Using electron beams to encode data in nanocrystals

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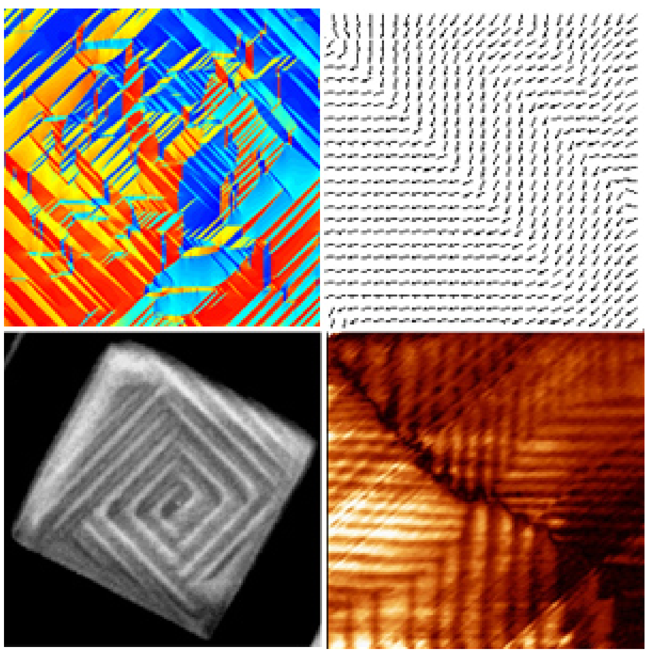

A simulated polarization pattern (top left), polarization vectors within the simulation (top right), and polarization patterns visualized using transmission electron microscopy (bottom left) and piezoresponse force microscopy (bottom right) in the ferroelectric material barium titanate. Credit: American Physical Society

Ferroelectric materials have an intrinsic electrical polarization caused by a small shift in the position of some of their atoms that occurs below a critical point called the Curie temperature. This polarization can be switched by an external electric field, an effect exploited in some computer memory devices.

By explaining the origin of puzzling polarization patterns previously seen in a ferroelectric material called barium titanate, Rajeev Ahluwalia and Nathaniel Ng at the A*STAR Institute of High Performance Computing in Singapore and colleagues have stumbled on a way to 'write' polarization patterns in nanoscale ferroelectric materials.

Ferroelectric crystals contain a patchwork of nanoscale 'domains', each with a different intrinsic polarization. While an understanding of how these domains form would help to develop reliable applications for ferroelectric materials, two different imaging techniques previously revealed contradictory results about the domains in barium titanate. Ahluwalia's team therefore set out to solve this puzzle.

One technique—transmission electron microscopy (TEM)—which uses a beam of electrons to probe a crystal's properties, suggests that the domains comprise long strips arranged in four quadrants, where the net polarization in each quadrant points inward or outward from the surface. The other technique—piezoresponse force microscopy (PFM)—also reveals a quadrant formation, but the polarizations are parallel to the surface so that the overall polarization of the crystal forms a closed loop.

Ahluwalia and his colleagues hypothesized that the TEM's electron beam changes the polarization pattern in the sample. PFM, in contrast, uses a sharp tip to detect deformations in the material caused by a localized electric field.

The scientists developed a theoretical model, which revealed that an increase in electron density in the crystal produced the same polarization pattern that they observed with TEM. They also calculated that the radial electric field created by an electron beam could generate other distinctive features of this pattern.

Under normal conditions, an electron beam might not alter the domains. But if the beam is strong enough to heat the sample above the Curie temperature, the material loses its intrinsic polarization. As it cools, the radial electric field induced by the electron beam shapes how the domains reform.

The team's discovery serves as a warning that electron beam techniques could alter the very domains that researchers are seeking to measure. However, electron beams could be used to deliberately alter polarization patterns in ferroelectric materials, something that is potentially useful for the next generation of memory devices with higher storage densities, says Ahluwalia.

More information: Ahluwalia, R., Ng, N., Schilling, A., McQuaid, R. G. P., Evans, D. M. et al. Manipulating ferroelectric domains in nanostructures under electron beams. *Physical Review Letters* 111, 165702 (2013). dx.doi.org/10.1103/PhysRevLett.111.165702

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