Electronic Materials and Photonics Division
Room Hall B - Session EM-ThP
Electronic Materials and Photonics Division Poster Session

EM-ThP-1 Femtosecond-Pulsed Laser Deposition of Erbium-Doped Glass Nanoparticles in Polymer Layers for Hybrid Optical Waveguide Amplifiers.*, Eric Barimah,* University of Leeds, UK, United Kingdom of Great Britain and Northern Ireland*; M Ziarko, N Bamiedakis, I White, R Penty,* University of Cambridge, United Kingdom of Great Britain and Northern Ireland*; G Jose,* University of Leeds, UK

Tellurium oxide (TeO_2) based glasses are widely used in many applications such as fibre optic, waveguide devices and Raman gain, and are now being considered for use in optical waveguide amplifiers. These materials exhibit excellent transmission in the visible and near IR wavelength range (up to 2.0 µm), low phonon energy, and high rare-earth solubility. Siloxane polymer materials on the other hand, have remarkable thermal, mechanical and optical properties and allow the fabrication of low-loss optical waveguides directly on printed circuit boards. In recent years, various low-cost optical backplanes have been demonstrated using this technology.However, all polymer optical circuits used in such applications are currently passive, requiring therefore amplification of the data signals in the electrical domain to extend the transmission distance beyond their attenuation limit. The combination of the TeO_2 and siloxane technologies can enable the formation of low-cost optical waveguide amplifiers that can be deployed in board-level communications. However, there are significant technical challenges associated with the integration of these two dissimilar materials mainly due to the difference in their thermal expansion coefficients.

In this paper therefore, we propose a new approach for incorporating erbium (Er^{3+})-doped tellurium-oxide glass nanoparticles into siloxane polymer thin films using femtosecond pulsed laser deposition (fs-PLD). . Erbium-doped sodium zinc tellurite (Er-TZN) nanoparticles (NPs) are embedded into siloxane polymer films spin-coated on silica substrates using fs-PLD at low temperatures (100 °C) and under two different pulse energies. The surface morphology, and the compositional and structural characteristics of the samples fabricated are evaluated using scanning and transmission electron microscopy (SEM and TEM), TEM- energy-dispersive X-ray spectrometry, X-ray diffraction (XRD), and Raman spectroscopy. Additionally, photoluminescence (PL) and lifetime measurements are carried out at 1534 nm at room temperature under a 980 nm laser diode excitation. The SEM results show that average particle size of the Er-TZN NPs incorporated into polymer layer decreases with decreasing fs-pulse laser energy, while the PL measurements reveal a full-width at half-maximum (FWHM) of about 39 nm. The respective FHWM value obtained from the bulk glass is 51 nm. The obtained luminescence lifetime of the samples is in the range 3.52 to 4.18 ms, which is slightly lower than the value obtained from the bulk glass target of 4.37 ms.

EM-ThP-2 Precisely Determining the Band Offset at GaN/AlGaN Interfaces by Effectively Control the Surface and Interface States*, Sunan Ding, H Yang,* SuZhou Institute of Nano-Tech and Nano-Bionics, CAS, China

Devices based on III-V compounds for optical and electronic applications have various heterojunctions designed in their structures, such as, two-dimensional electron gas (2DEG), dielectric/semiconductor and metal/semiconductor interfaces. Different to Si devices, most of these heterojunctions are formed by epitaxial growth or ex-situ deposition, therefore, the properties of interfaces in the devices are very critical to device performance, and also impacted by many hardly controlled factors. We noticed that interfacial mixture at AlGaN/GaN interface leads its band offset uncertain if using MOCVD to prepare the junction, and also defects/impurities at metal/GaN interfaces modify the contact properties obviously. However, to investigate thoroughly the intrinsic properties and structures of interfaces in III-V compound devices is limited so far by the uncontrollable environments during experiments. To avoid unfavorable effects of contaminations on surfaces or interfaces introduced from atmospheric contacts, Ultra-high vacuum ambits are normally used to prepare and analyze sensitive materials and devices. Currently an ultra-high-vacuum (UHV) connected research facility (Nano-X) is being constructed at the SuZhou Institute of Nano-tech and Nano-bionics, CAS, by which it is possible to integrate all major functions of tools for material growth, device processing, and characterization under one UHV environment. With this facility, 30+ tools connected to a 100 meter UHV tube, wafers/samples could be transferred from one to another without exposure to air. Therefore, we were able to explore the intrinsic properties of heterojunctions during the formation of interfaces, as well as improve the device performance through interface controlling and modification. It has been found that surface states have large effects on the measurements of the band offsets at the GaN/AlGaN interfaces, which could be prepared by Molecular Beam Epitaxy (MBE), and precisely determined within an uncertainty of 45meV by combining *in-situ* Angle-Resolved X-ray Photoelectron Spectroscopy (ARXPS) and theoretical calculations of the total DOS in the valence bands of GaN and AlGaN.

