From the archive

River monitoring needed to address pollution, and the case for having a minister for science in government.

100 years ago

The difficulty in deciding a status of pollution … is well illustrated by … the lack of critical and co-ordinated information regarding … conditions in fresh-water streams, rivers, and in estuaries. The absence of this kind of information must render much work on the conditions in polluted waters inconclusive or even futile. The present letter is therefore written to demonstrate … the necessity for organised continuous work on the biological, physical, and chemical conditions in streams, rivers, and estuaries, *whether polluted or not*.
From *Nature* 16 February 1924

150 years ago

We are glad to see that the *Times* has at last opened its pages to the question of the propriety of appointing a responsible Minister, whose duty it shall be to look after the interests of Science and of scientific research and education, and take charge of the scientific institutions of the country … The whole question could not be better stated than in Colonel Strange's letter which … runs as follows: … "[S]cientific research must be made a national business … [T]he point at which Science, in most of its leading branches, has now arrived and the problems presented for solution are such as to need for their adequate treatment, permanent well-equipped establishments with competent staffs … [W]e are being rapidly outstripped by nations who, though they encourage private exertion, are wise enough not to rely on it, but to establish a system free from the caprice, the incompleteness, the liability to interruption and cessation incident to all individual labour in whatever field … [T]here must be a Minister for Science … Let this be done, and we should cease to witness the farce of consulting the Chancellor of the Exchequer about observing eclipses of the sun, the Prime Minister about scientific Arctic expeditions, and the Treasury about tidal reductions."
From *Nature* 12 February 1874

data is that it shows more evidence that data generation and sharing are broadening, and that there is a shift towards a culture of acceptance and openness as members of the public become more comfortable with sharing their genetic information. The collection and study of such data call for cultural sensitivity and a combination of ethical and scientific rigour, so it is encouraging to see progress in this area. We should also be excited about having a deeper understanding of populations, sociodemographic histories and fresh biological insights, as well as about the willingness of BIGCS participants to take part. Indeed, although ancestry, genetic association and applied research are illuminating, it is incumbent on the research community to remember the commitment of those who make this type of work possible.

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Materials science

Layered ferroelectric materials make waves

Berit H. Goodge

By combining materials-synthesis techniques, researchers have come up with a way of building layered structures that display intriguing wave-like patterns of electric polarization, and could be useful for next-generation electronics. **See p.529**

A household refrigerator magnet has an inherent polarity, a characteristic it shares with other magnets of its kind, known as ferromagnets. Ferroelectric materials are also polarized – electrically rather than magnetically – with positive and negative charges instead of north and south poles. This polarity can be flipped by strong electric fields, a property that makes ferroelectrics attractive materials for computing, memory and sensing devices, especially if they can be manipulated at the nanometre scale. It also allows complex patterns of ferroelectric polarization to be generated through careful materials design and synthesis[1]. On page 529, Sánchez-Santolino *et al.*[2] describe a technique that combines strategies from several areas of materials research to generate and stabilize ferroelectric patterns.

A simple model of electric polarization holds that a charged ion that is offset from the charge centre of its neighbours will shift the distribution of electric charge to create a local polarization (Fig. 1a). Ferroelectricity is therefore closely tied to the arrangement of atoms in the bulk of a material, to the surfaces and interfaces that the atoms form, and to how these geometrical features impart mechanical stress, all of which affect the interactions between atoms.

Careful engineering of these 'boundary conditions' – by growing structures with several layers, for example – has proved to be a powerful way of generating ferroelectric textures such as waves, vortices and other twisting configurations[3–5]. Now, Sánchez-Santolino and colleagues have added a 'twist' to this approach by stacking two existing layers so that they are rotated relative to each other.

When a layer that is a single atom or a few atoms thick is placed on top of another such layer and rotated by a small angle, the overlap between the two crystal lattices creates a third distinct pattern. This pattern is termed a moiré lattice – named after a French method of fabric pressing – and the periodicity of this lattice is considerably larger than those of the original layers (Fig. 1b). The interactions between the two layers can impart entirely new properties to the overall twisted structure, and this 'twist and stack' approach has therefore garnered immense interest in physics and materials research[6].

Moiré structures are typically fabricated by peeling apart larger crystals of each material to isolate a thin layer, which can then be stamped

