

Nanoscale Science and Technology

Room Central Exhibit Hall - Session NS-ThP

Nanoscale Science and Technology Poster Session

NS-ThP-1 Characterization of MOS Capacitors on 4H Silicon Carbide Substrate Submitted to Beta Ionizing Radiation, *E. Magalhaes*, Center for Semiconductor Components and Nanotechnology - CCNano, Brazil; *R. Reigota Cesar*, **José Alexandre Diniz**, Center for Semiconductor Components and Nanotechnology - CCNano, Brazil

This work presents a study of the characterization of the MOS capacitors when subjected to ionizing radiation. Such experiments support analyzing the robustness of silicon carbide semiconductor devices, which has attracted increasing attention due to its robustness properties and tolerance to ionizing radiation. For these studies, beta radiation was applied as a source of ionizing radiation, and the Capacitance - Voltage and Current-Voltage characteristics were obtained for devices as-fabricated and post-irradiation. The extracted Flat-band Voltage (VFB) and Leakage Current (LC) parameters were compared to evaluate the irradiation robustness.

In our experiments, MOS capacitors were fabricated with 300 nm thick aluminum upper and down electrodes and 50 nm thick silicon oxide deposited on the N-type 4H-SiC wafers with a 30 μm thick epitaxial layer (3x1015 cm⁻³), and a 350 μm thick substrate (3x10¹⁸ cm⁻³). We carried out the beta irradiation experiment on one sample (post-irradiation). Another control sample (as-fabricated) without irradiation was used to compare the electrical values. To irradiate the sample, a Strontium 90 was a beta source with an energy of 1955.7 KeV, a dose rate of 566 Rad/hand, and an exposure time of 72 hours.

Table 1 presents the average values of VFB and hysteresis, which were extracted from C-V curves, and leakage current for accumulation region, extracted from I-V curves. From Table 1, the average values of VFB of -2.01 and -2.33 for as-fabricated and post-irradiation devices were obtained, respectively. If these values are more negative, an increase in effective charge densities at SiO₂/SiC structures can be expected after beta irradiation. The difference between them of 0.32 V indicates a 16% charge density increase. The hysteresis values also increased to 0.05 V for 0.36 V, seven times higher. This agrees with the VFB results. Therefore, MOS capacitors are damaged after beta irradiation. However, it can be expected that this damage was not high due to the extracted average values of leakage currents of 297 μA and 201 μA for as-fabricated and post-irradiation devices were obtained, respectively. These values are the same level of magnitude order with a reduction of 32% in the comparison. Thus, our results indicate that the irradiation damage at MOS capacitors on the SiC substrate was not severe. So, SiC devices can be used for applications with irradiation exposure, such as in space aircraft.

NS-ThP-2 Multidimensional Contact Potential Difference Measurements at the Nanoscale in Inorganic Oxides, *B. Guner*, **Omur E. Dagdeviren**, École de technologie supérieure, University of Quebec, Canada

Inorganic oxide-based sample systems are popular for applications in catalysis, sensing, renewable energy, and fuel cells in which electronic properties play important roles. Environmental conditions, e.g., temperature, can greatly impact the electronic properties and thereby the performance. The lack of basic knowledge of the local variation of electronic properties as a function of temperature limits the fundamental understanding of systems and hampers their robustness. Here, we demonstrate the multidimensionality of contact potential difference (CPD, i.e., the difference in the work functions of the gold-coated probe and the sample when they are in proximity and under thermodynamic equilibrium, a.k.a., volta potential) at the nanoscale in inorganic perovskites and metal-oxides with scanning probe microscopy (SPM) measurements [1, 2]. We concentrated on single-crystal, inorganic perovskites (e.g., strontium titanate, SrTiO₃) and metal-oxides (e.g., titanium dioxide, TiO₂) to have the least amount of uncertainty of sample properties. We employed an undoped SrTiO₃ and TiO₂, as they are vastly utilized due to their ideal lattice match for similar systems, cost efficiency, stability, and technological and scientific importance. Our experiments reveal three important results: (I) the CPD of both SrTiO₃ and TiO₂ evolve with temperature, (II) the measured CPD is dominated by the local surface state at small tip-sample separations (i.e., tip-sample distance < 10 nm), and (III) the thermodynamically driven intrinsic doping of the material is the governing mechanism of the variation of the CPD for these sample systems. These results clearly show that care must be given to identify the temperature-dependent change of electronic

properties to attain and preserve the desired performance of inorganic oxide-based sample systems.