Key words: III-V compounds; Vacuum; Surface; Interface

EM-ThP-3 Thermal Engineering for High-Power, Flexible Electronics*, Katherine Burzynski,* University of Dayton and Air Force Research Laboratory, Materials and Manufacturing Directorate*; E Blanton, N Glavin, E Heller, M Snure, E Heckman,* Air Force Research Laboratory*; C Muratore,* University of Dayton

Consumers and military personnel are demanding faster data speeds only available through fifth generation (5G) wireless communication technology. Furthermore, as wearable sensors and other devices become more ubiquitous, devices demonstrating enhanced flexibility and conformality are necessary. A fundamental challenge for flexible electronics is thermal management. Even on rigid substrates with significantly higher thermal conductivity than polymeric and other flexible substrates, the full potential of semiconducting materials is often thermally limited. The flexible gallium nitride (GaN) high electron mobility transistors (HEMTs) employed in this work are grown on a two-dimensional boron nitride (BN) release layer that allows the conventionally processed devices on sapphire wafers to be transferred using a polymeric stamp and placed onto a variety of rigid and flexible substrates. Characterization of the GaN device behavior on the as-grown sapphire wafers (prior to transfer) provide a baseline for evaluation of the thermal performance of engineered interfaces and substrates. With conventional substrates, device performance (specifically, the saturation current) is reduced when the device is transferred to polymeric substrates. The thermal dissipation is further restricted due to the addition of an adhesive layer to the substrate. Thermal imaging of devices in operation reveals that the current passing through an as-grown GaN transistor on a sapphire wafer reaches the target operating temperature at approximately five times the power of the same device transferred to a flexible substrate. Printable, thermally conductive nanocomposites integrating 1D, 2D, and 3D forms of carbon in a flexible, photocurable polymer matrix, as well as metal nanoparticles, were developed to maximize heat transfer from GaN devices. The thermal conductivity of the candidate substrate materials was measured experimentally, and the performance of devices transferred to these novel flexible composite substrates was characterized. The measured thermal data was used in computational simulations to predict flexible substrate architectures effectively promoting point-to-volume heat transfer to improve device performance. Additive manufacturing for engineered architectures of the flexible, thermally conductive substrate materials was demonstrated to substantially reduce the thermal limitation of high-power flexible electronics.

EM-ThP-4 Growth and Magneto-optical Properties of ZnO/$Zn_{1-x}Mn_xO$ Thin Films on Si Substrates*, Da-Ren Liu,* ITRC,NARL,Taiwan, Republic of Korea, Taiwan, Republic of Korea*; C Weng,* ITRC,NARL, Taiwan, Republic of Korea

ZnMnO is one of the most promising diluted magnetic semiconductors (DMS) materials due to its predicted above room temperature ferromagnetism. In this study, ZnO layer was conformally deposited on the Si substrates by atomic layer deposition (ALD). Then the $Zn_{1-x}Mn_xO$ ($0.01 < x < 0.10$) coatings were grown on ZnO layer by Nd:YAG pulsed laser deposition (PLD). The thickness and roughness of the films were characterized by grazing-incidence x-ray reflectivity (GIXR). According to the results of high-resolution x-ray diffraction, the ZnO/ $Zn_{1-x}Mn_xO$ thin films are polycrystalline with a preferential growth direction of (002). The surface and cross-section morphologies of films were analyzed by the field-emission scanning electron microscope (FE-SEM). Photoluminescence spectra demonstrate ultraviolet emission peaks which have shift with the increase of Mn ion concentration. The temperature-dependent magnetization (M-T) curves of the ZnO/ $Zn_{1-x}Mn_xO$ thin films were measured by a superconducting quantum interference device (SQUID) magnetometer and the magneto-optical properties were measured by micro-MOKE spectroscopy. The results show the room temperature ferromagnetism of the ZnO/ $Zn_{1-x}Mn_xO$ thin films suggested that the possibility for the application to diluted magnetic semiconductors.

