a syringe. Furthermore, self-assembly of the peptides is triggered by the ionic environment of the blood, and when broken down, the amino acid building blocks of the hydrogel can be used by the body to repair the injury.

Ellis-Behnke, So and co-workers found that the self-assembling peptide is a good haemostat in a variety of different tissues (the brain, liver and skin of hamsters, rats and mice) and that it works for different rates of bleeding, including cuts to the femoral artery in the thigh, a notoriously high-pressure bleeder.

In the experiments, they start by making a precise cut at the location of interest to induce bleeding, and then apply the aqueous solution of the peptide assembler with a syringe (Fig. 1b). Immediately on contact with biological fluid, the peptide assembles into a hydrogel, which completely controls the bleeding in less than 15 seconds. The effectiveness of the peptide can only be fully appreciated by viewing the video that accompanies the paper[1]. The speed at which the peptide assembles and controls bleeding is striking. Even more impressively, the cut treated with the hydrogel is robust and does not reopen, even on intentionally rough physical handling (Fig. 1c).

This paper illustrates a very practical application of a nanostructured self-assembling system in a medical environment. With this discovery, the ability to quickly control bleeding can radically reduce the quantity of blood needed during surgery in the near future. Although the mechanism by which the hydrogel controls the flow of blood is still not fully understood, the MIT–Hong Kong team has already dismissed blood clotting because it takes much longer than 15 seconds for clots to form. They have also ruled out simple mechanical properties of the hydrogels playing a role because stiffer hydrogels, which would seem to be more effective for controlling high-pressure bleeders, did not stop bleeding. Nevertheless, this and related types of sophisticated biomedical nanomaterials are likely to become the norm in the operating room of the future.

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DEVICE PHYSICS

Super-semiconducting Nanowires

Semiconducting heterostructures have long been used to control the transport of electrons in circuits. Now, researchers have shown that a semiconducting nanowire can control the current in a superconducting device.

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The unrivalled versatility of semiconducting nanostructures makes them the heart of present-day microelectronics. Integrating these various semiconductor structures with superconducting metals opens exciting possibilities in many fields of fundamental solid-state devices, but faces the practical challenge of how to combine two types of materials that often have very different electronic and structural properties. Now, on page 208 of this issue, Jie Xiang and colleagues at Harvard University show how to efficiently overcome this obstacle[1].

They have fabricated an electronic device made of a single semiconductor heterostructure — a germanium nanowire core coated with a silicon shell — with superconducting aluminium contacts (Fig. 1a). Because conduction through the nanowire is quantized, the wire functions as a controllable valve on the superconducting current. Moreover, the devices are of such high quality, that the authors can almost approach the ideal limits of electron conduction predicted by theory.

In superconducting metals, the electric current can flow without any dissipation, even over macroscopic distances — a phenomenon that can only be understood on a quantum mechanical basis. The prediction[2] and subsequent verification more than 40 years ago that a supercurrent can flow through a thin non-superconducting barrier, or Josephson junction, is one of the most important and fascinating consequences of superconductivity. Indeed, a huge number of applications and fundamental properties of the Josephson effect have been, and are still being, studied in laboratories worldwide. Superconducting quantum interference devices (SQUIDs), which contain two Josephson junctions in a superconducting loop, can detect extremely weak magnetic fields, such as those produced by the human brain. Microwave-irradiated Josephson junctions serve as voltage standards with quantum precision. Furthermore, Josephson junctions also play a key role in the current effort to design and build quantum bits for quantum computation.

In the device studied by Xiang and co-workers, the Josephson junction linking the superconducting aluminium is the germanium–silicon nanowire. The electrons in germanium are highly mobile and the silicon shell in this heterostructure nanowire provides a 'clean' wall that confines the conducting electrons in the radial direction. Two other advantages of these wires help the authors observe a number of interesting effects: the electrons can travel the 100–150 nm length of the nanowire without scattering, and it is possible to make good ohmic contacts with the aluminium wires.

The electrons in the nanoscale semiconductor wire mimic the particle-in-a-box problem in quantum mechanics: only electrons with certain wavelengths — or equivalently, energies — are allowed in the nanowire. The gate voltage in the device (Fig. 1a) controls the energy of the conduction electrons in the semiconductor wire. Quantization of the allowed electron energy thus appears as steps in the wire conductance plotted as

