Nanometer Structures
Room 316 - Session NS-MoM

Quantum Dots and Nanoscale Devices
Moderator: E.T. Yu, University of California, San Diego

8:20am **NS-MoM1 Conductance and Stability of Atom-sized Al Contacts under High Biases**, *J. Mizobata,* Toshiba Corp., Japan*; A. Fujii, S. Kurokawa, **A. Sakai**,* Kyoto University, Japan

Single-atom contacts (SACs) of metals are known to exhibit various unique properties and considered to be a candidate of interconnects in nanoelectronics. In our previous experiments, we studied high-bias conductance of Au and Au-alloy SACs and showed that they can be observed up to 2 V. In order to know the maximum rating of other metal SACs, we carried out conductance measurements of Al SACs for biases from 0.1 to 0.8 V and investigated the formation and the lifetime of Al SACs as a function of the bias voltage. All measurements were made in UHV at room temperature on breaking Al pin-plate contacts, where SACs were observed just before their complete breakage. We found that the formation probability p@sub Al@ of Al SACs decreases with increasing the bias and leads to the suppression of the first peak in the conductance histogram. Both p@sub Al@ and the first peak vanish at around 0.8 V. On the other hand, the average lifetime of Al SACs, <@tau@@sub Al@>, decreases almost linearly with increasing the bias but remains finite at 0.8 V. For comparison, we re-measured the high-bias conductance of Au SACs and found that p@sub Au@ and <@tau@@sub Au@> show similar bias dependence to that of p@sub Al@ and <@tau@@sub Al@>, respectively, though the relevant bias range is much higher for Au SAC: p@sub Au@, for example, survives up to 2.4 V. We consider that the reduction of p@sub Au@ and p@sub Al@ is due to a contact instability induced by electromigration, which fractures contacts in the middle of their deformation and hence reduces the chance of forming SACs. On the other hand, we found it difficult to explain the observed linear bias dependence of <@tau@@sub Al@> and <@tau@@sub Au@> by a simple rate theory since we know little about the effective contact temperature under high biases.

8:40am **NS-MoM2 In-situ Monitoring of Quantum Conductance in Electrodeposited Magnetic Point Contacts@footnote 1@**, ***C.-S. Yang***, *J. Thiltges, B. Doudin,* University of Nebraska, Lincoln*; M. Johnson,* Naval Research Laboratory

The goal of our research is to investigate the magnetoresistance properties of magnetic quantum point contacts. A two-steps fabrication process is used. First, a 50 nm gap between two planar Au electrodes of 1-2 microns widths is patterned using focused ion beam milling. Second, a metallic film is slowly electrodeposited over the electrodes. In-situ measurements of the inter-electrodes impedance monitors the contact resistance during the growth. Keeping electrochemical control of the electrodes ensures optimum purity of the nanocontact, as well as the absence of oxides. Experiments are performed under sweeping magnetic field reaching 1600 Oe amplitude. Quantum conductance steps in Au and Ni point contacts are observed. For Ni, we find that an external field is helpful to observe quantum conductance in multiples of e@super 2@/h, lifting the spin degeneracy. Opening and closure of nanocontacts seldomly occur during the magnetic field sweeping. No significant magnetoresistance was observed for samples of conductance values smaller than 50 e@super 2@/h. Optimizing the measurement speed, we show that no magnetoresistance values larger than 10 % occur when the resistance is stabilized at quantum plateau values during a few magnetic field sweeps. @FootnoteText@ @footnote 1@This research is supported by ONR and NSF MRSEC.

9:00am **NS-MoM3 Quantum Dot Nucleation and Growth in a Microfluidic Reactor**, ***T.L. Sounart***, *J.A. Voigt, T.A. Michalske,* Sandia National Laboratories