EM-ThP-5 The Formation of Stable GeO_2 Oxide on Germanium Epitaxial Layer using the High Pressure Oxidation*, I Chung,* ***Nakjun Choi****, J Bae,* Sungkyunkwan University, Republic of Korea

Thermal oxidized of Ge films under high pressure have been investigated to examine the possibility for the gate oxide. Ge oxides were grown either Ge wafers or Ge epitaxial films grown on Si wafer. The temperature range was from 450 °C to 550 °C, and three different pressures such 10, 30, and 50 atm were chosen for a high pressure dry oxidation. The physical property of GeO_2 films were analyzed using the transmission electron microscopy (TEM) and X-ray photoelectron spectroscopy(XPS). Additionally, Au/GeO_2/Ge MOS capacitors were characterized using C-V and I-V measurement. The hysteresis behavior in C-V characteristics and the interface trap density (D_{it}) are significantly reduced through the high pressure oxidation. Consequently, the properties of both GeO_2 film and GeO_2/Ge interface are successfully improved by suppressing GeO volatilization utilizing high pressure.

EM-ThP-6 NH_4OH Solution Wet Etching for Silicon Channel Thinning of Junctionless-FET*,* ***Lucas Stucchi-Zucchi****, A Silva, J Diniz,* University of Campinas, Brazil

Junctionless-FET (JL-FET) devices were fabricated on SOI substrate using NH_4OH solution silicon etching as means to thin the channel substrate. The devices gate dielectric was silicon oxynitride grown using O_2/N_2 ECR (Electron-Cyclotron-Resonance) plasma, and its gate metal was TiN defined through lift-off and deposited using reactive sputtering. The electric contacts were fabricated with sputtered aluminum defined through lift-off and annealed on a conventional oven. Samples were characterized during the fabrication processes using optical microscopy and scanning electron microscopy (SEM). The device electrical performance was measured using a probestation and then cross-section SEM images were extracted using Ga+ Focused Ion Beam milling.

The final channel thickness was 65nm measured in the cross-section images, which also showed the angled sidewalls characteristic of the NH_4OH solution wet etching. The channel dopant concentration was estimated at approximately 10^{17} atoms/cm^3 through Pseudo-MOS electrical measurements, this was the doping concentration that was planned according to the simulation steps to ensure transistor behavior by sacrificing electrical contact quality. Electrical measurements showed transistor behavior and low leakage currents, despite the negative threshold voltage and poor electrical contacts, which distorted the I-V measurements due to their Schottky-like behavior. These results are as expected due to the measured channel thickness and the estimated channel dopant concentration and point favorably towards the silicon etching in NH_4OH solution being a viable technique to fabricate JL-FET devices.

In the future, Atomic Force Microscopy (AFM) measurements will be used to measure the surface roughness after the silicon wet etching in NH_4OH solution. With a more accurate etching rate, new samples will be fabricated with thinner channel thicknesses and higher dopant concentration. The enhanced fabrication process is expected to result in JL-FET devices that rival the performance of state-of-the-art MOSFET devices.

References

[1] J.P. Colinge et al., "Nanowire transistors without junctions", Nature Nanotechnol. 5, p. 225-229 (2010).

[2] S. Migita, Y. Morita, T. Matsukawa, M. Masahara, and H. Ota, "Experimental Demonstration of Ultrashort-Channel (3 nm) Junctionless FETs Utilizing Atomically Sharp V-Grooves on SOI", IEEE Trans. on Nanotechnol., vol. 13, no. 2, p. 208-215 (2014).

[2] A. R. Silva, J. Miyoshi, J. A. Diniz, I. Doi and J. Godoy, "The Surface Texturing of Monocrystalline Silicon with NH4OH and Ion Implantation for Applications in Solar Cells Compatible with CMOS Technology.", Energy Procedia, v. 44, p. 132-137 (2014).

