New nanodevice builds electricity from tiny pieces

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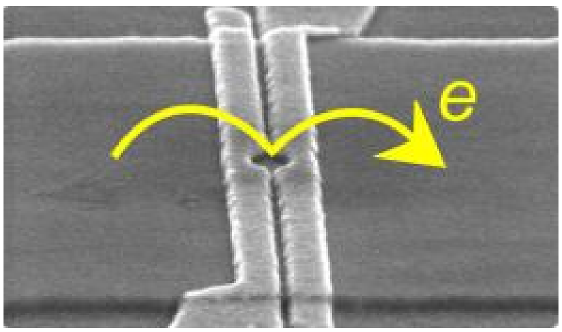

Scanning electron microscope image of the electron pump. The arrow shows the direction of electron pumping. The hole in the middle of the electrical control gates where the electrons are trapped is ~0.0001 mm across.

(Phys.org) -- A team of scientists at the National Physical Laboratory (NPL) and University of Cambridge has made a significant advance in using nano-devices to create accurate electrical currents. Electrical current is composed of billions and billions of tiny particles called electrons. They have developed an electron pump - a nano-device - which picks these electrons up one at a time and moves them across a barrier, creating a very well-defined electrical current.

The device drives electrical current by manipulating individual electrons, one-by-one at very high speed. This technique could replace the traditional definition of electrical current, the ampere, which relies on measurements of mechanical forces on current-carrying wires.

The key breakthrough came when scientists experimented with the exact shape of the voltage pulses that control the trapping and ejection of electrons. By changing the voltage slowly while trapping electrons, and then much more rapidly when ejecting them, it was possible to massively speed up the overall rate of pumping without compromising the accuracy.

By employing this technique, the team were able to pump almost a billion electrons per second, 300 times faster than the previous record for an accurate electron pump set at the National Institute of Standards and Technology (NIST) in the USA in 1996.

Although the resulting current of 150 picoamperes is small (ten billion times smaller than the current used when boiling a kettle), the team were able to measure the current with an accuracy of one part-per-million, confirming that the electron pump was accurate at this level. This result is a milestone in the precise, fast, manipulation of single electrons and an important step towards a re-definition of the unit ampere.

As reported in Nature Communications, the team used a nano-scale semiconductor device called a 'quantum dot' to pump electrons through a circuit. The quantum dot is a tiny electrostatic trap less than 0.0001 mm wide. The shape of the quantum dot is controlled by voltages applied to nearby electrodes.

The dot can be filled with electrons and then raised in energy. By a process known as 'back-tunneling', all but one of the electrons fall out of the quantum dot back into the source lead. Ideally, just one electron remains trapped in the dot, which is ejected into the output lead by tilting the trap. When this is repeated rapidly this gives a current determined solely by the repetition rate and the charge on each electron - a universal constant of nature and the same for all electrons.

The research makes significant steps towards redefining the ampere by developing the application of an electron pump which improves accuracy rates in primary electrical measurement.

Masaya Kataoka of the Quantum Detection Group at NPL explains: "Our device is like a water pump in that it produces a flow by a cyclical action. The tricky part is making sure that exactly the same number of electronic charge is transported in each cycle.

The way that the electrons in our device behave is quite similar to water; if you try and scoop up a fixed volume of water, say in a cup or spoon, you have to move slowly otherwise you'll spill some. This is exactly what used to happen to our electrons if we went too fast."

Stephen Giblin also part of the Quantum Detection Group, added: "For the last few years, we have worked on optimising the design of our device, but we made a huge leap forward when we fine-tuned the timing sequence. We've basically smashed the record for the largest accurate single-electron current by a factor of 300.

Although moving electrons one at a time is not new, we can do it much faster, and with very high reliability - a billion electrons per second, with an accuracy of less than one error in a million operations.

Using mechanical forces to define the ampere has made a lot of sense for the last 60 or so years, but now that we have the nanotechnology to control single electrons we can move on.

The technology might seem more complicated, but actually a quantum system of measurement is more elegant, because you are basing your system on fundamental constants of nature, rather than things which we know aren't really constant, like the mass of the standard kilogram."

More information: The full paper, published in Nature Communications, can be found here: www.nature.com/ncomms/journal/ … /abs/ncomms1935.html

Provided by National Physical Laboratory