Nanometer-Scale Science and Technology
Room 210 - Session NS+EM-TuM

Nanoscale Electronic Devices & Detection

Moderator: P. Grutter, McGill University

8:20am **NS+EM-TuM1 Single Electron Spin Detection in Si-Based Semiconductor Structures*, H.W. Jiang,*** UCLA **INVITED**

Several schemes for electron spin based qubit in compound semiconductor structures have been proposed recently for quantum information processing. In order to physically implement any of the proposals, it is essential to measure the state of a single spin. Towards this end, we have done a sequence of measurements to probe the spin state of a single paramagnetic spin center adjacent to a sub-micrometer silicon metal-oxide-semiconductor field-effect transistor. Stochastic switching between two discrete values of channel current, known as random telegraph signal (RTS), has been used as a tool to sense the single spin. Magnetic-field-induced Zeeman splitting of the single spin center was measured. Using microwave radiation, we have observed that the statistical distribution between the two states changes when the electron spin resonance condition is matched. Experiments with a series of pulsed gate voltages showed promise of using the field effect transistor channel for single-shot spin state read-out. Our ongoing effort of single spin measurements in electrostatic quantum dots in a Si/SiGe 2D electron gas will be described.

9:00am **NS+EM-TuM3 Few Electron SiGe Quantum Dots*, L.J. Klein,*** *S. Goswami, K.A. Slinker, S.N. Coppersmith, D. Savage, M.G. Lagally, M.A. Eriksson,* University of Wisconsin

Spins in silicon quantum dots are promising qubits for quantum information processing. Here we present an approach to combine trenchline and metal gates to fabricate quantum dots in modulation doped Si/SiGe heterostructures. Electron-beam lithography and reactive ion etching are used to define single and tunnel coupled double dots. Both Schottky and in-plane two-dimensional electron gas gates are used. Transport measurements at 0.2 K for the single and tunnel coupled double dots show Coulomb blockade with single electron charging. For the double quantum dots a transition from a single to split peaks are observed as voltages applied to the gates became more negative. A transition is observed from a large single dot to two tunnel coupled quantum dot with a well defined tunnel coupling between pairs of quantum dots. The tunnel coupling between the dots is determined by the width of the channel between the dots. To achieve a higher control of the tunnel coupling between the dots we integrate metal gates on the top of the channel in addition to side gates. The fabricated quantum structures are stable over long periods of time with minimal charge noise fluctuations. We also discuss progress towards the achievement of few electron dots using both etched and Schottky gates for electrostatic confinement.

9:20am **NS+EM-TuM4 Top-gated Quantum Dots in Silicon / Silicon-Germanium Two-Dimensional Electron Gases*, K.A. Slinker,*** *L. McGuire, K.L.M. Lewis, C.C. Haselby, S. Goswami, L.J. Klein,* University of Wisconsin - Madison*; J.O. Chu,* IBM Research Division, T. J. Watson Center*; M. Friesen, M.A. Eriksson,* University of Wisconsin - Madison

Electrons in silicon/silicon-germanium two-dimensional electron gas (2DEG) quantum dots are a promising architecture for spin based quantum computation. Schottky gated quantum dots allow precise tuning of electron shape and interdot coupling; however, up until now top gates on Si/SiGe heterostructures have not been used to deplete into the tunneling regime, most likely due to problems with gate leakage. We have overcome these problems by reducing the active 2DEG area into sub-micron mesas and back gating the 2DEG to tune the carrier concentration to be depleted by the top gates. We report on the depletion characteristics of these Schottky gates as well as successful Si/SiGe quantum dot architectures incorporating top gates. For one quantum dot device, an 800 nm channel is fabricated by electron beam lithography and subsequent reactive ion etching. Metal gates are deposited across the channel to define the leads of the dot, and an etch-defined side gate is used to vary the potential in the dot. The sides of dot are defined by surface depletion from the etched sidewalls. In another device, six metal gates are used to electrostatically define the dot on all sides - a set of pincher gates on each lead and two plunger gates. Properties of the dots are presented and compared.

