

Counting electrons one by one - Measurement of very small electrical currents

The ongoing process of downscaling the size, and reducing the dissipation, of integrated circuits in electronics, particularly those which are portable and battery operated, is leading to the reduction of the electrical currents that flow through these circuits. The challenge of measuring and controlling such small (sub nano-ampere) electrical currents is becoming more and more important to the electronics industry.

Using present day nanotechnology techniques, electronic devices can be fabricated down to sizes that enable the manipulation of individual electrons. High-speed operation of these nano-devices makes them suitable for use not only as high-precision instruments for measuring very small electrical currents, but also to produce a standard of current (ampere) that is based on fundamental constants, and therefore independent of time, location and environmental conditions.

The Technology

The problem addressed is the lack of instrumentation for accurate and traceable measurements of electrical current smaller than one nano-ampere. **The COUNT project aims to develop both instrumentation and the related fundamental measurement standards.**

The way proposed to take up this challenge is to exploit the phenomenon of single electron transport (**SET**). **SET** nano-devices provide a means of manipulating individual electrons and detecting the motion of these electrons with extraordinary precision. They consist of metallic islands that are small enough to make the absence or presence of a single extra electron energetically important. In this way, they can "store" individual electrons for hours. Tunnel junctions, formed by insulating oxide layers of typically a few nano-metre (nm) thick and 20x40 nm wide, separate the islands. By manipulating the voltages of nearby "gate" electrodes, electrons can be made to individually flow, by "tunnelling" from island to island, thus generating a current I that is equal to the frequency f of clock pulses times e , the electron charge (a universal constant):

$$I = e \cdot f$$

The amplitude of this current is typically of the order of a few pico-ampere (pA), with uncertainties smaller than one part per million, i.e. within tens of electrons per second.

In the **COUNT** project two complementary **SET** instruments will be developed. The first is a **SET current source**, based on a so-called electron pump, for current generation up to a few pA, with an uncertainty of 1 part in 10^6 . The second is a **SET current meter** called single electron counter for currents up to a few pA with an uncertainty of 1 part in 10^6 .

The expected **exploitable project outputs** are:

- A **quantum primary standard** for electrical current (ampere), with, as a spin off, a quantum standard for capacitance.
- A **current measurement device** for extremely low currents.

Achievements

The **COUNT** project is now in its third year. The targets for the first two years have essentially been achieved.

The highlights are:

- **Single electron counter as a current meter**

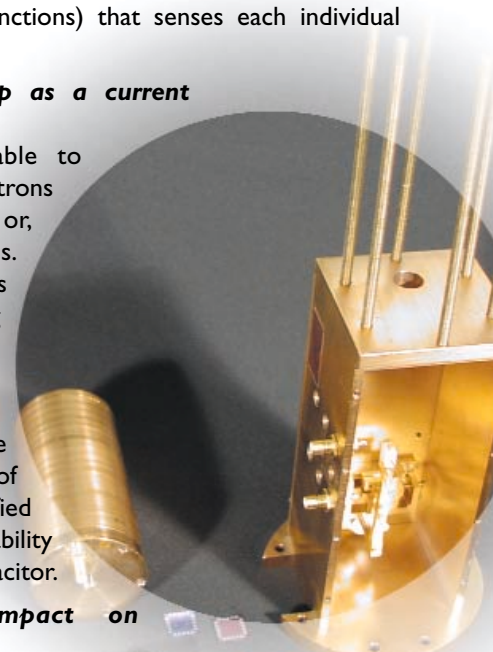
A small current is applied to an array of typically 50 islands with tunnel junctions in between. One of the islands is coupled to a single electron transistor (itself consisting of a single island with two junctions) that senses each individual passing electron.

- **Single electron pump as a current source**

An electron pump able to actively transport electrons one by one, with 3, 4 or, if necessary, 5 junctions. Sufficient accuracy is obtained by depositing on-chip resistive elements (7 nm thick, 80 nm wide, 10 μ m long) in series with the pump. The accuracy of the pump is being verified by charging a high stability tuneable cryogenic capacitor.

- **Knowledge and impact on metrology**

The project will provide the basis for future measurement technology and the definition and establishment of the fundamental current standards. The project has also developed advanced fabrication processes for nano-electronics devices.



The Project Team

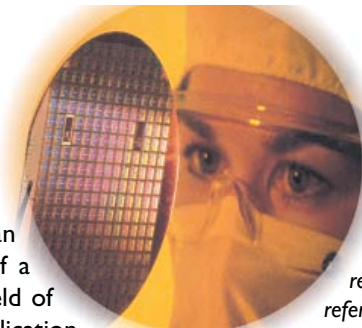
The project team consists of six prominent European metrological institutes and a department of physics of a University. All partners have a proven record in the field of high accuracy measurements and in research on the application of single electron effects. The inclusion of several partners with comparable profile is a major requirement in the project, because of the international role to harmonise high precision measurements and because of the size of the technological effort.

Application examples

The direct use of the project results will be mainly by metrology and research institutes. However its indirect relevance and European impact will be much larger, since industry leans heavily on traceability, precision measurements and technological knowledge. Manufacturers of high precision, low current sources and meters will have their equipment calibrated against these standards.

Traceability of small electrical current is of importance for other reference standards. The common denominator is "detectors for small signals". For instance, light detectors (trap detectors) used in telecommunications generate small electrical currents. Another example which requires a practical method for traceability is the measurement of radioactive radiation by means of ionisation dosimetry (radiation is transferred to a small electrical current).

The use of SET instrumentation is limited by the need for cryogenic cooling below 50 milli-Kelvin (mK). However, a range of applications may be foreseen in fields where commercially available pico-ampere meters fail. An example is for the high quality testing of silicon wafers. In the longer term, SET devices may be used as elements of quantum computers.



Glossary

Measurement standard: measuring system intended to define, realise, conserve or reproduce a value of a quantity to serve as a reference.

Picoampere: 10^{-12} ampere = 6,25 million electrons per second (pA)

Single electron device: device based on single electron transport (SET)

Traceability: Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

Tunnelling: ability for particles (electrons) to penetrate classically forbidden regions

Tunnel junction: interface between layers with different electrical properties, engineered so as to allow and detect tunnelling.

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Count

Contract number: G6RD-CT-1999-00046

Start date: 01.01.2000

End date: 31.12.2002

Duration: 36 months

Project cost: 2 250 000 euros

Funding: 1 340 000 euros

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Physikalisch-Technische Bundesanstalt

National metrology and safety institute
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Braunschweig (D)

Federal Office of Metrology and Accreditation

National metrology institute
<http://www.metas.ch>

Bern (CH)

Useful links

<http://www.cordis.lu/nanotechnology/home.html>

<http://europa.eu.int/comm/research/growth/>

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Release May 2002