EM-ThP-7 Fabrication of Highly-Efficient Nanoscale Multilayered Thin-Film Thermoelectric Devices*,* ***Alandria Henderson****, J Kimbrough, Z Duncan, K Davis, M Howard, J Elike, T Wimbley, M Glenn, Z Xiao,* Alabama A&M University

We report the growth of nanoscale multilayered thermoelectric thin films and fabrication of integrated thermoelectric devices for high-efficiency energy conversion and solid-state cooling. Nanoscale multilayered thin films such as Sb/Sb_2Te_3 and Te/Bi_2Te_3 thin films were grown using the e-beam evaporation. Integrated thermoelectric devices were fabricated with the nanoscale multilayered thin films using the clean room-based microfabrication techniques such as UV lithography. X-ray diffraction and reflection and high-resolution tunneling electron micrograph (HR-TEM) were used to analyzed the e-beam-grown nanoscale multilayered thin films. SEM was used to image and analyze the fabricated devices. The thermoelectric characteristics of the fabricated devices were measured and analyzed, and highly-efficient thermoelectric thin-film materials and integrated devices will be demonstrated and reported.

EM-ThP-8 Plasmonic Studies of Metallic Nanostructures Fabricated by DNA Origami*,* ***Enrique Samano****, D Ruiz, K Cardos,* Universidad Nacional Autónoma de México, Mexico

The organization of nano-objects such as metal nanoparticles, quantum dots, and carbon nanotubes with nanometer-scaled precision is one of the central challenges in nanotechnology. DNA origami provides a feasible method to address this problem. DNA origami with unique addressability may build complicated nanomaterial architectures via self-assembly. The DNA origami-metal nanoparticles conjugates can be tailored by functionalization of the nanoparticles with nucleic acids that enable them to hybridize with a docking strand that protrudes out from a nanostructure with a 6 nm resolution. In addition, their overall size of about 100nm is easily accessible by top-down lithographic methods. A commercially viable route for fabricating photonic devices with nanometer-scale features may be pursued by combining the strengths of top-down lithography and bottom-up self-assembly using DNA nanostructures. Electron beam lithography is a prime top-down technique used to write a pattern on a substrate, usually a dielectric material. Among many other applications, it is employed to localize and isolate specific nanostructures. This is done by creating an array of apertures, or "windows", separated 5 µm apart with a size slightly larger than each nanostructure to be positioned. The DNA origami nanostructures in this case have a rectangular shape with a 70 × 90 nm size. Two gold nanoparticles, 5nm in diameter each, are attached on opposite corners of the rectangular DNA origami, as shown in figure 1. These seed nanoparticles were later enlarged up to 20 nm in size by electroless deposition of silver. Preliminary results on localized surface plasmon resonance studies by dark-field microscopy are presented as well. The high addressability and custom design of DNA nanostructures make this technique possible to be used for transferring and harvesting energy in a way that is similar to that of the natural system.

EM-ThP-9 Control of Randomness in Microsphere-Based Photonic Crystals Assembled by Langmuir-Blodgett Process*,* ***Sarun Atiganyanun****, O Abudayyeh, S Han, S Han,* University of New Mexico

Photonic structures in biological systems typically exhibit an appreciable degree of disorder within their periodic structures. Such disorder contributes to unique optical properties but has not been fully understood. Towards the goal of improving this understanding, we have investigated Langmuir-Blodgett (LB) assembly of silica microspheres to controllably introduce randomness to photonic structures. We theoretically modeled the LB assembly process and determined a condition for surface pressure and substrate pulling speed that results in maximum structural order. For each surface pressure, there is an optimum pulling speed, and vice versa. Photonic structures fabricated at various conditions were characterized by scanning electron microscopy and light scattering analysis, which confirms the modeled optimum condition. However, along the trajectory defined by the optimum condition, the structural order decreases moderately as the pulling speed increases. This moderate decrease in structural order would be useful for controlled introduction of randomness into the periodic structures. Departing from the trajectory, our experiment reveals that a small change in pulling speed at a given surface pressure can significantly disrupt the structural order. According to these observations, mechanism of forming structural order in LB assembly is proposed. Additionally we also find that, for multilayer LB assembly at a fixed pulling speed, the surface pressure should increase as the number of layers increases to achieve maximum structural order. In summary, this work quantitatively presents the optimum trajectories for n^{th} layer assembly relating surface pressure and pulling speed.

