Conductance measurements on graphene nanoribbons tell researchers how molecular wires can be optimised

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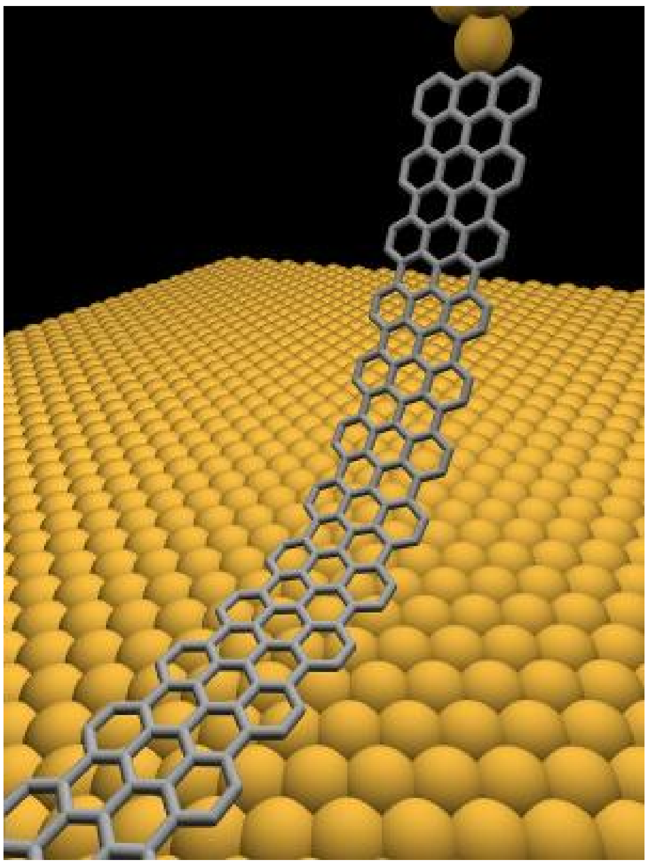

Electric circuit with nanocable: Max Planck researchers from Berlin lift a graphene ribbon from a gold surface with the tip of a scanning tunnelling microscope and investigate how the conductance of the carbon ribbon depends on its length. Credit: Leonhard Grill / Fritz Haber Institute of the Max Planck Society

(Phys.org)—The electronics of the future could use molecules to do their arithmetic. The tiny particles could then take over the tasks which are presently done by silicon transistors, for example. Researchers from the Fritz Haber Institute of the Max Planck Society in Berlin have used a nanowire which could potentially conduct current between molecular transistors or different components. The tiny conducting track consists of a narrow graphene band, that is a strip of a single layer of carbon. Their next step was to use a scanning tunnelling microscope to perform complicated measurements to determine how the conductance of the carbon strip depends on its length and the energy of the electrons. They thus learned more about how charge in the form of electrons is transported through the nanowire and how the conducting tracks can be improved for potential applications in nanoelectronics.

A wire can hardly be any thinner. But the record-breaking dimensions of graphene wires not only offer new opportunities, they also confront physicists with challenges. Leonhard Grill and his colleagues at the Berlin Fritz Haber Institute of the Max Planck Society have now taken on these challenges. They began by producing a narrow graphene ribbon, its design based on their own work and that of others. Firstly, they vaporised molecular snippets of graphene strips onto a surface. The molecules were provided with chemical bonds so that they initially combined into a long chain and finally formed a flat, rigid ribbon.

A delicate touch is needed to measure the conductance of nanowires

Then the researchers in Leonhard Grill's group started their real project: they measured the conductance of one individual nanowire as a function of its length. "This enables us to find out how the charge transport in the graphene nanowire works," explains Leonhard Grill. This approach primarily allows the researchers to find out whether their nanowire is a perfect conductor whose conductance does not vary with length, as would be the case with a metal nanowire. The researchers obtained their findings in a tricky experiment: they determined the current flow through one individual graphene ribbon, which connected the tip of a scanning tunnelling microscope with a gold surface, at different voltages, that is electron energies, and at different distances.

This meant they initially had to lift the nanowire up off the surface. This is like lifting a scrap of paper with a wet finger, except that lifting up the nanowire requires an infinitely more delicate touch. "The wire easily drops down again, particularly at higher voltages between the tip and the gold surface," explains Matthias Koch, who conducted the experiments as part of his doctoral work. "Although we now have some tricks for keeping hold of the graphene ribbons with the tip, we still need many attempts."

The edge of the graphene strip affects the charge transport

The measurements showed that the current through the graphene wire did not flow with relatively low resistance as it does through a copper wire. On the contrary, the electrons flowed through the wire by means of a quantum mechanical process: they tunnelled through it. Only quantum particles can tunnel, and they always do this when a barrier which they could not overcome according to the laws of classical physics offers resistance. The particles get through the barrier nevertheless only because of their quantum properties. The larger the distance which the electrons have to overcome, the fewer arrive at the other side. "The conductance in a nanowire therefore depends greatly on its length," says Matthias Koch. In addition, significantly less current flows overall in the tunnelling process than in the charge transport in a conventional conductor.

The scientists also showed for the first time how the charge transport depends on the electron energy. If they select the electron energy so that it matches the energy of the molecular orbitals, the charge transport immediately improves. Orbitals are the spaces in atoms and molecules which electrons, each having a precisely defined energy, occupy. "Molecular orbitals serve as channels which extend over the whole molecule and allow efficient charge transport," says Leonhard Grill. "If we are outside these channels, energetically speaking, then the charge transport is dramatically restricted." This behaviour has been suspected for some time, but the Berlin researchers have now demonstrated it on an individual molecule for the first time.

The graphene ribbons are therefore interesting research objects for the physicists, but they are not yet very suitable for applications in nanoelectronics. Nevertheless, a further finding from their experiments points the Berlin researchers in the direction of a perfect nanowire: the nature of the electron transport depends on how the edge of the strip is formed. The scientists differentiate between a zigzag and an armchair structure. With the armchair structure the carbon atoms are arranged such that their silhouette resembles a row of seats and armrests, while with the zigzag pattern they follow a simple up and down.

The conductance changes if the wire is bent

In order for such a nanowire to really exhibit perfect conductance – regardless of the molecular length – the scientists at the Fritz Haber Institute must change their experiment as well. When the tip of the scanning tunnelling microscope lifts the graphene ribbon from the gold surface, the strip bends slightly. This changes its electronic characteristics, just as water flows through a straight river bed unobstructed, yet experiences strong turbulence around narrow bends. "We have seen indications that we can observe outstanding conductance in a graphene ribbon which is not bent," says Leonhard Grill.

The physicists therefore now want to design experiments which allow conductance measurements with straight nanowires. Simply measuring a graphene ribbon lying on a level surface will not instantly produce the desired result. "In an experimental setup like this, the conductance of the carbon strip is influenced by the surface it is lying on," explains Leonhard Grill. His group is therefore looking for ways of avoiding these interactions. Furthermore, the Berlin scientists want to investigate molecular wires with different structures and compositions – always with a view to getting molecules to do the arithmetic, as Leonhard Grill explains: "The aim of our work is to gain a fundamental insight into the physical processes in such systems in order to eventually not only find the perfect nanowire, but also design further electronic components from individual molecules."

More information: Koch, M., et al. Voltage-dependent conductance of a single graphene nanoribbon. *Nature Nanotechnology*, 14 October 2012, Vol. 7, page 713.

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