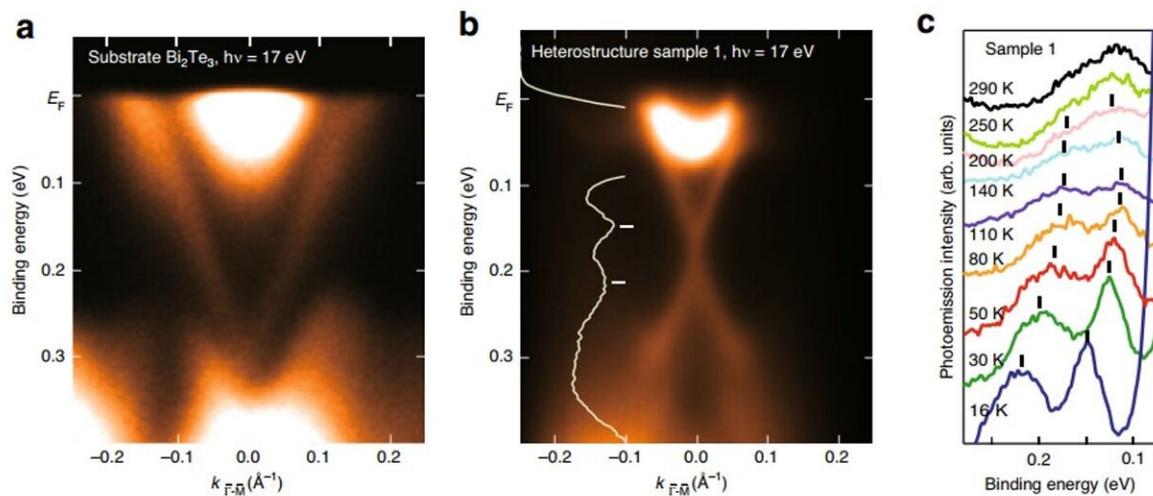


Bridging the gap between the magnetic and electronic properties of topological insulators

September 24 2020



(a) and (b) show the electronic band structures of Bi₂Te₃ and a magnetic topological insulator sample; the Dirac cone structure is much more prominent in the latter. (c) The two highlighted photoemission peaks and their progressive fusion were ascribed to the closing of the DC gap as temperature increases.

Credit: Nature Communications

Scientists at Tokyo Institute of Technology shed light on the relationship between the magnetic properties of topological insulators and their electronic band structure. Their experimental results offer new insights into recent debates regarding the evolution of the band structure with temperature in these materials, which exhibit unusual quantum

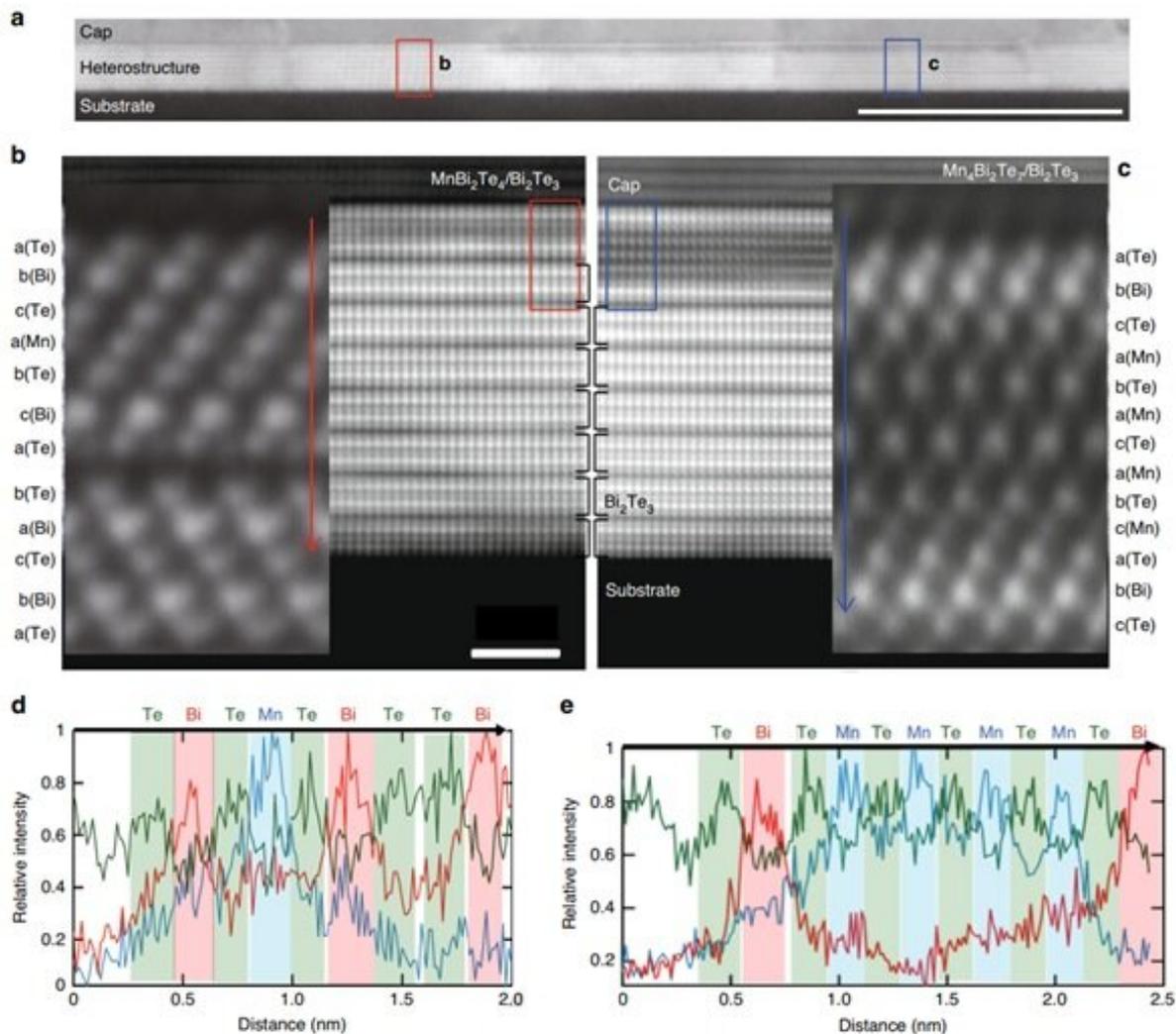
phenomena and are envisioned to be crucial in next-generation electronics, spintronics, and quantum computers.

