The calculation of the electrostatic screening length has been an open issue in electron scattering problems in semiconductors since pointed out by Nevill Mott, more than eighty years ago. Over that time, Thomas-Fermi screening has been the dominant approach for calculating the screening constant in degenerate materials. In its formulation, parabolic energy bands are assumed. In the case of degenerate semiconductors, the assumption of parabolic bands can become a serious source of error. The Thomas-Fermi formula predicts screening that is too weak relative to self-consistent field methods in highly degenerate systems, including metal alloys. We have found an analytical solution for the calculation of the Fermi level and the electrostatic screening length for semiconductors and metal alloys in the degenerate limit using non-parabolic energy bands and Fermi statistics. This solution yields a more accurate determination of Fermi levels than methods that assume parabolic energy bands and presents a more accurate determination of screening length than the Thomas-Fermi formula. It is hoped that these equations will be useful to researchers investigating highly degenerate material systems, including metal alloys, from theoretical and numerical viewpoints.

Multinary semiconducting compounds of the I-III-VI group (I – Cu, Ag; III – Al, Ga, In; VI – S, Se, Te) with crystal structure of chalcopyrite CuFeS$_2$ are at the focus of current research as absorbing materials which are used in solar cells. By this reason studying the Cu-Fe-S system and metal alloys, from theoretical and numerical viewpoints. Thomas-Fermi screening has been the dominant approach for calculating the screening constant in degenerate materials. In its formulation, parabolic energy bands are assumed. In the case of degenerate semiconductors, the assumption of parabolic bands can become a serious source of error. The Thomas-Fermi formula predicts screening that is too weak relative to self-consistent field methods in highly degenerate systems, including metal alloys. We have found an analytical solution for the calculation of the Fermi level and the electrostatic screening length for semiconductors and metal alloys in the degenerate limit using non-parabolic energy bands and Fermi statistics. This solution yields a more accurate determination of Fermi levels than methods that assume parabolic energy bands and presents a more accurate determination of screening length than the Thomas-Fermi formula. It is hoped that these equations will be useful to researchers investigating highly degenerate material systems, including metal alloys, from theoretical and numerical viewpoints.
and B sites of the perovskite lattice, co-doping STO with these lesser known impurities in addition to Al, Mg, and Ni may enhance p-type conduction in certain processing conditions. The authors acknowledge financial support from AFOSR BRI grants FA9550-14-1-0264 and FA9550-17-1-0138 and a DoD NDSEG fellowship.

**PS07**
Plasmonic Terahertz Response of P-Diamond Michael Shur, Sergey Rudin1, Greg Rupper1 and Tony Ivanov1; 1Army Research Laboratory, Adelphi, Maryland, United States; 2Rensselaer Polytechnic Institute, Troy, New York, United States.

The wide bandgap of 5.46 eV, the high breakdown field of over 10 MV/cm, and a high thermal conductivity over 20 W/cmK make diamond to be a promising semiconductor material for high-power and high-temperature operation. The diamond transistors operated to at least 350°C with a very low leakage currents and steep slopes in the subthreshold regime (down to ~10^-17 A and close to 60 mv/decade, respectively). The highest reported values of the diamond electron and hole mobilities are 7,300 cm²/Vs and 5,300 cm²/Vs, respectively. The reported values of the hole effective mass range from 0.74 to 2.12. For the highest reported values of these parameters, the room temperature momentum relaxation time could be as high as 6 ps. At such high values of the momentum relaxation time, the phonon impact factor can be on the order of 10⁻¹⁰ and sub-THz radiation for feature sizes from 20 nm to 120 nm in the entire THz frequency range from 100 GHz to 30 THz. The results reveal a great potential of p-diamond plasmonic FETs for THz applications.

**PS09**
Tunable Giant Magnetocapacitance in Single Layer Capacitative Device on Epitaxial Nickel Zinc Ferrite Thin Film Rajeev S. Joshi1, Debangsu Roy1, Sidharth Dash1, Sukhjot Singh1, S Bhat2, P Anil Kumar3; 1Department of Physics, Central University of Karnataka, Kalaburagi, India; 2Physics, Nano-magnetism Research Center, Institute of Nanotechnology and Advanced Materials, Bar-Ilan University, Ramat-Gan, Israel; 3Department of Physics, Indian Institute of Science, Bengaluru, India.

Spintronics is one of the most important and emerging areas of electronics. It uses spin of the electron and its transport in solids for development of new devices [1]. Development of tunable high frequency spin based devices is one of the major quests in the field. In the present work we demonstrate large magnetocapacitance in interdigital capacitor based device formed on Ni0.8Zn0.2Fe2O4 epitaxial thin films. Ni0.8Zn0.2Fe2O4 thin films were grown on isostructural single crystalline MgAl2O4 (004) by pulsed laser deposition. The structural and magnetic properties of the films deposited were analyzed using X-ray diffraction, Raman scattering and vibrating sample magnetometry. It was found that the films grown along [111] orientation. The epilayer in these films was investigated using pole figure analysis and asymmetric reciprocal space mapping (RSM). The RSM measurement on the film showed small dispersion in Q vector (Scattering vector reciprocal space) values compared to substrate Q values indicating higher degree of ordering. This result is corroborated through a detailed [100] mode observed in Raman shift measurements. Uniformity in the magnetic environment is confirmed using the ferromagnetic resonance (FMR) measurements in these films. FMR measurements were performed in X band, at room temperature in a microwave cylindrical cavity TE011. The saturation magnetization was of the order of 1.5 x10^6 emu in these films. A planar capacitative device was fabricated on the film using optical lithography. The pattern was formed with gold with an extended contact pad for two probe measurement of capacitance. Before subjecting the device to electrical measurement, the structure was simulated in finite element environment to evaluate the DC capacitance and the change in permittivity with applied frequency on a magnetic substrate (Nickel Zinc Ferrite). The permeability of the film was estimated with applied magnetic field using a micromagnetic framework, solving Landau-Lifshitz-Gilbert equation. The capacitance and the dispersion in permittivity were measured for this device using an impedance analyzer in the frequency range 100 Hz to 110 MHz. An in-plane magnetic field was applied to look at the change in capacitance. A large change in capacitance of the order of 20% was observed in these devices, which did not change above the coercive magnetic field. A similar change was observed in the loss measurement as well. The change in capacitance is tuned using magnetic field, frequency of excitation and structural parameters. The change in capacitance is attributed to change of surface permeability and effective spin diffusion along the metallic probe [3]. These devices can be used for development of tunable spintronic micron size patterned oscillators.1. Marrows, C.H. et al. (August 2009). “Spintronics and functional materials”. Materials Today12, (7–8):70.2. Hong, S. J. (January 2012) “Possibility of Magnetocapacitor for Multilayered Thin Films” Journal of Magnetics17(2):78-82.3. McCarthy, K.T.; et al. (March 2003). “Magnetocapacitance: Probe of Spin-Dependent Potentials”. Physical Review Letters 90 (11): 117201.

**PS10**
Effect of Film Forming Technique on the Performance of Poly Acrylic Acid Based Electrolyte in All-Solid-State Zn/Ag O Printed Flexible Battery Gaganjit Singh1, 2, Sangha Mitra1, 2 and Monica Kativiy1, 2; 1Materials Science & Engineering, Indian Institute of Technology, Kanpur, India, Kanpur, India; 2National Centre for Flexible Electronics, Indian Institute of Technology, Kanpur, India, Kanpur, India.

