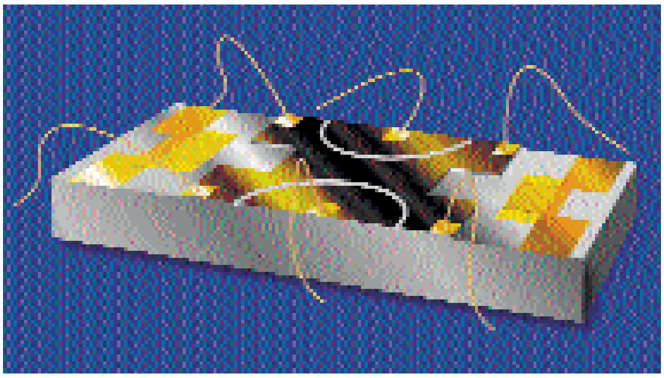
Research Matters

Single-electron transport and quantum current standards

How the Heliox ^{3}He refrigerator is helping NPL's quantum computing research

Dr Jan-Theodoor Janssen and his team at the National Physical Laboratory are using the controlled transport of individual electrons to develop a prototype quantum standard of current. Oxford Instruments supplies the cryogenic capability of the experimental set-up, allowing for wide-ranging variation of the sample temperature.



Schematic illustration of a SETSAW device. The constriction in the middle forms a 1D channel for the electrons and its width can be controlled by applying static voltages to the side contacts. The IDTs are placed on both sides of the device which allow current to be generated in both directions.

Transporting single electrons

The manipulation of individual single electrons has become possible as a result of the steady advances in nano-lithography over the last 10 years. Today the transport of single electrons can be routinely achieved at very low temperatures in specially designed circuits having critical dimensions of several hundred nano-meters or less. In single-electron transport devices electrons can be clocked through a circuit at a certain frequency. The resulting electrical current (I) through the circuit is the electron charge (e) times the clock frequency (f). If the frequency is locked to a standard, a fundamental or quantum standard of current is generated. A quantum standard of current will be of great interest to the metrological community concerned with the derivation of electrical units from basic physical laws and dissemination of these for commercial calibrations. This is because a quantum standard of current would complete the so-called "metrological triangle" of connections between the already existing electrical standards of resistance and voltage which are based on the quantum Hall effect and the Josephson effect respectively and the new quantum standard of current.

An acousto-electric current device

At the National Physical Laboratory (NPL) research is focused on single electron transport by a surface acoustic wave (SETSAW) technique to develop a new quantum standard of current.

The basis for the SETSAW device is a GaAs-GaAlAs heterostructure which contains a two dimensional electron gas (2DEG) just underneath the surface. By means of electron beam lithography a narrow constriction (approximately 100 nm) is created in the 2DEG which serves as a very narrow one-dimensional (1D) channel for the electrons. Using the same technique interdigitated transducers (IDTs) are produced on either side of the channel which serve as antennas to launch the surface acoustic waves.

When a surface acoustic wave propagates on a piezoelectric substrate (such as GaAs), a wave of electrostatic potential travels along with it and can interact with electrons in the substrate. In the SETSAW device the wave drives electrons through the 1D channel and a situation can be created where each cycle of the wave "pushes" exactly an integer number of electrons though the channel, resulting in a current I=nef, where an n is a small integer. This technique can be made to operate at gigahertz frequencies, thereby creating nano-amps of quantised current.

Oxford Instruments have supplied the researchers with a HelioxVL ^{3}He cryogenic insert, with a sample holder in a vacuum, allowing for variation of the sample temperature between 300 mK and approximately 80 K which has enabled a detailed study of the temperature dependence of the current quantisation. Successful demonstration of the SETSAW principle as a quantum standard of current will strengthen the NPL's electrical research supporting many calibration services. In addition the technology for manipulation of individual electrons is relevant to more general applications, such as for example quantum information transmission and quantum computing.

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