Semiconductor quantum dots have the potential to transform important technologies including (bio-)chemical sensors, efficient light sources, catalysts, and supercapacitors. The current ability to control nanoparticle properties, however, is at a state of infancy. Quantum dots are synthesized in batch operations with no feedback and poor control of thermal, chemical, and fluid transport, resulting in a distribution of particle size and batch-to-batch variations. Microfluidic technology, which has revolutionized analytical chemistry and only more recently has been applied to chemical synthesis, offers numerous potential advantages over existing techniques. It is expected that laminar flow, high heat transfer rates, and short mixing lengths can be exploited to precisely control crystal size and morphology, and that microreactor conditions can be adjusted instantaneously to tune output particle properties in real time. In addition to providing better control of reactor conditions, microfluidic systems provide a unique platform for investigation of fundamental reaction processes. Using optical measurement techniques, which are particularly suitable to quantum dot synthesis, we present here for the first time, an on-chip analysis of the nucleation and growth of nanoparticles. CdS early growth processes that are too fast to observe transiently have been resolved spatially in a continuous flow microreactor, and examined by imaging the fluorescence field in the microchannel upon excitation at 365 nm. Early results indicate, e.g., that cysteine-capped quantum dots are formed in less than a second of contact between Na@sub 2@S and CdSO@sub 4@. We are currently analyzing the fluorescence field using hyperspectral imaging to extract data on particle size and concentration variations within the reactor for different chemistries and flow rates. This data is being incorporated into microreactor models to learn how to control quantum dot size and morphology.

9:20am **NS-MoM4 Formation of 31P Qubit Test Structures by Single Ion Implantation**, ***T. Schenkel***, Lawrence Berkeley National Laboratory*; J. Bokor,* UC Berkeley and Lawrence Berkeley National Laboratory*; D.H. Schneider,* Lawrence Livemore National Laboratory*; A. Persaud,* Lawrence Berkeley National Laboratory*; S.-J. Park,* UC Berkeley and Lawrence Berkeley National Laboratory*; J. Nilsson,* Lawrence Livemore National Laboratory*; J.A. Liddle,* Lawrence Berkeley National Laboratory

Electron and nuclear spins of 31P atoms in silicon are promising candidates for the realization of a scalable solid state quantum computer architecture. Single ion implantation with low energy (<10 keV), highly charged ions offers a path to the formation of single 31P atom arrays. We describe our development of single ion placement technology and the integration of atom arrays with control gates and single electron transistor readout structures. Silicon nanowire based single electron transistors are formed in SOI (silicon on insulator) by electron beam lithography and stress limited oxidation. We will discuss critical process integration issues. @footnote 1@ @FootnoteText@ @footnote 1@ We thank the staff of the UC Berkeley Microlab for technical support. This work was supported by the National Security Agency and Advanced Research and Development Activity under Army Research Office contract number MOD707501, and by the U. S. Department of Energy under contract No. DE-AC03-76SF00098. Work at LLNL was performed under the auspices of the U. S. Department of Energy under contract No. W-7405-ENG-48.

9:40am **NS-MoM5 Spin Based Qubit Fabrication in SiGe**, ***L.J. Klein***, *K.A. Slinker, J.L. Truitt, M. Friesen, D.W. van der Weide, S.N. Coppersmith, R. Joynt, M.A. Eriksson,* University of Wisconsin, Madison

A promising approach to solid-state implementation of quantum computers is electron spins in silicon devices. The design incorporates vertical and lateral tunneling into quantum dots defined by nanostructured top gates in the 2DEG of a strained Si quantum well. The potential in the two-dimensional electron gas is modulated by the voltages applied to the top metallic gates. Work is underway to fabricate quantum point contact and quantum dots in strained Si layer and quantum phenomena are investigated related to discrete charge variations. The ultimate goal is the fabrication of qubit: a quantum dot with single electron occupancy with a well defined spin state which is immune from decoherence. This scalable approach allows entanglement of two qubits by varying the voltage applied to top gates separating two quantum dots. Recent measurements of spin lifetime in stained SiGe structures shows decoherence times larger than micro seconds. This large decoherence time should allow many qubit logic operations, initialization, and read-out of a single spin qubit.