Printable batteries have attracted great attention as an emerging power source for wearable electronics such as RFID tags, implantable medical devices etc. It has been reported that printed Zn/Ag2O batteries have low cost, light weight and easy processing methods. The electrodes have been prepared using zinc (un-doped) and silver oxide powders. SAZO (ZnO/AO/ZnO) superlattice thin films, which were prepared by atomic layer deposition, and the evaluation of their in-plane electrical and TE properties. All the in-plane TE properties, including Seebeck coefficient, electrical conductivity, and thermal conductivity of the AO/ZnO superlattice and AO/ZnO film were evaluated in the temperature range from 40 to 300 K. Furthermore, the electrical power generation efficiency of the TE energy generator, consisting of four couples of n-AO/ZnO superlattice films and p-Bi2-Sb2-Te3 (p-BST) thin-film legs on the substrate, was demonstrated.
Local Photovoltage Imaging of ZnTe/CdTe Heterojunction

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Polycrystalline thin-film solar cells (e.g., Cu(In, Ga)Se, CdTe) represent the most successful photovoltaic (PV) technology in the market today, owing to the stability, the ability to achieve high-throughput processing, and the flexibility to integrating them to various substrates. At the best cell efficiency of 22%, however, the efficiencies remain well below the theoretically predicted limits (~32%). Among the key PV parameters, recent advances have made significant enhancements in the short-circuit current (Jsc) and the fill-factor (FF), whereas the open-circuit voltage (Voc) of standard CdTe devices remains pinned at about 850 mV. One of the requirements for high Voc (e0 = 2.26 eV) is one such interfacial material that acts as a back surface field to repel the carriers from the CdTe/ZnTe heterojunction. With the presence of electrically-active grain boundaries in CdTe, the heterojunction interface properties of CdTe/ZnTe are not presently well understood.

In this work, we present a characterization technique that can visualize the local interface photovoltage of individual grains and grain boundaries at the nanoscale. Prior to the measurements, we fabricated a n-Si/SiO2/SiO2/Si structure on a MgZnO/TiO2/Si glass substrate. A thin layer of ZnTe was sputtered on p-CdTe. High-resolution SEM/EDS (Scanning Electron Microscopy / Energy Dispersive X-ray Spectroscopy) images showed a conformal deposition of the ZnTe layer. The nominal size of the CdTe grains was 4 μm. A conventional setup of Kelvin Probe Force Microscopy (KPFM) was used to measure the contact potential difference (CPD) in the dark using a low frequency (635 nm) coupled to the optical fiber and collimator was then used to irradiate the sample at 30° to the surface, so that the probe did not block the incident light. DCPD images were obtained by subtracting the dark CPD from photo-excited CPD at 100 mW/cm² (1 sun illumination). Unlike the DCPD of the CdTe control, the ZnTe/CdTe device showed a higher DCPD near the grain boundaries than in the grain interiors. It is likely that the presence of the ZnTe interfacial layer promotes the energy band-bending grain boundaries under light illumination. Further investigation of the role of the ZnTe interfacial layer in conjunction with near-field photocurrent microscopy measurements.

Wafer Mapping with Scanning Projected-Frame Reciprocal Space Maps

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Wafer mapping with X-ray diffraction is used to monitor uniformity or to quantify spatial gradients for combinatorial processing. Wafer maps are usually produced from a series of triple-axis rocking curves. Rocking curves provide limited information, but are the only traditional X-ray diffraction technique that are fast enough to produce a wafer map with adequate throughput. Recent innovations in hybrid pixel detector technology have allowed the collection of “ultrafast” double-axis reciprocal space maps using a scanning frame-based method. This method reduces the data collection time for reciprocal space mapping from hours to minutes. This speed, combined with automated data analysis in new software, makes it possible to map wafers using information-rich reciprocal space maps. This poster will explain the methodology and advantages of wafer mapping with scanning projected-frame reciprocal space maps.
increase of both blue- and red-shift. Films with different concentration of dopant and different concentration of oxygen vacancies were grown by using a pulsed KrF excimer laser. The structural, electrical, magnetic and optical properties of the films were studied. Photoluminescence spectrum (PL) of the films were recorded. A magnetometer was used to measure their magnetic moment. Films grown at higher temperature have a larger concentration of oxygen vacancies, and therefore a larger magnetic moment. We observe a blue-shift in 4% Mn-doped ZnO that is in agreement with theory. Interestingly we observe a shift to longer wavelengths (red-shift) in 2% Mn-doped ZnO. This behavior is similar to that reported at low temperature for other dilute magnetic semiconductors, such as Zn$_x$Mn$_{1-x}$Se and Cd$_x$Zn$_{1-x}$Te [5]. The decrease of the band-gap is attributed to the $sp$-$d$ interaction between free charge carriers in the band of the semiconductor and the localized magnetic moments. The effect has been theoretically modeled by using a second order perturbation theory [5]. On the other hand, ferromagnetism in Mn-ZnO is commonly believed to be due to interaction between the localized magnetic moments mediated by the free charge carriers. It is therefore reasonable to expect that an increase of the charge carriers should lead to an increase to magnetic moment and, consequently, an increase of the red-shift in the near band edge emission peak. In films grown at room temperature and 600 °C the red-shift is, respectively, $\Delta \lambda_{600} = 7.6$ nm and $\Delta \lambda_{300} = 9.2$ nm with a peak position for the ZnO at $\lambda_{300} = 275.9$ nm, independent on the growth temperature [6,7]. Similar results were obtained on films deposited by sol-gel method [8].

References


PS17

(Studant) Benchmarking Digital Logic Styles for High-Performance OTFT Circuits Zhihong Yao, Bing-Jang Chang, Ryoto Sekine, David Wentzlar and Barry P. Rand – Electrical Engineering, Princeton University, Princeton, New Jersey, United States;

Organic thin-film transistors (OTFTs) are a promising technology for large area electronics, but choosing an appropriate circuit style is key to OTFT circuit functionality and reliability. Typically, p-type logic is implemented for OTFTs. This is owing largely to lower stability of n-type materials and that complementary logic is complicated by difficulties of side-by-side material processing. Thus, benchmarking various logic styles is an important step for circuit optimization and application viability. Here, we design and evaluate three types of logic styles – ratioed logic (diode-load, biased-load), pseudo-CMOS logic (pseudo-D, pseudo-E), and complementary logic has the best gain and power of a weak pull-down network and high static power consumption at low source/drain. Ultimately, from analysis of inverters, NAND/NOR gates, and ring oscillators, we find that complementary logic has 2X voltage gain, 10X reduced power consumption, 2X integration density and better AC response than the best pseudo-CMOS p-type only logic. For OTFTs with a stable mobility and threshold voltage, complementary logic is most suitable for large-scale system applications. Pseudo-CMOS logic can be an alternative technology with better post-fabrication tunability and simpler fabrication.

PS18

Organic Thin-Film Transistors with Liquid Crystalline Semiconducting Polymers on Photo-Aligned Polymeric Insulator Kigook Song and Jinwoo Bae – Advanced Materials Engineering, Kyung Hee University, Yongin, Korea (the Republic of).

