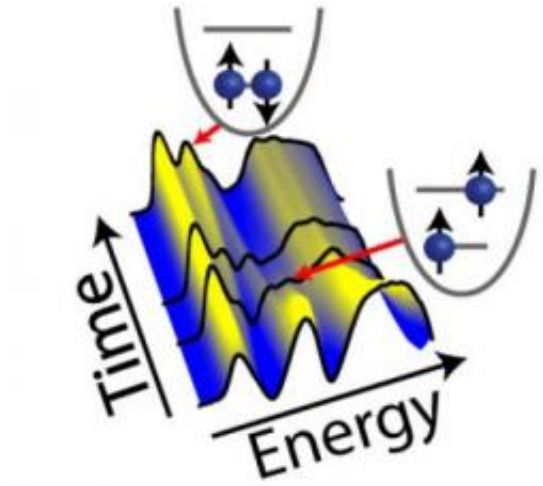
Direct electronic readout of 'artificial atoms'

February 25 2011



Distribution of energy of the occupied electronic states in a QD ensemble and their evolution time: An excited state is occupied in the second curve from the front, which changes to the ground state in the subsequently adopted rear-most curve, as all electrons 'drop' into allowed lower energy states. The occupations of the states is schematically depicted in the gray parabolas that symbolize the confinement-potential of QDs. Credit: RUB

In addition to flows of electrons, researchers are seeking options for the spin of electrons to be used in future information processing. In combination with these characteristics, a considerably larger volume of information can be stored than merely "zero" and "one." Because this is difficult with individual atoms, German physicists at Ruhr-University Bochum place "artificial atoms" into solids.

Through his participation, the research team from Bochum, Duisburg-

Essen, and Hamburg now has succeeded in an energy-state occupancy readout of those artificial atoms – using common interfaces to classic computers. This is a big step towards the application of such systems. They report about their findings in *Nature Communications*.

One million instead of individual atoms

In principle, the spin of electrons in individual atoms can be read-out, but the minuteness of the signals and the difficulty of localising individual atoms limit this technology to highly specialised laboratories. It requires an ultra-high vacuum and costly laser technology. 'It would be considerably more elegant to incorporate atom-like systems into solids,' said Prof. Wieck. In this case, quantum mechanics are helpful: For standard electron densities in semiconductors, the wavelength of electrons (and holes) is several tens of nanometres (nm), which means a distance of 100 atoms. It therefore is not necessary to isolate or insert individual atoms. It suffices to define areas that expand in each direction by about 100 atoms, thus comprising around 1003 = one million atoms. 'But even that is not all that simple, because today's high-level integration controls a resolution that reaches only down to around 50nm,' explained Prof. Wieck.

Trick: Stacking oranges on mandarins

Here is a little useful trick that relates to the inter-atomic distance in the crystal lattice: Electrons prefer residing in indium arsenide (InAs) than in gallium arsenide (GaAs). Since indium is a considerably larger atom than gallium, one can sonsider the compressive stress of an InAs layer on GaAs in the same way as when stacking oranges on top of mandarins. The first layer or oranges (InAs) is arranged so that the oranges on top of the mandarins (GaAs) are 'squeezed', which results in a 'strained' layer. The second orange (InAs) layer must be strained as well, but if several of

such layers are placed on top of one another, the orange system 'forgets' its underlying mandarin layer order. The strain 'relaxes', which means it causes defects and gaps and piles up the oranges into individual heaps. Such InAs heaps – InAs quantum dots or 'QD' (derived from the English term 'Quantum Dots') – therefore grow in a self-organised way. They are several 10nm wide and around 5nm high, and therefore are ideally suited for the quantum mechanical charge carrier inclusion. It is just large enough to fit into a wavelength of electrons and/or electron holes. The QDs force the electrons into quantified energies by means of which they can be used as 'artificial atoms' for information processing purposes.

10 million times smaller than a hamburger

For several years now, the Bochum researchers have been producing the most homogenous QD 'ensembles': All produced QDs practically have the same size and, because of their flat bottom, resemble a 'hamburger' top, but are around 10 million times smaller. 'We place a few electrons into each QD of an QD ensemble comprising one million QDs, in which we start with the lightest, namely hydrogen, helium and lithium,' explained Prof. Wieck. So far, the energy levels containing these electrons have been read out only by means of optical methods. 'This may be very elegant, but requires an extensive measuring operation with specialised lasers, detectors and spectrometers', explained Wieck. During the actual work, the researchers adopted quite a different approach: They prepared the QDs on (close to) a conducting layer of electrons and only measured the electric resistance of this layer, which changes with the QD's electron occupation. 'Consequently, this gives us direct electronic access to the occupied states in the QDs and these are capable of being read with the common interfaces of classic computers.'

More information: B. Marquardt, M. Geller, B. Baxevanis, D. Pfannkuche, A. D. Wieck, D. Reuter, and A. Lorke: Transport spectroscopy of non-equilibrium many-particle spin states in self-

assembled quantum dots. In: *Nature Communications*, 22.2.2011, doi: 10.1038/ncomms1205