Nanometer-scale Science and Technology Division
Room: Central Hall - Session NS-ThP

Nanometer-scale Science and Technology Poster Session

NS-ThP1 Co-deposition of Nanoparticle – Diamond-Like Carbon Composite Thin Films, ***Ajai Iyer***, *J. Etula, N. Wester, J. Koskinen,* Aalto University, School of Chemical Engineering, Finland

Nanoparticles have been proven to have properties very different from bulk materials and extensive research is undertaken to ascertain application based nanoparticle functional properties. One of the most elegant solutions for nanoparticle usage is to form a composite thin film with desired nanoparticles embedded in a matrix. Such composite films are generally fabricated in one of two ways. Either the nanoparticles are synthesized in-situ during the film growth process or the nanoparticles are seeded prior to film growth process. We propose a unique method of using physical vapour deposition methods to co-deposit pre-processed nanoparticles in tandem with the matrix material forming a composite thin film. These composite films could be deposited as single or multi-layer bulk films or as films with nanoparticle concentration gradient throughout the film thickness. The matrix material is chosen to be diamond-like carbon (DLC) with controllable sp^3 to sp^2 bonded carbon ratio, allowing the film to have a wide range of mechanical, optical and electrical properties. Co-deposition of nanoparticles with DLC results in composite films where nanoparticles are embedded into a DLC matrix. The effect of the type and concentration of nanoparticles on the mechanical, optical and electrical properties of the composite film are currently under study with possible application fields related to sensors, electrically conductive coatings, thin film optical waveguides and energy storage. In this work we demonstrate detonation nanodiamonds (DNDs) co-deposited with high quality DLC using a pulsed filtered cathodic vacuum arc (p-FCVA) method to form DND-DLC composite film. Transmission electron microscopy (TEM) has been used to verify the presence of DND agglomerates (sized few tens of nm) in the composite film as well as the crystallinity of the embedded DND nanoparticles. The DND nanoparticle concentration has been estimated to be of the order of 0.1 vol% in the composite film. The DND-DLC composite film has been measured to have around 16% enhancement in hardness and 40% reduction in wear in comparison to DLC film. Preliminary tests indicate that the composite film has potential as an electrochemical sensor and further tests are in progress. Results of co-deposition of other nanoparticles with DLC to form composite film are also discussed.

NS-ThP2 Atmospheric Pressure Plasma Functionalization of Diamond Particles, ***Gary McGuire***, *O.A. Shenderova, N.J. Nunn,* Adamas Nanotechnologies, Inc.

Dielectric barrier discharges are non-equilibrium plasmas which may operate at atmospheric-pressure avoiding the necessity of generating vacuum conditions. Operation at atmospheric pressure facilitates the introduction and surface functionalization of gram quantities of nanoparticles within minutes at room temperature as an alternative means to high temperature processes which typically takes hours. In this study nanodiamond particles of detonation origin were fluorinated using CF_4. Surface analysis using x-ray photoelectron spectroscopy confirmed a fluorine concentration of up to ~4.5 at% of the nanodiamond particles surface. Fourier transform infrared spectroscopy revealed the presence of F-bands, related to CF_3 - (CF_2) stretching vibrations and symmetric and asymmetric CF_2 vibrations. Fluorine surface functional groups can serve as a means for further chemical substitution reactions so that other, more complex functional groups such as amino acids, oligonucleotides, peptides, etc. can bond to the surface, facilitating material applications for biosensors. It has been demonstrated that an atmospheric pressure dielectric barrier glow discharge is a highly effective means to rapidly fluorinate, oxidize and aminate diamond surfaces.

NS-ThP3 Nanometer-scale Etch Characteristics of TiN Thin Films using Inductively Coupled Plasma of $Cl_2/C_2F_6/Ar$, ***JaeSang Choi***, *J.Y. Lee, D.H. Cho, C.W. Chung,* Inha university, Republic of Korea

As the information era has come, high performance semiconductor memory devices which have the characteristics containing high density, fast process time, lower power consumption for faster mass data transfer has been required. To satisfy these demands, scaling down to nanometer scale for etching process has been important in fabricating semiconductor devices. Titanium nitride (TiN) thin film has been widely employed as a hard mask due to its fine property such as good thermal and chemical stability, and good adhesion than conventional inorganic masks. In the past, there were some studies on TiN films using Cl_2, BCl_3, NF_3, CF_4, and SF_6 gases [1-3]. However, the etching process of nanometer-sized TiN films was rarely investigated.