Organic thin-film transistors (OTFTs) have been extensively investigated because of their potential applications in ultrathin, large-area, low-cost, and flexible electronics. Numerous efforts have been made to improve the OTFT performance of organic semiconductors and organic gate insulators. In particular, it has been proven that control of the molecular ordering and crystalline orientations of organic thin film semiconductors in OTFTs is essential for achieving high carrier mobility because the movement of charge relies on intermolecular and interchain orientation of organic semiconductor films or to induce better molecular chain ordering of liquid crystal (LC) polymeric semiconductors, several methods such as mechanical stretching, liquid-crystalline self-organization, rubbing, and interface treatments between the semiconductor and gate dielectric insulator have been developed for the application of LC-based OTFTs. Among them, orientation-controlled pentacene semiconductor films have been recently investigated due to their superior potential for enhancing mobilities and providing more unusual properties such as optical and electrical anisotropic characteristics. In this study, we fabricated OTFTs onto a photo-aligned polyvinylcammanamate (PVCN) gate insulator to facilitate a highly oriented microstructure of liquid crystalline poly(2,5-bis(3-tetraclyhythiophen-2-yl)thieno[3,2-b]thiophene) (PBT2TT) as an active layer. The photoinduced PVCN layer, which is a mechanically unrubbed alignment surface, was introduced as an alignment layer to induce favorable molecular orientation of the liquid crystalline polymeric semiconductor. Also, this photo-alignment technique avoids the many drawbacks associated with traditional rubbing techniques. Therefore, it is expected that the photo-aligned PVCN film, which effectively induces the alignment of the liquid crystalline semiconducting polymer chains can be simultaneously used as a gate insulating layer of OTFT. Unlike inorganic gate dielectrics, PVCN polymer gate dielectrics can be deposited by solution processing such as spin-coating, spray-coating, and printing. The PVCN layer plays an important role in the fabrication of OTFTs with solution processable liquid crystalline semiconducting polymers, such as PBTTT, because it provides orientation of liquid crystalline polymer chains as well as gate insulating characteristics. PBTTT-OTFT was fabricated with the LPUV irradiated PVCN film as the underneath gate insulator and LC-like PBTTT as the semiconducting layer. The PVCN layer provides orientation of the liquid crystalline polymer chains as well as gate insulating characteristics. The orientation of LC-like PBTTT chains induced on the LPUV irradiated PVCN film was investigated using a polarized UV/Vis spectroscopy. The PBTTT layer shows the UV/Vis dichroism which indicates that PBTTT chains preferentially orient along the perpendicular direction against LPUV. In the perpendicular PBTTT-OTFT, more PBTTT chains orient parallel to the channel direction whereas more chains are oriented perpendicular to the channel direction in the parallel PBTTT-OTFT. Therefore, it is understandable that the perpendicular PBTTT-OTFT (0.025 cm$^2$/V) has larger carrier mobility than the parallel PBTTT-OTFT (0.008 cm$^2$/V). These results suggest that use of the photo-aligned PVCN film as a dielectric layer and power for the circuit design of OTFTs with solution processable LC-like semiconducting polymers.
For decades, nonlinear optical (NLO) polymers have been studied extensively because of their multimodal applications in ultrafast optical switching, high-speed optical modulator, optical fiber communications and high-density optical data storage. NLO polymers have many advantages superior to conventional inorganic ones such as light weight, low cost, ultrafast response, wide response wave band, high optical damage threshold, and good processability to form optical devices. A potential NLO polymer must contain highly polarizable conjugated electronic systems and has to be mechanically very strong. NLO polymers for electro-optic device applications, stabilization of electrically induced dipole alignment is one of important considerations. In this work reported here, we prepared new polyester 4 containing dinitrodioxyazobenzene group as NLO chromophores, which are components of the polymer backbone. We selected the latter as NLO chromophore because it was expected to have high optical nonlinearities and thermal stability. Furthermore, this dinitrodioxyazobenzene group constitutes a novel X-type NLO polyester, and this X-type NLO polyester is expected to exhibit high voltages. The polyester 4 is soluble in common organic solvents such as acetone and N,N-dimethylformamide. It shows a thermal stability up to 280 °C in thermogravimetric analysis with glass-transition temperature (T_g) obtained from differential scanning calorimetry near 130 °C. The second harmonic generation (SHG) coefficient (d_33) of polydopan crystal at the 1064 nm fundamental wavelength is around 2.13 pm/V. The dipole alignment exhibits a thermal stability even at 5 °C higher than T_g, and there is no SHG decay below 125 °C due to the partial main-chain character of polymer structure, which is acceptable for NLO device applications.

**PS20 Fast Hall™—What Determines the Smallest Hall Voltage that can be Measured? Jeffrey Lindemuth, Lake Shore Cryotronics, Westerville, Ohio, United States.**

The Hall effect is the primary method to measure carrier density, mobility and carrier type in materials. The most common method for measuring the Hall effect in semiconductors uses a DC magnetic field. The community has developed a well-defined protocol for removing spurious voltages in the measurement. Reversing the magnetic field and subtracting the measured Hall voltage will remove any voltage that does not depend on the magnetic field. As research interest in studies of the transport mechanisms expands beyond semiconductors, with moderate to high mobility, the standard DC field method reaches its limit of applicability. We present a new measurement protocol based on the reverse-field reciprocity theorem. The reverse-field reciprocity theorem considers a four port network with current inputs and voltage measurements and an applied magnetic field. If a current is applied to two of the inputs (say 1 and 3) and a positive field B a voltage (V) is measured on terminals 2 and 4. This voltage can depend on the magnetic field V(B). If the current and voltage leads are interchanged, current on terminals 2 and 4, voltage measured between 1 and 3, V(B). The theorem states that V(B) = V(-B). This is a very general result; the only requirement of the material is that it is electrically linear. This means that thermoelectric voltages require special treatment. In the above example, V(B) - V(-B) removes the offset voltage without physically reversing the magnetic field. Measurements using the Fast Hall™ method on InAs, IGZO, ZnO, pyrite, Graphene and GaAsSb have demonstrated excellent agreement between measurements using DC or AC field hall and Fast Hall. There are many factors that limit the performance of the Fast Hall method, but two important factors are the ability to completely remove the misalignment voltage and the ability to remove thermal electric voltages. Measurements of the ability to remove the misalignment voltage were made using samples with large misalignment voltage and theoretically zero hall voltage. Any residual measured hall voltage in these samples is a measure of the ability to remove this voltage. The results of these measurements are that the misalignment voltage can be reduced by more than 100 dB. The hall voltage was measured to be in the range of 10-50 nanovolts. Measurement of low mobility material requires careful handling of the thermal electric voltages in the measurement. Since these voltages are not removed by the reciprocity theorem and are often the same order of magnitude as the hall voltage extreme care is required in the measurement and calculations. Finally, it is noted that Fast Hall can extend the range of materials that can be reliably measured. Many of these materials have conduction mechanism other than drift conduction. For instance, hopping conduction is common in materials with low mobility. For these materials the interpretation of hall coefficient as related to material parameters (carrier concentration and mobility) is not necessarily straightforward.

**PS21 ZnO Nanoparticle Based Ink as Electron Injection Layer for Organic Light Emitting Diodes Chandra Kant,1,2 Mukul Jalanbhu,3 Yashwant Singh,1,2 and Monica Katyar1,2. 1Materials Science and Engineering, Indian Institute of Technology, Kanpur, India, 2National Center for Flexible Electronics, IIT Kanpur, India, Kanpur, India. **

Printable organic light emitting diodes (OLED) are being developed for applications such as aesthetic lighting and signage. Major challenge is to develop materials that can be printed, in other words a functional ink needs to be formulated. Specifically, development of ink for electron injection layer (EIL) which is typically a low work function metal like Ca in inorganic OLEDs. Calcium carbonate, caustic steam, ZnO and other oxides are some solution processable alternatives suggested in the literature. However, calcium carbonate powder, before preparing ink, is not stable in air due to moisture absorption and synthesis and purification process of calcium stearate is quite complicated. We have decided to develop ZnO as it is air stable and can be easily incorporated in low cost printing processes. We are investigating ZnO nanoparticle film as a solution processed EIL, in our standard OLED stack (ITO/PEDOT/PSS/ MEH-PPV/ZnO NPs /Al). In this normal OLED structure (EIL is deposited on the emissive layer), processing temperature should be less than 200°C, otherwise high temperature will damage the emissive layers. In order to reduce the annealing temperature, we have adopted the approach of first synthesizing the nanoparticles of ZnO which can be annealed at low temperatures around 100°C. The process described by Sun et al. is used to synthesize ZnO nanoparticles[1]. We varied temperature during synthesis from 25, 40 and 65°C, TEM image analysis shows nanoparticle size changes from 12, 6 and 4nm, respectively. Dynamic light scattering measurements show size in 100s of nm indicating aggregation and poor film formation. To suppress aggregation repeated purification (up to three times) process led to narrow particle size distribution and reduced particle size. This colloidal solution was made in different solvents and used to make thin films on glass using spin coating. Film morphology and structure is studied using AFM, XRD and thickness is measured using profilometer. Film compatibility with the MEH-PPV emissive layer was also evaluated. Finally, solution processed OLED were fabricated using this EIL, and compared with the performance of the evaporated EIL layer. References:[1] JD. Sun, M. Wong, L. Sun, Y. Li, N. Miyatake, H.J. Sue Journal of Sol-Gel Science and Technology 43(2) (2007) 237–43.