[1] Bugrahan Guner and Omur E. Dagdeviren, ACS Applied Electronic Materials **4** (8), 4085 (2022).

[2] Bugrahan Guner, Simon Laflamme, and Omur E. Dagdeviren, Review of Scientific Instruments **94** (6) (2023).

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NS-ThP-3 Distributed Injection into a 1D Ballistic Channel, **Bert Voigtländer**, *K. Moors*, Forschungszentrum Juelich GmbH, Germany; *C. Wagner*, Forschungszentrum Jülich GmbH, Germany; *H. Soltner*, *F. Lüpke*, *S. Tautz*, Forschungszentrum Juelich GmbH, Germany

The injection of charge carriers into a 1D ballistic channel is usually considered as local injection at opposite ends of the channel. However, in important cases like edge channels of 2D materials, the injection can happen in a distributed manner along the 1D channel. We calculate the potential in the 2D half-plane, terminated by a 1D ballistic channel using proper boundary conditions for the injection of charge carriers into a ballistic channel. We identify hallmark potential-signatures for an 1D ballistic channel and compare them to the behavior of an ohmic conductive channel.

NS-ThP-4 Atomic Force Microscope Customization for Multidimensional Measurements, *Bugrahan Guner*, *O. Dagdeviren*, École de technologie supérieure, University of Quebec, Canada

Atomic force microscopy (AFM) is an analytical surface characterization tool that reveals the surface topography at a nanometer-length scale while probing local sample properties. Advanced imaging techniques, such as frequency modulation, to achieve high resolution and quantitative surface properties are not implemented in many commercial systems. In this presentation, we illustrate the step-by-step customization of a commercial atomic force microscope [1]. The original instrument was capable of surface topography and basic force spectroscopy measurements while employing environmental control, such as temperature variation of the sample/tip, etc. We demonstrate the capabilities of the customized system with (automated) frequency modulation-based experiments, e.g., voltage and/or distance spectroscopy [2], time-resolved AFM, and two-dimensional force spectroscopy measurements under ambient conditions. We also illustrate the enhanced stability of the setup with active topography and frequency drift corrections. We think that our methodology can be useful for the customization and automation of other scanning probe systems.

[1] Bugrahan Guner, Simon Laflamme, and Omur E. Dagdeviren, Review of Scientific Instruments **94** (6) (2023).

[2] Bugrahan Guner and Omur E. Dagdeviren, ACS Applied Electronic Materials **4** (8), 4085 (2022).

Funding information:

This work was supported by the Canada Economic Development Fund, Natural Sciences and Engineering Research Council of Canada, and Le Fonds de Recherche du Québec - Nature et Technologies.

NS-ThP-5 Improving Leakage Current from a Super Clean STI Technology of DRAM, *Hyojin Park*, *B. Choi*, Sungkyunkwan University, Korea

With the arrival of the fourth industrial era represented by AI, the Internet of things (IoT), demands for diverse products and characteristics are increasing in the semiconductor market, and the difficulty of developing semiconductor processes to satisfy these demands is rapidly increasing. Especially, under the extreme scaling, even small parameters can easily change the characteristics or structures unlike before, and new failure situations that did not exist in the past are continuously occurring. For example, in the case of DRAM, making a right size of active layer was also hard with a previous way, but it is successful making the structure as we designed with silicone liner process called thin poly. With this result, we thought there will be no difficulties with the Si liner, but unfortunately extreme size shrinkage revealed a problem of Si liner scheme. It is the increasing of interfacial leakage current in STI because of the defects in Si liner itself. Fortunately, we were able to develop the new Si liner process that can form liner like epitaxial Si, and with this super clean STI technology we were able to improve the defects of Si liner. The reduction in defects led to an enhancement in interfacial leakage current, and through this, the

