HL 11: Quantum dots and wires: Transport properties I

Time: Monday 14:45–17:30 Location: H15

HL 11.1 Mon 14:45 H15

Quantum gates between capacitively coupled double quantum dot two-spin qubits — •Dimitrije Stepanenko and Guido Burkard — Department of Physics and Astronomy, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

We study the two-qubit controlled-not gate operating on qubits encoded in the spin state of a pair of electrons in a double quantum dot. We assume that the electrons can tunnel between the two quantum dots encoding a single qubit, while tunneling between the quantum dots that belong to different qubits is forbidden. Therefore, the two qubits interact exclusively through the direct Coulomb repulsion of the electrons. We find that entangling two-qubit gates can be performed by the electrical biasing of quantum dots and/or tuning of the tunneling matrix elements between the quantum dots within the qubits. The entangling interaction can be controlled by tuning the bias through the resonance between the singly-occupied and doubly-occupied singlet ground states of a double quantum dot.

HL 11.2 Mon 15:00 H15

Scaling analysis of transport properties of GaAs-based nanocolumns — •Jakob Wensorra[1], Klaus Michael Indlekofer[1], Mihail Ion Lepsa[1], Katharina Peter[1], Arno Förster[2], and Hans Lüth[1] — [1]Centre of Nanoelectronic Systems for Information Technology (IBN-1), Research Center Jülich, 52425 Jülich, Germany — [2]Aachen University of Applied Sciences, Section Jülich, D-52428 Jülich, Germany

Semiconductor nanocolumns are ideal systems not only for basic research in the field of quantum transport but also for finding novel nanodevice concepts for information technology. By means of built-in heterostructures, one can easily implement tunnel barriers and quantum well structures within such nanocolumns, with tailored electronic transport properties.

We present a scaling analysis of quantum transport properties of GaAs-based resonant tunnelling nanocolumns down to 30 nm lateral dimensions. The electronic transport properties of the smallest devices are strongly influenced by the lateral depletion region, which defines the vertical conductive channel within the device. Simulations of the 2D-potential map of the device structure suggest a transport model based on a quantum collimation effect due to a saddle point in the potential profile. For structures with a lateral dimension of 60 nm - 45nm, this quantum collimation effect leads to a distinct improvement of the nanodevice performance at room temperature. For the lowest dimensions (< 45 nm) we observe a degradation of device performance due to a depletion of the channel within the nanocolumns.

HL 11.3 Mon 15:15 H15

Trägheitsballistische Gleichrichtung und Halleffekt in nanoskaligen Si/SiGe-Kreuzstrukturen — •Egmont Fritz[1], Ulrich Wieser[1], Ulrich Kunze[1] und Thomas Hackbarth[2] — [1]Werkstoffe und Nanoelektronik, Ruhr-Universität Bochum, D-44780 Bochum — [2]DaimlerChrysler Forschungszentrum Ulm, D-89081 Ulm

Wir untersuchen den Einfluss eines externen Magnetfeldes auf den trägheitsballistischen Elektronentransport in mesoskopischen Si/SiGe-Gleichrichterstrukturen. Ausgehend von einer Si/SiGe-Heterostruktur mit einem eingebetteten 2DEG hoher Elektronenbeweglichkeit werden laterale gabelförmige Strukturen präpariert, bei denen drei 250 nm breite parallele Wellenleiter geradlinig in einen 1 μm breiten Stamm münden. Die Bauelementgeometrie erlaubt die Unterscheidung verschiedener Gleichrichtermechanismen. Legt man an die beiden äußeren schmalen Wellenleiter eine antisymmetrische Spannung an, lässt sich sowohl am mittleren Wellenleiter als auch im Stamm ein modenkontrolliertes gleichgerichtetes Spannungssignal messen. Auf Grund der zum Stamm orientierten Impulskomponente der injizierten Elektronen ist im Stamm zusätzlich ein gleichgerichtetes trägheitsballistisches Signal überlagert, das durch Differenzbildung extrahiert werden kann. Wir zeigen die Auswirkungen eines schichtsenkrechten Magnetfeldes auf diese Signale. Wird die Eingangsspannung zwischen dem zentralen Wellenleiter und dem Stamm angelegt, ermöglicht die Geometrie, den Einfluss ballistischer Elektronen auf die Hall-Spannung zu untersuchen, die in dieser Messkonfiguration zwischen den beiden äußeren Wellenleitern abgegriffen wird.