9:40am **NS+EM-TuM5 Spin Physics in Few-Electron Quantum Dots*, L. Kouwenhoven,*** Delft University of Technology, The Netherlands **INVITED**

Few-electron quantum dots are realized in various semiconductor materials. The conventional system for transport studies is an AlGaAs/GaAs heterostructure in which quantum dots are defined by surface gates. We have studied the spin states in one and two-electron dots. The spin states are resolved in a magnetic field that splits the one-electron spin states and also the triplet states for two electrons. We manipulate the spin states using a pulse technique that allows to determine the spin of individual electrons. As a spin off we measure the spin relaxation times under various circumstances (e.g. magnetic field). The obtained time scales are in good agreement with theory based on spin-orbit and hyperfine interaction. A new class of materials are semiconductor nanowires. We have fabricated quantum dot devices in InP and InAs wires with diameters around 50 nm. We observe discrete states and resolve Zeeman splitting of the spin states in a magnetic field. In addition we have used superconducting contacts to bias the nanowires with supercurrents.

10:20am **NS+EM-TuM7 Single Spin Detection Using Magnetic Resonance Force Microscopy*, H.J. Mamin,*** IBM Research Division*; R. Budakian,* University of Illinois at Urbana-Champaign*; B.W. Chui, D. Rugar,* IBM Research Division **INVITED**

Magnetic resonance force microscopy (MRFM) has been proposed as a method for greatly improving the sensitivity and spatial resolution of magnetic resonance imaging, perhaps even to the atomic level. In this talk, I describe recent experiments at IBM that demonstrate an important step toward this goal, namely the detection of an individual subsurface electron spin. In this technique, the spin is detected via the attonewton-scale force it exerts on a 150-nm sized magnetic tip that is attached to the end of an ultrasensitive micromachined cantilever. The spin, which is associated with a dangling bond in silicon dioxide, is manipulated by cantilever-driven cyclic adiabatic inversion, which results in a slight frequency shift of the cantilever. With this method, we were able to unambiguously detect a single spin located more than 100 nm below the magnetic tip of the cantilever and obtain a spatial resolution of 25 nm in one dimension. I will also describe recent experiments on relatively small ensembles of nuclear spins, and discuss the challenges of pushing the technique toward single nuclear spin detection. This work was supported by the DARPA-QUIST program administered through the Army Research Office.

11:00am **NS+EM-TuM9 Fabrication and Characterization of Nanolayered Electron Emitters*, A.A. Dixit,*** *A. Raigoza, T. Engstrom, A. Lapicki, K. Akutsu, D.C. Jacobs,* University of Notre Dame

Nanolayered electron emitters (vertical dimension ~ 100 nm), based on a Metal-Insulator-Metal (MIM) architecture, are fabricated by sequential deposition of thin films. A combinatorial approach is employed to efficiently screen different materials and fabrication conditions, and an array of 24 devices is fabricated in each batch. The electrical performance of each device is characterized as a function of the voltage bias applied across the metal electrodes. The total vacuum emission of electrons exhibits a non-linear increase as a function of the applied voltage bias. The kinetic energy distribution of emitted electrons is recorded at a series of bias voltages by a hemispherical energy analyzer. The energy distribution is quasiballastic with minimal inelastic losses. A change in the applied voltage bias results in a corresponding linear shift in the position of the peak in the energy distribution. The role of defects on the electron transport mechanism is discussed.