problems encountered with STI appeared to be resolved. However, the introduction of this super clean STI technology has also caused new problems that we don't expect before. Due to abnormal growth in some STI top regions, a bridge failure occurred between adjacent STI, making it impossible to properly isolate the STI and causing interference between adjacent cell transistors. We conducted various evaluations to solve this problem, and as a result, we were able to provide a truly novel STI technology that improved bridge defects through Si liner thickness control. In the future, scaling will continue, and new and unprecedented problems will continue to arise. However, this super-clean STI technology has become a reassuring cornerstone that supports the STI development even in the middle of difficult hardships and will become a major force in DRAM development beyond D1a node.

NS-ThP-6 Surface Assembly of Tetraphenylporphyrin Mediated by Reaction with Tin Tetrachloride Pentahydrate Investigated with Atomic Force Microscopy, *Quynh Do, J. Garno*, Louisiana State University

Free-base tetraphenylporphyrin (H₂TPP) was linked to a Si(111) substrate by reaction with tin tetrachloride pentahydrate (SnCl₄ · 5H₂O). Introduction of SnCl₄ · 5H₂O into a solution containing free-base porphyrin resulted in the coordination of a tin atom at the center of the H₂TPP macrocycle. The resulting metalated molecules (Sn-TPP) are skewered together to produce a cofacial arrangement. The metal Sn atom is coordinated to the center nitrogen atoms of the porphyrin macrocycle with O-Sn-O bonding to adjacent molecules. Nanopatterns were prepared by colloidal lithography for subsequent characterizations with atomic force microscopy (AFM). Unsubstituted porphyrin molecules typically attach randomly to surfaces through physisorption. However for Sn-TPP, covalent bonds to the surface and linked individual Sn-TPP molecules was facilitated by O-Sn-O bonds.

The coordination of Sn atoms within the macrocycles of H₂TPP was tracked with UV-Vis spectral analysis, exhibiting a red shift in the Soret band and changes in the relative intensities of the four Q-bands of the porphyrin. The red shift in the Soret band is attributable to the expansion of the porphyrin macrocycle to accommodate the larger Sn atom. Nanostructures were produced using colloidal lithography to facilitate AFM characterizations and to evaluate the influence of experimental parameters of concentration and reaction time for producing stacked Sn-TPP assemblies. A surface mask of silica mesospheres was used to guide the adsorption of Sn-TPP molecules to form defined geometries. After removal of the silica particle mask by steps of rinsing and sonication, nanorings of Sn-TPP were observed. Periodic arrangements of nanorings over broad areas of Si(111) were evident for topography images captured with tapping-mode AFM. Precise control of material properties can be gained by directing the assembly of porphyrins to form nanostructures, and colloidal lithography enables high-throughput at the nanoscale. The conjugated electronic structure of porphyrins leads to thermal stability and distinct electronic and optical properties which are tunable by the choice of functional substituents. Nanomaterials of porphyrins have promising applications in molecular electronics, solar cells, and sensors.

NS-ThP-7 Probing Isotopic Effects on Hyperbolic Phonon Polaritons in MoO₃ with Nanoscale IR Imaging, *Jeremy Schultz, S. Krylyuk*, National Institute of Standards and Technology (NIST); *J. Schwartz*, University of Maryland, College Park; *A. Davydov, A. Centrone*, National Institute of Standards and Technology (NIST)