**PS22 The Importance of an Ethynyl Spacer for Lowering the Band Gap Energy in Organic Semiconductors Exemplified by 2,7-Bis(phenylethynyl)-3,4,3′,4′-bifenzeno|α|thiophene Michael R. Korn1, Joshua Kowalczyk1, Vincent M. Lynch1, Matthew Brynteson1 and Paul Savas2. 1Biology & Chemistry, Liberty University, Lynchburg, Virginia, United States; 2Chemistry and Faulkner Nanoscience and Technology Center, University of Texas, Austin, Texas, United States.**

For decades, nonlinear optical (NLO) polymers have been studied for their multimodal applications in ultrafast optical switching, high-speed optical modulator, optical fiber communications and high-density optical data storage. NLO polymers have many advantages superior to conventional inorganic ones such as light weight, low cost, ultrafast response, wide response wave band, high optical damage threshold, high thermal stability and good processability to form optical devices. A potential NLO polymer must contain highly polarizable conjugated electronic systems and has to be mechanically very strong. NLO polymers for electro-optic device applications, stabilization of electrically induced dipole alignment is one of important considerations. In this work reported here, we prepared new polyester 4 containing dinitrodioxyazobenzene group as NLO chromophores, which are components of the polymer backbone. We selected the latter as NLO chromophore because it was expected to have high optical nonlinearities and thermal stability. Furthermore, this dinitrodioxyazobenzene group constitutes a novel X-type NLO polyester, and this X-type NLO polyester is expected to exhibit high voltages. The polyester 4 is soluble in common organic solvents such as acetone and N,N-dimethylformamide. It shows a thermal stability up to 280 °C in thermogravimetric analysis with glass-transition temperature (T_g) obtained from differential scanning calorimetry near 130 °C. The second harmonic generation (SHG) coefficient (d_33) of polydopan crystal at the 1064 nm fundamental wavelength is around 2.13 pm/V. The dipole alignment exhibits a thermal stability even at 5 °C higher than T_g, and there is no SHG decay below 125 °C due to the partial main-chain character of polymer structure, which is acceptable for NLO device applications.
Recently, terahertz (THz) sources based on InAs nanowires (NWs) are expected to be applied to biomedical fields due to larger effective interface between chemical and biological features compared to that of epilayer wafers. That is, the contact area of NWs with biomedical specimens can be enhanced because of the additional side-wall contact compared to commercial InAs wafers, resulting in an increase in the reliability level of information. In this paper, we report structural and THz radiation characteristics of catalyst-free InAs NWs formed on Si(111) substrates, grown by a molecular beam epitaxy. Field-emission scanning electron microscope images of InAs NWs revealed that height and spatial density were systematically manipulated by varying flux ratio of indium to arsenic, substrate temperature, and deposition time. For example, the height of InAs NWs measured was 0.6, 1.2, 2.1, 4.6, and 5.8 μm for the V/H III ratios of 50, 100, 200, 300, and 400, respectively. The spatial density of InAs NWs was increased from 8x10^6 to 1.5x10^7 cm^-2 with increasing V/H III ratio. Both zinblende (ZB) and wurzite (WZ) structures including stacking faults were observed in transmission-electron microscope images measured along the vertical direction of InAs NWs. The structural ratio of ZB to WZ was also controlled by changing growth parameters including doping. The THz radiations of InAs NWs were successfully obtained without a direct-current bias due to the large difference of mobility between electrons and holes generated from an external excitation source. The peak-to-peak current signal (PPCS) of undoped InAs NWs with the average height of 10 μm, obtained from THz time-domain (TD) spectroscopy, was measured to be 4.95 nA, which is 40% of an undoped InAs wafer. Considering the factor of 0.005 for the InAs NWs, defined as the ratio of the total area of the top surfaces for InAs NWs to the flat surface, it is noteworthy that the amplitude of the PPCS is comparable to that of the InAs wafer. The THz spectra of the InAs NWs, obtained by applying a fast Fourier transformation to the TD current signals, show the frequency of ~0.5 THz. The amplitude of the THz spectra of InAs NWs linearly increased with increasing excitation intensity at ~0.5 THz. Even though the bandwidth for InAs NWs is smaller than that of the InAs wafers (~2–2.0 THz), the NWs can be applied to biomedical specimens such as basal cell carcinoma and normal human skin tissue sensitive to the frequency range of ~0.3 THz. By using catalyst-free InAs NWs, we successfully obtained a clear THz image from a small piece of pork belly.

**PS24**

**Resources for Uncertainty Analysis**

**Kris Bertness:** National Institute for Standards and Technology, Boulder, Colorado, United States.

It can be argued that science is not the pursuit of what we know with certainty, but rather that pursuit in which we evaluate how well we know what we assert is true. Uncertainty analysis thus becomes a key component in the evaluation of scientific “truth.” This poster will describe resources made available by the National Institute of Standards and Technology (NIST) and other world-wide national metrology institutes to aid technologists in the evaluation of uncertainty in their data. These resources include the NIST Uncertainty Machine, a free on-line Monte Carlo simulator https://uncertainty.nist.gov/, NIST Technical Note 1297, https://www.nist.gov/pml/nist-technical-note-1297, and the more comprehensive Guide to the Expression of Uncertainty in Measurement, the “GUM”, https://www.bipm.org/en/publications/guides/gum.html. We will illustrate uncertainty analysis using measured atomic beam optical maser transition frequencies, random error and statistical independence. Student attendees of the Electronic Materials Conference are encouraged to use this information in applications for the NIST-sponsored Student Uncertainty Analysis award.

**PS25**

**A New Directly Placement Method for Individual Carbon Nanotube Devices and Its Applications to the Nanoelectromechanical Systems (NEMS)**

**Xinhe Wang1, 2, Xinliang Lin1, Guangwei Deng2, Guangwei Deng2, Xinhe Wang1, 2, Xinliang Lin1, Guangwei Deng2, Xinhe Wang1, 2, Xinliang Lin1, Guangwei Deng2, Xinhe Wang1, 2, Xinliang Lin1, Guangwei Deng2**

Though carbon nanotube (CNT) is acknowledged as an ideal system for one-dimensional physics, making ultraclean nanotubes with electrical circuits of arbitrary complexity is still a challenge. We develop a new directly deterministic placement technique that allows us to operate each CNT under an optical microscope and ambient conditions. For an individual ultralong few walled CNT, after deposit nanoparticles on the suspended part of it for visualization, we draw the inner shell of the CNT, and transfer it between the two homemade tips, then place it to the target placement on the device chip. The CNTs transferred in this method are perfect clean since they are inner shell of the CNTs and not suffer from any wet process. The way to transfer and placement is so flexible and steerable that the construction of complex multi-nanotube devices can be achieved. Using this technique, we fabricate the CNT electromechanical resonators and study the different types of coupling effects, including the Rabi oscillation of the coherent phonon between the coupling modes and the nonlocal coupling of phonon. Further, we realized the stressed CNT devices for high tunability, high quality factor, single mode GHz resonators. Our CNT resonator is promising for ground-state cooling and quantum manipulation, as well as the RF applications. It also enables the integration of homogeneous devices, and will play a key role in the emerging applications of NEMS.
PS30
(Student, LATE NEWS) Low Temperature Hydrothermal Synthesis of ZnO Nanowire Arrays on Metal Substrates for Energy Harvesting