EM-ThP-10 Incorporation of Ferroelectric HfO_2 into Magnetoelectric Random-Access Memory (MeRAM) Devices*, K Fitzell,* ***Jeffrey Chang****, A Acosta, H Ma, X Li, K Wang, J Chang,* University of California, Los Angeles

In contrast to manipulating magnetization with applied current, using an applied electric field can significantly reduce the required energy and result in less heat generation, leading to increased ene rgy density. This can be accomplished using the voltage-controlled magnetic anisotropy (VCMA) effect, which forms the basis of next-generation magnetoelectric MRAM devices. Specifically, applying an electric field across a CoFeB/MgO interface can decrease the perpendicular magnetic anisotropy field as a result of the altered electron density at the interface, thus destabilizing the magnetization state and allowing for its efficient and deterministic reorientation with a small applied magnetic field. This op eration principle stands in contrast to that of STT-RAM, which uses upwards of 100 fJ to write a single bit (300,000 times more energy than the actual energy barrier to switching).

Previous research on CoFeB/oxide interfaces has shown that increasing the dielectric constant of the oxide layer also increases the sensitivity of the interfacial magnetic anisotropy energy to an applied electric field (Kita et al., 2012). Our previous work involving MgO/PZT/MgO composite tunneling barriers showed a 40% increase in the VCMA effect upon addition of PZT to the tunneling barrier. However, the ferroelectric order of PZT is very weak at such small dimensions, and the leakage current and high annealing temperatures required of PZT prevent this technology from being industrially relevant. On the other hand, the orthorhombic phase of HfO_2 has been shown to possess desirable ferroelectric properties even in ultrathin films. In addition, ferroelectric HfO_2 boasts superior compatibility with CMOS technology as well as desirable electrical properties for device integration.

In this work, a method for depositing orthorhombic phase HfO_2 (FE-HfO_2)-based thin films via a radical-enhanced atomic layer deposition process is described. These ferroelectric thin films were subsequently incorporated into the tunneling junctions of CoFeB/MgO-based magnetic tunnel junction in an effort to enhance the VCMA effect and introduce ferroelectric functionality into magnetoelectric random-access memory devices.

EM-ThP-11 Extreme Environment Operation of $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$ High Electron Mobility Transistors, ***Patrick Carey***, *F Ren,* University of Florida*; A Baca, B Klein, A Allerman, A Armstrong, E Douglas, R Kaplar,* Sandia National Laboratories*; S Pearton,* University of Florida

$Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$ high electron mobility transistors (HEMT) underwent DC characterization across the temperature ranging from room temperature to 500°C. Due to a high Schottky barrier height and low gate leakage current achieved on Al0.85Ga0.15N barrier layer, drain current modulation up to a gate voltage of 10 V was demonstrated at 500°C. The high aluminum content in these devices enables stability at high temperature due to the ultra-wide bandgap of ~ 5.7 eV. Conventional low Al content HEMT devices have previously shown improved elevated temperature operation as compared to their Si or GaAs counterparts, but are unable to operate under extreme temperature tested herein and suffer from high gate leakage current with heating. The drain current on/off ratio of 1011 were obtained with low gate leakage currents. The drain current degraded by ~50% from room temp to 500°C. The subthreshold slope of 80 mV/dec and 230 mV/dec were obtained at room temperature and 500°C, respectively. From the subthreshold slopes, trap densities were calculated to be 2.3×10^{11} cm^{-2} at room temperature and 3.3×10^{12} cm^{-2} at 500°C. These novel devices show great promise for application in the power, space, and defense industry where extreme performance is necessary.

