Department of Physics & Astronomy

PHYSICS NEWS FLASH

Electrical Properties of Atom Wires Unravelled

UT and Delft scientists reveal new behavior of electrons in atomic wires with unparalleled resolution

February 22, 2006

UT's Hanno Weitering and his fellow scientists from Stichting FOM and the Kavli Institute of Nanoscience Delft (The Netherlands) have clarified the way electrons confined in an atom wire behave. Such wires, being only one atom wide, are a source of fundamental knowledge on electrical conduction and open up a vista on a new generation of chips that are orders of magnitude smaller than the current generation. It was already known that electrons in atom wires arrange themselves in a smart way. Dr. Weitering and the Delft scientists have discovered that it is possible to have more than one different arrangement of electrons in a single atom wire. The team also succeeded in visualizing a fundamental quantum mechanical property of these ultra-small wires at the atomic scale by using a Scanning Tunneling Microscope. This finding is of vital importance for the research on ultra-small chips that are governed by the laws of quantum mechanics. The results will be published in the leading journal *Physical Review Letters*.

Necklace of atoms
Atom wires generate a lot of attention because of their dimensions: an atom is typically on the order of 0.5 nanometer (a nanometer is one-billionth of a meter). Depending on their properties they could serve as interconnects in future atomic or molecular scale computer chips. Instead of neatly placing the atoms in a row with a Scanning Tunneling Microscope, there is a smarter way: make nature do the job for you. This principle is called self-organization.

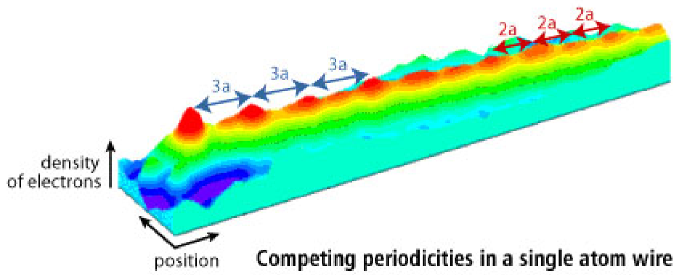
The team, consisting of Dr. Weitering and Paul Snijders and Sven Rogge from Delft, produced atom wires using this approach. Gold atoms were evaporated in an ultra-high vacuum and deposited on a special kind of silicon surface. This surface is sawed from a silicon crystal in a deliberately slanted way in order to generate a periodic "flight of stairs" made of the planes of atoms arriving under an angle at the surface. It appears that in this environment the gold atoms organize themselves in perfect rows parallel to the steps of the stairway – atom wires have been fabricated, resembling the chain of beads in a necklace, but instead made of atoms.

Electrons in an atom wire
Electrons always have a negative charge and therefore avoid each other. But in the atom wires studied here they cannot dodge one another because the diameter of the wire, being only one atom wide, is too small for evasion. A phenomenon that can occur in such wires is the formation of a so-called Charge Density Wave (CDW) – a periodic modulation of the density of charge. Electrons cluster in a spatial undulating pattern, with a wavelength exactly fitting an integer amount the interatomic distance in the wires. Generally, by transforming to this smart arrangement, the system attains a more favorable state with a lower energy; the so-called "ground state" has been reached. But the measurements in Delft show that this is not always the case.

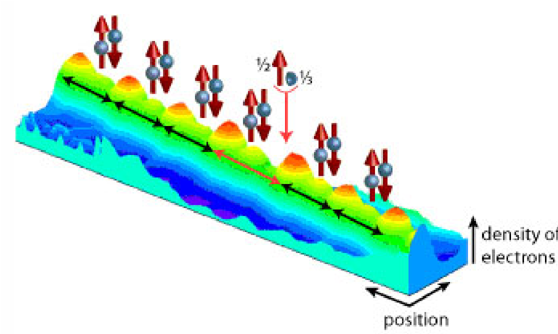
Two transitions
The experiments in Delft were performed with a Scanning Tunneling Microscope capable of imaging surfaces with atomic resolution. These measurements showed, surprisingly, that in these self-organized wires two transitions with different wavelengths take place, one after the other. A doubling of the wavelength was observed when the system was cooled down from room temperature. The measurements indicate that this is a conventional Charge Density Wave. But fully unexpected at lower temperatures was the observation of another transition in the same atomic wire, this time having a tripled wavelength. At intermediate temperatures both states can even be observed to coexist in the wires. It is the first time that two subsequent Charge Density Wave transitions are observed in one chain.

Fractional electrons
The UT-Delft way of studying atom wires with an STM generates yet another unique result: the observation of phase slips. Phase slips are locations where the periodicity of the CDW makes a "mistake;" in between wavelengths of three atomic distances suddenly one period of four atomic distances is located. Nobel laureate Schrieffer already predicted in 1981 that these "mistakes" possess a charge equal to ?1/3 or ?2/3 of an electron charge – despite the fact that electrons cannot be split at all!

Also the magnetic moment of the electron (spin) exhibits this peculiarity; these phase slips either have no spin at all or half a spin. The exceptionality of these experiments is that this is the very first time that such fractional quantum numbers are accessible for further research in a spatially resolved experiment.



Competing periodicities in a single atom wire



Fractional quantum numbers in a phase slip

Competing periodicities in fractionally filled one-dimensional bands
P.C. Snijders, S. Rogge, H.H. Weitering
Physical Review Letters (February 24, 2006)