Electronic Materials and Processing
Room: Hall 3 - Session EM-TuP

Electronic Materials and Processing Poster Session

EM-TuP1 Ionic Liquid Gated Electric Double Layer Transistors based on a-IGZO Thin Films, ***PushpaRaj Pudasaini**, J.H. Noh, A. Wong, A.V. Haglund,* The University of Tennessee Knoxville*, S. Dai, T.Z. Ward,* Oak Ridge National Laboratory*, D. Mandrus,* University of Tennessee, Knoxville and Oak Ridge National Laboratory*, P.D. Rack*, The University of Tennessee Knoxville

The electric filed effect with the field effect transistor configuration is a powerful approach for externally tuning the carrier density of a material and investigating associated changes in the electronic properties of the material. To this end, ionic liquid gated field effect transistors have been extensively studied due to their low operation voltage, ease of processing and the realization of high electric fields at low bias voltages. Herein, we report ionic liquid (IL) gated field effect transistor based on amorphous Indium Gallium Zinc Oxide (IGZO) thin film active layers. The transport measurement of the IL revealed the intrinsic n-channel property of the IGZO thin film with high ON/OFF ratio ~10^5 and a large field effect electron mobility of 5.38 $cm^2V^{-1}S^{-1}$ at 300K and a threshold voltage of 0.1V. Comparable measurements on the bottom SiO_2 gate insulator revealed an ON/OFF ratio ~10^9 and field effect electron mobility of 12.53 $cm^2V^{-1}S^{-1}$ and a threshold voltage of 2.5V. Furthermore, we found that the ionic liquid gating of a-IGZO thin film leads to not only an electrostatically induced carrier accumulation but also the field induced creation of O_2 vacancy, with constituent migration of oxygen in and out of the film depending on the polarity of the bias used. This could leads to the bias induced control of carrier density in an amorphous oxide semiconductors.

EM-TuP2 Resistor Thermal Noise Rectification for Energy Harvesting, ***Amina Belkadi**, S. Joshi,* University of Colorado at Boulder, *G. Moddel*, University of Colorado at Boulder and Redwave Energy

Resistor noise produces real power and can, in principle, be rectified for thermal energy harvesting. For ambient temperatures and above, the peak frequency in the noise spectrum is at least 30 THz, which requires an ultra-high-speed diode for rectification and a quantum-based theory to describe the rectification process. In this study, we analyze harvesting energy through the rectification of resistor thermal noise. The electrical noise spectrum generated by a warm resistor is similar to that from one-dimensional blackbody radiation channeled through an antenna. This allows the use of optical rectenna circuitry and concepts, in the presence of a temperature gradient between the resistor and the diode, by merely replacing the antenna with a resistor. We use the semi-classical theory of photon-assisted tunneling to explain the diode rectification behavior. In contrast to an antenna-coupled diode, using a resistor modifies and may help resolve some optical rectenna challenges such as the RC time constant and optical coherence limitations, impedance matching to the diode, and undesired heating of the diode. However, a key challenge remains: the very low power produced by the hot resistor. This limits the diode rectification efficiency. If challenges of low power and low rectification efficiency are overcome, the concept can be used for applications such as (i) efficient harvesting of energy from waste heat sources and even from the earth, when a suitable heat sink is provided, and (ii) conversion of solar energy either directly or via an intermediate thermal transducer. The fact that conventional photovoltaic devices use only the high energy part of the solar spectrum to produce power places a limit on their conversion efficiency. Therefore, integration of solar cells with a resistor-based thermal noise energy harvesting device could potentially increase the overall efficiency of solar cells.

EM-TuP5 Electrical and Optical Properties of the Porous Nickel Oxide Thin Film as Counter Electrode for the Application to Electrochromic Devices, ***WonChang Lee**, J.U. Wie, E.C. Choi, B.Y. Hong*, Sungkyunkwan University, Republic of Korea

Electrochromic materials are able to change the optical properties persistently and reversibly by an external voltage. Applications of electrochromic materials include rearview mirrors, smart windows, display panels, etc. A large number of transition metal oxides such as the well-known tungsten trioxide (WO_3) cathodic material, which reversibly switches from transparent to blue upon lithium or proton insertion.

