, at best, indirectly related to their multiferroic order⁴. Hence, although they originated as a specialist's topic, multiferroics are now a substantial part of materials research. ■

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GEOLOGY

Evidence of life in Earth's oldest rocks

When did life first arise on Earth? Analysis of ancient rocks in Greenland that contain structures interpreted as bacterial in origin suggest that Earth might have been an abode for life much earlier than previously thought. [SEE LETTER P.535](#)

ABIGAIL C. ALLWOOD

Did life on this planet begin only after a relatively long planetary evolution, until suitable environments emerged that allowed life to gain a toehold, or was the cradle of life ready and rocking when Earth itself was but an infant? An answer may come from a paper on page 535 by Nutman *et al.*¹ that analysed 3.7-billion-year-old rocks in the Isua Greenstone Belt in Greenland. These are not the kinds of rocks that palaeobiologists would consider a good prospect for signs of life, because they are not sedimentary like those that host most of Earth's fossil record. Rather, they are metamorphic, which means that they have been extensively deformed and altered by heat and pressure during deep burial

and are no longer the sedimentary rocks they once were.

However, Nutman and colleagues came across a rarity in the Isua Greenstone Belt. In a small area newly revealed by snow melt, they found relatively well preserved rocks that have survived geological time with some of their original sedimentary attributes intact. In this tiny window into the deep past are subtle geochemical and textural clues to an ancient surface environment that is surprisingly familiar as a habitat for life. Within the rocks can be seen ancient ripple marks and piles of rock fragments deposited during an ancient storm. Combined with seawater-derived mineral chemistry, these features all point to a shallow marine, carbonate, mineral-depositing environment similar to those that have hosted