Topological insulators have the peculiar property of being electrically conductive on the surface but insulating on their interior. This seemingly simple, unique characteristic allows these materials to host a plethora of exotic quantum phenomena that would be useful for quantum computers, spintronics, and advanced optoelectronic systems.

To unlock some of the unusual quantum properties, however, it is necessary to induce magnetism in [topological insulators](#). In other words, some sort of 'order' in how electrons in the material align with respect to each other needs to be achieved. In 2017, a novel method to achieve this feat was proposed. Termed 'magnetic extension,' the technique involves inserting a monolayer of a magnetic material into the topmost layer of the topological insulator, which circumvents the problems caused by other available methods like doping with magnetic impurities.

Unfortunately, the use of magnetic extension led to complex questions and conflicting answers regarding the [electronic band structure](#) of the resulting materials, which dictates the possible energy levels of electrons and ultimately determines the material's conducting properties.

Topological insulators are known to exhibit what is known as a Dirac cone (DC) in their electronic band structure that resembles two cones facing each other. In theory, the DC is ungapped for ordinary topological insulators, but becomes gapped by inducing magnetism. However, the [scientific community](#) has not agreed on the correlation between the gap between the two cone tips and the magnetic characteristics of the material experimentally.



Scanning transmission electron microscopy images were used along with energy-dispersive spectroscopy to determine the atomic composition of the two possible structures of the samples. Credit: Nature Communications

In a recent effort to settle this matter, scientists from multiple universities and research institutes carried out a collaborative study led by Assoc Prof Toru Hirahara from Tokyo Tech, Japan. They fabricated magnetic topological structures by depositing Mn and Te on Bi_2Te_3 , a well-studied topological [insulator](#). The scientists theorized that extra Mn

layers would interact more strongly with Bi_2Te_3 and that emerging magnetic properties could be ascribed to changes in the DC gap, as Hirahara explains: "We hoped that strong interlayer magnetic interactions would lead to a situation where the correspondence between the magnetic properties and the DC gap were clear-cut compared with previous studies."

By examining the electronic band structures and photoemission characteristics of the samples, they demonstrated how the DC gap progressively closes as temperature increases. Additionally, they analyzed the atomic [structure](#) of their samples and found two possible configurations, $\text{MnBi}_2\text{Te}_4/\text{Bi}_2\text{Te}_3$ and $\text{Mn}_4\text{Bi}_2\text{Te}_7/\text{Bi}_2\text{Te}_3$, the latter of which is responsible for the DC gap.

However, a peculiarly puzzling finding was that the temperature at which the DC gap closes is well over the critical temperature (TC), above which materials lose their permanent magnetic ordering. This is in stark contrast with previous studies that indicated that the DC gap can still be open at a temperature higher than the TC of the material without closing. On this note, Hirahara remarks: "Our results show, for the first time, that the loss of long-range magnetic order above the TC and the DC gap closing are not correlated."

Though further efforts will be needed to clarify the relationship between the nature of the DC gap and magnetic properties, this study is a step in the right direction. Hopefully, a deeper understanding of these quantum phenomena will help us reap the power of topological insulators for next-generation electronics and quantum computing.

More information: T. Hirahara et al, Fabrication of a novel magnetic topological heterostructure and temperature evolution of its massive Dirac cone, *Nature Communications* (2020). [DOI: 10.1038/s41467-020-18645-9](https://doi.org/10.1038/s41467-020-18645-9)

Provided by Tokyo Institute of Technology

Citation: Bridging the gap between the magnetic and electronic properties of topological insulators (2020, September 24) retrieved 24 April 2024 from <https://phys.org/news/2020-09-bridging-gap-magnetic-electronic-properties.html>

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