In contrast, nickel oxide (NiO) is an anodically coloring material but despite promising features such as high coloration efficiency, good optical memory and cost effectiveness. NiO is often used as a secondary electrochromic material to complement cathodically coloring WO_3 in prototype electrochromic devises. Because NiO have for a long time attracted attention as counter electrode regarding their brownish color in the oxidized state that, together with the blue color of the reduced WO_3, yields a neutral gray color device in the colored state. The electrochromism in NiO films is rather complicated although it is generally accepted that the reversible transition between colored and bleached states is related to redox process between the NiOOH and NiO. Moreover, owing to their rapid degradation on cycling, difficulties in using nickel oxide films have been encountered. However, the problems of NiO thin films that limit their commercialization and poor durability are still debated. When NiO film is formed as porous structure, the surface area to the volume ratio is large and the same probably lead to an increase in the ion intercalation and deintercalation. The large-area surface of the porous film structure can be helpful for the augmenting the optical modulation.

In our study, the porous NiO thin film was deposited using sol gel-method and dip-coating technique on the Indium Tin Oxide (ITO) glass. The NiO thin film was formed by annealing process at different temperatures after the dip-coating technique. Studies on the effect of annealing temperature to improve the crystallinity and the electrochromic properties of the NiO thin films have been carried out. So, we confirmed that the electrochromic efficiency was improved by optimizing of the annealing condition.

EM-TuP6 Tunable Optical Extinction of E-Beam Fabricated Nano-Rectennas Modified by Atomic-Layer Deposition, ***Raymond Wambold,*** The Pennsylvania State University*, G.J. Weisel, D.T. Zimmerman,* The Pennsylvania State University, Altoona*, J. Qi, B.G. Willis*, University of Connecticut

We present a systematic study of plasmon extinction characteristics of arrays of tunable nanoscale rectennas, which have possible application as solar-energy harvesting devices and optical-IR sensors. Each nanorectenna is composed of a triangular prism and a flat counter-electrode, both made of palladium. We fabricate arrays of rectennas on silica using standard electron-beam lithography. We then use atomic-layer deposition (ALD) of copper to control the gap distance between the two electrodes. To measure optical extinction we employ a broadband (Quartz-tungsten-halogen) light source in a confocal, transmission arrangement. Our measurements demonstrate that the plasmon extinction resonance can be tailored by varying the e-beam dose and the cycles of ALD. The most important feature of our work is the ability to reduce the gap spacing between the two electrodes, which serves to systematically redshift the extinction peak and ultimately bring the two electrodes into the tunneling regime. We also investigate the effects of overall size, morphology, and material properties on the extinction resonance. We employ Finite-Difference Time-Domain simulations to support our device design and to corroborate our experimental measurements. In addition, we use scanning electron microscopy to correlate the device-dimension and morphology changes to the plasmon extinction characteristics.

EM-TuP7 The Study of Light Control using Nanoantenna, ***JeongHee Shin**, S. Kim, J.E. Jang*, Daegu Gyeongbuk Institute of Science and Technology (DGIST), Republic of Korea

Recently, the antenna has been scaled down to nanometer to absorb higher electric-magnetic wave. Traditionally in communication area, high frequency is required to transmit or receive much more information. Nanometer antenna is different from general antenna in communication area due to properties and applications. Nanoantenna can cover the visible to near-infrared (NIR) wavelength regions; thus, it has a lots of applications in communication, optics, bioelectronics and so forth. Especially in optics area, not only the light control but also structure-depended absorption, reflection, and transmission using nanoantenna have been studied. The light absorption using nanoantenna can be useful to harvest electrical energy instead of solar cells expected to be much higher efficiency as well. The optical properties of nanoantenna can be affected by geometry factors such as structure, shape, and pitch. It cannot correspond traditional antenna theory due to surface plasmons (SPs) which are coherent delocalized electron. This penomenons exist at the interface between two materials, strong couplings between electrons on metal and incident light. Designing nanoantenna is much more complicate than that of general antenna so that it does not simply follow conventional antenna theory. To apply the nanoantenna to various applications, the study of parameters to define optical properties in nanoantenna should be necessary. We focused on control of color via nanoantenna depending on various geometries. First of all, we investigated the relation between parameters and color change. We can design the target peak wavelength in visible region. Then, we will report optical transistor to control colors. It can be applied to various

applications such as color filter, next-generation display, energy harvesting system with higher efficiency, and so on.

