Electrons surfing on a sound wave

Single-electron circuitry is a promising route for processing quantum information, but it requires a mechanism to transport single electrons from one functional part of the circuit to another. Until now, this has only been possible between quantum dots (small electronic islands that can contain as little as a single electron) if they are spaced extremely close to each other. However, when propelled by a sound wave, a single electron can be transferred between two distant quantum dots with very high fidelity. This opens new avenues in the field of quantum computing with electrons.

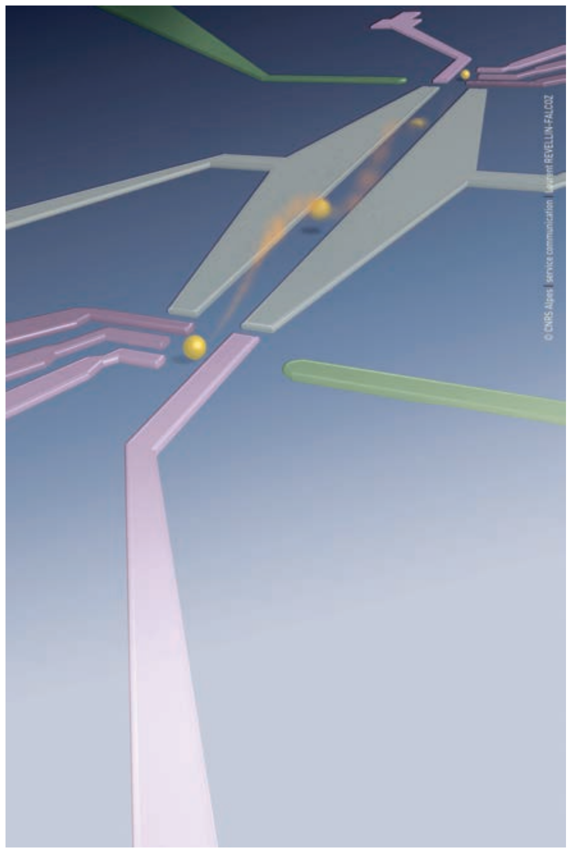
A single electron can be isolated in a small region of a two-dimensional electron gas that is sandwiched at the interface between two semiconductors GaAs and AlGaAs. To achieve this, negative voltages are applied to electrostatic gates deposited on the surface of the semiconductor (areas represented in magenta in Fig. 1). A sufficiently high voltage depletes the underlying region to the point where only a single electron remains trapped, within a so-called quantum dot formed by the electric field. In such structures, one can perform efficient quantum manipulations that operate on the spin of the electron.

To use the quantum properties of the electron spin in computation, an important requirement is to be able to interconnect distant quantum dots and to displace a single electron within a semiconductor chip in a controlled manner. However, for distances greater than a few hundred nanometers, this has remained a challenge. In a recent experiment, our research team at the Néel Institute has finally achieved this goal.

Working with colleagues from the University of Tokyo and the Ruhr University, Bochum (Germany), we have demonstrated that a single flying electron – an electron "surfing on a sound wave" - can be sent on demand from one quantum dot via a one dimensional quantum channel – the "quantum bus" – and re-trapped in a second quantum dot, after propagation, with very high efficiency.

The quantum bus consists of a several microns long region that is entirely depleted of electrons, within the two-dimensional electron gas. It is defined by the two large (grey-coloured) gate electrodes shown in Fig. 1. Initially, a single electron is trapped within the left quantum dot defined by the electrostatic gates highlighted in magenta. Utilizing the piezoelectric properties of GaAs, we can generate a sound wave that propagates at the surface of the chip. When we trigger the sound wave, the electron is literally expelled from the quantum dot, propelled through the quantum bus and captured in the second quantum dot.

With a sound velocity of approximately 3000 m/s this voyage takes only a few nanoseconds. Moreover, we have demonstrated that transfer of the electron could be launched on demand at a timescale smaller than the coherence time (the time over which phase information is lost) in GaAs spin "qubits" (quantum bits), an important ingredient necessary for the distant manipulation of qubits. Our demonstration of single-electron transfer between two distant quantum dots brings the technology a step closer to this goal.



Artist's view of single electron transport between two distant quantum dots, assisted by a sound wave. The two quantum dots, defined by the electrostatic gates coloured in magenta, are interconnected by a long "quantum bus" (grey). A single electron, trapped initially in the left quantum dot, is propelled by a sound wave towards the second quantum dot, at distance 3 microns.

CONTACTS

Christopher BAUERLE
christopher.bauerle@grenoble.cnrs.fr

Tristan MEUNIER
tristan.meunier@grenoble.cnrs.fr

Ph.D STUDENT

Sylvain HERMELIN

FURTHER READING

ELECTRONS SURFING ON A SOUND WAVE AS A PLATFORM FOR QUANTUM OPTICS WITH FLYING ELECTRONS

S. Hermelin, S. Takada, M.Yamamoto, S. Tarucha, A. D. Wieck, L. Saminadayar, C. Bäuerle & T. Meunier
Nature 477, 435 (2011).