In this study, nanometer-scaled e-beam resists were patterned on TiN thin films and inductively coupled plasma reactive ion etching using $Cl_2/C_2F_6/Ar$ gas mixtures was applied to investigate the characteristics of TiN thin films. First, a variety of gas ratio was examined to find out best etch profile using micro-patterned TiN thin films. Then, based on these results, the nanometer-patterned TiN thin films using $Cl_2/C_2F_6/Ar$ gas mixtures were investigate in terms of etch selectivity and etch profile. Finally, energy dispersive X-ray spectroscopy and X-ray photoelectron spectroscopy will be performed on the etched TiN films to elucidate the etch mechanism.

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NS-ThP4 Etch Characteristics of Magnetic Tunnel Junction Stacks using Pulse-modulated RF Source Plasma, ***JaeYong Lee***, *J.S. Choi, D.H. Cho, C.W. Chung,* Inha University, Republic of Korea

The source/bias pulse-time modulated RF plasma has been introduced to progress further in convoluted challenges from conventional continuous wave (CW) plasma such as fatal etch damage, low etch selectivity, and etch residues. This modulated plasma means the plasma condition modified by a specific matching system which can change on-off duty ratio of 13.56MHz RF power and frequency on the specific duty ratio. Especially, since the magnetic materials used for magnetic random access memory (MRAM), which is a promising candidate for next generation semiconductor, have less reaction with even corrosive gases, this process can offer a prospective approach. Some researches on etch characteristics of magnetic materials using bias-pulse time modulated plasma has been reported, resulting in improved etch profiles compared to CW plasma . However, few studies on the magnetic materials using source-pulsed plasma can be found.

In this study, etch characteristics of nanometer-scale patterned magnetic tunnel junction stacks (MTJs), which is a critical component of MRAM, using the pulsed modulated RF source plasma were investigated. The MTJs consisted of TiN/Ta/CoFeB/MgO/CoFeB/Ta on the SiO_2 substrate and E-beam resists of 70×70 nm^2 were patterned on the TiN hardmasked MTJ stacks. In the plasma process, the non-corrosive gas mixture of $CH_4/O_2/Ar$ was used. The effects of on-off duty ratio and frequency of pulsed plasma on the etch characteristics of MTJ stacks were examined.

NS-ThP5 Dry Etching of Nanometer-scale Patterned CoFeB Thin Films under Pulse Modulated Plasma, ***DooHyeon Cho***, *J.S. Choi, J.Y. Lee, C.W. Chung,* Inha University, Republic of Korea

Dynamic random access memory device has been commercially sucessful. However this device has disadvantages such as volatility and scaling problem. Spin transfer torque magnetic random access memory(STT-MRAM) has been recieved a great attention as the next-generation memory device owing to the advantages such as non-volatility, high density, unlimited endurance and low operating voltage[1]. The STT-MRAM devices are composed of magnetic tunnel junction stacks (MTJs) and CMOS. As the dimension of MTJs is decreased, perpendicular magnetic anisotropy (PMA) is necessary for high density MRAM. Therefore, the MTJs comprised of multilayers incluing CoFeB thin films should be fabricated in nanometer-scale dimension for PMA [2]. In order to realize this demand for high density MRAMs, the magnetic thin films such as CoFeB, CoPt, PtMn and so on should be patterned in nanometer-scale.

In the previous studies, micrometer-scale patterned CoFeB thin films showed relatively good etch profiles using CH_3OH, CH_3COOH and $CH_4/O_2/Ar$ [3,4,5]. In this study, the etch characteristics of nanometer-scale patterned CoFeB thin films using $CH_4/O_2/Ar$ gas mixture under pulse-modulated plasma were investigated. The main parameters in pulsed-modulated plasma, which are on-off duty ratio and pulse frequency, were applied to investigate the etch characterisitic of CoFeB thin films. Finally, high degree of anisotropy of the etched CoFeB films with 70 x 70 nm^2 patterns were obtained and the etch mechanism also was examined using optical emission spectroscopy, X-ray photoelectron spectroscopy and TEM micrographs.

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NS-ThP6 The Formation of Stable GeO_2 Oxide using the High Pressure Oxidation, ***Juhyun Bae***, *I.S. Chung*, Sungkyunkwan University, Republic of Korea

Thermal oxidation of Ge has been investigated under high pressure ambient to suppress GeO vaporization. Ge oxide was grown in the temperature range of 450 °C to 550 °C in dry O_2 ambience at three different pressures such 10, 30, and 50 atm. The physical property of GeO_2 is analyzed using the transmission electron microscopy (TEM) and X-ray photoelectron spectroscopy (XPS). Additionally, C-V characteristics were obtained from GeO_2/Ge MOS capacitors. The hysteresis in C-V characteristics and the interface trap density (D_{it}) are significantly reduced as the pressure increases. Consequently, the properties of both GeO_2 film and GeO_2/Ge interface are successfully improved by suppressing GeO volatilization utilizing high pressure.