EM-TuP8 MIM: Role of Design and Fabrication, ***Aparajita Singh***, *S. Bhansali*, Florida International University

The early assumptions have been that thin-film development and contact area the two major issues in defining characteristics of the MIM tunnel diode. Based on this the focus has rigorously been on patterning and various thin-film deposition techniques for MIM formation. Several designs with varied fabrication methods have been considered for fabrication of MIM devices till date for applications like energy-harvesting devices, terahertz electronics, macro electronics, etc. Here we elaborate upon each design and associated fabrication challenges for Ni-NiO based MIM and MIIM diodes. The goal is to optimize the MIM device design for: (1) ease of integration with other circuit devices, and (2) simpler fabrication steps for minimizing alteration in oxide property and inherent device impedance. Fabrication issues such as material selection, metal deposition, oxide growth/deposition, and patterning are discussed. Since ALD is currently the leading way to provide uniform, pinhole free and ultra-thin oxide layers, we present a comparison of oxide properties deposited by sputtering and ALD (the leading techniques) along with their impact on I-V characteristics. Influence of surface preparation on oxide and growth/deposition temperature are also discussed.

EM-TuP9 Comparison of Hafnium Oxide and Zirconium Oxide Thin Films for Fabricating Electronic Devices, ***Jouantrey Spence***, *F. Cunningham, R. Moten, Z. Xiao*, Alabama A&M University

Thin films of hafnium dioxide (HfO_2) and zirconium oxide (ZrO_2) are used widely as the gate oxide in fabricating integrated circuits (ICs) because of their high dielectric constants. In this research, we report the growth of hafnium dioxide (HfO_2) and zirconium oxide (ZrO_2) thin films using e-beam evaporation, and the fabrication of complementary metal-oxide semiconductor (CMOS) integrated circuits using the HfO_2 and ZrO_2 thin films as the gate oxide. MOSFETs, CMOS inverters, and CMOS ring oscillator were fabricated, and the electrical properties of the fabricated devices were measured. The measurement results on the devices fabricated with the two films were compared, and will be reported in the Conference.

EM-TuP10 Non-Equilibrium First-Principles Study on Electron Scattering Processes in Magnetic Tunnel Junction, ***Masaaki Araidai***, Nagoya University, Japan, *T. Yamamoto*, Tokyo University of Science, Japan, *K. Shiraishi*, Nagoya University, Japan

Investigation of magnetic tunnel junction (MTJ) is a key issue for the development of advanced magnetoresistive random access memories (MRAMs). MTJs consist of two metal ferromagnets, thick magnetization-fixed and thin magnetization-free layers, separated by a thin insulator, and they exhibit two resistances, low or high, depending on the relative direction of the magnetizations of fixed and free layers, parallel (P) or antiparallel (AP) configuration. The simplest way to reverse the magnetization of free layer is switching by external magnetic fields. However, absolute currents required for the magnetic-field switching do not scale with reducing the junction size. At present, current-induced magnetization switching (CIMS) proposed by Slonczewski [1] and Berger [2] is drawing attention as the most promising candidate for a mechanism of magnetization reversal of free layer, owing to the scalability of CIMS [3]. Although CIMS has been successfully applied to the operation of MRAM, it has not been sufficiently understood yet.