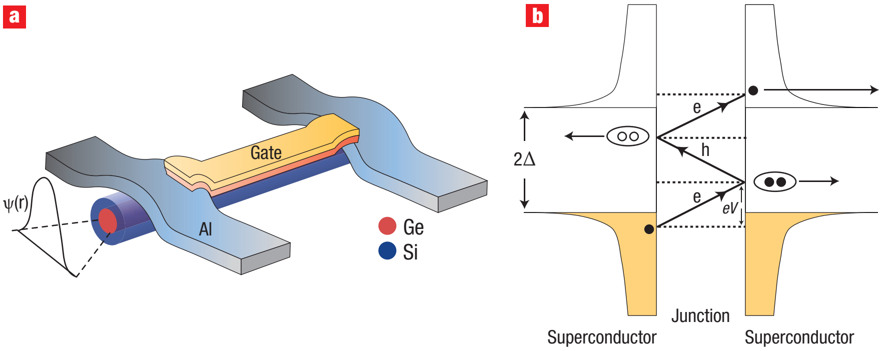

Figure 1 Multiple Andreev reflections can be observed in a semiconductor nanowire Josephson junction. A schematic of the device structure is shown in **a**. The germanium nanowire core (red), 15 nm in diameter is coated with a 1.5–2 nm silicon shell (blue) and contacted with aluminium wires (grey), which superconduct below 1.6 K. The electronic wavefunctions (black curve) in the germanium are confined in the radial direction. The electron energy in the nanowire is controlled by a voltage on the gate electrode. An energy level diagram (**b**) shows the steps involved in multiple Andreev reflections at the interfaces of a superconductor–junction–superconductor. In the $n = 3$ step process shown here, an electron entering from the left superconductor undergoes an Andreev reflection at the right nanowire–superconductor interface, and a subsequent reflection at the left interface (creating and removing a Cooper pair, respectively) to end up as an electron in the right superconductor. Each time the electron (e) or hole (h) traverses the junction, it increases in energy by eV (V is the bias voltage). The reflections occur until either electron or hole has enough energy to propagate into the superconductor.

a function of applied gate voltage. Note that these measurements are taken above the superconducting temperature of 1.6 K, where the aluminium wires behave as normal metals.

The effects of this quantization persist when the device is cooled below 1.6 K and the aluminium wires become superconducting. The authors use the gate voltage to control the critical supercurrent — the maximum supercurrent the Josephson junction can transmit — and show that the critical current does not increase continuously with the gate voltage, but in steps. The precise correlation between the steps in the normal state conductance and the supercurrent is in almost perfect agreement with the predictions of mesoscopic transport theory[3]. This demonstrates the high quality of the fabricated junctions as the observed supercurrent, which is close to the theoretical maximum, can only be obtained in perfect quantum wires without imperfections and contact barriers. Notably, to observe a clean supercurrent, the measurement setup also has to be fine tuned by eliminating all possible external noise sources.

Nowadays, it is understood that charge transport through a non-superconducting junction can be explained by a process called Andreev reflection[4]. To explain this effect, it is necessary to know that the electrons in a superconductor are bound to one another in Cooper pairs, with a total charge $2e$ and a binding energy 2Δ. In order for an electron to leave the junction to form a Cooper pair in the superconductor, a positive hole, travelling in the opposite direction, must be left behind in the junction (Fig. 1b). This process is called an Andreev reflection, as is the reverse process, when a hole is reflected into an electron at the other superconductor–junction interface and removes a Cooper pair. For each respective reflection, the electron or hole picks up an energy eV when it travels across the nanowire junction, where V is the bias voltage.

Multiple Andreev reflection processes can occur if there are multiple conversions of Cooper pairs to electrons and vice versa. When the total energy gain of the electron or hole equals the binding energy, 2Δ, the electrons that enter the superconductor have enough energy to conduct as 'normal' electrons. Multiple Andreev reflections appear as features in the current versus bias voltage, spaced at $neV = 2\Delta$, where n corresponds to the number of times the electron traverses the junction (Fig. 1b). In the nanowire sample the authors found peaks associated with multiple Andreev reflections up to n=5 and, quite remarkably, also for n = 9, 13 and 25.

It is worth emphasizing that a process of order n implies that the charge created in the Andreev reflection can travel back and forth across the nanowire junction n times without scattering — a further testament to the high quality of the nanowire fabricated by Xiang *et al*. The extreme sensitivity to the junction quality has previously been used, for example, to investigate details of the transport in atomic contacts[5–7]. The features with $n \leq 5$ behave largely as expected by theory, whereas the features associated with multiple Andreev reflections with n = 9, 13 and 25 show qualitatively different behaviour. Furthermore, it is not clear why features are only observed at certain values of n and not all n, as expected.

These observations suggest that the details of the transport process are not completely understood. One may ask, for example, whether the peaks are associated with multiple Andreev reflections at all, or if they have an entirely different origin. One possible route to answer this question is to combine these devices with recent efforts in superconductor nanoelectronics, such as the measurement and analysis of current fluctuations in superconducting atomic point contacts[8–10], which can reveal the true nature of the charge transfer process.

The experiment of Xiang and co-workers has two important upshots. First, it is now possible to create high-quality superconducting junctions with a semiconducting nanowire that very precisely follow the predictions of mesoscopic transport theory. This will allow more sophisticated superconducting nanoelectronic circuits to be used in advanced applications, such as nanowire SQUIDS or superconducting switches, as well as making contributions to fundamental research. Second, it is interesting to note that, more than forty years after the prediction of the Josephson effect, surprising discoveries such as the astonishing low-energy structure of the current–voltage characteristics are still being made and continue to stimulate further theoretical research.

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