Nanometer-scale Science and Technology Division
Room 6C - Session NS2-MoA

Quantum Dots and Wires

Moderator: M. Weimer, Texas A&M University

2:00pm **NS2-MoA1 High Resolution Optical Spectroscopy and Control of Single GaAs Quantum Dots**, ***D. Gammon***, Naval Research Laboratory **INVITED**

Recently it has become possible to probe individual excitons localized laterally in narrow GaAs quantum wells using high spatial and spectral resolution optical techniques. Discrete, atomic-like spectra with homogeneously-broadened linewidths as narrow as a few tens of micro-eV have been measured. These linewidths are two orders of magnitude narrower than the ensemble linewidth arising from inhomogeneous broadening and an order of magnitude narrower than the narrowest observed in wide quantum well samples. This extraordinary reduction in linewidth can be explained in part by the removal of inhomogeneous broadening accomplished by probing individual localized excitons, and in part by the reduction in homogeneous linewidth in going from 2D to 0D. In fact, the linewidths are in the regime expected for the intrinsic broadening mechanisms of exciton-phonon interactions and radiative emission. In other words the linewidths may be close to their natural linewidths.@footnote 1@ This great reduction in linewidth attained in PL by probing individual QDs has led to a number of new observations including fine structure splittings,@footnote 2@ hyperfine structure splittings @footnote 3@ and the measurement of the nonlinear response of a single quantum dot.@footnote 4@ Using coherent picosecond pulses, coherent control and the generation of superposition states have been demonstrated.@footnote 5@ These examples of advanced spectroscopies on individual excitons are first steps toward what may eventually lead in its maturity to coherent optical control of QDs comparable to what is now possible in atoms. @FootnoteText@ @footnote 1@ D. Gammon, et al., Science 273, 87 (1996). @footnote 2@ D. Gammon, et al., Phys. Rev. Lett. 76, 3005 (1996). @footnote 3@ S.W. Brown, et al., Phys. Rev. B 54, R17339 (1996); D. Gammon, et al., Science 277, 85 (1997). @footnote 4@ N. H. Bonadeo, et al., Phys. Rev. Lett. 81, 2759 (1998). @footnote 5@ N. H. Bonadeo, et al., Science 282, 1473 (1998).

2:40pm **NS2-MoA3 Quantum Dots; The Small World of Artificial Atoms**, ***L.P. Kouwenhoven***, Technical University of Delft, The Netherlands **INVITED**

We performed transport experiments on quantum dots in which the electron number can be tuned from 0 to 1, 2, etc. The addition spectrum shows a shell structure corresponding to a 2D harmonic confinement potential. The magnetic field dependence shows that the single particle states are spin degenerate and filled with two electrons. The filling of a shell occurs according to Hund's rule: electrons occupying degenerate states prefer to have parallel spins which lowers the total energy due to an increased exchange interaction. We observe such Hund's rule states at zero magnetic field and also at level crossings in a finite magnetic fields. In non-linear transport characteristics also the first few excited states are visible which we have studied over a magnetic field range up to 16 Tesla. The magnetic field induces transitions between ground states and excited states and also between excited states. In the high magnetic field regime all electrons are in the lowest orbital Landau level. This is the quantum Hall regime for a small electron system where the electrons form a strongly interacting many-body system. We have observed in the few-electron regime (N<10) so-called singlet-triplet oscillations. On increasing the magnetic field for a fixed electron number, we first observe spin-flips (between the two spin states of the lowest orbital Landau level), then the maximum density droplet (when all electrons are spin polarized and occupy the state with the lowest angular momentum), and then a reconstruction (probably an edge reconstruction, either spin polarized or with a spin texture). @FootnoteText@Work done in collaboration with D. Austing, M. Eto, T. Honda, S. Tarucha, M. Danoesastro, J. Janssen, R. van der Hage, and T. Oosterkamp.