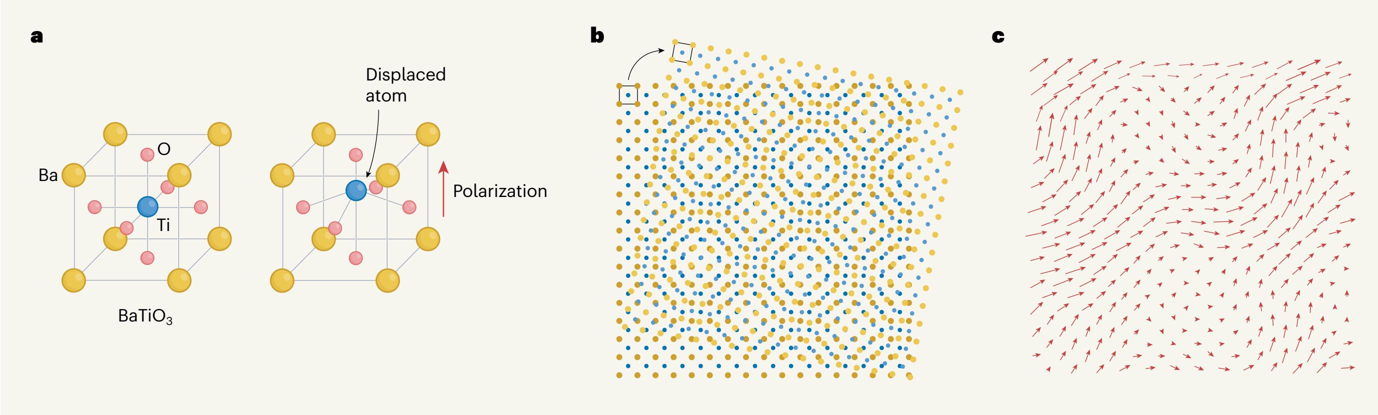

Figure 1 | Engineering electric-polarization textures in ferroelectric materials. **a**, The displacement of an atom in a ferroelectric material (such as a titanium atom in barium titanate, $BaTiO_3$) can give rise to a local electric polarization. **b**, Sánchez-Santolino *et al.*[2] induced this effect by stacking thin layers of barium titanate together and twisting them relative to each other so that the two crystal lattices overlapped. **c**, The authors showed that the structural and electronic interactions (not shown) between these two layers gave rise to complex polarization textures, including vortices and waves. (Adapted from Extended Data Fig. 4a of ref. 2.)

on top of another layer at a precisely specified twist angle. So far, this approach has been limited mostly to naturally layered materials – stacks of sheets of single-atom thickness that are only weakly bonded to each other, and can therefore be easily separated. Yet some researchers have focused on extending this approach to more strongly bound compounds[7,8].

Sánchez-Santolino *et al.* have now generalized twist engineering to materials that are not easily peeled apart. To do so, the authors used a method of growing thin films of a target compound on top of a sacrificial layer, which is later dissolved to release a free-standing membrane[9]. Different membrane layers can then be carefully manipulated – twisted and stacked – in analogy to conventional moiré systems comprising layers that have been peeled off larger structures.

Combining these strategies, the authors created thin membrane layers of the common ferroelectric compound barium titanate ($BaTiO_3$), in which titanium ions that are offset from the centre of their atomic neighbours give rise to local ferroelectric polarization. These atomic displacements can be directly measured with advanced electron-microscopy imaging to reveal ferroelectric patterns[3,10]. When they stacked two layers of barium titanate with relative twist angles of several degrees, Sánchez-Santolino and colleagues observed ferroelectric wave and vortex patterns (Fig. 1c) that they ascribe to the specific boundary conditions formed by the moiré pattern of the interface between membrane layers.

Future investigations of the switching behaviour of these intriguing mesoscopic ferroelectric textures might reveal promising functional properties that could be used in high-density data storage or other technological applications. For example, in another system showing polarization waves, applying an electric field does more than change the polarization – it also changes both the electrical and the optical conductivity considerably. This ability could be harnessed to build devices with several functions[11]. The free-standing-membrane platform built by Sánchez-Santolino and colleagues might also be suitable for integrating into flexible electronics, replacing the stiffer materials typically used in electronic devices.

Further details of the many multiscale interactions that give rise to these textures could be investigated using a newly devised method of imaging atomic structure with 3D resolution[12]. Using this technique, researchers could compare the arrangement of atoms near the twisted interface with those at the exposed surfaces. Sánchez-Santolino and colleagues focused on characterizing the ferroelectric patterns in the plane of the twisted membranes, but further analysis of a cross-section of the interface could provide useful insights about the structural and electronic interactions between the two layers.

> **"The free-standing-membrane platform built by the authors might also be suitable for integrating into flexible electronics."**

The authors observed that the details of the ferroelectric pattern depend not only on the twist angle, which sets the length scale of the repeated moiré pattern, but also on the thicknesses of the membranes. Intuitively, the effect of the interface diminishes as membrane thickness increases, because the atoms at the interface comprise a smaller fraction of the total system. Systematic examination of the atomic structure at, near to, and far from the interface in samples with different membrane thicknesses could shed light on how these competing effects are balanced in the composite structure. These experiments could also be carried out while the structure is subjected to an external electric field, so that the switching characteristics of these ferroelectric waves and vortices can be directly observed *in situ*.

More broadly, Sánchez-Santolino and colleagues' work shows how combining strategies developed in different fields – atomic-resolution imaging and analysis, twist-and-stack engineering and the use of free-standing membranes – can be leveraged to develop platforms for experimental research and, hopefully, technological advances.

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