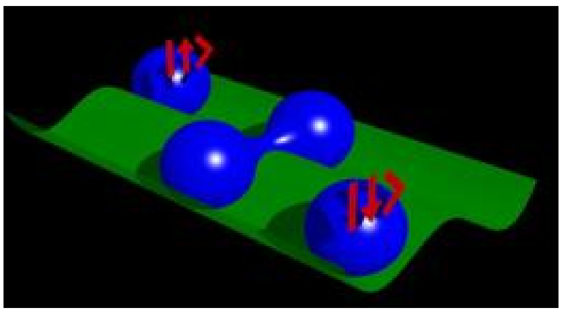
How the alphabet of data processing is growing: Research team generates flying 'qubits'

March 21 2012



Electron one-way street In this dual channel, electrons (blue) move on defined, parallel paths. Only one single electron fits through at a time. By means of tunnel coupling, the electron can switch back and forth between the channels, thus occupying two different states, which are denoted by “arrow up” and “arrow down”. The electron virtually flies in both tracks at the same time, its two states overlap. © Andreas Wieck

The alphabet of data processing could include more elements than the "0" and "1" in future. An international research team has achieved a new kind of bit with single electrons, called quantum bits, or qubits. With them, considerably more than two states can be defined. So far, quantum bits have only existed in relatively large vacuum chambers. The team has now generated them in semiconductors.

They have put an effect in practice, which the RUB physicist Prof. Dr.

Andreas Wieck had already theoretically predicted 22 years ago. This represents another step along the path to quantum computing. Together with colleagues from Grenoble and Tokyo, Wieck from the Chair of Applied Solid State Physics reports on the results in the journal *Nature Nanotechnology*.

The basic units of today's data processing are the bit states "0" and "1", which differ in their electrical voltage. To encode these states, only the charge of the electrons is crucial. "Electrons also have other properties though" says Wieck, and these are exactly what you need for quantum bits. "The extension from bits to quantum bits can dramatically increase the computational power of computers" says the physicist.

A quantum bit corresponds to a single electron in a particular state. Together with his colleagues, Wieck used the trajectories of an electron through two closely spaced channels for encoding. In principle, two different states are possible: the electron either moves in the upper channel or in the lower channel – which would then only form a binary system again. According to quantum theory, however, a particle can be in several states simultaneously, that is, it can quasi fly through both channels at the same time. These overlapping states can form an extensive alphabet of data processing.

In order to generate quantum bits with different states, the researchers allowed individual electrons to interfere with each other. This works with the so-called Aharonov-Bohm effect: powered by an external voltage, the electrons fly through a semiconducting solid. Within this solid, their trajectory is first forked and then reunited. Thus, each electron flies simultaneously on both possible paths. When the two paths come together again, there is interference, i.e., the two electron waves overlap and quantum bits with different overlapping states are generated.

Normally, an electron wave moves through a solid body on many different paths at the same time. Due to impurities in the material, it loses its phase information and thus its ability to encode a particular state. To maintain the phase information, the researchers at the RUB grew a high-purity gallium arsenide crystal and used a dual channel proposed by Wieck more than 20 years ago.

An electron reaches the fork via two closely spaced channels. These are coupled with each other (tunnel-coupling), so that the electron flies simultaneously on two different paths. The phases of the electron waves are maintained by the coupling. The same dual channel was also used by the team after the electron waves were reunited at the end of the fork. In this way, they produced quantum bits with clear states which are suitable for encoding information. "Unfortunately, not all the electrons take part in this process, so far it's only a few percent" commented Wieck. "Some students in my department are, however, already working on growing crystals with higher electron densities".

More information: M. Yamamoto, S. Takada, C. Bäuerle, K. Watanabe, A.D. Wieck, S. Tarucha (2012): Electrical control of a solid-state flying qubit, *Nature Nanotechnology*, doi: 10.1038/nnano.2012.28

Provided by Ruhr-University Bochum