Unlocking topological phase transitions in $HfTe_5$ through strain

What if you could turn an ordinary material into a topological material? In a recent study published in *Nature Communications* (https://doi.org/10.1038/s41467-023-44547-7), researchers demonstrated transitions in $HfTe_5$ from a weak to a strong topological insulator phase under applied strains of 4.5 percent. This research provides a blueprint for exploring topological phase transitions (TPTs) in other materials as well as determining whether other materials can be made topological.

"Can we now close the electronic gap of this material, and in that, can we invert it and make it topological?" asks Luis Jauregui, assistant professor of physics and astronomy at the University of California, Irvine. The research team, led by Jauregui, synthesized bulk single crystals of $HfTe_5$ via chemical vapor transport and investigated how strain influenced the electronic transport. While theoretical predictions suggest that the topological properties of $HfTe_5$ are sensitive to strain, experimental evidence of the topological surface states have not been reported. "From first-principle calculations and electrical measurements, we show that strain can close the electronic gap, then reopen it, and by reopening it, it becomes topological," Jauregui says.

One of the challenges in applying strain is that the material's mechanical properties can lead to buckling and deformation. Typically, piezoelectric materials can be used as substrates, but only up to strains of 0.1 percent. "We were looking at angle-resolved photoemission spectroscopy papers that look at the band structure of materials, where they use a metallic bending station where they can bend the sample and look at the band structure with the sample under strain," Jauregui says, "but they had not looked at electronic transport in these materials, because it is hard to do. If you put a sample on a metallic surface, it will short all the electrical connections in the sample."

Instead, the researchers used a titanium beam that they could bend and then exposed it to oxygen, creating titanium oxide on the surface before mounting the sample. The titanium oxide created an insulating layer, allowing the research team to take electrical transport measurements without the grounding issue created by other designs. Applying this method in their study of $HfTe_5$ revealed that the resistivity increased by 195,000% after applying strain along the *c*-axis and converting $HfTe_5$ from a weak topological insulator to a strong topological insulator. The study also showed that the topological surface states dominate the transport at cryogenic temperatures, which agrees with the first-principles calculations that the mechanism observed is a TPT.

In addition to demonstrating the topological phase transition in $HfTe_5$, the researchers showed evidence of robust topological surface states. Topologically protected surface states have important implications on the field of quantum computing, as their topological protection makes them robust to perturbations and defects. "We see robust topological surface states below 70 K. If we can apply more strain, that temperature will increase further," Jauregui says. "Can we have room-temperature topological surface state conducting materials that we can couple with high-T_c superconductors? Then, we could make qubits that work at 70 K," which would be a significant improvement on current superconducting qubits that work only at temperatures on the order of 0.02 K.

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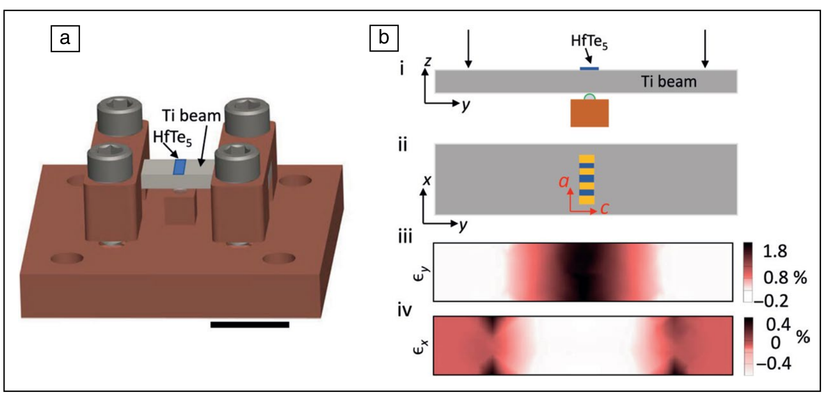

(a) Schematic of bending station. The scale bar corresponds to 1 cm. (b) (i) Diagram of Ti beam being bent while applying strain to a $HfTe_5$ crystal; (ii) top-down view of sample, showing the configuration for applying strain on the *c*-axis; (iii) and (iv) show the distribution of strain of ϵ_x and ϵ_y. Credit: *Nature Communications.*