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One-dimensional (1D) nanostructures demonstrate enthralling properties due to their quantum confinement effects which result from their low dimensionality. Piezoelectric properties intertwined with the semiconducting properties of several 1D nanostructures (e.g. ZnO and GaN) offers noble way of manipulating charge-carrier transport, generation, recombination or separation through the application of external mechanical strain that leads to unprecedented device characteristics. Not only ZnO nanowires are non-centrosymmetric which comes from their wurtzite structure, but also their largeelectromechanical coupling make them ideal candidate for use in a variety of electronic devices mostly as piezoelectric material. Structural health monitoring (SHM) system is a damage detection and characterization technique for engineering structures which is based on three salient advantages: (1) from an array of sensors. To make the SHM system self-powered, environmental energies from sources such as solar, wind, vibration, temperature differentials, electromagnetic, and acoustic can potentially be used to supply energy for sensors. Piezoelectric nanogenerator (PENG) based on ZnO nanowire arrays is quite mature technology for harvesting ambient tiny mechanical energies and converting them into electrical energy. Our goal is to make PENGs directly fabricated on metal substrate (e.g. Cr, Al) which requires first to grow the patterned vertically aligned ZnO NWs on metal substrate. We used a two-step hydrothermal method to grow p-n junction type ZnO NWs as they show better performance compared to either n-type or p-type ZnO NWs in terms of piezoelectric response. After cleaning a 1.2 x 1.2cm² shim substrate using standard cleaning process, a thick layer of Cr (200nm) is deposited using magnetron sputtering which serves as the bottom electrode. After that a seed layer of aluminum doped zinc oxide (AZO) is deposited on top of the Cr layer using plasma enhanced chemical vapor deposition (PECVD) for the subsequent ZnO hydrothermal growth of ZnO nanowires. In the first step of n-type ZnO NWs a mixture of zinc nitrate hexahydrate (25 mM), hexamethylenetetramine (HMTA) (25 mM) and aluminum nitrate nonahydrate (25 mM) is used. In the second step, to obtain p-type ZnO NWs (Li-doped), a doping reagent, lithium nitrate (75 mM) along with both solutions are added. In both steps, the solution is kept at a constant 88°C during reaction which is optimum for the growth of nanowires instead of growing nanoballs (below 75°C) and nanorods (above 95°C), and the ZnO NW length is simply controlled by growth time. All samples are cleaned using a standard process. After the growth and characterization of ZnO NWs, they are encapsulated with PMMA which protects the NWs from damage and prevents the electrical shortage between top and bottom electrode thus increasing the robustness of the PENG. After that a 100 nm thick Al layer is deposited as the top electrode. Finally two Cu wires are connected to the top and bottom electrode for characterization. NG piezoelectric response is measured using a system that includes a close loop controller and a linear shaker that is capable of providing mechanical strain to the device with a particular frequency, known acceleration and particular amount of force. For this device, the output open circuit voltage has an average peak of 5.1V and output short circuit current has an average peak of 175nA with 5Hz frequency and 5mm peak-to-peak displacement of the shaker hammer. Output voltage and current signals are measured using Stanford low-noise voltage/current preamplifier (Model SR560/570) when 100 Ω (SR560) and 10 kΩ (SR570) resistors are used as the input resistances of the preamplifiers, respectively.

Development and Thermoelectric Properties of Vanadate Oxide System Amorphous Thin Films

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Thermoelectric materials include wide range of compounds, chalcogenides as typified by Bi–Te and semiconductors such as Si–Ge system and Mg,Si for example; there have been large efforts to improve their properties owing to modification of composition and structure, and also to nano-
We present the Ga$_2$O$_3$ epitaxial growth on c-plane sapphire substrates under different growth temperatures, ranging from 600 to 1100 °C in a MOVPE reactor, as shown in Fig. 1. The MOVPE reactor is made of quartz tube, and the reactor has two gas inlets for trimethylgallium (TEG) and O$_2$ as the carrier gas, the gallium source, and the oxygen source, respectively. During 30-minute epitaxial growth, the TEG/O$_2$ partial pressure ratio was kept at 0.0104 (0.03 Torr/2.874 Torr) and the temperature ranged from 600 to 1100 °C with the step of 100 °C at 100 Torr. The samples, grown from 600 to 1100 °C, are defined as S1 to S6. The surface roughness and morphology, crystal structure and quality, growth rate, and transmission spectrum of the epitaxies have been characterized in this study. The surface roughness and morphology were characterized by an atomic force microscope (AFM). The roughness of S1 to S6 are 5.46, 14.14, 34.70, 24.94, 18.92, and 28.39 nm, respectively, as shown in Fig. 1. The roughness increases from S1 to S3, then the roughness decreases from S3 to S5. S1 was denoted as green, S3 as yellow, S5 as black. The surface morphology shows: there are circular grains on the surface at S1, and then the circular grains turns into rectangular plates at S2 and the size of plate is increased to the maximum at S3. At S4, the rectangular plates turn into square plates with round corner, and the size of plate is decreased at S5. Finally, the plates become irregular shape at S6. It is noted that the surface roughness is correlated to the size of plates, which have surface with circular grains or smaller plates have smoother surface. The crystal structure and quality were characterized by X-ray diffraction (XRD), as shown in Fig. 2. For S1, the XRD result shows the epitaxial film has a mixed phase of β- and ε-Ga$_2$O$_3$, and the peaks intensity of ε-Ga$_2$O$_3$ are stronger than that of β-Ga$_2$O$_3$, indicating the ε-Ga$_2$O$_3$ might be dominant. Among the rest of the samples, the β-Ga$_2$O$_3$ was not observed and the epitaxial films are pure β-Ga$_2$O$_3$. However, except the most common (-201) oriented peaks, minor peaks such as (601), (20-4) show up when the temperature raises from S2 to S6. For S3, there are eight minor peaks appear which might be correlated to large rectangular plates on the root of the surface and rectangular plates have many facets with different orientations and thus contributed to the minor peaks. For S6, all the minor peaks disappear except for the (401) and (620) peaks. The full width at half maximum (FWHM) of (201) peaks by the rocking curves for S1 to S6 are 0.93°, 1.63°, 1.52°, 1.39°, 1.59°, and 2.36°, respectively. This means the higher temperature did not improve the crystal quality of β-Ga$_2$O$_3$. The ε-Ga$_2$O$_3$ is 3-coordinated O in the same polymer of -201 orientation thin-film analyzer. The growth rates, at the precursor concentrations used, of S1 to S6 are 1.2, 1.13, 1.07, 1.01, 0.9, and 0.75 μm/hr, respectively. The growth rate linearly decreased versus the temperature and the decreasing rate is higher after 900 °C. The transmission was measured by UV-Vis spectrometer. All the samples show a sharp absorption edge and visible-transparency, which means they have deep level absorption and low impurity concentration in the film. Except S3 has lower absorption edge at 4.75 eV, the rest of samples have absorption edge at 4.82 eV, as shown in Fig. 3.