EM-ThP-12 Electrical Characterization of the Reduced Effective Schottky Barrier Height by Nanoscale Ge bi-layer of CZTSe Solar Cells, ***Sanghyun Lee,*** Indiana State University

In the past ten years, there have been constant attempts to develop high efficient thin film solar cells, which are cost-effective, environmentally benign, and reliable. The most strongest candidate of emerging alternatives is $Cu_2ZnSn(S,Se)_4$ (or kesterite) solar cells, herein CZT(S,Se). With abundant elements in earth's crust, CZT(S,Se) shows high absorptions coefficient (>10^4 cm^{-1}) and a tunable direct band gap energy, ranging from 1 to 1.4 eV, which makes it an ideal platform for future renewable energy devices . However, the efficiency improvement and understanding of emerging CZT(S,Se) is still in early stage compared to the counterparts such as $Cu(In,Ga)Se_2$ (CIGS) and CdTe. In recent progress, Germanium (Ge) incorporation into CZT(S,Se) solar cells has received extensive attention to deepen the understanding of this types of devices as Ge-alloyed CZT(S,Se) solar cells have demonstrated improvements in device performance. However, several challenges still remain such as a large Voc-deficit, sever heterojunction interface recombination, and a Schottky-type back contact barrier.

The presence of Schottky barrier near back contact limits the hole movement which influences the current-voltage characteristics and deteriorates the Voc-deficit as well. To investigate the impact of this back contact barrier height, we fabricated and characterized a set of CZTSe solar cells by utilizing DC magnetron sputtering by applying ultra thin Ge nanolayers. We investigated the back contact interface between CZTSe/$MoSe_2$ and Mo metal contact in an effort to improve a back contact barrier. By incorporating nanoscale Ge bi-layers below and below the absorber, a barrier height is considerably improved. The results indicate that nanoscale Ge bi-layers improves the back contact barrier height by 27 % as compared to CZTSe:Ge monolayer devices (see a supporting document device A). The back contact improvement is possibly caused underlying Ge nanolayer (<2.5 nm) between the absorber and Mo metal contact. The improvement of the efficiency loss caused by the series resistance component is reduced by 50%, which is attributed to the improved Schottky-type back contact barrier. This allows the improved efficiency up to 8.3% by incorporating nanoscale CZTSe: Ge bi-layers.

EM-ThP-13 Optimal Contact Photolithography Techniques For HEMT Substrates using I-line Photoresist, ***Whitney Ingram****, A Jones, B Klein, A Baca, A Armstrong, A Allerman, E Douglas,* Sandia National Laboratories

Gallium nitride-based high electron mobility transistors (HEMTs) utilize a variety of substrates, including those that are optically transparent in the visible and ultraviolet wavelength spectrum such as sapphire and silicon carbide(SiC). Compared to silicon substrates, SiC and sapphire substrates can exhibit a distinct set of photolithography patterning challenges such as backscattering (from the underlying chuck and other areas of the substrate) which can influence the critical dimension (CDs), pattern integrity, and pattern resolution. In this study, computational photolithography and rigorous coupled wave guide analysis are used to calculate the optical reflectivity, the transmission and absorption of a multilayered stack comprised of i-line photoresist and an antireflective coating on sapphire substrates with $Al_xGa_{1-x}N$ epitaxial layers (with x ranging from 0 to 1). These simulations are used to target optimal resist and arc thickness, and exposure energy needed to reach the target feature with high fidelity. As a proof of concept, fully resolved patterns down to 0.5 µm are experimentally obtained on sapphire substrates using conventional contact photolithography driven by simulated for optimal conditions. Due to the lack of experimental information on photolithography on optically transparent substrates with ultra-wide bandgap heterostructures, this method can provide relevant insight into determining optimal process window for optically transparent substrates.

This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

EM-ThP-14 High-mobility Helical Tellurium Field Effect Transistors Enabled by Transfer-free, Low-temperature Direct Growth, ***Guanyu Zhou****, R Addou, Q Wang, S Honari, C Cormier, L Cheng, R Yue, C Smyth, A Laturia, J Kim, W Vandenberghe, M Kim, R Wallace, C Hinkle,* University of Texas at Dallas

