# Graphene supercurrents go ballistic

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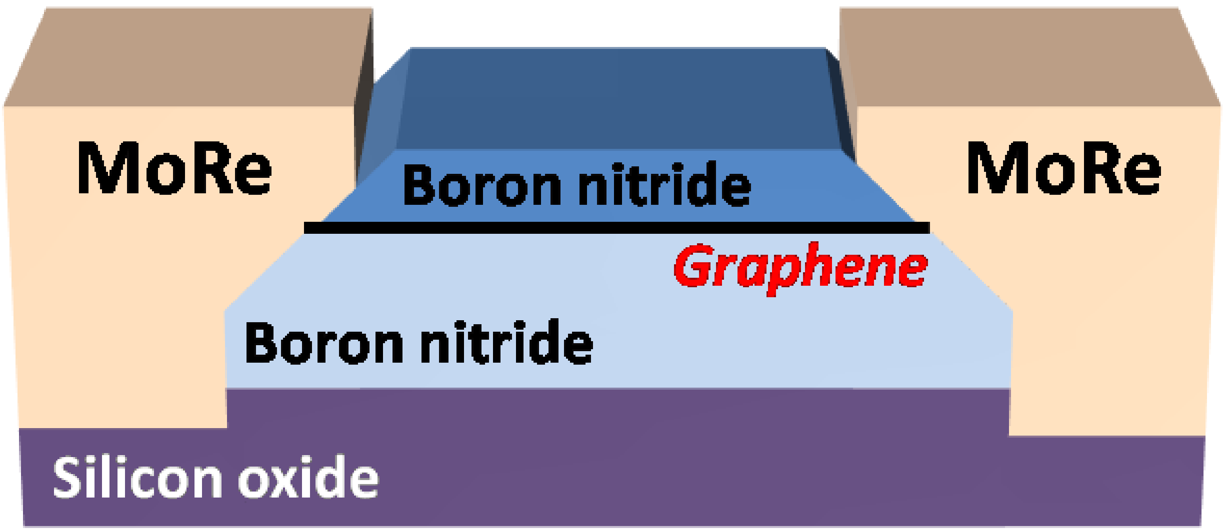



Credit: Technical University of Delft

Researchers with Europe's Graphene Flagship have demonstrated superconducting electric currents in the two-dimensional material graphene that bounce between sheet edges without scattering. This first direct observation of the ballistic mirroring of electron waves in a 2d system with supercurrents could lead to the use of graphene-based Josephson junctions in applications such as advanced digital logic circuits, ultrasensitive magnetometers and voltmeters.

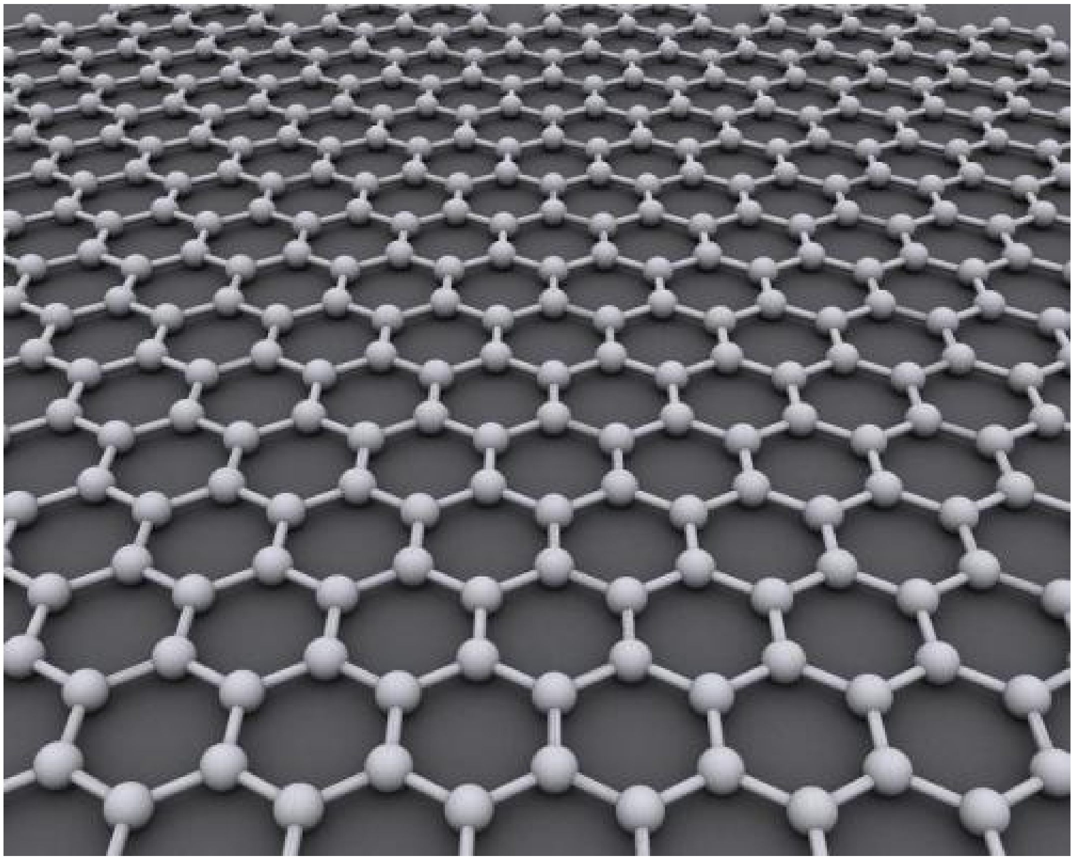
A Josephson junction is made by sandwiching a thin layer of non-superconducting material between two superconducting layers. Entwined pairs of superconducting electrons known as Cooper pairs are in certain circumstances able to travel without resistance through the insulating or partially-insulating middle layer.