In this work, we investigated electron scattering processes in CIMS of a MTJ by the non-equilibrium Green's function technique coupled with the density-functional theory [4]. We employed a Fe/MgO/Fe MTJ sandwiched between ferromagnetic Fe and paramagnetic Ta electrodes, as a typical MTJ model. The current-voltage characteristics indicated high tunnel magnetoresistance of the MTJ (about 600% at zero bias) and was highly antisymmetric with respect to the bias voltage, originating from the antisymmetric structure and the magnetization configuration. We found from the current density dependence of magnetization of the free layer that the switching from AP to P configuration could be realized by lower electrical power than P-to-AP case. From detailed analyses of the density of states subject to a finite bias voltage, we clarified that the asymmetric behavior originates from the difference in the electron scattering processes between switching directions.

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EM-TuP11 First Principles Study on Switching Mechanism of Superlattice $(GeTe)_2/Sb_2Te_3$ Phase Change Memory, ***Masayuki Takato***, *H. Shirakawa, M. Araidai, K. Shiraishi*, Graduate School of Engineering, Nagoya University, Japan

Superlattice phase change memory (superlattice PCM) consisting of $(GeTe)_2/Sb_2Te_3$ stacked structure is one of the most promising candidates for next-generation non-volatile memories and has received considerable attention in recent years [1,2]. The memory operations are attributed to small structural change between two atomic configurations before and after switching. Therefore, the energy required for switching between higher and lower resistive states is much lower than that of conventional PCMs utilizing phase transition between crystal and amorphous phases [3]. However, the reaction pathway in switching of superlattice PCM has not yet been clarified and the detailed analyses of the structural transition between high-resistive and low-resistive states are prerequisites for fully understanding the switching mechanism.

In this work, we investigated the switching process of the superlattice $(GeTe)_2/Sb_2Te_3$ PCM using the first-principles electronic states calculations. The atomic structures and the electronic states were calculated by VASP code [4], which is based on density functional theory with the plane-wave basis sets, a PBE-type exchange-correlation functional and the projector augmented-wave method. For the calculations, $\boldsymbol{k}$ points of 8 x 8 x 4 Monkhorst-Pack grid were used and the cutoff energy was 500eV.

We found that atomic configurations of high-resistive and low-resistive states are not stable but metastable [5]. Therefore, the superlattice $(GeTe)_2/Sb_2Te_3$ PCM can do cyclic operations due to the metastability. In addition, we clarified the structural transition process between high-resistive and low-resistive states. I will show the detail process in the announcement. Furthermore, the validity of our proposal will be shown from the detailed analyses of the potential energy surface and electron-density distribution.

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EM-TuP12 First Principles Study on Atomic-scale Behavior of N, H Atoms and O Vacancy Related Defects in SiO_2 Layer of MONOS Memories, ***Hiroki Shirakawa***, Graduate School of Engineering Nagoya University, Japan, *M. Araidai*, Graduate School of Engineering, Nagoya University, Japan, *K. Kamiya*, Center for Basic Education and Integrated Learning, Kanagawa Institute of Technology, Japan, *K. Shiraishi*, Graduate School of Engineering, Nagoya University, Japan

Metal-Oxide-Nitride-Oxide-Semiconductor (MONOS) memories have attracted a great attention as one of the next generation NAND flash memories. MONOS memories can trap charges inside defect sites in charge trap layers (SiN) that are spatially separated each other, leading to great merits for integration techniques such as 3D-structure and multi-level-cell operation. On the charge trapping layer in MONOS memories, it has been reported that large amounts of O and N atoms are incorporated into SiO_2/SiN interfaces, leading to the formation of electron occupied defects near the interfaces [1]. In addition, Vianello et al. have found that a lot of H atoms distribute in SiO_2, SiN and interface [2]. Yamaguchi et al. have also reported atomic-scale behavior of such defects in MONOS SiN layers during program/erase (P/E) cycles [3]. However, for SiO_2 layer of MONOS memories, the decisive atomic-scale information has not been clarified yet.

In this work, we investigate the behavior of N, H atom and O vacancy in SiO_2 during P/E cycles using VASP code [4], which is based on the density functional theory with GGA of Perdew-Wang-91. Core valence interactions were described by the ultrasoft pseudo potential. To simulate N related defects in SiO_2 layer near SiN/SiO_2 interface, we employed the 72 atoms super-cell of α-quartz including the defects. The defects formed by substituting two N atoms for two O atoms in SiO_2. The P/E operations correspond to the electron and hole injections into the defects in our calculation.