10:00am **NS-MoM6 A Systematic Study of SiGe Quantum Fortresses and Possible Applications to Quantum Cellular Automata**, ***T.E. Vandervelde***, *P. Kumar, T. Kobayashi, J.L. Gray, T.L. Pernell, R. Hull, J.C. Bean,* University of Virginia

In this study we detail conditions that result in the generation and evolution of novel hetero-epitaxial surface structures in SiGe/Si created either by spontaneous self-assembly or by ion beam seeding. These self-assembled structures strongly resemble the proposed parameters for a Quantum Cellular Automata (QCA) unit cell. Specifically, we define the growth conditions (i.e. temperature, epi-layer thickness, Ge concentration, and growth rate) under which self-assembly of strain-stabilized quantum fortresses (QFs) and their precursors form. This growth progression can be dissected into a series of surface features that evolve before and after the

appearance QFs. These kinetically limited configurations exist over a wide range of growth conditions, however they are destabilized by excessive adatom surface mobility or strain relaxation resulting from the introduction of misfit dislocations. To characterize these self-assembled structures and their destabilization, we have systematically studied and are basing simulations on their basic dimensional parameters, within this functional space. One natural application would be to use QFs in QCA based architectures. A fully developed QCA circuit requires arrays of QF-like structures, but nature only provides us with isolated randomly located QFs. To overcome this limitation we also report work directed at a guided self-assembly technique that relies on gently altering the substrate before growth. This is achieved using a 25 KeV in-situ Ga+ focused ion beam to locally enhance Ga+ concentration and alter the substrateâ€™s surface topography. The intent is to use the surfactant-like nature of low Ga doses, to cause local nucleation of Ge clusters without greatly disturbing surface topology. We also explore the effects of higher Ga+ dosages, which cause the appearance of significant surface topology, on the localization of Ge cluster nucleation. This work, in part, was supported by NSF through FRG and MRSEC grants.

10:20am **NS-MoM7 Current Challenges in Nanocrystal-Quantum-Dot Lasing**, ***V.I. Klimov,*** Los Alamos National Laboratory **INVITED**

Semiconductor quantum dots (QDs) offer important advantages for lasing applications that are associated with their size controlled emission wavelengths (and, hence, output color) and low, temperature-insensitive optical-gain thresholds. QDs have been fabricated using epitaxial techniques (epitaxial or self-assembled QDs) or using chemical synthesis routes [nanocrystals or nanocrystal QDs (NQDs)]. Despite the impressive success of laser technologies based on epitaxial QDs, the first unambiguous demonstrations of amplified spontaneous emission@footnote 1@ and lasing@footnote 2@ involving chemically synthesized NQDs were performed only recently. The difficulties in achieving lasing in NQDs are due to both materials-quality issues and the existence of intrinsic physical mechanisms that complicate the development of stimulated emission. One such complication is ultrafast gain decay due to highly efficient, nonradiative, multi-particle Auger recombination. In our work we explore "geometrical" methods (e.g., nanocrystal shape control) for suppressing the multi-particle recombination. In particular, we study the effect of the zero- to one-dimensional (1D) transformation on Auger decay using series of elongated semiconductor nanocrystals (quantum rods). We observe an interesting new effect, namely, the transition from a three- to a two-particle recombination process as the nanocrystal aspect ratio is increased. This transition implies that in the limit of 1D confinement, Auger decay is dominated by Coulomb interactions between 1D excitons that recombine in a bimolecular fashion. One consequence of this effect is strongly reduced decay rates of higher order multi-particle states that lead to the increased optical gain lifetime and efficient light amplification due to excited-state transitions. These unique rod properties suggest that shape control may be key to developing practical lasing applications for nanocrystals. @FootnoteText@ @footnote 1@ V. I. Klimov et al., Science 290, 314 (2000). @footnote 2@ H.-J. Eisler et al., Appl. Phys. Lett. 80, 4614 (2002); M. Kazes et al., Adv. Mater 14, 317 (2002); A. Malko et al., Appl. Phys. Lett. 81, 1303 (2002).

11:00am **NS-MoM9 Si Nanocrystal Synthesis in an Oxide Matrix: A Multiscale Computational Study**, ***D. Yu,*** *G.S. Hwang,* University of Texas at Austin