The resistance-free current occurs up to a critical current, above which a time-varying (alternating) voltage is set up across the junction. Detecting and measuring the change between current states is the basis of many applications that exploit Josephson junctions.

Electronic logic circuits can be constructed from arrays of Josephson junctions, which are also used in superconducting quantum interference devices. SQUIDs are extremely sensitive to electromagnetic fields, and form the basis of magnetometers that can measure fields as low as a few attoteslas (10-18T), and voltmeters responsive to potential differences of picovolts (10-12V).

Practical uses of such ultra-sensitive devices include the measurement of neurological currents in the brain or heart, and geophysical research. Military applications include remote submarine detection.

In the latest issue of the journal *Nature Nanotechnology*, an international team of physicists led by Graphene Flagship member Lieven Vandersypen, who is based at the Kavli Institute of Nanoscience in Delft, demonstrate unambiguous signatures of Josephson junctions in graphene, a two-dimensional allotrope of carbon atoms arranged in a hexagonal lattice. In the paper, the lead authors of which are Victor Calado and Srijit Goswami, the researchers look at ballistic supercurrents in graphene, with the electrons mirroring between one-dimensional edge contacts made of molybdenum-rhenium.



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The ultraclean graphene used in the experiment – required in order to preserve the material's unique electrical properties – is shielded from environmental contamination by being encapsulated between sheets of the insulating 2d material hexagonal boron nitride. This three-layer stack is then cut into the desired shape, and the graphene placed in contact with the superconducting alloy.

Just as with light bouncing back and forth between two mirrors, leading to an interference pattern set up by the superposition of incident and reflected electromagnetic waves, electrons can reflect from the edges of a superconductor. The difference is that electron interference is only observed in ultraclean samples, in which it is possible for the charged particles to move in ballistic trajectories with minimal scattering from impurities in the material.

This is what Calado, Goswami and colleagues observed in their setup, with a striking modulation of the supercurrent. In their Nature Nanotechnology paper, the researchers refer to the critical current oscillating as a result of phase-coherent interference of the electrons and electron holes that carry the current. This is caused by the formation of a resonant (Fabry-Pérot) cavity between the mirror points. Furthermore, relatively large supercurrents are seen, travelling over distances of up to 1.5 micrometres. The researchers believe this to be the first direct observation of the ballistic mirroring of supercurrents in graphene.

"This work allows us to unravel new physics related to the interplay between superconductivity and the relativistic behaviour of electrons in graphene," said Goswami. "With this technology, we can study and exploit graphene Josephson junctions in a new, exciting regime."

**More information:** "Ballistic Josephson junctions in edge-contacted graphene," *Nature Nanotech*. (2015); DOI: 10.1038/NNANO.2015.156

Provided by Graphene Flagship