We found that O vacancies are induced by the two N-substituted defects, forming the complex defect (VoN2) that consists of one O vacancy and two N atoms. Then, VoN2 defect cannot traps charges when the Fermi energy of MONOS is within the ranges of SiN band gap. We also found that the diffusing H atoms in SiO_2 change the characteristics of VoN2 defect. VoN2 defect is transformed to another defect including H atoms (VoN2-H) by adsorbing hydrogen atoms. While VoN2-H defect is energetically unstable compared with VoN2 in the neutral charge state, VoN2-H defect becomes very stable in the negative charge state. This indicates that VoN2-H defect is able to trap electrons.

These results suggest that the amount of trapped charges on MONOS memories strongly depends on the dynamics of H atoms in SiO_2 during P/E

cycles; namely, the thermal diffusion of H atoms would bring about the threshold voltage shift of MONOS memories.

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EM-TuP14 Hybridization and Characterization of Reduced Graphene Oxide with Copper Nanoparticles, *J.D. Lee, L.R. Hubbard,* ***Anthony Muscat***, University of Arizona

An in-situ crystallization technique was used to prepare a hybrid containing Cu nanoparticles (NPs) bound to reduced graphene oxide (rGO) sheets. The hybrid material was investigated with scanning electron microscopy (SEM), Raman spectroscopy, ultraviolet visible spectroscopy (UV/vis), X-ray photoelectron spectroscopy (XPS), and Fourier transform infrared spectroscopy (FTIR). SEM results show that spherical Cu nanoparticles ranging from 1.6 to 7.4 nm in diameter and agglomerates were randomly dispersed on rGO sheets. SEM images show that Cu NPs were intercalated between rGO sheets to form a hybrid material. UV/vis of the rGO:Cu hybrid contained peaks associated with GO and Cu NPs with a blue shift in the peak resulting from $n \rightarrow pi^*$ transitions of C=O bonds to 283 nm and a red shift in the peak indicative of the Cu surface plasmon resonance to 585 to 630 nm. XPS confirmed the presence of CuO and $Cu(OH)_2$ with peaks at 933.4 and 934.5 eV respectively. The presence of imidazole, from the ionic liquid [Bmim][BF_4] used to synthesize the Cu NPs, was confirmed by the XPS peak found at 400.4 eV and the contributions to fingerprint regions in the FTIR. The as synthesized rGO:Cu hybrid had an electrical conductivity of 3.5×10^6 S/m. This value is intermediate between GO with a baseline of 0.04 S/m and Cu NP thin film conductivity of 2.0×10^7 S/m.

EM-TuP15 Hybrid Transparent Conductive Electrodes Embedded with Pt Nanoclusters for Reliable and Efficient GaN-based Light-Emitting Diodes, *K. Kim,* ***Hyunsoo Kim***, Chonbuk National University, Republic of Korea

A key technology to fabricate highly efficient and reliable GaN-based light-emitting diodes (LEDs) is transparent conductive electrodes (TCEs), which are used as the Ohmic contact to *p*-GaN and the current spreader. Indeed, a lot of attempts have been made to fabricate better TCEs with high optical transmittance, low sheet resistance, and low contact resistance by employing Pt, oxidized Ni/Au, indium tin oxide (ITO), zinc oxide (ZnO), carbon nanotubes, graphene, et c. Among these TCEs, ITOs are the best in terms of their high optical transmittance in the visible wavelength range, low sheet resistances, feasible Ohmic contact to *p*-GaN, and guaranteed robustness, enabling them to be practically used in commercial products. Unfortunately, however, the sputtering process, which can produce the best quality of ITO films, cannot be used for the deposition of ITO film to p-GaN, associated with the sputtering damage of *p*-GaN surface. As an alternative, therefore, the *e*-beam evaporation technique, which is a representative physical vapor deposition technique free of ion damage, has been used for the ITO deposition. However, the evaporated ITO films were relatively poorer than the sputtered films due to the lack of stoichiometry and insufficient crystallinity of the ITO.