The transfer-free direct growth of high performance materials and devices could enable transformative new technologies. Here we report room temperature field-effect hole mobilities as high as 707 $cm^2V^{-1}s^{-1}$, achieved using transfer-free, low-temperature (≤120°C) direct growth of helical tellurium (Te) nanostructure devices on SiO_2/Si. The Te nanostructures exhibit significantly higher device performance than other low-temperature grown semiconductors, and we demonstrate that through careful control of the growth process, high-performance Te can be grown on other technologically relevant substrates including flexible plastics like polyethylene terephthalate (PET) and graphene in addition to amorphous oxides like SiO_2/Si and HfO_2. The morphology of the Te films can be tailored by the growth temperature, and we identify different carrier scattering mechanisms for films with different morphologies. The transfer-free direct growth of high-mobility Te devices could enable major technological breakthroughs, as the low-temperature growth and fabrication is compatible with the severe thermal budget constraints of emerging applications. For example, the vertical integration of novel devices atop a silicon complementary metal oxide semiconductor (CMOS) platform (thermal budget <450 °C) has been theoretically shown to provide a 10x systems level performance improvement, while flexible and wearable electronics (thermal budget <200 °C) could revolutionize defense and medical applications.

EM-ThP-16 Investigation of Field Emission from Single ZnO Nanowire*, **Yicong Chen**, X Song, Y Wang, Z Zhang, Z Li, J She, S Deng, N Xu, J Chen,* State Key Lab of Optoelectronic Materials and Technologies, Guangdong Province Key Lab of Display Material and Technology, Sun Yat-sen University

Electron field emission, a phenomenon that electrons emitted from solid surface under strong electrical field, is the basis of cold cathode, which has important applications in modern high-resolution electron microscopy, flat panel e-beam lithography and X-ray source. ZnO nanowires have been regarded as one of the most important cold cathode materials due to their excellent field emission properties, chemical stability and simple synthesis method. To further improve the device performance, the understanding of their electron field emission mechanism is significant. Although many efforts have been devoted to investigating the influence of resistance, geometry structure, doping and back contact with substrate on the field emission of ZnO nanowires, their underlying mechanism is still remained unclear. One important reason causing this difficulty is that many of these works were based on the measurement of ZnO nanowires film, which should induce average effect on the results. Therefore, in-situ field emission measurement of single ZnO nanowire is necessary to obtain its intrinsic field emission properties and physical mechanism.

Here, our recent works on the field emission characteristics of individual ZnO nanowire are presented. The influence of both the nitrogen doping and environment temperature on the field emission of the same nanowires have been investigated. It is found that the nitrogen-doped ZnO nanowires with higher carrier density and lower work function have unusual poorer field emission properties. Besides, the temperature dependent field emission from a single ZnO nanowire is different from the nanowires film, which has a divergent FN plot. The field induced hot electrons emission model for semiconductor with consideration of penetration length has been proposed to explain the results. All of these should be helpful for a better understanding on the field emission from ZnO nanowire.

EM-ThP-17 Photoemission under Different Mechanisms from Single- and Dual-gate Carbon Nanotubes Field Effect Transistors*, S Yang, **Bo Wang**, S Cronin,* University of Southern California

We observe bright electroluminescence from carbon nanotube (CNT) field effect transistors (FETs). Here, bright thermal emission(radiation) occurs under negative applied gate voltages, with the FET in its "on" state. This enables us to apply high bias voltages (4V) without heating the CNT. Under these conditions, we observe light emission at currents as small as 1nA, which is three orders of magnitude lower than previous studies. The mechanism of light emission is understood on the basis of steep band bending that occurs in the conduction and valence band profiles at the contacts, which produces a peak electric field of 500kV/cm, enabling the acceleration of carriers beyond the threshold of exciton emission. The exciton-generated electrons and holes are then accelerated and emit excitons in an avalanche process. We also observe light emission at negative applied gate voltages in its "on" state. However, substantial Joule heating (T>1000K) is also observed so that it is difficult to separate the mechanisms of thermal emission from hot carrier photoemission in this regime.

EM-ThP-18 100 keV Proton Irradiation Effects on AlGaN/GaN Epistructures*, **Min Khanal**, S Uprety, K Yapabandara, V Mirkhani, S Wang, B Schoeneck, T Isaacs-Smith, A Ahyi, M Bozack, M Park,* Auburn University

