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TOPOLOGICAL MATERIALS

Livin' on the edge

Topologically protected spin-filtered edge modes — channels in which electrons with opposite spins move in opposite directions — naturally developing at the surface of a 3D topological crystalline insulator are presented by Paolo Sessi and colleagues in *Science*.

Topological materials are a hot topic of research because they host states that are very robust against perturbations. In particular, topological insulators are insulators in the bulk but host conductive states at their surface that are protected by the symmetries of the system. In the case of topological crystalline insulators, this topological protection is ensured by crystal symmetry rather than by the more common time-reversal symmetry (which is realized if the system looks the same when the flow of time is reversed).

Edge modes that are topologically protected and spin filtered are very attractive for, for example, spintronic applications, but they are experimentally difficult to realize. There are only few systems in which they are known to arise, such as 2D topological insulators, which are complex to synthesize; indeed, only a handful of these materials are known. Moreover, the electronic channels obtained in 2D topological insulators have proven difficult to measure, and their properties are not ideal for applications, mainly because of their very small bandgap.

The researchers show that topological electronic channels spontaneously arise at the step edges on the surface of a material that is much simpler to synthesize than 2D topological insulators: lead tin selenide, which is a 3D topological crystalline insulator. To start with, they cleave the crystal to expose a surface; the surface is not perfectly flat, but exhibits terraces separated by steps that are a few atoms thick. If a step is 'even', meaning that it has a height of two atomic layers (or of any even number of atomic layers), the pattern of the atomic lattice is preserved across the step (that is, translational symmetry is preserved). Conversely, if the step is 'odd' (if it has a height corresponding to an odd number of atomic layers), there is a discontinuity in the atomic lattice across the step. This atomic-scale discontinuity has far-reaching implications for the electronic properties of the material. Along the odd steps, a homogeneous topologically protected electronic channel develops, whereas even steps display the same electronic structure as the terraces. The topological protection means that the electronic channels are very stable and can survive even if relatively high temperatures or magnetic fields are applied.

Lead tin selenide is a topological material only above a critical tin concentration. By varying the chemical composition of the sample, the researchers could characterize the appearance of the 1D electronic channel as the material entered the topological phase. This way they could directly link the emergence of the edge states with the topologically non-trivial 3D bulk band structure of the sample. Theoretical calculations confirmed that the breaking of the translational symmetry at the odd steps is the essential ingredient for the creation of the topologically protected states.

"Beyond their fundamental relevance, these 1D states offer superior properties with respect to other edge channels known so far," explains Sessi. "Their intrinsic presence at surfaces eliminates the need for sophisticated sample preparation techniques, and their robustness against defects, strong magnetic fields and elevated temperatures opens interesting possibilities for accessing topological states without the need for extreme experimental conditions." Because these conductive channels are characterized by the absence of scattering, low conduction losses and a high degree of spin polarization, they have potential for sensing, quantum information processing and spintronics. "The combined action of the crystal symmetry protection mechanism and of the strong paraelectricity characterizing topological crystalline insulators opens fascinating opportunities for the purely electrical control of these 1D states. The successful implementation of these concepts would open a new avenue for topological-based electronics," concludes Sessi.

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Giulia Pacchioni

ORIGINAL ARTICLE Sessi, P. *et al.* Robust spin-polarized midgap states at step edges of topological crystalline insulators. *Science* **354**, 1269–1273 (2016)