HL 11.4 Mon 15:30 H15

Charge detection for ballistic electron spectroscopy — •Frank Hohls[1,2], Michael Pepper[2], Jonathan P. Griffiths[2], Geb A.C. Jones[2], and David A. Ritchie[2] — [1]Institut für Festkörperphysik, Universität Hannover — [2]Cavendish Laboratory, University of Cambridge, UK

We have shown that a quantum dot can be used for the direct energy resolved detection of ballistic electrons [1]. This allows us to measure the energy and angle distribution of ballistic electrons injected by e.g. a quantum wire or another dot. In the original scheme the usable energy range was limited by the presence of excited states to a few 100 μeV.

Here we will present a modified detector design that allows us to extend the energy range to at least 1 meV. We largely increase the excitation energy by using a small quantum dot on the transition between 0 and 1 electron. The readout is performed by a nearby quantum point contact utilised as charge detector. The average charge on the dot is a direct function of the density of electrons attempting to enter the dot at its resonance energy.

We apply this scheme to assess the energy spectrum of non-equilibrium ballistic electrons that are injected by a quantum point contact and have traversed a few micrometer through a two-dimensional electron system. We discuss the energy distribution and scattering mechanisms.

[1] F. Hohls *et al.*, Appl. Phys. Lett. 89, 212103 (2006).

HL 11.5 Mon 15:45 H15

Transportmeasurements on quantum dots formed in a GaAs/AlGaAs quantum ring — •A. Mühle[1], R. J. Haug[1], and W. Wegscheider[2] — [1]Institut für Festkörperphysik, Universität Hannover, D-30167 Hannover — [2]Angewandte und Experimentelle Physik, Universität Regensburg, D-92040 Regensburg

We present transport measurements of a quantum ring formed in a GaAs/AlGaAs heterostructure. This ring was fabricated by atomic force microscope lithography utilizing local anodic oxidation [1]. Using in-plane gates, the energy of the electrons in the arms of the rings as well as the coupling of the structures to the leads can be controlled.

When the structure is operated in the regime with weak coupling to the leads, sweeping the gates shows different sets of Coulomb-blockade lines, thus revealing the existence of three different dots formed in the arms of the ring.

By analyzing the structure's transport features, the dots are characterized and their spatial distribution in the ring is determined.

[1] U. F. Keyser et al., Phys. Rev. Lett. **90**, 196601-1 (2003)

15 min. break

HL 11.6 Mon 16:15 H15

New aspects of electronic transport in GaAs/AlAs nanocolumns — •Mihail Ion Lepsa[1], Klaus Michael Indlekofer[1], Jakob Wensorra[1], Katharina Peter[1], Arno Förster[2], Hans Lüth[1], and Detlev Grützmacher[1] — [1]Center of Nanoelectronic Systems for Information Technology (IBN-1), Forschungszentrum Jülich GmbH, 52425 Jülich — [2]Fachhochschule Aachen, Abteilung Jülich, Physikalische Technik, Ginsterweg 1, 52428 Jülich

Vertical sub-100nm GaAs nanocolumns with an embedded GaAs/AlAs resonant tunneling heterostructure have been processed using a top down approach [1, 2].

Electronic transport properties are investigated using DC electrical measurements. The results show that specific discrete features in the energy spectrum of the structure can be probed even at room temperature. We observe a multi-peaked I-V curve which is enhanced for a certain range of column diameters. The experimental findings can be explained qualitatively by a transport model based on a non-uniform lateral quantization profile. The latter results from the formation of a saddle-point in front of the double barrier quantum well (DBQW) region [1].

[1] J. Wensorra, K.M. Indlekofer, M.I. Lepsa, A. Förster, and H. Lüth, Nano Letters, 5, 2470 (2005).

[2] J. Wensorra, M.I. Lepsa, K.M. Indlekofer, A. Förster, P. Jaschin-

sky, B. Voigtländer, G. Pirug, and H. Lüth, Phys. Stat. Sol. (a) 203, 3559 (2006).