The electronics that are used in spacecraft are subject to space radiation hazards. The space radiation environment includes trapped electrons and protons of the Van Allen radiation belts, and non-trapped transient solar and galactic cosmic rays and solar flare particles. The protons with the cut-off energy of 100 keV are present above the upstream of the Earth's bow shock. Since gallium nitride and its alloys are proven to be relatively radiation tolerant, these materials are considered as promising candidates for space electronic applications. Therefore, it is consequential to study the effect of 100 keV protons on the AlGaN/GaN HEMTs if the devices are to be used for space applications. In this research, the effect of 100 keV protons with the fluences 1×10^{10}, 1×10^{12}, and 1×10^{14} cm^{-2} on materials/device characteristics of AlGaN/GaN HEMTs constructed on Si wafers were studied by means of optical and electrical characterization. The electrical characteristics of the devices were analyzed by using conventional transistor I-V and C-V measurements in order to relate the material's fundamental properties to the device performance. The slight degradation on the electrical characteristics and the shift in the threshold voltage was observed in the irradiated samples. The crystal quality of the epilayer was examined *via* micro-Raman spectroscopy and no substantial degradation in the crystal quality was observed.The possible introduction and/or the alternation of the defects were probed using the photoluminescence (PL) spectroscopy and spectroscopic photocurrent-voltage techniques. The surface morphology of the samples was studied by atomic force microscopy (AFM) and scanning electron microscopy (SEM), and a slight increase in the surface roughness was observed. The surface analysis was performed using X-ray photoelectron spectroscopy, and the surface elemental composition was not altered after irradiation. It is concluded that the crystal quality of the AlGaN/GaN HEMT layers and the electrical characteristics of the AlGaN/GaN HEMTs were not severely degraded in spite of the exposure to a high fluence of protons with the energy 100 keV.

EM-ThP-19 Properties of WSe_2 Thin Films Grown by Molecular Beam Epitaxy*, P Litwin, K Freedy, T Zhu, M Zebarjadi, **Stephen McDonnell**,* University of Virginia

The synthesis of high quality transition metal dichalcogenide (TMD) films is of significant interest for potential applications in nanoelectronic and thermoelectric devices. Molecular beam epitaxy (MBE) is a promising route, providing fine control over growth conditions. To further understand the growth conditions on film quality, we study the effect of processing conditions on the resultant material quality. MBE is used to synthesize bilayer $WSe_2$and it is shown using in-vacuo x-ray photoelectron spectroscopy (XPS) that the process conditions can directly influence the resultant chemistry and electronic structure. Specifically, we show that the initial nucleation conditions are critical to achieving repeatable and high-quality WSe_2. Our combination of MBE and in-situ XPS studies show that WSe_2chemistry can be controlled through processing conditions. We also use ex-situ characterization to determine properties such as cross-plane resistance and Seebeck coefficient. It is shown that Ni and Au contacts result in negative and positive Seeback coefficients respectively. Furthermore, Ni contacts are found to degrade over time.Presented will be our results showing the process control of WSe_2chemistry. Also shown will be the impact of these changes on device relevant properties, such as resistance and Seebeck coefficient.

EM-ThP-20 Effects of O_2 Partial Pressure on Ga_2O_3 Thin-films*, **Seth King**,* University of Wisconsin - La Crosse

Gallium oxide (Ga2O3) has recently become recently become a material of great interest due as it is a stable, wide bandgap oxide which is capable of being used as a transparent conducting oxide or dielectric layer in the next generation of electronic devices [2]. While the majority of work has focused on single crystal materials, few results exist regarding the growth and nucleation of polycrystalline Ga2O3 materials [2,3].

The present study utilizes spectroscopic ellipsometery, x-ray diffraction, and four-point resistivity measurements to investigate how the physical properties of Ga2O3 thin-films may be altered by changing the partial pressure of O2 during reactive RF sputter deposition. The results will yield important information regarding how material properties are related to deposition conditions using an industrially applicable fabrication process.

[1] "Guest Editorial: The dawn of gallium oxide microelectronics",

Masataka Higashiwaki and Gregg H. Jessen, Appl. Phys. Lett. 112, 060401 (2018)

[2] "Chemical vapour deposition and characterization of gallium oxide thin films",

G.A .Battiston, R. Gerbasi, M. Porchia, R. Bertoncello, and F. Caccavale, Thin Solid Films 279, 115-118, (1996)

[3] "Structure, Morphology, and Optical Properties of Amorphous and Nanocrystalline Gallium Oxide Thin Films", S.S. Kumar et al., J. Phys. Chem. C, 2013, 117 (8), pp 4194–4200

Author Index

Bold page numbers indicate presenter