Nanometer-scale Science and Technology
Room: L - Session NS-ThA

Characterization & Imaging at the Nanoscale II

Moderator: U. Schwartz, Yale University

2:00pm **NS-ThA1 Nanoelectrical Probing with Multiprobe SPM Systems Compatible with Scanning Electron Microscopes**, *J. Ernstoff,* Nanonics Imaging Ltd., Israel, ***A. Lewis***, Hebrew University of Jerusalem, Israel, *A. Ignatov, H. Taha, O. Zhinoviev, A. Komissar, S. Krol, D. Lewis*, Nanonics Imaging Ltd., Israel

A scanning electron microscope compatible platform that permits multiprobe atomic force microscopy based nanoelectrical characterization will be described. To achieve such multiple parameter nanocharacterization with scanning electron microscope compatibility involves a number of innovations both in instrument and probe design. This presentation will focus on how these advances were achieved and the results obtained with such instrumentation on electrical nano-characterization and electrical nano-manipulation. The advances include: 1. Specialized scanners; 2. An ultrasensitive feedback mechanism based on tuning forks with no optical feedback interference that can induce carriers in semiconductor devices; and 3. Unique probes compatible with multiprobe geometries in which the probe tips can be brought into physical contact with one another. Experiments will be described with such systems that will include multiprobe electrical measurements with metal and glass coated coaxial nanowires of platinum. This combination of scanning electron microscopes integrated with multiprobe instrumentation allows for important applications not available today in the field of semiconductor processing technology.

2:20pm **NS-ThA2 Nanocone Chemical Analysis with High Resolution Scanning Auger Microscopy**, ***S.N. Raman***, *J.S. Hammond, D.F. Paul, D.G. Watson, P.E. Larson, R.E. Negri*, Physical Electronics

The recent dramatic increase in nanotechnology research has pushed the development of analytical techniques to elucidate the growth mechanisms of nanostructures. Scanning electron beam techniques, including Scanning Auger Microscopy, have provided valuable imaging and elemental characterization tools for these structures with a spatial resolution better than 10 nm. To enhance the Auger analysis for nanocones, high energy resolution chemical state spectroscopy and imaging has been combined with the imaging capabilities of a CMA based Scanning Auger. Using a combination of these Auger analytical capabilities, the analysis of nanocones grown by plasma enhanced chemical vapor deposition reveals a non-uniform chemical composition between several different nanocones. The quantitative elemental analysis as well as the imaging of different chemical states has been obtained without imaging artifacts induced by the shapes of the vertically oriented nanocone structures. These results provide further insights into the nanocone growth mechanisms.

2:40pm **NS-ThA3 Epitaxial Growth of Al on Sapphire for Qubit Applications**, ***F. da Silva***, University of Colorado, Denver, *B.P. Gorman, M. Kaufman,* Colorado School of Mines, *J.S. Kline, D.A. Braje, D.S. Wisbey, D.P. Pappas*, National Institute of Standards and Technology

The pursuit of new low loss materials and epitaxial structures to enhance the performance of superconducting quantum bits (qubits) has heightened in recent years. The small number of defects observed in epitaxially grown structures, compared with polycrystalline and amorphous materials, accounts for several improvements reported in qubit operation such as the reduction in the density of two-level fluctuators and longer coherence times **[1]**. Qubit structures of interest are superconductor-insulator-superconductor (SIS) tri-layers deposited on an insulating substrate. Two candidates for the substrate and superconductor metal are sapphire (α-Al_2O_3) and Al respectively **[2]**. Complete defect removal requires a study of each layer and its corresponding interfaces. In this work we focus our attention on the interface between the substrate and the first superconductor layer. We used transmission electron microscopy (TEM) techniques to analyze the growth of Al (111) films on sapphire (0001) substrates. While the sapphire substrate induces the growth of epitaxial Al along a <111> direction as desired, the subsequent [111[planes grow with either ABC or ACB stacking resulting in twin-related "grains" within the epitaxial film. In addition, slight (1-5°) in-plane misorientations are observed in adjacent, twin-related Al grains and appear to correspond to the slight rotations between the oxygen atoms along the c-axis of the sapphire. In other words, because the Al orients itself with the oxygen atoms on the sapphire basal planes, any miscuts of the sapphire substrate to within ±1/6 of the unit cell c-axis will slightly misorient the Al due to the slight rotation of the oxygen atoms with respect to the c-axis of the sapphire cell **[3]**. Finally, these twinning and misorientation effects appear to induce other growth defects in the subsequent layers used in the qubit circuit. Based on these results, we propose the use of a chemically compatible oxide buffer layer which does not have rotations between successive O layers within its unit cell.

