Tuesday Morning, November 3, 1998

Nanometer-scale Science and Technology Division
Room 321/322/323 - Session NS-TuM

Quantum Structures and Molecular Electronics

Moderator: C.R.K. Marrian, Naval Research Laboratory

8:20am **NS-TuM1 Quantum-Dot Cellular Automata**, ***G.L. Snider***, *A.O. Orlov, I. Amlani, G.H. Bernstein, C.S. Lent, J.L. Merz, W. Porod,* University of Notre Dame **INVITED**

Quantum-dot Cellular Automata (QCA) is a promising architecture which employs quantum dots for digital computation. It is a revolutionary approach which addresses the issues of device density and power dissipation. It represents a concrete device design, scalable down to atomic dimensions, with possible implementations in both metals and semiconductors. A basic QCA cell consists of four quantum dots coupled capacitively and by tunnel barriers. Two excess electrons within the four dots are forced to opposite "corners" of the four-dot system by Coulomb repulsion. These two possible polarization states of the system represent logic "0" and "1". Properly arranged, arrays of these basic cells can implement the Boolean logic functions and memory needed for general purpose computation. An introduction to the QCA architecture will be presented, along experimental results from a functional QCA cell built of nanoscale metal dots defined by tunnel barriers. The QCA cell to be presented consists of two Al double-dot islands defined by tunnel junctions, capacitively coupled to each other. Al/AlO@sub x@/Al tunnel junctions are fabricated using a standard e-beam lithography/shadow evaporation technique. In addition to the QCA cell, two single-dot Al islands are capacitively coupled to the QCA cell to act as electrometers. Direct measurements of the charging diagram of QCA cell, combined with electrometer measurements of the cell, show a controlled polarization switch of the QCA cell. These and additional results confirm the control of the switching of a single electron by a single electron, and demonstrates a non-linear, bistable response in the QCA cell. There is excellent agreement between the experimental results and theory.

9:00am **NS-TuM3 A Proposal of Atom/Molecule Switching Devices**, ***Y. Wada***, Hitachi Ltd., Japan **INVITED**

This paper describes the possibility of atom/molecule switching devices, Atom Relay Transistor (ART)@footnote 1@ and MOlecular Single Electron Switching transistor (MOSES),@footnote 2@ which would supersede present semiconductor devices beyond their ultimate limitations. ART consists of an atom wire, a switching atom, a switching gate and a reset gate. MOSES devices consist of a conducting molecule and an insulating molecule, the former being the quantum dot and the latter the tunnel barrier. ART and MOSES devices are evaluated on the basis of the five major characteristics necessary for information processing integrated circuit devices,@footnote 1@ and indicated that they are the most promising candidates for the future information processing. Scanning Tunneling Microscope (STM) should be the most probable tool to fabricate these devices. Technology development to realize these atom/molecule devices are described, including Beam Assisted STM (BASTM)@footnote 3@ which enables insulator observation, Needle Formation and Tip Imaging (NFTI)@footnote 4@ which directly evaluates STM tip apex for reliable atom/molecule manipulation, micromachine STM@footnote 5@ which makes possible the direct observation of vacuum tunneling gap. Gallium (Ga) atom wire was successfully fabricated on Si (100)-H surface by removing hydrogen atoms by STM and filling the dangling bond by Ga atoms,@footnote 6@ which is theoretically predicted to be conductive.@footnote 7@ Those technologies should lead to a successful ART/MOSES demonstration. @FootnoteText@ @footnote 1@Y.Wada, et al., J. Appl. Phys., 74, 7321 (1993). @footnote 2@Y.Wada, Trans. IEICEJ, OME 93-54, 31 (1994). @footnote 3@S.Heike, et al., Appl. Phys. Lett., 64, 1100 (1994). @footnote 4@S.Heike, et al., Japan. J. Appl. Phys., 34, L1061 (1995). @footnote 5@M.I.Lutwyche et al., Appl. Phys. Lett., 66, 2807 (1995). @footnote 6@T.Hashizume, et al., Japan. J. Appl. Phys., 35, L1085 (1996). @footnote 7@S.Watanabe, et al., Phys. Rev. B, 54, 17308 (1997).

9:40am **NS-TuM5 Self-Assembled Single Electron Tunneling Devices**, *S.H.M. Persson,* ***L.K. Hedberg***, *L.G.M. Olofsson, B. Kasemo,* Chalmers Univ. of Technology and Univ. of Gothenborg, Sweden

Single electron tunneling effects were studied in self-assembled devices, by contacting a nanoscale gold cluster to two gold electrodes. The size of the gold cluster was around 5 nm, which is controlled by the chemical synthesis. Coulomb blockade of tunnelling was observed at room temperature and Coulomb staircase at 4.2 K. With a third gate terminal it was possible to modulate the tunneling characteristic by electric field effect at 4.2 K. Nanoscale electronic devices can be made with refined lithographical techniques, e.g. using scanning probe instruments, but these methods are very slow and not practical for large scale fabrication. The electrodes were made by electron beam lithography and angled evaporation to control the gap between the electrodes to distances smaller than 10 nm. The surface of the gold electrodes were modified by a self-assembled monolayer of 1,8-octanedithiol and gold clusters were found to be captured in the electrode gap after immersion of the sample in a hexane solution of clusters. The characteristic feature of single electron tunneling can be seen in the current voltage characteristic as a number of steps, that is named the Coulomb staircase. The Coulomb blockade is observed at room temperature with a blockade voltage of the order 0.2 V. Recent theoretical results@footnote 1@ predict a new "electron shuttle" mechanism for systems similar to ours, where the middle electrode is softly coupled to the outer ones via organic molecules. The softness of the molecular links implies that charge transfer could give rise to deformation of these structures. Under certain conditions this would result in oscillation of the gold nanoparticle and a current through the structure that is proportional to the cluster vibration frequency. One aim of our work is to verify these predictions experimentally. @FootnoteText@ @footnote 1@L.Y.Gorelik, A.Isacsson, M.V.Voinova, B.Kasemo, R.I.Shekter and M.Jonson, Phys. Rev. Lett., 80 (1998), 4526

