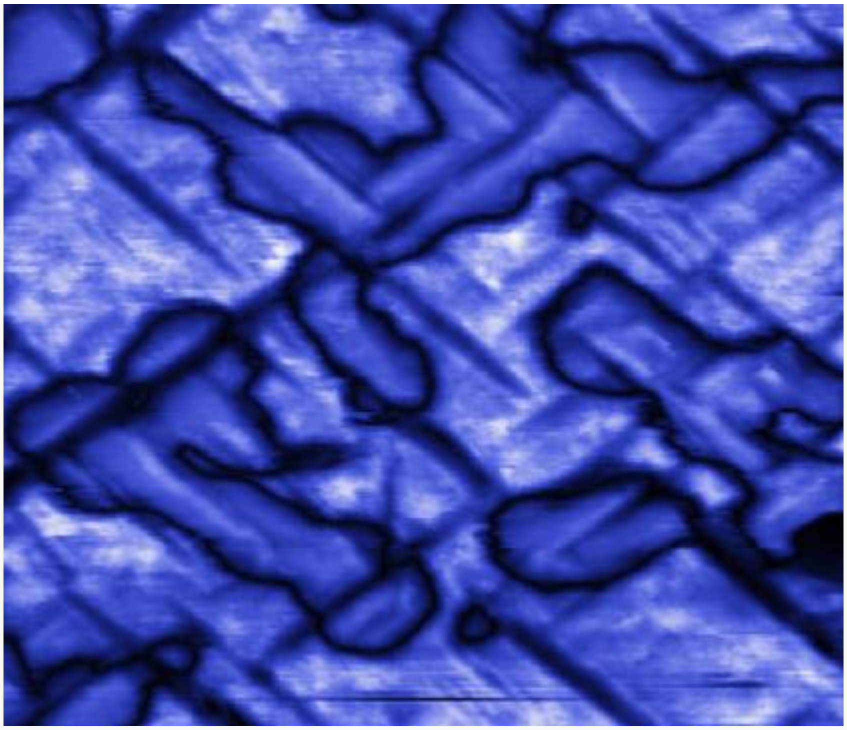
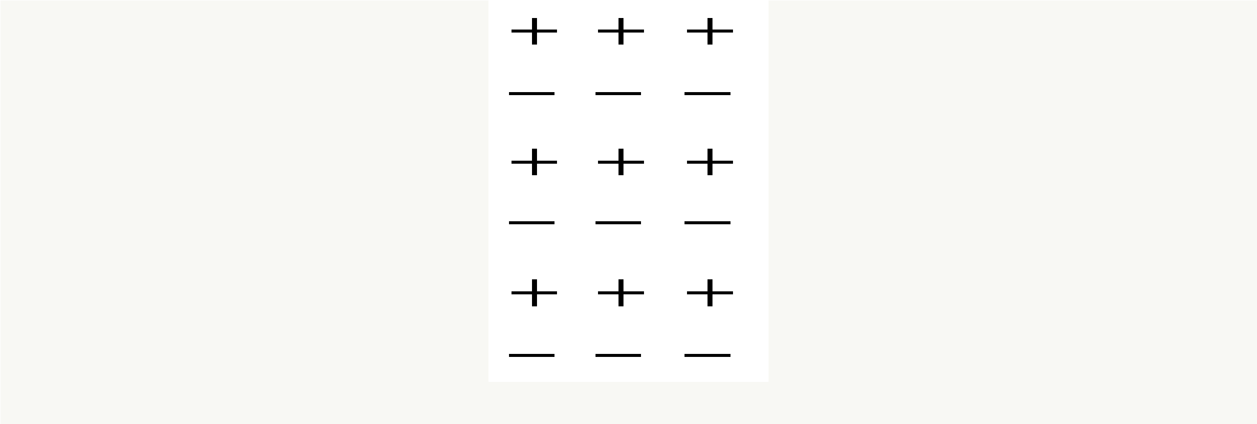
TEACHING NEW TRICKS TO INSULATORS



Domains in a ferroelectric material, where electric charges have a different orientation. Here, there are two separate sets of domains. The cross-hatched patterns indicate domains in the plane, the rounder shapes are domains where the polarization points out of the plane. Reprinted by permission from Macmillan Publishers Ltd. Nature Materials 7, 209-215 (2008).

Insulators might seem pretty boring materials for an electronic device such as a computer memory, because by the very nature of their definition, they don’t conduct any electrical current. But some insulators show some pretty intriguing properties. Amongst them are the so-called ferroelectrics.