3:20pm **NS2-MoA5 Low-Temperature Tunneling Spectroscopy of the Tip-induced Quantum Dot on n-InAs(110)**, *R. Wiesendanger,* ***M. Morgenstern***, *R. Dombrowski, Ch. Whittneven,* University of Hamburg, Germany

The local tip-induced band bending in scanning tunneling microscopy (STM) studies of semiconductor surfaces leads to a quantum-dot-like potential. Scanning tunneling spectroscopy (STS) on n-InAs(110) at negative sample bias has been applied to determine the energies of the quantized states of the tip-induced quantum dot. Additionally, the magnetic-field dispersion of these states has been studied showing clearly the expected splitting of the first excited state in agreement with Hartree-Fock calculations. At positive sample bias the local tunneling spectra were found to be dominated by the Landau bands of the tip-induced quantum dot. Moreover, spatially-dependent spin splittings of the Landau bands were observed, induced by the spatially varying spin polarization of the tip-induced quantum dot.

3:40pm **NS2-MoA6 Coherently Strained Sn Quantum Dot Formation in Si via Phase Separation**, ***K.S. Min***, *H.A. Atwater, N.J. Choly,* California Institute of Technology

Diamond cubic @alpha@-Sn is a zero band gap semiconductor and band structure calculations predict a direct and tunable energy gap for Sn-rich Sn@sub x@Si@sub 1-x@ alloy system. One approach for realization of a direct band gap material based on coherently strained Sn-rich Sn@sub x@Si@sub 1-x@/Si system is to synthesize coherently strained Sn-rich quantum dots. For high Sn concentration Sn@sub x@Si@sub 1-x@/Si quantum dot structures, one might potentially take advantage of quantum carrier confinement to further tune the energy gap over a wide range in the infrared frequency range. The biggest difficulty in growing Sn@sub x@Si@sub 1-x@ quantum dots via conventional epitaxial growth techniques, however, is the strong tendency for Sn atoms to segregate to the surface during growth at ordinary Si epitaxy temperatures. We report a novel two-step process for synthesizing coherent Sn-rich quantum dots contained within Si, where the enthalpy of mixing is highly positive. First, an ultrathin homogeneous Sn@sub x@Si@sub 1-x@ metastable solid solution sandwiched between Si is grown by temperature-modulated molecular beam epitaxy. The as-grown epitaxially stabilized ultrathin homogeneous film is then thermally annealed in high vacuum, whereupon the quantum dots precipitate as the ultrathin alloy film phase separates. The quantum dots appear in planar-view transmission electron micrographs as square-shaped with facets along the elastically soft direction. The mean size ranges from 2 nm to 3 nm for annealing temperature between 500°C and 800°C. Cross-sectional high-resolution transmission electron microscopy reveals that the dots are completely coherent with the Si matrix. The early stage of phase separation proceeds via spinodal decomposition, followed by diffusion-limited coarsening in the late stage. The optical properties of the quantum dots will also be presented.

4:00pm **NS2-MoA7 Hybrid Electrochemical/Chemical Routes to Epitaxial, Luminescent, and Size Monodisperse Semiconductor Nanocrystals on Surfaces.**, ***R.M. Penner***, University of California, Irvine