10:00am **NS-TuM6 Quantum Transport in Metallic Nanowires Fabricated by Electrochemical Deposition/Dissolution**, ***N.J. Tao***, *C.Z. Li, A. Bogozi, J. D'Agnese, B. Duong,* Florida International University

A non-mechanical method for fabricating a metallic narrow constriction between two electrodes using electrochemical deposition is described. The width of the constriction can be adjusted by slowly dissolving metal atoms away or re-depositing atoms onto the constriction which can be controlled flexibly by the electrodes' potentials. Well-defined plateaus near the integer numbers of the conductance quantum have been observed in these constrictions at room temperature. Since no mechanical movements are involved, nano-constrictions with long term stability have been fabricated. @FootnoteText@ Financial support is acknowledged through grants from AFSOR (F49620-96-1-0346) and NIH (GM-08205).

10:20am **NS-TuM7 Conductance of Molecular Junctions**, ***M.A. Reed***, Yale University **INVITED**

The charge transport and conductance measurement of a single atom or moiety, is an intriguing, experimentally challenging, and long sought goal. We have developed a number of techniques for the electrical measurement of single and/or few molecule systems. First, we have measured the electrical transport properties of a single molecule self-assembled onto the electrodes of a mechanically controllable break junction, allowing for direct observation of charge transport through the molecules. Current voltage I(V) measurements at room temperature demonstrate a highly reproducible apparent gap at about 0.7 V and a corresponding resistance of 22 MOhms. Second, we have developed a nanostructure device technique called a "nanopore" approach to measure the electronic transport of a class of stable self-assembled conjugated oligomers. This has allowed us to determine the barrier heights and transport mechanisms in these conjugated oligomer systems. We have also measured for the first time the molecular equivalent of a resonant tunneling device, and experimental results on a new molecular switching mechanism.

11:00am **NS-TuM9 Carbon Nanotubes: Manipulation, Properties and Functional Electronic Devices**, *R. Martel, T. Hertel, T. Schmidt, H. Shea,* ***Ph. Avouris***, IBM T.J. Watson Research Center

Carbon nanotubes (CNT) are materials with unique properties. Depending on their atomic structure, their electronic structure can be that of a metal or semiconductor, and this coupled with their extreme mechanical strength and high thermal conductivity makes them ideal candidates for novel nanoelectronic devices. While discussions of the CNT properties are usually confined to isolated perfectly symmetric tubes, CNT are supported on a solid substrate in actual applications. We will first explore the changes in atomic structure (axial and radial deformations) that result from the adhesion forces between the CNT and the substrate. For this we employee AFM measurements, molecular mechanics and electronic structure calculations. We will show that the deforma tions are significant and can have important consequences for the electrical transport properties of CNT. Next, we will demonstrate that by using the AFM we can manipulate not only the position but also the shape of individual CNTs and in this way

fabricate model nano-electronic devices. We will demonstrate a field effect transistor based on a single nanotube (CNT-FET) connected via Schottky barriers to gold electrodes. The resulting band-bending can be controlled by a gate to change the source-drain current by four orders of magnitude at 300 K. Nanotube-based single electron transistors (CNT-SET) will also be demonstrated.

11:20am **NS-TuM10 Simultaneous Study of the Formation and Conductance of Single Wall Carbon Nanotube at STM Tunnelling Gap by Transmission Electron Microscopy**, ***J. Yamashita***, *H. Hirayama, Y. Oshima, K. Takayanagi,* Tokyo Institute of Technology, Japan

It is theoretically predicted that the single wall carbon nanotube (S WNT) has metallic and semiconducting property depending on its helicity, or diameter. Little experimental study has been done on the electric properties of the SWNT, although several works reported those of the carbon nanotubes. To study the structure and conductance of the SWNT simultaneously, we devised a miniaturized scanning tunnelling microscope (STM) in a UHV transmission elecron microscope (UHV-TEM). We observed formation process of SWNT and measured its conductance and I-V characteristics. The miniaturized STM had two tungsten tips, and graphitized carbon layers adhered to the surfaces of the both tips. The STM tip was touched to other tip and withdrawn from. At the moment of the touch and withdrawal, a SWNT with diameters 1~5nm was formed to bridge the both graphitized layers. The bridge of the SWNT grew and its conductance decreased as the withdrawal of the STM tip. The I-V characteristics were measured(-1.5~1.5V) in the course of the withdrawal of each SWNT. These I-V characteristics were found to fit with a formula, I=@alpha@V(1+ßV@super 2@). We calculated the resistivity for each SWNT by @pi@dt/l@alpha@. Here, l, d and t=0.17nm are the length, diameter, and thickness of each SWNT, which were measured from TEM images. The diameter is an average value for a SWNT, because each SWNT has shapes like coca-cola bottle. We found that the resistivities were from 0.0001 to 0.01(@OMEGA@cm). The magnitude of the resistivity is of high doped semiconductors. This result suggests that the coca-cola bottle like SWNT has metallic part and semiconducting part which are mixed alternately along the SWNT axis.

Author Index

Bold page numbers indicate presenter