[1] S. Oh, K. Cicak, J. S. Kline, M.A. Sillanpää, K.D. Osborn, J.D. Whittaker, R.W. Simmonds, and D.P. Pappas, Phys. Rev. B **74**, 100502R (2006).

[2] J. Martinis, Quantum Information Process **8**, 81 (2009).

[3] D.L. Medlin, K.F. McCarty, R.Q. Hwang, S.E. Guthrie, and M.I. Baskes, Thin Solid Films **299**, 110 (1997).

3:00pm **NS-ThA4 Real Time Scatterometry for Profile Control during Resist Trimming Process in a HBr/O_2 Plasma**, ***M. El Kodadi***, LTM-CNRS, France, *S. Soulan, P. Schiavone,* Georgia Institute of Technology, *M. Besacier*, LTM-CNRS, France

In situ , real time control of the different process steps in semiconductor device manufacturing becomes a very important challenge, especially for the lithography and plasma etching processes. We have developed a specific software and hardware tools to perform dynamic scatterometry, using in situ spectroscopic multi-wavelength ellipsometry. This technique is non-invasive, non-destructive optical metrology technique. It uses the analysis of the signature of the light scattered by periodic structure to infer the shape of a feature.

In this study the authors show that dynamic scatterometry can be used for real time monitoring during the resist trimming process of two different resist materials, the M78Y resist from JSR, exposed at 248nm wavelength using an ASML/300 scanner, and the 193 nm resist "JSR 1682" . The etch gases used in this study are HBr and O_2.with two different bias power conditions "0 and 50" WBias power. Then we discuss about the influence of chemistries and bias power on the etched profile. We report how the plasma conditions can induce some chemical modifications of the resist films, and we explain how this issue can be addressed in the scatterometric real time control of the resist trimming process. A Jobin-Yvon ellipsometer, capable of real time acquisition of sixteen wavelengths, is plugged onto chamber of a Decoupled Plasma Source (DPS) from Applied Materials. The measurements are made in real time in the etch chamber during the process.

For validation purposes, the same process has been interrupted at several different times and the trimmed feature profiles have been measured using a 3D AFM from Veeco Instruments. The comparison between scatterometry and AFM measurement shows an excellent match for both CD and height parameters with a difference less than 2% .

This proves that dynamic scatterometry provides reliable results and shows a great potential as a real time monitoring technique for etch process control. This characterization technique can be viewed as an invaluable tool for the accurate control of the patterning of current and next generations of semiconductor devices.

3:40pm **NS-ThA6 Advancing QPlus AFM Performance at 5K Towards Lower Oscillation Amplitudes and Higher Frequencies**, *A. Bettac, J. Koeble,* ***K. Winkler***, *B. Uder, M. Maier, A. Felz*, Omicron NanoTechnology GmbH, Germany

The QPlus sensor with its high spring constant and an optimized quality factor allows operation at very small oscillation amplitudes and is therefore ideal for atomically resolved imaging on all types of surfaces, i.e. for insulators, semiconductors and also for metallic surfaces. We have integrated the QPlus technology into an established low temperature STM platform. The extremely low signal of the QPlus sensor due to small oscillation amplitudes requires the first amplification stage to be very close to the sensor, i.e. it has to be compatible with low temperatures.

We present atomic resolution imaging on single crystal NaCl(100) with oscillation amplitudes below 100 pm_{pp} (peak to peak) and operation at higher flexural modes at frequencies of up to 318 kHz in constant df imaging feedback at 5K. We also present atomic resolution measurements on metallic Au(111) and Ag(111) surfaces with an extremely high stability at 5 K [1]. On a reconstructed Si(111) 7x7 surface further investigations in a temperature range between 50 K and 1070 K demonstrate the capability of the QPlus sensor for ultimate resolution in pure NC-AFM and dynamic STM measurements. At low temperatures, atomically resolved images of the rest atom layer will be presented. High temperature measurements close to the phase transition between the (1x1) and (7x7) show dynamics in the formation of step edges and kinks.