NS-ThP8 Controlling Kondo Resonances of Magnetic Molecules on Au(111) by Binding of Metal Atoms, ***MinHui Chang***, Korea University, Republic of Korea, *Y.H. Chang*, Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea, *H. Kim*, *S.H. Lee*, Korea University, Republic of Korea, *Y.H. Kim*, Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea, *S.-J. Kahng*, Korea University, Republic of Korea

Controlling and sensing spin states of magnetic molecules at the single molecule level is essential for spintronic molecular device applications. The exchange coupling between magnetic-molecules and metallic substrates has been actively studied by measuring Kondo resonances at Fermi level. The resonances have been controlled by small molecule bindings, but not by adsorption of metal atoms to magnetic-molecules. Here, we demonstrate that Kondo resonances of Co-porphyrin on Au(111) can be controlled by adsorption of metal atoms, and be sensed using scanning tunneling microscopy and spectroscopy (STM and STS). Bare Co-porphyrin showed a clear zero-bias peak, a signature of Kondo resonances in STS, whereas Co-porphyrin adsorbed metal atoms showed modified zero-bias resonances, with reduced full width half maximum or Kondo temperature. Our density functional theory calculation results explain it with spatial redistribution of unpaired spins in d-orbitals of Co-porphyrin by the adsorption of metal atoms. Our study shows that the spin-state of metallo-porphyrin can be modified in multiple ways by the adsorption of additional metal atoms, and be probed through Kondo resonances with STS.

NS-ThP9 Nanolithography Toolbox: Design Solutions for Nanoscale Devices, ***Roberto De Alba***, *K.C. Balram*, *D.A. Westly*, *M. Davanco*, *K.E. Grutter*, *Q. Li*, NIST, *T. Michels*, GenISys GmbH, *C.H. Ray*, *L. Yu*, *R.J. Kasica*, *C.B. Wallin*, NIST, *D.A. Czaplewski*, *L.E. Ocola*, Argonne National Laboratory, *S. Krylov*, Tel Aviv University, Israel, *P. Neuzil*, Brno University of Technology, Czech Republic, *K. Srinivasan*, *S.M. Stavis*, *V.A. Aksyuk*, *J.A. Liddle*, *B.R. Ilic*, NIST

Various lithography patterning technologies can be used to define structures with nanometer-scale lateral dimensions. The first step in any lithographic process consists of device design. There are a number of available design packages that output semiconductor-standard graphic database system (GDSII) files, which is a binary format representing planar geometric shapes. The predominance of IC devices in manufacturing has led to the development of software packages that are ideal for designing and laying out integrated circuits, which typically have rectilinear geometries, where shape edges are parallel to the *x* and *y* axes. Consequently, many of these software packages are not ideal for designing curved geometries with aggressively-scaled dimensions for nanophotonic, nanoplasmonic, nanofluidic, and nanomechanical devices. To solve this design problem, we have developed a computer-aided design (CAD) software package for streaming complex shapes to GDSII. The platform-independent Nanolithography Toolbox runs on Linux, Windows and MacOS, and is free for users to download from the Center for Nanoscale Science and Technology at the National Institute of Standards and Technology (CNST) website (http://www.nist.gov/cnst/).

The CNST developed the Toolbox to help users of the CNST NanoFab to design their nanoscale devices, particularly those with curved features and small dimensions. The Toolbox offers design features that are difficult to implement in software optimized for IC design, and allows users to rapidly customize nanoscale shapes of arbitrary complexity. The Nanolithography Toolbox offers hundreds of parameterized shapes that are useful in a variety of applications spanning nanoscale photonics, mechanics, fluidics, electronics, and other disparate fields of scientific endeavor. Furthermore, the Toolbox allows users to precisely define the number of vertices for each shape or to create vectorized shapes using Bezier curves. In the former case, the Toolbox constructs the resulting shapes with a uniform vertex distribution along the periphery, rendering symmetric objects. A shape-rendering parameter controls the number of vertices for vectorized objects. The parameter is set globally for all shapes, or individually for each shape. In the latter case, the resulting rendered shapes have an increased vertex density at higher curvatures. A full description of the all the capabilities of the Toolbox can be found in the manual.