A fundamentally new approach for synthesizing semiconductor nanocrystals - size-selectively - is described in this talk. Cadmium sulfide (CdS) nanocrystallites (NCs) have been synthesized on the atomically smooth graphite basal plane surface using a hybrid electrochemical/chemical (henceforth E/C) method. This method involves the following steps: 1) Electrochemical deposition of cadmium NCs onto an electrode surface, 2) Electrochemical oxidation of cadmium NCs to yield cadmium hydroxide (hexagonal) Cd(OH)@sub 2@ and, 3) Displacement of oxygen (or hydroxide) by sulfide either in the gas phase (via H@sub 2@S at 300 K) or in the liquid phase (using aq. Na@sub 2@S) solution. Electron diffraction is employed to monitor the progress of this synthesis, and the c rystal structures and orientations of the resulting nanocrystals which have mean diameters ranging from 30Å to 150Å. Wurtzite phase CdS nanocrystals generated by the E/C method possess the following characteristics: Single crystallinity, good-to-excellent si ze monod ispersity, epitaxial alignment (with the hexagonal periodicity of the graphite(0001) surface). In addition, E/C deposited particles on graphite exhibit strong room-tempera t ure photoluminescence (PL) spectra in which virtually no trap state emis sion is o bserved, and the energy of the emitted phonons is tunable based on the crystallite diameter. Extraordinarily good size monodispersity is possible for the CdS nanocrystals prepared by this method. One consequence is that the PL emission line widths seen for ensembles of 300,000 CdS nanocrystals can be as narrow as those seen for single CdS nanocrystals (15 meV at 20 K). V.

4:20pm **NS2-MoA8 High-Bias Conductance of Au Nanowires at 4 K**, ***A. Sakai***, *K. Yuki,* Kyoto University, Japan

We have studied the bias dependence of the quantized conductance of Au nanowires at 4 K. The experiment was carried out on Au relay contacts which were directly immersed in liquid He. A well-defined 1G@sub 0@ peak (G@sub 0@=2e@super 2@/h is the conductance quantum unit) appears in the conductance histogram, as observed in previous work.@footnote 1@ With increasing the bias, the 1G@sub 0@ peak

decreases in height, while its position remains unshifted. This behavior of the 1G@sub 0@ peak is just the same as that observed at room temperature.@footnote 2@ The critical bias V@sub c@ at which the 1G@sub 0@ peak disappears is 2.4 V, which is slightly higher than the values at room temperature (1.9 V) and at 77 K (2.2 V). This weak temperature dependence of V@sub c@ implies that the high-bias instability of the 1G@sub 0@ state of Au is not due to Joule heating effects. Our experimental results are rather consistent with the electromigration of contact atoms which predicts linear and moderate increase in V@sub c@ with decreasing temperature. @FootnoteText@ @footnote 1@J. L. Costa-Krämer, N. García, and H. Olin, Phys. Rev. B 55, 19 (1997). @footnote 2@H. Yasuda and A. Sakai, Phys. Rev. B 56, 1069 (1997).

4:40pm **NS2-MoA9 Quantized Conductance of Metal Nanowires: Is It Useful as a New Device?**, ***K. Takayanagi,*** Tokyo Institute of Technology, Japan **INVITED**

As the scale of microelectronic engineering continues to shrink, interest has focused on the quantum nature of electron transport through quantum wires and/or carbon nanotubes and electron storage on quantum dots. We report here firstly measurements of the quantized conductance of metal quantum poin contacts (QPC's) prepared with an STM that we can simultanelusly image using ultra-high vacuum (UHV) electron microscope. This STM-UHV electorn microscope technique allows us to directly observe any relationship between the structure and conductance of the QPC's. We observed gold metal QPC's, and found a single chain of gold atoms suspended between the electrodes. We can thus confirmed that the conductance of a single strand of atoms is 2e@super 2@/h, (13k@ohm@)@super -1@ , where 'e' is the electron charge and 'h' is Planck's constant. The QPC's often can form a very long nanowire suspended between the electrodes, which are ideal one-dimensional channel similarly to carbon nanotubes. To verify structures of such long matal wires, we made stable nanowires by electorn beam irradiation onto a very thin gold film. We first obtained high-resolution images of a linear chain which consists of four suspended gold atoms. The gold atoms had anomalous spacing compared with the nearest neighbor distance of the bulk crystal. Second, the nanowire which appears as three or four atom rows the diameter in TEM images have a structure different from the bulk crystal. It is very promising for microelectronic engineering that long gold nanowires have thier own specific structure and, thus, have definit conductances specific to their structures. @FootnoteText@ H.Ohnish, Y.Kondo, and K.Takayanagi, Nature, 395 (1998) 780.

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