11:20am **NS+EM-TuM10 Low Temperature Scanning Tunneling Spectroscopy on Cleaved InAs Quantum Dots*, A. Urbieta,*** IEMN, (CNRS, UMR 8520) France, France*; B. Grandidier, J.P. Nys, D. Deresmes, D. Stiévenard,* IEMN, (CNRS, UMR 8520) France*; Y.M. Niquet,* CEA/DRFMC/SP2M, France

InAs quantum dots (QDs) have attracted increasing attention in recent years due to their application in optoelectronic devices such as infrared solid state lasers.@footnote 1@ Therefore, a complete knowledge of the electronic structure of the mentioned dots is essential in order to improve device design, performance and reliability. QDs are zero-dimensional structures also known as artificial atoms since they exhibit three dimensional confinement leading to atomic-like electronic states. Much effort has been devoted in the last decade to determine the characteristics of these states from both theoretical and experimental viewpoints. The spectroscopic mode of scanning tunneling microscope (STM) at cryogenic temperatures is a powerful tool to study low dimesional structures, since it enables a detailed characterization of their local electronic properties with high resolution. Actually, electron states in free-standing InAs QDs grown on n-type GaAs have been successfully investigated using this technique.@footnote 2@ However, a complete characterization of QD-related hole states is still lacking. In this work, scanning tunneling spectroscopy at low temperatures has been used to investigate the electronic structure of cleaved InAs quantum dots growth on p-type (001) GaAs. Several peaks related to energy levels of electrons and holes confined in the dots have been observed. The experimental results are compared with tight-binding calculations of the electronic structure of similar quantum dots, which allow us to determine both the ground state and first excited states of electrons and holes. Wave function mappings have been also carried out in order to assess the symmetry of the QDs states. @FootnoteText@ @footnote 1@ Y. Qiu, P. Gogna, S. Forouhar, A. Stintz and L. F. Lester, Appl. Phys. Lett. 79, 3570 (2001).@footnote 2@ T. Maltezopoulus, A. Bolz, C. Meyer, C. Heyn. W. Hansen, M. Morgenstern and R. Wiesendanger, Phys. Rev. Lett. 91, 196804 (2003).

11:40am **NS+EM-TuM11 Nanometer Spaced Electrodes on Ultra Flat GaAs-AlGaAs Heterostructures for Molecular Electronics Applications***,*
S.M. Luber*, F. Zhang, S. Strobel, A. Hansen,* Walter Schottky Institut, TU Muenchen, Germany*; D. Schuh,* Universitaet Regensburg, Germany*; M. Bichler, M. Tornow,* Walter Schottky Institut, TU Muenchen, Germany

Current efforts in molecular electronics both aim for novel devices as well as the fundamental understanding of the electronic transport in molecular "wires". Here one of the major challenges is the preparation of well defined electrodes which allow reliably contacting and electrically investigating molecules of a given size. We pursue a novel strategy to fabricate nanometer spaced (nanogap) metal electrodes which is based on a cleavage plane of a GaAs-AlGaAs heterostructure. This allows for a precisely predetermined spacing of the electrodes. In recent studies@footnote 1@ we successfully fabricated, characterized and verified the electrical functionality of such nanogap electrodes. Using Molecular Beam Epitaxy (MBE) we embedded a thin (5-20nm) GaAs layer in between two AlGaAs layers. By cleaving the substrate and selectively etching the GaAs layer, the remaining AlGaAs layers are used as a support for deposited metal (Au) electrodes. This device is especially useful for measuring plenty of nanoscale objects in parallel, as the lateral size of the electrodes is defined by optical lithography. In our contribution we will report on a) first electrical investigations on thiolated @pi@-conjugated aromatic molecules assembled on 5nm spaced electrodes, and b) on our recent progress to reduce the lateral electrode size to a few nanometers only. Such electrode shape will allow for the contacting of merely a few or even single nanoscale objects. The downsizing is possible by the insertion of a second MBE growth step perpendicular to the first growth direction using the Cleaved Edge Overgrowth (CEO) technique. We successfully fabricated metallized electrodes of various widths (5-50nm) and various distance (15-30nm). We investigated these electrodes by AFM and SEM and made a first electrical characterization. @FootnoteText@ @footnote 1@SM Luber, S Strobel, HP Tranitz, W Wegscheider, D Schuh, and M Tornow, Nanotechnology 16 (2005), in press.

Author Index

Bold page numbers indicate presenter