Hyperbolic phonon polaritons (HPhPs), hybrids of light and lattice vibrations in polar dielectric crystals, enable nanophotonic applications by providing a method to confine and manipulate light at the nanoscale. Molybdenum trioxide (α -MoO₃) is a naturally hyperbolic material, meaning that anisotropy in its dielectric function determines the directional propagation of in-plane HPhPs within its reststrahlen bands. A range of strategies are being developed to alter the intrinsic dielectric functions of natural hyperbolic materials and control the confinement and propagation of HPhPs. Since isotopic disorder can limit phonon-based processes such as HPhPs, here we synthesize isotopically enriched ⁹²MoO₃ (⁹²Mo: 99.93 %) and ¹⁰⁰MoO₃ (¹⁰⁰Mo: 99.01%) crystals to tune the properties and dispersion of HPhPs with respect to natural α -MoO₃, which is composed of seven stable Mo isotopes. Real-space, near-field maps measured with the photothermal induced resonance (PTIR) technique were used to compare in-plane HPhPs in α -MoO₃ and isotopically enriched analogues within a reststrahlen band ($\approx 820 \text{ cm}^{-1}$ to $\approx 972 \text{ cm}^{-1}$). We found that isotopic enrichment (e.g., ⁹²MoO₃ and ¹⁰⁰MoO₃) alters the dielectric function and shifts the HPhP dispersion (HPhP angular wavenumber \times thickness vs IR frequency) by $\approx -7 \%$ and $\approx +9 \%$, respectively, and changes the HPhP group velocities by $\approx \pm 12 \%$, while the lifetimes ($\approx 3 \text{ ps}$) in ⁹²MoO₃ were found to

be slightly improved, by $\approx 20 \%$. The latter improvement was attributed to a decrease in isotopic disorder. Altogether, isotopic enrichment was found to offer fine control over the properties that determine the anisotropic in-plane propagation of HPhPs in α -MoO₃, which is essential to its implementation in nanophotonic applications.

NS-ThP-8 Ratiometric Ph Sensing at the Nanoscale for Biochemical Applications, *Bradley Demosthene, J. Pereira, S. Santra, L. Tetard*, University of Central Florida

The ability to probe pH at the microscale and nanoscale is highly sought after in life sciences and chemistry applications. Existing pH probes are suitable for large scale measurements only a few studies have proposed nanoscale pH probes to date. These involved the development of a tip with embedded electrodes for electrochemical-based measurements. However, some living systems, such as the plant leaves, are not amenable to electrochemical measurements.

Here we present the development of a fluorescence-based nanoscale pH probe based on novel dual dye-doped nanoparticles. Two dyes are selected to obtain a self-calibrated ratiometric pH reading: pyranine, a pH sensitive dye, and tris (bipyridine) ruthenium (II), a pH insensitive dye. We show that the two dyes can be successfully encapsulated in silica nanoparticles using a water-in-oil microemulsion method. The synthesized nanoparticles are characterized by electron microscopy, dynamic light scattering (DLS), Zeta potential, UV-Visible and fluorescence spectroscopy. The encapsulation of the two dyes in the silica nanoparticles is demonstrated. The performance of the nanoparticles as a pH sensor are evaluated for pHs between 5.5 and 8.5, relevant to conditions in living systems. Initial applications of the pH sensor are demonstrated.

NS-ThP-9 Effect of Thermal Annealing on Electrical Property of Platinum Nanowires Deposited by Focused Electron Beam Induced Deposition, *Rajendra Rai, U. Dhakal, B. D.C., Y. Miyahara*, Texas State University

Focused Electron-Beam Induced Deposition (FEUID) is a direct writing technique which can be used for fabrication of nanoelectronic devices such as single-electron transistor. However, FEUID-deposited nanoelectrodes exhibit high resistance because the as-deposited structures contain unwanted precursor elements like carbon due to its precursor Me₃CpMePt (IV), (Me: methyl, Cp: cyclopentadienyl). We report the electrical properties of Pt nanowires with thickness ranging from 2 nm to 200 nm deposited by FEUID technique. We investigated the post-deposition processing techniques to turn the deposited nanowires into electrically conducting as pure Pt metals. We found that the thermal annealing of the as-deposited Pt nanowires can increase in electrical conductance by five orders of magnitude. The resulting annealed wire shows metallic electrical conduction down to 100 mK. We will present the length and width dependence of the electrical conductance and their correlation with the structure of the nanowires which are measured by atomic force microscopy and Kelvin probe force microscopy.