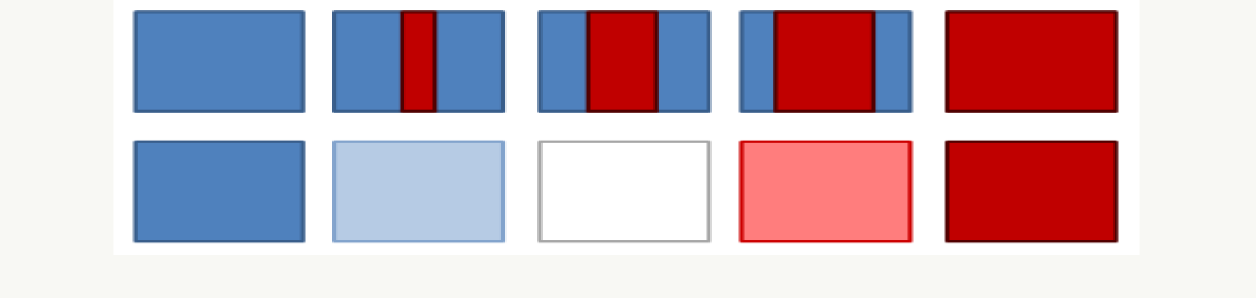
Dipoles in a ferroelectric. During switching, positive and negative charges interchange.

A ferroelectric is a material where positive and negative electrical charges, are permanently separated along a common direction. These are the positive and negative ions that make up the crystal. Their order leads to an overall electrical polarization of the material. This can only happen in an insulator, because if the crystal would enable electrical charges to move around the separated plus and minus charges could be compensated easily by such movements of electrons.

In some special materials, ferroelectricity and magnetism occur simultaneously. These are known as multiferroics and I blogged about their potential applications before. In particular, the dipoles in a ferroelectric can be switched by an electric field, which makes them attractive for electronic applications as ferroelectrics can be used to permanently store information as a new form of computer memory.

But how can the electric polarization in a ferroelectric be switched? There are two options. One mechanism is similar to what happens in a magnet. If an electric field is applied, new domains with a polarization aligned in direction of the external field form (see figure below). These domains gradually replace the old ones. This process is abrupt, because as the new domains expand, the ions in the crystal swap places in a single process.

The second possibility of switching electric polarization is a continuous mechanism. There, the positive and negative ions move slowly in opposite direction. First, the electric polarization weakens, vanishes, and then builds up again in opposite direction. This process occurs without the involvement of any domains. Of these two processes, the domain-based switching is far more favourable, which is why the switching process without domains hasn't been observed before. Two independent papers now both claim to have seen switching without domains.



The two switching mechanism in a ferroelectric: domain-based (top) and without domains (bottom).

The reason why switching without domains has been proven so difficult to observe is that domains form too easily, in particularly if a sample contains impurities.

The two studies that now claim to have achieved observed switching a ferroelectric without domains both use thin films, where this domain formation is suppressed. One study uses a polymer, the other in a lead-based ceramic. The polymer, based on poly(vinylidene fluoride) or PVDF, is favourable because there the formation of domains occurs very slowly. However, the issue is not straightforward. Ten years ago, a study already claimed switching without nucleation in PVDF. These results were controversial, as for example the switching times used were on the order of seconds, which is far too long to conclusively rule out the formation of domains.

In the latest study on PVDF, published in *EPL*, Lei Zhang from Pennsylvania State University, observes both switching processes, depending on parameters such as applied electric field and temperature. This makes the identification of the switching without domains easier, particularly as both processes occur precisely where they are expected by theory.

The editor that handled the paper at EPL, Jim Scott from Cambridge University, has a very long history in this field. He has published a comment on Zhang's work in the journal *Advanced Materials.* His text is very helpful introduction into the physics of this switching process. And also, for a more general video introduction into ferroelectrics and multiferroics, there is his online lecture "Why study insulators?"

The other study, on the lead-based ceramic, is from Stephen Streiffer, Brian Stephenson and colleagues from Argonne National Laboratory. Their work, published in *Physical Review Letters*, takes a different approach. They monitor the sample during switching by x-ray diffraction. Studying the properties of the x-rays scattered from the sample during the switching process they can deduce whether domains are involved or not. And indeed, for certain switching regimes they conclude the absence of domains in their sample.

What one might argue in both cases is that neither paper shows directly and conclusively the absence of any domains, for example by imaging the sample. Unfortunately, it is not possible to do such experiments with the necessary speed. So the debate on this issue might continue as for example in case of the experiments done at Argonne, the x-ray imaging used is an indirect method and no electronic data is presented. Hence, there is no electrical demonstration of two switching regimes in the way Zhang showed it in his paper.

Either way, both papers illustrate beautifully the intriguing physics of ferroelectrics. And by learning more about the way ferroelectrics can be switched and electric charges can be controlled, these insulators may very well lead to new electronic applications such as memory devices.

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