**PS35**

**Molecular Dynamics Studies of Point Defect Diffusion in Ultra Wide Band Gap Semiconductors**

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Due to large bandgap β-Ga$_2$O$_3$, promising material for high voltage FETs with high on/off ratio and high breakdown field. However poor thermal conductivity and excessive device heating can lead to the degradation of electronic and mechanical properties of the material due to vacancy and dopant mobility in high electric field and high temperature conditions. The problem has possible engineering solution by specific device design that eliminates high gradient of electric field. Another diffusion problem is using multilayered and epitaxial structures that would allow increasing carrier concentration and restricting vacancy / dopant mobility in the same time. The correct orientation of epitaxial crystalline layers could effectively alleviate the problem. The suggested molecular modeling approach could provide practically important solutions. In this work we have studied two cases: O$_2$ and Si atoms in β-Ga$_2$O$_3$. O$_2$ vacancy diffusion. The modeling of diffusion in crystalline solids is generally difficult because it is intrinsically molecular process which is also very slow on the molecular scale. We apply a multi-scale approach to transfer interatomic interactions from electronic-level methods (DFT, TB-DFT) to classical molecular dynamics (MD). The problem of local interatomic interactions in the presence of the electric field was solved using a quasiparticle, collective electronic oscillator representations. The classical forcefield derived from it was used in MD modeling to generate macroscopic diffusion patterns. However, the forcefield potential targets material properties near equilibrium such as elastic constants, phonon dispersion, thermal conductivity, thermal expansion. This potential is usually not suitable for studying properties far from the equilibrium, including the enthalpy of formation and the diffusion coefficients. We introduce modified Tersoff potential that can be used for molecular modeling of the diffusion. Using newly developed interaction parameters, the modeling of test crystalline β-Ga$_2$O$_3$ structures containing large number of atoms (up to 80,000) was performed. This includes lattice parameters verification, structure optimization, thermal expansion and melting processes. Potential proved to be robust and providing reasonable results in good agreement with the experiments (within 5% for all of these constants). We introduce modified Tersoff potential for the 3-coordinated O and have provided diffusion distance and activation enthalpy about 75.9 kJ/mol and the value of the diffusion coefficient is about (3.1 ± 0.8)×10$^{-10}$ cm$^2$/s. The three structures of oxygen divacancies were stable at high temperatures up to the melting point. This is the indication that oxygen vacancies have tendency for agglomeration and forming a cluster. The agglomeration rate at different temperatures was further evaluated.

**PS34**

**MOVD- Grown β-Phase Ga$_2$O$_3$ Thin Films on Al$_2$O$_3$ with Different Temperature**

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We present the Ga$_2$O$_3$ epitaxial growth on c-plane sapphire substrates under different growth temperatures, ranging from 600 to 1100 °C in a MOVPE reactor, as shown in Fig. 1. The MOVPE reactor is made of quartz tube, and the reactor has two gas inlets for trimethylgallium (TEG) and O$_2$ as the carrier gas, the gallium source, and the oxygen source, respectively. During 30-minute epitaxial growth, the TEG/O$_2$ partial pressure ratio was kept at 0.0104 (0.03 Torr/2.874 Torr) and the temperature ranged from 600 to 1100 °C with the step of 100 °C at 100 Torr. The samples, grown from 600 to 1100 °C, are defined as S1 to S6. The surface roughness and morphology, crystal structure and quality, growth rate, and transmission spectrum of the epi-layers have been characterized in this study. The surface roughness and morphology were characterized by an atomic force microscope (AFM). The roughness of S1 to S6 are 5.46, 14.14, 34.70, 24.94, 18.92, and 28.39 nm, respectively, as shown in Fig. 1. The roughness increases from S1 to S3, then the roughness decreases from S3 to S5. S1 was denoted as green, S3 as yellow, S5 as black. The surface morphology shows: there are circular grains on the surface at S1, and then the circular grains turns into rectangular plates at S2 and the size of plates is increased to the maximum at S3. At S4, the rectangular plates turn into square plates with round corner, and the size of plate is decreased at S5. Finally, the plates become irregular shape at S6. It is noted that the surface roughness is correlated to the size of plates, which have surface with circular grains or smaller plates have smoother surface. The crystal structure and quality were characterized by X-ray diffraction (XRD), as shown in Fig. 2. For S1, the XRD result shows the epitaxial film has a mixed phase of β- and ε-Ga$_2$O$_3$, and the peaks intensity of ε-Ga$_2$O$_3$ are stronger than that of β-Ga$_2$O$_3$. However, except the most common (-201) oriented peaks, minor peaks such as (601), (20-4) show up when the temperature raises from S2 to S6. For S3, there are eight minor peaks appear which might be correlated to large rectangular plates on the root of the surface and rectangular plates have many facets with different orientations and thus contributed to the minor peaks. For S6, all the minor peaks disappear except for the (401) and (620) peaks. The full width at half maximum (FWHM) of (201) peaks by the rocking curves for S1 to S6 are 0.93°, 1.63°, 1.52°, 1.39°, 1.59°, and 2.36°, respectively. This means the higher temperature did not improve the crystal quality of β-Ga$_2$O$_3$. The ε-Ga$_2$O$_3$ is 3-coordinated O in the same polymer of -201 orientation thin-film analyzer. The growth rates, at the precursor concentrations used, of S1 to S6 are 1.2, 1.13, 1.07, 1.01, 0.9, and 0.75 μm/hr, respectively. The growth rate linearly decreased versus the temperature and the decreasing rate is higher after 900 °C. The transmission was measured by UV-Vis spectrometer. All the samples show a sharp absorption edge and visible-transparency, which means they have deep level absorption and low impurity concentration in the film. Except S3 has lower absorption edge at 4.75 eV, the rest of samples have absorption edge at 4.82 eV, as shown in Fig. 3.
respectively at 40 V. The UV-to-Visible rejection ratio was > 10 nm, responsivity measuring 0.6 A/W and 0.75 A/W at 256 nm and 365 nm, conditions, the response at 365 nm gets enhanced compared to that at 256 biased positive at 5 V, a high SR of 3.7 A/W was measured for both 256 and GaN as active layers, on a silicon (111) platform. This is also the first report of a device with both β-Ga
to allow for efficient extraction of carriers and to provide a flat band at the hetero-interface. The composite material has a band gap of ~ 3.4 eV, which is close to the band gap of GaN, and the absorption of the composite material is high for wavelengths shorter than 380 nm. The composite material is deposited on a silicon substrate and the Schottky diode is fabricated using TiAlNiAu ohmic contacts that are annealed at 750°C for 1 min. The Schottky diode is tested for its current-voltage (I-V) characteristics and it is found that the device exhibits high responsivity of ~ 3.7 A/W at 5 V, and the near-zero-bias specific detectivity was estimated to be 4.7 x 10^9 cmHz^0.5/W. With a sufficiently higher β-GaO_N, this device design would yield a dual-band UV detector. Given the vertical topology and the silicon platform, the MDM heterojunction detector demonstrated here is easily scalable and holds promise for enabling broadband UV-A/UV-C FPA. [1] P. Li, H. Shi, K. Chen, D. Guo, W. Cui, Y. Zhi, S. Wang, Z. Wu, Z. Chen and W. Tang, J. Mater. Chem. C, 2017

