Revealing ballistic transport in topological bismuth nanowires

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The current through two-dimensional topological insulators is predicted to run only through a few, perfectly conducting, narrow channels. We have used superconducting electrodes to reveal the ballistic nature of the current through bismuth nanowires, suggesting they are good topological insulator candidates.

One of the striking consequence of the macroscopic quantum nature of the superconducting state is the propensity of a supercurrent to flow through a thin insulating layer separating two superconductors. Brian Josephson even predicted how the supercurrent would flow across this Superconductor/Insulator/Superconductor (SIS) junction: the supercurrent should be proportional to the sine of the superconducting phase difference, i.e. the difference between the phases of the macroscopic order parameter of each superconductor. This phase difference is controlled by a magnetic field in a loop geometry, and is proportional to the magnetic flux through the loop. The sine is related to the fact that the superconducting wave functions decay exponentially in the insulating layer, which should not be greater than a few angstroms in order for the supercurrent to flow through it. In contrast, it was later discovered that a supercurrent can propagate over several micrometers through non superconducting (also called "normal") materials, and the exact relation between the supercurrent and the phase difference (the so-called current-phase relation or CPR) can reveal how the propagation occurs through the normal metal. It turns out that a diffusive propagation through a disordered conductor should resemble a sine function, whereas a ballistic propagation (in a straight line) in a disorderless material should have a sawtooth-like dependence on the phase difference.

We have exploited this sensitivity of the CPR to probe conduction through topological insulators. The current through such materials is predicted to run only through a few perfectly ballistic channels, called topological edge states. The topological insulator candidate is a monocrystalline bismuth nanowire whose crystalline orientation is chosen such that it contains two topological surfaces, each with one-dimensional edge states. And indeed, we have found that the supercurrent through a 1.4 micrometer-long monocrystalline bismuth nanowire has just such a sawtooth-shaped dependence on the phase difference between the superconductors at its ends. The signal is actually the sum of two sawtooths of slightly different periods, indicating that there are two such one dimensional ballistic conduction paths in the wire, defining two slightly different loop areas. The fact that transport is ballistic over such a long distance hints to a possible topological protection against scattering in those wires. High frequency experiments are currently undertaken to demonstrate this topological protection.

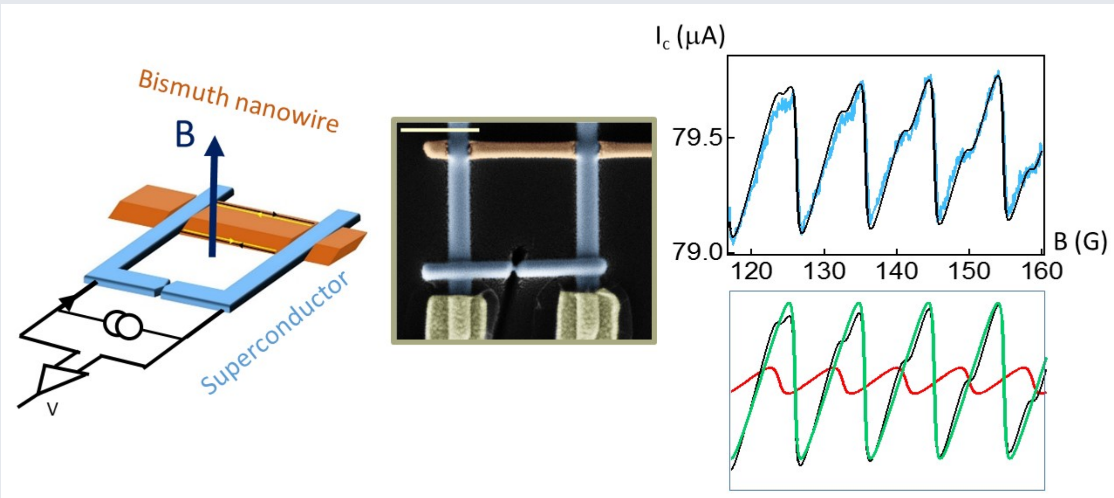

Figure: The current phase relation is determined by measuring the critical current (maximum supercurrent that can flow) of two junctions in parallel, a so-called SQUID (Superconducting Quantum Interference Device) configuration: The SQUID is a superconducting loop (made of tungsten, in blue) containing one reference junction with a high critical current (constriction in the bottom tungsten wire), in parallel with the second junction whose current-versus-phase relation is unknown (tungsten/Bismuth nanowire/tungsten junction, with the Bi nanowire shown in brown). The SQUIDs total critical current is modulated by the CPR of this second junction if its critical current is small. The top plot displays the CPR of the S/Bi/S junction (blue curve), which is the sum of two sawtooth-shaped CPR with slightly different periods (see decomposition of the CPR in the sum of two sawtooths below) demonstrating that the supercurrent in the bismuth nanowire is carried ballistically along only two paths at two edges of the nanowire.

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