HL 11.7 Mon 16:30 H15

SOI-Based Single-Electron Transistors Fabricated by a Combination of Self-Assembly and Self-Alignment Techniques

— •Conrad R. Wolf, Klaus Thonke, and Rolf Sauer — Institut für Halbleiterphysik, Universität Ulm, 89069 Ulm

We present a technique to fabricate single-electron transistors (SETs) with silicon quantum dots (QDs) as conducting islands making use of a combination of self-assembly and self-alignment effects. Starting from an ultra-thin silicon-on-insulator (SOI) substrate we employ self-assembled gold colloidal particles as an etch mask. Quantum dots are then fabricated by applying a CF_4 reactive ion etch (RIE) process to remove the silicon layer everywhere except below the gold colloids. A 100-200 nm wide metal wire together with side gate electrodes is patterned by electron beam lithography (EBL) onto the QD-covered sample and a nanometer-sized gap is created in these wires by a controlled electromigration process. The metal wires will preferentially break at the positions of the QDs, because the metal layer is dilated there resulting in a locally higher current density. This leads to a self-alignment effect of the evolving nano-electrodes with respect to the QDs. The native oxide layer covering the silicon QDs is used as a tunneling barrier. Its thickness can optionally be adjusted in a controlled manner by self-limiting thermal oxidation to obtain an accurate tunneling resistance. The devices are electrically characterized at liquid helium temperature and show clear Coulomb blockade behavior, Coulomb staircase features as well as the so-called Coulomb diamonds, typical for SETs.

HL 11.8 Mon 16:45 H15

Nonequilibrium transport through quantum point contacts

— •Andreas Helzel, Leonid Litvin, Werner Wegscheider, and Christoph Strunk — Institut für experimentelle und angewandte Physik, Universität Regensburg, D-93040 Regensburg, Germany

We investigate the nonequilibrium transport properties through a quantum point contact (QPC) defined by split gates on top of a GaAs/AlGaAs heterostructure with a 230 nm deep 2 DEG. At low temperatures the QPC develops a resonant structure in the differential conductance around zero bias below half of a conductance quantum. Then with increasing conductance this resonance splits in two peaks even in absence of magnetic field. Recent theory [1] suggests for this double peak a double Anderson-impurity arising in the QPC. As already measured before, between 0.7 and 1 conductance quantum a Kondo anomaly can be seen. But in our case with satellites next to it, that merge out of the mentioned split peaks. The Kondo effect can appear in a QPC by a trapped spin in a potential valley arising due to the nonlinear screening of the gate potential in the 2DEG.

[1] T. Rejec, Y. Meir, Nature 442 (2006)

HL 11.9 Mon 17:00 H15

Random-telegraph-signal noise and device variability in ballistic nanotube transistors

— •Neng-Ping Wang[1], Stefan Heinze[1], and Jerry Tersoff[2] — [1]Institut für Angewandte Physik, Universität Hamburg, Jungiusstrasse 11, 20355 Hamburg — [2]IBM Research Division, T. J. Watson Research Center, Yorktown Heights, NY 10598, USA

The last few years have seen remarkable progress in carbon nanotube field-effect transistors (CNFETs). High performance and even ballistic transport have been demonstrated, and there is increasing focus on integrating such transistors into operational device circuits. Device integration requires stable and uniform behavior of the individual transistors. However, all materials exhibit some low-frequency electrical noise; and such noise increases inversely with the system size, so it is important to develop a microscopic understanding of noise in nanotubes.

In field-effect transistors, charge trapping in the gate oxide is known to cause low-frequency noise and threshold shifts. Here we calculate the effect of single trapped charges in a CNFET, using the non-equilibrium Greens function method in a tight-binding approximation. We find that a single charge can shift and even rescale the entire transfer characteristic of the device. This can explain both the large "random telegraph signal" (RTS) noise and the large variations between nominally identical devices. We examine the dependence on both the thickness and dielectric constant of the gate dielectric, suggesting routes to reduce electrical noise.

HL 11.10 Mon 17:15 H15

Source gating enhanced threshold hysteresis in electron Y-branch switches with quantum dots

— •Christian R. Müller, Lukas Worschech, Philipp Höpfner, and Alfred Forchel — Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

On the basis of modulation doped GaAs/AlGaAs heterostructures with self-assembled InGaAs quantum dots embedded in the undoped spacer, Y-branched nanojunctions controlled by four independent side-gates were fabricated by electron beam lithography and etching techniques. Charging of the quantum dots in the Y-junction is demonstrated by pronounced threshold hysteresis. Interestingly, the gate voltage at which the quantum dots are discharged shifts to lower values with increasing Fermi energy of the source indicating that the charges in the sources have a considerable gate effect on the channel. In particular, by switching the Fermi energy of the source a drastically enhanced threshold hysteresis was observed.