PS41

Development of a GaN Nanowire Laser for Atomic Force Microscopy and Lithography

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Gallium nitride (GaN) nanowires (NWs) have a strong potential for application in tip based nanometrology and lithography due to its hardness, geometry, and direct band gap optical properties in the UV spectral range. Here, we report the use of GaN NWs to fabricate an AFM probe with a bandwidth of ~ 10^6 Hz and a gain of ~ 10^5. The AFM probe was fabricated using Metal Organic Chemical Vapor Deposition (MOCVD) of AlN film grown at 800°C and a 1 μm sputtered AlN film and TiAlNiAu ohmic contacts that were annealed at 750°C for 1 min. The threshold lasing power and laser wavelength were measured to be ~ 100 μW and ~ 330 nm, respectively. At 365 nm the detectivity was estimated to be 4.7 x 10^9 cmHz^0.5/W. With a sufficiently higher β-GaO_N, this device design would yield a dual-band UV detector. Given the vertical topology and the silicon platform, the MDM heterojunction detector demonstrated here is easily scalable and holds promise for enabling broadband UV-A/UV-C FPA. [1] P. Li, H. Shi, K. Chen, D. Guo, W. Cui, Y. Zhi, S. Wang, Z. Wu, Z. Chen and W. Tang, J. Mater. Chem. C, 2017

PS40

Demonstration of High Responsivity Epitaxial β-GaO_N/GaN Metal-Heterojunction-Metal (MHM) Broadband UV-A/UV-C Detector

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We report on the first demonstration of a β-GaO_N/GaN-based vertical metal-heterojunction-metal (MHM) broadband UV-photodetector on a silicon (111) platform. This is also the first report of a device with both β-GaO_N, and GaN as active layers, on a silicon platform. The device design utilised the small conduction-band offset (ΔE_c) of 0.1 eV between GaO_N, and GaN to realise devices with an asymmetric spectral response with respect to applied bias. Two peaks at 256 nm and 365 nm are observed corresponding to the band gaps of β-GaO_N, and GaN. When GaO_N, was biased positive at 5 V, a high SR of 3.7 A/W was measured for both 256 and 365 nm, giving a broadband UV-A/UV-C response. For the reverse bias condition at 365 nm gets more prominent, respective 256 nm, responsivity measuring 0.6 A/W and 0.75 A/W at 256 nm and 365 nm, respectively at 0 V. The UV-to-Visible rejection ratio was ~ 10^5 for the devices with a photo-to-dark current ~ 10^5. This new vertical MHM detector was tested on silicon is fully scalable and is promising for enabling focal plane arrays (FPAs) for broadband UV sensing. The possibility of growing monolaminic β-GaO_N epitaxially on wurtzite GaN and the small conduction-band offset (ΔE_c) between GaO_N, and GaN to form a p-n junction; our novel design uses Mg diffusion on an existing Si doped n-type GaN NW to form a p-type shell. This design of electrically or optically pumped AFM lasing probes has the potential to reduce the fabrication costs of NSOM probes as it is possible to use the probe as light emitter, collector and nanometrology tool.

PS42

Effects of Annealing Capped HVPE GaN Films Grown at High Temperatures

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Ion implantation used to locally dope semiconductor device structures requires removing induced damage by annealing the sample at prescribed temperatures and times. The temperatures are usually ones where at least one of the constituents is significant and will evaporate. For compound semiconductors this causes the surface to roughen and the preferential evaporation of one of the constituents will create vacancies that are almost always electrically active. This is a particularly difficult problem for the III-Nitrides. We show that other processes occur that can affect the electrical properties of the material when it is heated to annealing temperatures as high as 1300°C for times as long as 8 min even when there is no physical evidence that N has escaped from the GaN surface. We do this by showing that the electrical properties of Schottky diodes fabricated on samples annealed in this way can have quite different electrical properties even though the band edge of the hetero-interface and low hole mobility in β-GaO_N, respectively. At 365 nm illumination, carriers will be generated only in the GaN layer since the top GaO_N, is transparent to this wavelength. These carriers will get efficiently collected under forward-bias but will be blocked under reverse-bias due to the high lateral sheet resistance in this case, leading to a lower spectral response in this configuration. The I-V characteristics displayed by asymmetry with a photo-to-dark current ratio ~ 10^5 for both 256 and 365 nm illumination while the visible rejection was ~ 10^5. The devices exhibited high responsivity of ~ 3.7 A/W at 5 V, and the near-zero-bias specific.
Conventional sapphire substrates have very low thermal conductivity (TC). In particular, heat management is one of the serious problems to solve. Reliability of GaN-based LEDs is still limited by a number of issues that are intrinsic to the device and the substrate. These intrinsic properties typically result in serious degradation in heat-escaping properties of LED chips. It is revealed that hexagonal boron nitride (hBN) has very high TC (~2800 WmK⁻¹) in addition to its unique mechanical and electrical properties. Many studies have largely focused on obtaining the hBN-based composites with high TC. That is, there has been no study on the use of hBN as heat-escaping channels for optoelectronic devices. In this paper, we report on the improvement in heat dissipation performance of green LEDs with InGaN/GaN quantum wells (QWs) via the introduction of additional hBN heat-escaping medium. To reduce the defects/dislocations and strain at the QWs, Si-doped graded short-period InGaN/GaN superlattice, formed by indium-conversion technique, were inserted above n-type cladding layer. The strong and stable electroluminescence spectrum was observed at the wavelength of 531 nm. The fluorescent microscope image measurement of a local peak intensity shows that the injection current density of the LED shows that light emissions with flower-like patterns with six petals were periodically observed. After transferring hBN onto LEDs (hBN-LED), the maximum and minimum temperatures inside the chips at the driving current of 120 mA were measured with respect time using thermographic camera. As a reference, LEDs without the hBN (Ref-LED) were also prepared. The heat spreading coefficients of the LEDs due to the modification of the nanowire cavity modes at Stokes wavelength and holds true for a tunability of this ratio is directly proportional to the relative strength of the nanowire cavity modes at Anti Stokes scattering and vice versa. Experiments reveal that the room temperature Anti Stokes to Stokes Raman scattering ratio which is -0.1 in bulk Si can be varied in the range 0.035 - 0.45 demonstrating tunability of phonon phonon interactions by over an order of magnitude. Numerical calculations done to explain these results reveal that the tunability of Anti Stokes is directly proportional to the relative strength of cavity modes at Anti Stokes and Stokes wavelength and holds true for a wide range of nanowire diameters, cavity structure as well as excitation wavelength. Nanowire cavity modes can be easily changed by changing the nanowire diameter, cavity structure or wavelength which provides efficient ways of tuning these interactions. This is a new approach of controlling phonon interactions at the nanoscale and opens up new avenues of research and applications in the fields of Silicon photonics, telecommunication and optical cooling of semiconductors.

**PS43**

### Cavity Engineering of Phonon-Phonon Interactions in Silicon Nanowire Cavities

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Nanowires show interesting properties which are different from bulk materials and have applications in variety of areas such as photocatalysis, medicine and nanoscale devices. These exceptional properties are enabled because of tight confinement of light in resonant nanowires which is difficult to attain in bulk materials. The thermal properties of these materials have great impacts in tuning the phonon-phonon interactions in Si nanowire cavities using Raman spectroscopy. In bulk materials a phonon is equally likely to interact with a phonon in ground state (corresponding to Stokes Raman scattering) and in excited state (corresponding to Anti Stokes Raman scattering). But in Si nanowires, the nanowire cavity mode can be tuned to make a photon more likely to interact with a phonon in excited state than in the ground state (higher Anti Stokes scattering) and vice versa. Experiments reveal that the room temperature Anti Stokes to Stokes Raman scattering ratio which is ~0.1 in bulk Si can be varied in the range 0.035 - 0.45 demonstrating tunability of phonon-phonon interactions by over an order of magnitude. Numerical calculations done to explain these results reveal that the tunability of Anti Stokes is directly proportional to the relative strength of cavity modes at Anti Stokes and Stokes wavelength and holds true for a wide range of nanowire diameters, cavity structure as well as excitation wavelength. Nanowire cavity modes can be easily changed by changing the nanowire diameter, cavity structure or wavelength which provides efficient ways of tuning these interactions. This is a new approach of tuning phonon-phonon interactions at the nanoscale and opens up new avenues of research and applications in the fields of Silicon photonics, telecommunication and optical cooling of semiconductors.