Metallic Pt thin film was shown to act as efficient current spreader in the GaN-based LEDs due to its low R_{sh} value and feasible Ohmic contact associated with its large work function (5.65 eV). More interestingly, Pt thin film has a distinctive feature of agglomeration upon thermal annealing, a so-called Ostwald ripening, leading to the formation of Pt islands or nanoclusters. This feasibility suggests that the combination of sputtered ITO or ZnO films and Pt nanoclusters, namely, hybrid TCEs, may be successful for fabricating novel TCEs for GaN-based LEDs since Pt nanoclusters are expected to act as the preventer of ion damage or an Ohmic patch. In this regard, hybrid TCEs were investigated by combining Pt nanoclusters and sputtered films. Notably, hybrid ITO TCEs fabricated by combining interfacial Pt nanoclusters with a coverage ratio of 23.7 % (acting as an Ohmic patch) and a 100-nm thick sputtered ITO film yielded a low specific contact resistance of $\sim 1.3 \times 10^{-2}$ Ωcm^2, a sheet resistance of 24 Ω/sq, and a high optical transmittance of 90 % at 450 nm. LEDs fabricated with the hybrid ITO TCEs showed a 17.2 % brighter light output power compared to reference LEDs. This indicates that the high-quality sputtered ITO film can be practically used in LEDs by embedding Pt nanoclusters.

EM-TuP16 Selective Area Growth of InN on Patterned Substrate by Plasma-Assisted Metal-Organic Molecular Beam Epitaxy, ***Wei-Chun Chen***, National Applied Research Laboratories, Taiwan, Republic of China, *S.Y. Kuo,* Chang Gung University, Taiwan, Republic of China, *F.I. Lai,* Yuan-Ze University, Taiwan, Republic of China, *Y.C. Lee,* Chung Yuan Christian University, Taiwan, Republic of China, *C.N. Hsiao*, National Applied Research Laboratories, Taiwan, Republic of China

In this article, we investigated selective area growth of InN materials on sapphire substrate using molybdenum mask patterned with various growth temperature. The surface morphology, structural and optical properties of InN materials were analyses by field emission scanning electron microscopy (FE-SEM), transmission electron microscopy (TEM), X-ray diffractiometer and photoluminescence, respectively. XRD results indicated that the InN materials exhibited preferred orientation along the <0001> direction at 550 ºC. Surface morphology shows that the InN crystals were grown on Mo-patterned substrate with *hexagonal* micro-rods *array* surface texturing. TEM images show these InN films are single phase wurtzite crystals with preferred orientation along the *c* axis. Optical properties showed the peaks of near band-edge emission at energies between 0.72 - 0.9 eV.

EM-TuP17 N+-InGaP or N+-GaAs NanoWires for JunctionLess Transistors Fabricated by Focused Ion Beam (FIB) System, ***Cássio Almeida****, L.P.B. Lima,* UNICAMP, Brazil, *H.T. Obata, M. Cotta,* University of Campinas, Brazil, *J.A. Diniz*, UNICAMP, Brazil

N+-InGaP and N+-GaAs layers were grown by Chemical Beam Epitaxy (CBE) on GaAs substrates with (001) orientation. Two group of samples with N+-InGaP (350 nm)/GaAs-buffer layer (300 nm)/GaAs S.I. (Semi-Insulating) and N+-GaAs (300 nm)/GaAs-buffer layer (300 nm)/GaAs S.I. were obtained. X-Ray diffraction (XRD) analysis was used in order to determine the InGaP lattice mismatch on GaAs. N+-InGaP lattice-matched layers on GaAs were obtained using a growing temperature of 550ºC during the process in CBE reactor, while, for N+-GaAs on GaAs samples, the temperature was 550ºC. By Hall measurements, a silicon doping of 10^{+18} cm^{-3} was extracted for both group of samples, indicating the formation of N+-type layers. These samples are being used for MOS Junctionless (JL) Transistors applications, because III-V semiconductors present higher electron mobility values than silicon. These JL transistors (with three terminals: gate, source and drain) are being fabricated using Focused Ion Beam (FIB) System, based on similar process steps of the JL devices, which were fabricated on Silicon-on-Insulator (SOI) substrate[1]. Thus, Gallium (Ga^+) Focused Ion Beam (FIB) is used to define the III-V (InGaP or GaAs) nanowires (III-VNW), which are the electron conduction channel between source and drain, and for depositions of SiO_2 (as gate dielectric) and Pt (as gate, drain and source electrodes) layers[2]. Finally, drain-source current (I_{DS}) versus drain-source voltage (V_{DS}) and drain-source current (I_{DS}) versus gate-source voltage (V_{GS}) measurements of Junctionless devices will be extracted and will be able to indicate if these InGaP or GaAs nanowires are suitable for Junctionless transistors applications.

