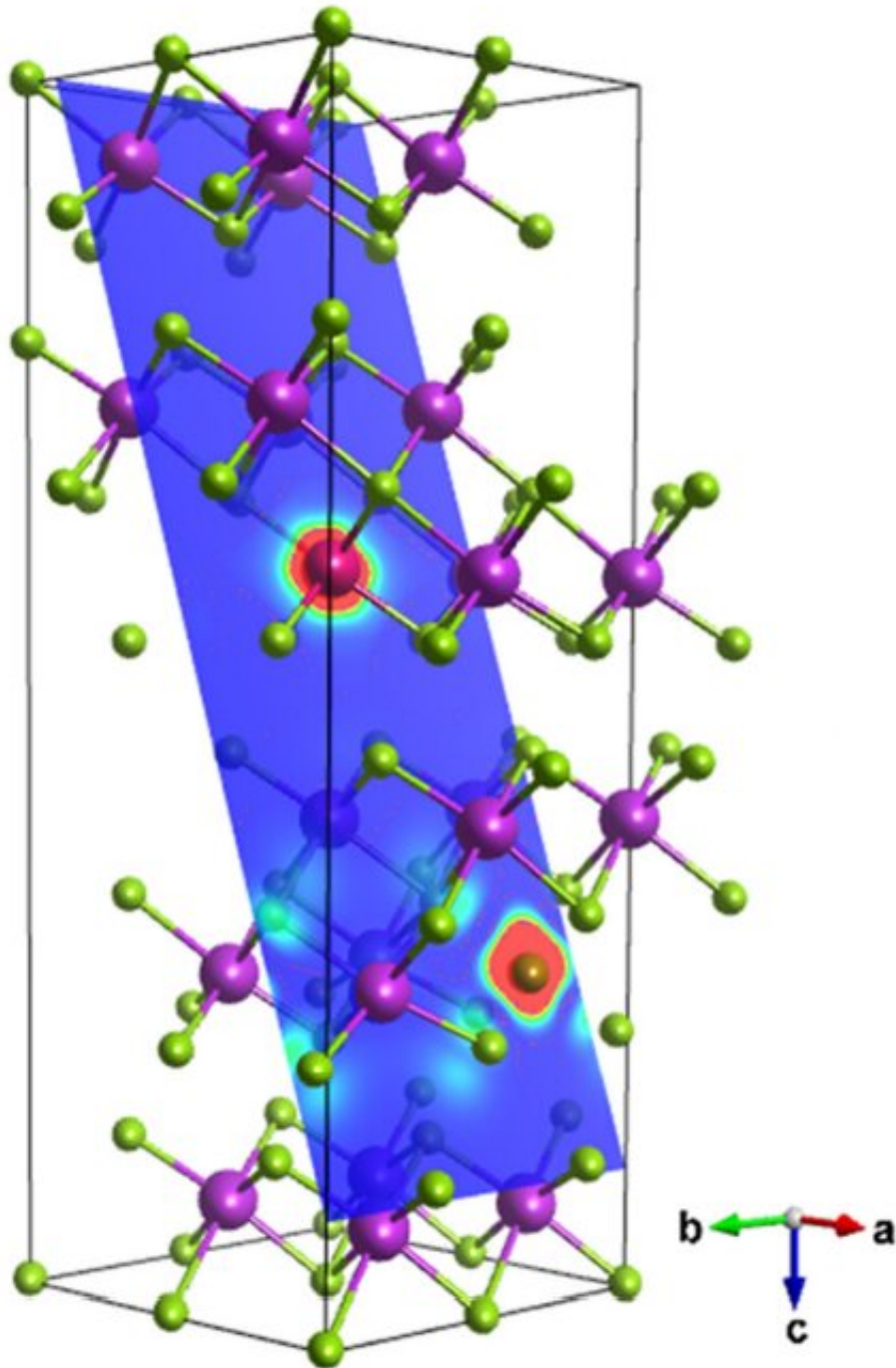


# Researchers combine two semiconductor doping methods to achieve new efficiencies

November 12 2021

---



In double-doped (Sm/Fe) bismuth-selenide, both Sm and Fe carry large magnetic moments (shown in red), with fainter induced moments appearing on selenium atoms (green) coordinating the Fe. Credit: *Physical Review B*

A University of Wollongong-led team across three FLEET nodes has combined two traditional semiconductor doping methods to achieve new efficiencies in the topological insulator bismuth-selenide ( $\text{Bi}_2\text{Se}_3$ ).