**PS44**

### (Student) Improvement in Heat Dissipation Performance of InGaN-Based Green LEDs via Introduction of 3° Boron Nitride Nucleus Chai Yeu Choi, Kwanjae Lee¹, Cheul-Roo Lee¹, Jin Soo Kim², Joo Song Lee² and Soo Min Kim²; ¹Department of Electronic and Information Materials Engineering, Division of Advanced Materials Engineering, and Research Center of Advanced Materials Development, Chonbuk National University, Jeonju, Korea (the Republic of); ²Institute of Advanced Composite Materials, Korea Institute of Science and Technology (KIST), Wanju, Korea (the Republic of).

Recently, GaN-based light-emitting diodes (LEDs) fabricated on sapphire substrates have been extensively studied for applications such as traffic-light lamps, lighting, solar cells, and full-color displays. However, the reliability of GaN-based LEDs is still limited by a number of issues that must be addressed before their potential application in practical systems. In particular, heat management is one of the serious problems to solve. Conventional sapphire substrates have very low thermal conductivity (TC) of 30 WmK⁻¹ at room temperature. Moreover, many defects/dislocations at the GaN-based epitaxial layers are generated mainly due to large difference in lattice constants and thermal expansion coefficients between the epitaxial layer and the substrate. These intrinsic properties typically result in serious degradation in heat-escaping properties of LED chips. Sulfur passivation of InAs surface with sulfur-doped GaN was suggested as an alternative method to reduce the defects/dislocations and strain at the QWs, Si-doped graded short-period InGaN/GaN superlattice, formed by indium-conversion technique, were inserted above n-type cladding layer. The strong and stable electroluminescence spectrum was observed at the wavelength of 531 nm. The fluorescent microscope image measurement of a local peak intensity shows that the injection current density of the LED shows that light emissions with flower-like patterns with six petals were periodically observed. After transferring hBN onto LEDs (hBN-LED), the maximum and minimum temperatures inside the chips at the driving current of 120 mA were measured with respect time using thermographic camera. As a reference, LEDs without the hBN (Ref-LED) were also prepared. The heat spreading coefficients of the LEDs due to the modification of the nanowire cavity modes at Stokes wavelength and holds true for a tunability of this ratio is directly proportional to the relative strength of cavity modes at Anti Stokes scattering and vice versa. Experiments reveal that the room temperature Anti Stokes to Stokes Raman scattering ratio which is ~0.1 in bulk Si can be varied in the range 0.035 - 0.45 demonstrating tunability of phonon-phonon interactions by over an order of magnitude. Numerical calculations done to explain these results reveal that the tunability of Anti Stokes is directly proportional to the relative strength of cavity modes at Anti Stokes and Stokes wavelength and holds true for a wide range of nanowire diameters, cavity structure as well as excitation wavelength. Nanowire cavity modes can be easily changed by changing the nanowire diameter, cavity structure or wavelength which provides efficient ways of tuning these interactions. This is a new approach of tuning phonon-phonon interactions at the nanoscale and opens up new avenues of research and applications in the fields of Silicon photonics, telecommunication and optical cooling of semiconductors.

**PS45**

### (Student) Effect of Sulfur Passivation Using Aqueous and Alcoholic Ammonium Sulfide Solution on the Specific Contact Resistivity of Ni to InAs Layer Epitaxially Grown on In₅₃Ga₄₇As Epilayer Sim-hoon Yuk, Chel-Jong Choi and Han-Soo Jang; School of Semiconductor and Chemical Engineering, Chonbuk National University, Jeonju-si, Korea (the Republic of).

We have investigated the effect of sulfur passivation using aqueous and alcoholic ammonium sulfide solutions on the specific contact resistivity of Ni contact to InAs layer epitaxially grown on In₅₃Ga₄₇As epilayer. Prior to 50 nm-thick Ni deposition using DC sputtering system, InAs epilayer was treated at room temperature in the aqueous or in alcoholic ammonium sulfide solution for 100 sec. The aqueous and alcoholic ammonium sulfide solutions were prepared using the dilution of ammonium sulfide by water and isopropyl alcohol in the ratio of 1:100 by volume, respectively. The specific contact resistivity of Ni/InAs contact with alcoholic ammonium sulfide treatment was much lower than that with aqueous ammonium sulfide one, of which values were 4.09 x 10⁻¹⁰ and 1.06 x 10⁻¹⁰ Ωcm², respectively. From X-ray photoelectron-spectroscopy analysis, As-S/As-In bonding ratios were calculated to be 3.1 and 0.8 for the InAs surfaces chemically treated by alcoholic and aqueous ammonium sulfide solutions, respectively, implying that alcoholic ammonium sulfide treatment was more effective in the sulfur passivation of InAs surface than aqueous ammonium sulfide treatment. The ultraviolet photoelectron spectroscopy measurements revealed that the work function of alcoholic ammonium sulfide treated InAs surface was higher than that of aqueous ammonium sulfide treated InAs one. Based on XPS and UPS results, the improvement of specific contact resistivity of the Ni/InAs contact through alcoholic ammonium sulfide surface treatment could be due to the reduction of contact barrier height between Ni and InAs associated with better sulfur passivation of InAs surface.
Epitaxial layer exfoliation of III-V materials from their respective substrates provides a cost-effective route for fabricating multi-junction solar cells. Porous indium phosphide (InP) electrochemically etched onto a InP substrate facilitates this layer transfer through weakened mechanical properties at the porous layer-substrate interface. We previously demonstrated high quality homoepitaxial overgrowth and layer transfer from such porous structures [1], but longer timescales (hours) at elevated (> 550 C) temperatures typical of epitaxy of multi-junction solar cells were not considered. Therefore, porous layer stability during device growth and whether layer exfoliation occurs during the growth remains unknown. This work studies the variation in porous InP morphology with annealing temperatures (550 C to 650 C) and times (2 hr) comparable to that of double-junction solar cell fabrication. Silicon nitride layers were deposited onto the porous layers prior to annealing to prevent phosphorous depletion at elevated temperatures. Our earlier work showed that the porous layer evolution during epitaxial growth was the same as annealing at the epitaxial growth temperature [1] so here, we only studied capped porous layers. Plan-view and cross-section secondary electron microscope (SEM) images show that the SiN layer deposition does not induce any pore coalescence in the layer. Increasing the annealing temperature from 550 C to 650 C showed an overall increase in pore coalescence both in the plan-view and at the porous-substrate interface. Plan view SEM images show that the surface porosity does not change for the 550 C annealed layer, while the surface porosity decreases from 11% to 8% for the 650 C layer. The void fraction at the interface, on the other hand, increased from ~28% to ~49% as the annealing temperature increased. Combining the plan-view and cross-section images, we observe that diffusion-induced coalescence of the pores is more significant after the 650 C process (resulting in voids at the InP interface and reduction in porosity at the surface). The porous InP layers remained single crystalline (as verified by triple axis x-ray diffraction omega scans and TEM cross section images). The peaks simultaneously show high crystalline contributions (i.e. narrow peak width) and tail broadening due to diffuse scattering from inhomogeneous materials (i.e. porous layer). Moreover, changes in the tail broadening with SiN deposition and porous InP are observed. Pore coalescence during annealing/epitaxial growth can facilitate layer transfer after the device has been grown, and we show that no premature exfoliation occurs for time scales and temperatures comparable to that of double-heterojunction solar cell epitaxy. References: 1. Chen, D., Kou, X., Saremimane, S. and Goorsky, M.S. ECS Transactions, 64, pp.49-55 (2014).