NS-ThP10 Visualizing Silicide Formation via Interface Electrostatics with BEEM, ***Westly Nolting***, SUNY Polytechnic Institute, *C. Durcan*, SUNY College of Nanoscale Science and Engineering, *V. LaBella*, SUNY Polytechnic Institute

Nanoscale fluctuations in the electrostatics of a metal semiconductor interface impact performance and are important to understand and measure, which can be accomplished with ballistic electron emission microscopy (BEEM), an STM based technique. In this work, we perform BEEM on Cr/Si Schottky contacts to visualize the interface electrostatics to nanoscale dimensions to understand the effects of silicide formation. This is accomplished by acquiring tens of thousands of spectra on a regularly spaced grid and fitting the results to determine the local Schottky barrier height. Monte-Carlo modeling is utilized to calculate the barrier height distributions that includes scattering of the electrons that traverse the metal layer and a distribution of electrostatic barriers at the interface. Improved agreement between the model and the data is achieved when specifying more than one barrier height, providing a signature of silicide formation. This, and recent work extended this method to the W/Si interface will be presented.

NS-ThP11 Dimensionality Effects in $FeGe_2$ Nanowires: Enhanced Anisotropic Magnetization and Anomalous Electrical Transport, ***Ivan Kravchenko***, Oak Ridge National Laboratory, *S. Tang*, Central South University, PR China, *T.Z. Ward*, *Q. Zou*, Oak Ridge National Laboratory, *J. Yi*, University of Tennessee, *C. Ma*, *M. Chi*, *G. Cao*, *A.-P. Li*, *D.G. Mandrus*, *Z. Gai*, Oak Ridge National Laboratory

We report the synthesis of single-crystal iron germanium nanowires via chemical vapor deposition without the assistance of any catalysts. The assembly of single-crystal $FeGe_2$ nanowires with tetragonal C16 crystal structure shows anisotropic magnetic behavior which is ferromagnetically coupled perpendicular to the wires and antiferromagnetically coupled parallel to the wires' long axis. Single $FeGe_2$ nanowire devices were fabricated using e-beam lithography. Transport in these devices show two resistivity anomalies near 250 K and 200 K which are likely signatures of the two spin density wave states in $FeGe_2$.

NS-ThP12 A High Coherence Package for Quantum Circuits Containing Topologically Isolated Qubits, ***Vivekananda Adiga***, *N.T. Bronn*, *S.B. Olivadese*, IBM Research Division, T.J. Watson Research Center, *X. Wu*, *D.P. Pappas*, NIST Boulder, *J.M. Chow*, IBM Research Division, T.J. Watson Research Center

We demonstrate a package containing a superconducting quantum processor wherein we use Pogo pins (50 Ohm) to access the topologically isolated qubits. This allows us to enclose our quantum processor in a non-magnetic environment where we can maintain RF-Hygiene and the entire assembly is compatible with low temperature operation. Self-alignment of the parts allows for rapid testing and scalable integration. We demonstrate low energy loss and high phase coherence comparable to the standard packages involving wirebonds. Single and two-qubit gate fidelities are on par with standard packaging schemes with cross talk less than -40 db at the frequencies of operation. Results are promising for integration with extensible qubit architectures.

NS-ThP16 Few-Wall Carbon Nanotube Coils, ***Dekel Nakar***, *R. Popovitz-Biro*, *K. Rechav*, *E. Joselevich*, Weizmann Institute of Science, Israel

Various electronic components based on carbon nanotubes (CNTs) have been produced, but an induction coil has not been demonstrated yet. Our group previously created defect-free single-wall CNT coils, but short-circuiting between turns prevents the coils from acting as inductors. To overcome this limitation, here we explore the use of few-wall CNTs, in which the outer walls may act as sheathing for the inner walls. We show the successful formation of the first few-wall CNT coils from individual CNTs and thin bundles.We characterized the structural properties of the coils using optical microscopy, SEM, AFM, top-view TEM and cross-sectional TEM. We also characterized their electrical properties. The coils comprised CNTs of two, three and four walls without observable defects. The coils had up to 163 turns and diameters between 1 and 5 μm. Based on the structural results, we

suggest a mechanism for the formation of the coils. These ordered coils extend the known repertoire of self-organized structures of 1D nanomaterials. They are also promising candidates for inductive devices, and for manifesting other interesting properties, such as electromagnetism and superconductivity.

Nakar, D.; Popovitz-Biro, R.; Rechav, K.; Joselevich, E., "Few-Wall Carbon Nanotube Coils", *in preparation*.

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