Nanocrystalline Si (nc-Si) embedded in a SiO@sub2@ matrix is receiving great attention due to its interesting fundamental physical properties and promising applications for advanced microelectronic devices and optoelectronic devices. The unique electrical and optical properties of embedded Si nanocrystals appear to be strongly influenced by their crystallite size, shape, density as well as Si/SiO@sub2@ interface structures. It is therefore necessary to develop a detailed understanding of the nc-Si growth and Si-SiO@sub2@ interfacial interactions. Although experiments offer many clues to the nanocrystal formation and interface properties, their interpretations often remain controversial. In this talk, we will present our multiscale computational model for the synthesis of Si nanoclusters in an oxide matrix. Our multiscale model integrates various state-of-the-art theoretical methods at different time and length scales, such as first principles quantum mechanics, molecular mechanics, and kinetic Monte Carlo. Using the multiscale approach, we have examined i) formation mechanism of Si clusters in silicon suboxide, ii) shape evolution of embedded nanoclusters, iii) Si-SiO@sub2@ interface structure and strains. Our simulations show that small silicon clusters agglomerate very rapidly at the early stage of thermal annealing mostly via coalescence. As the Si cluster density gets lower, the coalescence becomes less probable and the cluster growth continues mainly by Ostwald ripening (which appears be several orders of magnitude slower than the initial stage coalescence). Our theoretical study also demonstrates that the average size of silicon clusters is a strong function of the initial silicon supersaturation. Our results are in good agreement with recent experimental observations.

11:20am **NS-MoM10 Nanocrystalline Structures in Amorphous Silica**, ***J.Y. Cheng,*** Rensselaer Polytechnic Institute*; M.M.J. Treacy,* NEC Research Institute*; P.J. Keblinski,* Rensselaer Polytechnic Institute

We conduct the metamict transformation of crystalline silica in a transmission electron microscope. In this experiment, an alpha quartz crystal was transformed into an amorphous phase by electron irradiation at high dose. In the meantime, diffraction patterns of these phases were taken throughout the process. After that, we measured image fluctuations in dark field for the amorphous structure. From the images, the amorphous silica is "nanocrystalline." From the diffraction patterns, these crystallites are randomly oriented. Our results also show that the original alpha phase has ultimately disappeared in the new structure.

11:40am **NS-MoM11 Investigation of Nucleation and Growth of Si(Ge) Nanocrystals Embedded in HfO@sub 2@ as Floating Gate for Flash Memory Devices**, ***R. Gupta,*** National University of Singapore*; L.K. Bera,* Institute of Microelectronics, Singapore*; W.J. Yoo,* National University of Singapore, Singapore*; D.S.H. Chan,* National University of Singapore*; N. Balasubramanian,* Institute of Microrelectronics, Singapore

Charge storage in semiconductor nanocrystals is a very critical property to determine electrical performance of non-volatile memory devices. Nanocrystals embedded in high dielectric constant materials are not only effective to scale down the device size but also to enhance the programming and retention properties. Also, it is known that Si(Ge) nanocrystals of size @<=@ 10nm can have much better charge storage capability at room temperature than Si nanocrystals. This study is focused on understanding mechanisms to control shape, size, and composition of Si(Ge) nanocrystals that will be used for improving device properties of non-volatile memories. The Si(Ge) nanocrystals were deposited using Silane & Germane at the pressures of 0.5Torr - 5Torr and at the temperatures of 500°C-600°C on 40Å of either thermally grown SiO@sub 2@ or MOCVD HfO@sub 2@. The deposition time was varied from 5 seconds to 70 seconds at different flow rates of Silane & Germane. It was found that the evolution of size and density of Si(Ge) nanocrystals was dependent on pressure, deposition time, and substrate material. We found, as the deposition pressure decreased from 5 Torr to 0.5 Torr, the minimum size of Si(Ge) nanocrystal on SiO@sub 2@ decreased from 50 nm to 2 nm while density increased from 10@super 8@/cm@super 2@ to 10@super 11@/cm@super 2@. We observed that nanocrystal size increased in early stages but agglomeration took over with the further increase of deposition time. For SiO@sub 2@, we found that Ge atomic percent decreased from 18.4% to 14.6% as the deposition time increased from 5 seconds to 15 seconds at 5 Torr. However, Ge atomic percent on HfO@sub 2@ at same conditions at 5 seconds was lower at 12.3 %, showing significant difference in kinetics of the Si(Ge) nanocrystal formation between HfO@sub 2@ and SiO@sub 2@ substrates. Details on nucleation, growth, and electrical results on charge storage of Si(Ge) nanocrystals on HfO@sub 2@ will be presented.

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