[1] A. Bettac, J. Koeble, K. Winkler, B. Uder, M. Maier, and A. Feltz, Nanotechnology, in print

4:00pm **NS-ThA7 Monatomic In Adatom Chains Assembled on the InAs(111)A Surface by Low-Temperature Scanning Tunneling Microscopy**, ***J. Yang***, Paul Drude Institute for Solid State Electronics, Germany, *K. Kanisawa*, NTT Corporation, Japan, *Ch. Nacci*, *S. Fölsch*, Paul Drude Institute for Solid State Electronics, Germany

Atom manipulation by scanning tunneling microscopy (STM) at cryogenic temperatures has proven to be a powerful experimental tool to study the physics of assembled nanostructures at surfaces. Since its implementation in the early 1990s [1], STM-based manipulation has been applied mainly to atoms and molecules adsorbed on metal surfaces. Here we demonstrate the extension of this technique to III-V semiconductor materials and report the fully reversible repositioning of In adatoms on a InAs (111)A surface by vertical manipulation at 5 K, i.e., by transferring individual atoms from the surface to the STM tip and vice versa. This allows us to assemble compact structures with the In atoms added one by one and occupying nearest-neighbor vacancy sites of the (2x2)-reconstructed surface (separation of the vacancy sites $a_0\sqrt{2}$=8.57 Å, a_0: cubic InAs lattice constant). Combining this approach with scanning tunneling spectroscopy (STS), we studied the electronic properties of monatomic adatom chains representing a model case of a one-dimensional electron system. The STS data reveal substantial electronic coupling between the In chain atoms leading to the formation of an unoccupied quantum state delocalized along the chain. Regarding the substantial interatomic spacing of 8.57 Å present here it appears that substrate-mediated coupling is essential for the along-chain linking rather than direct interatomic coupling reported previously in metal-on-metal adatom chains [2,3]. Our results demonstrate that the combined approach of atom manipulation and local spectroscopy is applicable to explore atomic-scale quantum structures in a semiconductor-based system.

[1] J. A. Stroscio and D. M. Eigler, Science 254, 1319 (1991).

[2] N. Nilius, T. M. Wallis, and W. Ho, Science 297, 1853 (2002).

[3] S. Fölsch, P. Hyldgaard, R. Koch, and K. H. Ploog, Phys. Rev. Lett. 92, 56803 (2004).

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4:20pm **NS-ThA8 Making Mn Substitutional Impurities in InAs using a Scanning Tunneling Microscope**, ***Y.J. Song***, NIST and University of Maryland, College Park, *S.C. Erwin*, Naval Research Laboratory, *G.M. Rutter*, National Institute of Standards and Technology, *P.N. First*, Georgia Institute of Technology, *N.B. Zhitenev*, National Institute of Standards and Technology, *Y. Kuk*, NIST and Seoul National University, Korea, *J.A. Stroscio*, National Institute of Standards and Technology

The ability to manipulate single atoms has been demonstrated for both lateral and vertical manipulation using a tunable chemical-bond interaction between the scanning tunneling microscope (STM) probe tip and adsorbed atom [1]. More recently a new form of atom manipulation involving the exchange of two different surface atoms has been observed with Mn atoms on III-V surfaces; the motivation being the understanding magnetic interactions in these dilute magnetic semiconductors [2]. In this presentation we discuss detailed measurements and theoretical calculations of the STM induced exchange of Mn and In atoms on the InAs(110) surface. Mn was deposited onto the InAs(110) surface at 7K and were observed as single adatoms. We used the STM to artificially substitute the single Mn adatoms with In atoms in the top-most surface layer. This process involves raising the sample tunneling voltage beyond a certain threshold voltage of approximately -0.6 eV. We determined the statistical analysis of the threshold voltages for different offset tunneling currents and measured high resolution STM images of the initial and final Mn states as a function of tunneling voltage. We calculated the pathway and energetics for this atomic exchange with density functional calculations and compare with the STM measurements.

[1] J. A. Stroscio and D. M. Eigler, Science **254**, 1319 (1991).

[2] Dale Kitchen *et al*, Nature **442**, 436 (2006).

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