Two [doping](#) elements were used: samarium (Sm) and iron (Fe).

The resulting bismuth-selenide crystals show clear ferromagnetic ordering, a large bulk band gap, high electronic mobility, and the opening of a gap of surface state making this system a good candidate to achieve QAHE at the higher temperatures necessary for viable, sustainable future low-energy electronics.

"The combination of electronic and [magnetic properties](#) in topological systems is the keystone of novel topological devices, and one of the core projects in FLEET," says project- leader Prof Xiaolin Wang (UOW).

"We have proposed and successfully realized a new way to magnetize a novel electronic material—a topological [insulator](#)—by adding two different magnetic ions."

Each one of various different magnetic elements used in magnetizing a topological insulator possesses its own advantage and disadvantage. However, while in previously studies, only one element was employed, the UOW-Monash-RMIT team found that the combination of two elements also combined advantages of each.

"The dual doping strategy is thus proved viable for the growth of extremely high quality [topological insulators](#) with both magnetism and excellent electron mobility which are vital for low-energy electronic devices," says the study's lead author, Dr. Weiyao Zhao.

## **One dose is not enough: The limitations of transition-metal doping**

Topological insulators (TIs) are emergent materials with a unique band structure allowing the study of quantum effect in solids, as well being promising components of future, high-performance quantum devices.

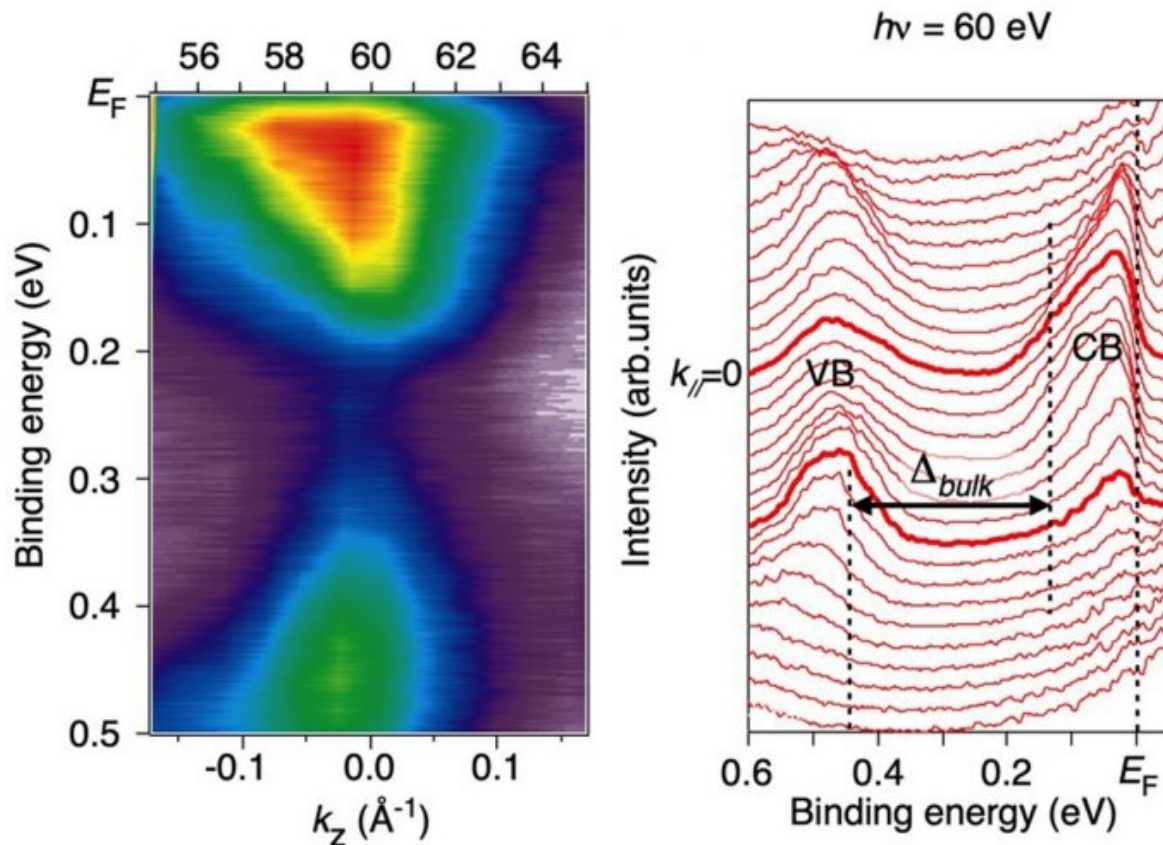
There are the two key elements in the quantum anomalous Hall effect (QAHE) that 'drives' desirable properties in topological insulators and all related electronic technology:

These are (a) ferromagnetism, and (b) the topological electronic insulating property.

The collaborative FLEET study, combining expertise from UOW, Monash and RMIT pioneered a 'dual element' doping strategy to introduce magnetism in a topological insulator, thus improving both key elements at once.

Combining the advantages of two different doping elements, iron and samarium, results in large crystal growth, with a large surface band-gap, and huge quantum transport effect.

The previous approach to realize quantum anomalous Hall effect (QAHE) in a topological insulator employed doping with a single transition-metal, such as iron (Fe), to create ferromagnetism.



Angle-resolved photoelectron spectroscopy (ARPES) at ALS Berkeley shows photon-energy dependence (left) and energy distribution curves (right). Credit: *Physical Review B*

The transition-metal doping technique has been successful in creating the desired magnetic ordering. However, there is a significant disadvantage of this method: The in-lattice transition metal jeopardizes the desired high-mobility of the topological insulator, which in the case of low-energy electronics, defeats the purpose of using topological insulators at all.

Thus, QAHE has been realized via transition metal doping strategy only

at extremely low temperatures, which would require energy-intensive cooling. Again, this reduces the viability of such materials for future low-energy electronics.

To increase the operating temperature of QAHE, stronger magnetic interaction and higher mobility are desired.

## **Double doping achieves the two key, desired elements of qahe**

After considering the successful elements of doping using transition metals such as iron (Fe), the research team decided to further introduce a stronger magnet, the rare earth element samarium (Sm), into the well-known topological insulator bismuth-selenide ( $\text{Bi}_2\text{Se}_3$ ).

The doping elements iron and samarium create the necessary ferromagnetic ordering in the crystals, which can open a massive gap at the Dirac cone of surface state. This is an essential element of achieving QAHE.

Further, the team proved that, in the dual magnetic doped crystals, the electron mobility remains very high, by confirming the presence of an ultra-strong quantum oscillation effect, and step-like Hall effect.

The mobility of topological insulators such as bismuth-selenide is several times faster than in classical semiconductors, such as silicon.

Such a crystal idealizes the two important elements of QAHE.

The resulting crystals show clear ferromagnetic ordering, a large ( $\sim 44$  meV) band gap, and high mobility ( $\sim 7400$   $\text{cm}^2/\text{Vs}$  at 3 K) and Hall steps in transverse resistivity, confirming the presence of QAHE.

"The samarium and iron dual-doped  $\text{Bi}_2\text{Se}_3$  crystal will be an ideal system to achieve QAHE at higher temperatures," says corresponding author Dr. Mark Edmonds (Monash). "This may be a new way to cover the shortage of magnetic elements."

"The dual doping strategy is also proved positive to utilize topological insulators in low-energy electronic devices."

"DFT calculation indicates that the dual doping results in a half-metallicity, fully spin polarized electrons in the system," adds corresponding author Prof Xiaolin Wang. "This paves another avenue to potential applications in spintronics, as well as contributing to the diversity of the topological matter family."

**More information:** Weiyao Zhao et al, Massive Dirac fermions and strong Shubnikov–de Haas oscillations in single crystals of the topological insulator  $\text{Bi}_2\text{Se}_3$  doped with Sm and Fe, *Physical Review B* (2021). [DOI: 10.1103/PhysRevB.104.085153](https://doi.org/10.1103/PhysRevB.104.085153)

Provided by FLEET

Citation: Researchers combine two semiconductor doping methods to achieve new efficiencies (2021, November 12) retrieved 26 April 2024 from <https://phys.org/news/2021-11-combine-semiconductor-doping-methods-efficiencies.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.