NS-ThP-10 Enhancing Ferroelectricity and Controlling Defects in Aluminum Nitride Thin Films through Ion Bombardment, *Bogdan Dryzhakov*, Oak Ridge National Laboratory; *K. Kelley*, Oak Ridge National Laboratory

The wurtzite ferroelectric aluminum nitride (AlN) is a promising multifunctional semiconductor in memory applications. However, its inherent structural factors raise coercive often even above breakdown voltage fields, making reducing the domain switching energy barrier is a key focus. Defects, such as Al and N vacancies and their complexes with native impurities like oxygen and carbon, play a crucial role in determining the dynamics of ferroelectric switching through the interaction with the lattice leading to domain nucleation, pinning, lattice softening, and polarization screening. In this study, we leverage the optical signatures of defect chemistries, probed by cathodoluminescence (CL), to correlate with the ferroelectric behavior of AlN. CL overcomes the wide bandgap of AlN (>6 eV) to excite color centers through ionization processes that exhibit nanoscale heterogeneity and small optical interaction cross-sections. With this understanding in hand, we employ helium ion irradiation to induce local structure changes and tune defect density and type by modulating the dose. CL spectra demonstrate irradiation-dose-dependent altered defect chemistry, suggesting the irradiation dose gradually evolves existing defects to favor the formation of nitrogen vacancies and diminishing oxide complexes. From functional atomic force microscopy measurements, the relative increase in dose correlates to a steep drop off in ferroelectric coercive field, which is accompanied by a significant enhancement of piezoelectric coefficient. By leveraging the method of He-ion irradiation to enhance potential nucleation sites, we reduce the barrier to switching by

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>40% and postulate the type and functionality of defect states crucial for engineering ferroelectric properties in AlN thin films.

NS-ThP-11 Delamination of Epitaxially-Grown Single-Crystalline GeTe Films for Flexible Phase Change Memory, *Seohui Lee*, University of Central Florida

Integrating phase change materials with flexible substrates is crucial for advancing technologies like phase change memory (PCM). This study focuses on GeTe as a fundamental PCM, synthesized over large areas using Chemical Vapor Deposition (CVD). Our objective is to develop thin, flexible GeTe-based materials for PCM applications.

To achieve this, we employ a Ni-electroplating-assisted spalling technique to separate GeTe films from Ge wafers. We confirm the successful delamination of GeTe through Raman spectroscopy and X-Ray Diffraction (XRD).

This work focuses on the development of thin, flexible GeTe-based materials to enhance phase change memory applications by integrating them with flexible substrates. By exploring it, we aim to explore new possibilities for future technologies.

NS-ThP-12 The Incorporation of Nanohelical Metamaterial Into 1D Photonic Topological Insulator System: A Route to the Generation of Strong Chiral Response, *Sema Guvenc Kilic*, University of Nebraska-Lincoln; *U. Kilic*, University of Nebraska - Lincoln; *M. Schubert, E. Schubert*, University of Nebraska-Lincoln; *C. Argyropoulos*, Penn State University

During the last two decades, 1D and 2D photonic topological insulators (PTI) have gained great interest due to their potential applications in quantum information technologies, waveguide systems, and next-generation photonic integrated circuits [1-4]. In this study, we propose to combine a 1D photonic crystal system with a 3D nanohelical metamaterial platform that can potentially achieve large chiral response. The optical manifestation of chirality known as circular dichroism (CD) is the differential absorption (A) of left circularly polarized (LCP) light from that of right circularly polarized (RCP) light case ($CD=A_{LCP}-A_{RCP}$). In the proposed system, we employ one-turn nanohelical structures comprising gold (Au) and silicon (Si) helical subsegments. This helical structure is integrated into a 1D photonic topological structure consisting of alternating TiO_2 and SiO_2 flat thin film layers. Based on our systematic finite element modeling studies, we observe a strong leak mode that emerges in the photonic gap region with perfect transmissivity and strong electric field confinement at the central two layers of 1D-PTI. The spectral location of the leak mode is in excellent agreement with the topological edge mode frequency in the superlattice energy dispersion diagram of the proposed PTI system. As a last step of this study, Si-Au plasmonic nanohelical structure with the highest chiroptical response was placed at the center of the topological interface where the electric field coupling is maximum. By engineering the thickness of individual layers in 1D photonic crystal system, we successfully spectrally matched the chirality of the nanohelical structure with the topological leak mode. We observed that the integration of nanohelical structure into the PTI system provided a solid route to generate a strong chirality response.

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