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EM-TuP18 Thermoelectric Figure of Merit of E-Beam-Grown Nanoscale Multilayered Bi_2Te_3/Sb_2Te_3 Thin Films, ***Zhigang Xiao****, S. Budak*, Alabama A&M University

Nanoscale multilayered Bi_2Te_3/Sb_2Te_3 thin films were grown using the e-beam evaporation. The in-plane and cross-plane micro thermoelectric devices were fabricated using the clean room-based microfabrication techniques such as UV lithography. The e-beam-grown multilayered thin films and the fabricated thermoelectric devices were measured and characterized. The nanoscale multilayered Bi_2Te_3/Sb_2Te_3 thin films can have much higher thermoelectric figure of merit than their bulk materials. The measurement results on the electrical and thermal properties of the nanoscale multilayered thin films will be reported in the conference.

EM-TuP21 Band-Gap Measurements of Low-K Porous Organosilicate Dielectrics using Vacuum Ultraviolet Irradiation, *H. Zheng,* ***Joshua Blatz****,* University of Wisconsin-Madison, *S.W. King,* Intel Corporation, *E. Ryan,* GLOBALFOUNDRIES, *Y. Nishi,* Stanford University, *J.L. Shohet*, University of Wisconsin-Madison

Porous low-k organosilicate dielectrics are of great interest in semiconductor fabrication due to their low-k properties and understanding their behavior during vacuum ultraviolet irradiation is important for their utilization in industry. Experimental measurements of the band-gap of low-

k organosilicate dielectrics are presented in this work. Specifically, vacuum ultraviolet (VUV) synchrotron photoemission spectroscopy was used to investigate the effect of VUV radiation on porous organosilicate (SiCOH) dielectrics during processing. By comparing photoemission spectroscopic data before and after VUV exposure, VUV irradiation with photon energies less than 9.0 eV was found to be beneficial in depleting accumulated charge in SiCOH films while VUV photons with higher energies did not have this effect. Moreover, VUV irradiation with 8.9 eV photons depletes the most charge. This energy serves as a reference point from which other properties of the materials such as the location and presence of defect states could be detected and band-gap energy of SiCOH could be achieved finally. [1] In addition, a comparison of band-gap measurements of low-k dielectrics made with other techniques, such as X-ray photoelectron spectroscopy (XPS) [2] is presented.

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EM-TuP22 VUV Curing Process for Low-k Organosilicate Dielectrics, ***Huifeng Zheng**, X. Guo,* University of Wisconsin-Madison*, S.W. King,* Intel Corporation*, E. Ryan,* GLOBALFOUNDRIES*, Y. Nishi,* Stanford University*, J.L. Shohet*, University of Wisconsin-Madison

