A balanced quantum Hall resistor provides a new measurement method

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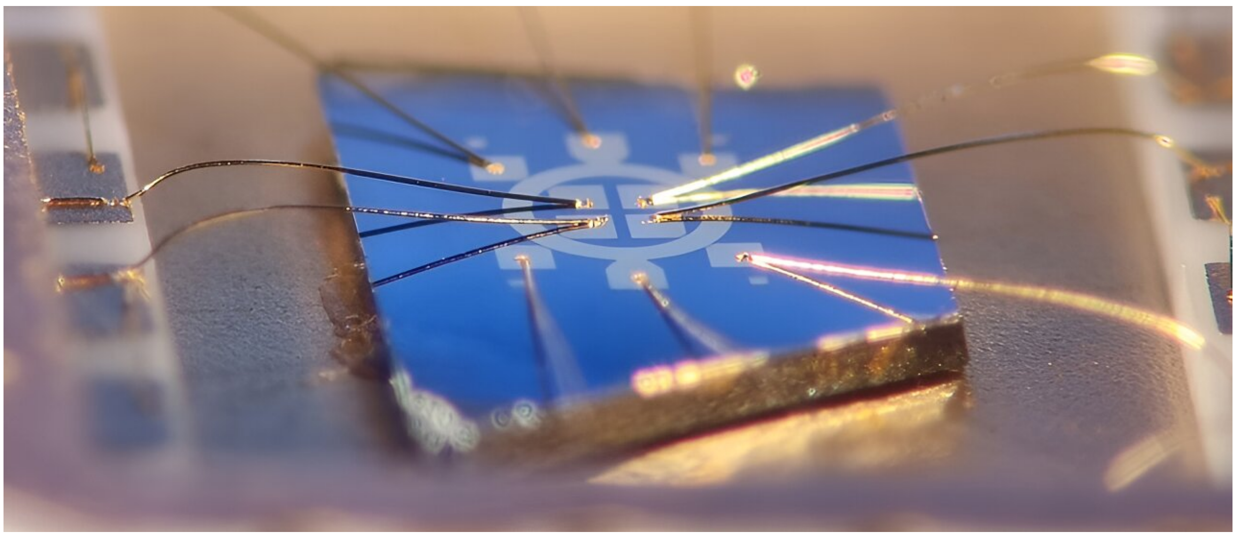

Until now, the zero magnetic field quantum anomalous Hall effect only occurred at very low currents. This device can change that. Credit: Kajetan Fijalkowski /JMU

Researchers at the University of Würzburg have developed a method that can improve the performance of quantum resistance standards. It's based on a quantum phenomenon called Quantum Anomalous Hall effect.

The precise measurement of electrical resistance is essential in industrial production or electronics—for example, in the manufacture of high-tech sensors, microchips and flight controls. "Very precise measurements are essential here, as even the smallest deviations can significantly affect these complex systems," explains Professor Charles Gould, a physicist at the Institute for Topological Insulators at the University of Würzburg (JMU).

"With our new measurement method, we can significantly improve the accuracy of resistance measurements, without any external magnetic field, using the quantum anomalous Hall effect (QAHE)."

The research is published in the journal *Nature Electronics*.

How the new method works

Many people may remember the classic Hall effect from their physics lessons: When a current flows through a conductor and it is exposed to a magnetic field, a voltage is created—the so-called Hall voltage. The Hall resistance, obtained by dividing this voltage by current, increases as the magnetic field strength increases.

In thin layers and at large enough magnetic fields, this resistance begins to develop discreet steps with values of exactly h/ne^2, where h is the Planck's constant, e is the elementary charge, and n is an integer number. This is known as the quantum Hall effect because the resistance depends only on fundamental constants of nature (h and e), which makes it an ideal standard resistor.

The special feature of the QAHE is that it allows the quantum Hall effect to exist at zero magnetic field. "The operation in the absence of any external magnetic field not only simplifies the experiment, but also gives an advantage when it comes to determining another physical quantity: the kilogram. To define a kilogram, one has to measure the electrical resistance and the voltage at the same time," says Gould "but measuring the voltage only works without a magnetic field, so the QAHE is ideal for this."

Thus far, the QAHE was measured only at currents which are far too low for practical metrological use. The reason for this is an electric field that disrupts the QAHE at higher currents. The Würzburg physicists have now developed a solution to this problem.

"We neutralize the electric field using two separate currents in a geometry we call a multi-terminal Corbino device," explains Gould. "With this new trick, the resistance remains quantized to h/e^2 up to larger currents, making the resistance standard based on QAHE more robust."

On the way to practical application

In their feasibility study, the researchers were able to show that the new measurement method works at the precision level offered by basic DC techniques.

Their next goal is to test the feasibility of this method using more precise metrological tools. To this end, the Würzburg group is working closely with the Physikalisch-Technische Bundesanstalt (German National Metrology Institute, PTB), who specialize in this kind of ultra-precise metrological measurements.

Gould also notes, "This method is not limited to the QAHE. Given that conventional quantum Hall effect experiences similar electric field driven limitations at sufficiently large currents, this method can also improve the existing state of the art metrological standards, for applications where even larger currents are useful."

More information: Kajetan M. Fijalkowski et al, A balanced quantum Hall resistor, *Nature Electronics* (2024). DOI: 10.1038/s41928-024-01156-6

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