Porous SiCOH films are of great interest in semiconductor fabrication due to their low-k properties. Post-deposition treatments of SiCOH thin films are required to decompose the labile pore generator (porogen) and ensure optimum network formation to improve the electrical and mechanical properties of low-k dielectrics. The currently used UV curing method has some weaknesses such as the required high curing temperature (400-425ºC) and the time for curing (several minutes). Vacuum ultraviolet (VUV) irradiation over specific energy ranges was found to overcome some of these drawbacks by efficiently decreasing the dielectric constant and increasing the hardness and elastic modulus of low k dielectrics at room temperature. Specifically, photon energies equal to or larger than 6.0 eV were found to decrease the k value of SiCOH films while lower energies did not have this effect. 6.2 eV photons were found to be most effective. [1] In addition, photons with energies equal to or larger than 8.3 eV enhanced the mechanical properties of SiCOH films significantly. Fourier Transform Infra-red Spectroscopy (FTIR) shows that the breaking of $C-H_x$ stretching bonds (3050-2850 cm^{-1}) in organic porogens and transitioning of Si-O-Si stretching bonds (1250-1000 cm^{-1}) from cage-like to network-like structures contribute to the decrease of dielectric constant and increase of hardness and elastic modulus of SiCOH films. [2] [#_edn2] These investigations show that the optimum photon energies for post-deposition treatment of SiCOH might exist in the VUV range and a VUV-involved curing process could be utilized as a post treatment method in low-k material deposition technologies.

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EM-TuP26 Identification of Topological Surface States in $(Bi_{1-x}Sb_x)_2Te_3$ Thin Films, ***Jenna Walrath**, A.S. Chang, V.A. Stoica, Y.H. Lin, W. Liu, L. Endicott, C. Uher, R. Clarke,* University of Michigan*, R.S. Goldman*, University of Michigan, Ann Arbor

Bi_2Te_3 and Sb_2Te_3 are well-known materials for thermoelectric applications, which have also recently been identified as topological insulators (Tis) with surface states consisting of a single Dirac cone. Spin-momentum locking in Tis make them desirable for spintronics and other applications. However, to be useful for such devices, these materials must be bulk insulating and have accessible surface states, requiring both the Fermi level and the Dirac point to be located within the bulk bandgap. Furthermore, it is desirable to possess these properties at room temperature in ambient conditions. Robust surface states in ambient conditions have been demonstrated for Bi_2Se_3, [1] but to our knowledge direct detection of topological surface states has yet to be demonstrated in BiSbTe systems. Here we use scanning tunneling microscopy and spectroscopy to characterize the band structure of 30nm MBE-grown $(Bi_{.42}Sb_{.58})_2Te_3$ thin films, revealing the presence of topological surface states within the bulk band gap. Both the Fermi level and the Dirac point are located inside the bulk bandgap, indicating bulk insulating behavior with accessible surface states. Furthermore, the surface states are robust to room temperature and limited air exposure.

[1] C. Chen, S. He, H. Weng, W. Zhang, L. Zhao, H. Liu, X. Jia, D. Mou, S. Liu, J. He, Y. Peng, Y. Feng, Z. Xie, G. Liu, X. Dong, J. Zhang, X. Wang, Q. Peng, Z. Wang, S. Zhang, F. Yang, C. Chen, Z. Xu, X. Dai, Z. Fang, and X.J. Zhou, Proc. Natl. Acad. Sci. U.S.A.**109**, 3694 (2012).

EM-TuP27 Quantitative Potential Profiling Across Metal-Oxide-Semiconductor Stacks, ***Sylvie Rangan**, M. Kalyanikar, J. Duan, G. Liu, R.A. Bartynski, E. Andrei, L. Feldman, E. Garfunkel*, Rutgers, the State University of New Jersey

Band alignment between materials and potential changes across thin films is of great importance for understanding electronic properties of multilayer structures and their resulting properties in devices. Although energy alignment and band bending has been studied for decades, an accurate profile of the potential across an ultrathin insulating layer (<10nm) has yet to be determined. In this work, we have developed a new approach to precisely measure the potential profile across Metal/Oxide/Semiconductor (MOS) stacks under in-situ gate-biasing conditions, using x-ray photoemission spectroscopy (XPS). Previous attempts of potential profile measurements have been limited to qualitative assertions due to the absence of controlled biasing. Here, interface dipoles and band bending at the oxide/semiconductor interface, as well as the effective potential across the oxide have been directly measured as a function of the bias applied between the semiconductor and the gate. This technique opens a large field of research, as it allows simultaneously a chemical mapping and a quantitative characterization of potential profiles in novel structures.

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