2D Materials Focus Topic
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2D Materials Poster Session

2D-ThP1 Extremely Low Impact Energy SIMS Characterization of Graphene, ***Alexander Merkulov***, *F. Horreard,* CAMECA, France, *W. Strupinski,* ITME, Poland, *A. Davis*, CAMECA Instruments Inc

Characterization of graphene forms an important part of graphene research and involves measurements based on various microscopic and spectroscopic techniques. Characterization involves determination of the number of layers and the purity of sample in terms of absence or presence of defects or doping species.

A quantitative estimation of the layer thicknesses can be obtained using attenuated secondary electrons emitted from the substrate. Transmission electron microscopy (TEM) can be directly used to observe the number of layers on viewing the edges of the sample, each layers corresponding to a dark line. The information on the defectness of the graphene layer or presence of dopant species can be provided by surface sensitive technique such as XPS and SIMS (Secondary Ion Mass Spectrometry).

The extreme sensitivity of SIMS to any doping constituents in the surficial layer could provide the important information, difficult to obtain by other technique. Application of SIMS to graphene is not yet established. This work is having the goal to advance in finding an approach for graphene layers characterization.

SIMS is a destructive technique based on physical sputtering and consecutive ionization of sputtered atomic or molecular particles. All problems inherent to sputtering itself, such as recoil mixing and ion enhanced diffusion reduce the depth resolution necessary for monoatomic layers characterization. In order to avoid such effect, an Extremely Low Impact Energy (EXLIE) ion beam approach is employed in our experiments. Sputtering with different ionic species and under different angles is performed, targeting the best possible depth resolution in graphene layers.

These EXLIE SIMS measurements are among the first SIMS results obtained on such structures. SIMS as many of the characterization processes needs subsequent tests to determine the validity of the results, using different SG, FG and SLG structures. The SIMS quantification aspects will be also discussed.

2D-ThP3 Synthesis and Characterization of Large-Area and Highly Crystalline Molybdenum Disulfide Atomic Layers by Chemical Vapor Deposition, ***Yooseok Kim***, *S.-H. Park, J.S. Kim, Y.H. Ko,* Sungkyunkwan University, Republic of Korea, *C. Jeon,* Korea Basic Science Institute, Republic of Korea, *C.-Y. Park*, Sungkyunkwan University, Republic of Korea

The Isolation of few-layered transition metal dichalcogenides has mainly been performed by mechanical and chemical exfoliation with very low yields. In particular, the two-dimensional layer of molybdenum disulfide (MoS_2) has recently attracted much interest due to its direct-gap property and potential application in optoelectronics and energy harvesting. However, the synthetic approach to obtain high-quality and large-area MoS_2 atomic thin layers is still rare. In this account, a controlled thermal reduction sulfurization method is used to synthesize large-MoO_x thin films are first deposited on Si/SiO_2 substrates, which are then sulfurized (under vacuum) at high temperatures. Samples with different thicknesses have been analyzed by Raman spectroscopy and TEM, and their photoluminescence properties have been evaluated. We demonstrated the presence of single-, bi-, and few-layered MoS_2 on as-grown samples. It is well known that the electronic structure of these materials is very sensitive to the number of layer, ranging from indirect band gap semiconductor in the bulk phase to direct band gap semiconductor in mono-layers. This synthetic approach is simple, scalable, and applicable to other transition metal dichalcogenides. The transferability of MoS_2 films onto other arbitrary substrates like SiO_2/Si makes our MoS_2 a perfect candidate for engineering a variety of applications in nanoelectronics and optoelectronics. Furthermore, this thermal reduction-sulfurization method of synthesizing large WS_2 could now be implemented for the synthesis of other TMDs such as WSe_2, $MOSe_2$, NbS_2, NbS_2, etc.

2D-ThP6 XPS Depth Profiling: A Viable Alternative to Secondary Ion Mass Spectrometry, ***Michael Williams***, Clark Atlanta University, *B.R. Strohmeier*, Thermo Fisher Scientific

Secondary ion mass spectrometry (SIMS) is a workhorse for the depth profile characterization of epitaxial materials in the optoelectronics industry. Most notable is its parts-per-billion sensitivity and nm depth resolution for the III- V semiconductors. XPS depth profiling was used to study the effect of substrate temperature on the composition and growth rate of InGaAs/InP multiple layers grown by chemical beam epitaxy. The results are in excellent agreement with published results from SIMS analysis. We show that XPS with its characteristic sensitivity to the environment of the constituent elements in conjunction with argon ion sputtering yields depth profile information on layered systems that exceeds the utility of SIMS.

2D-ThP7 Investigation of Luminescent Properties of $Ca_5(PO_4)_3OH:Gd^{3+},Pr^{3+}$ Phosphor for Application in Displays, Phototherapy Lamps and Thermoluminescence Dosimetry, ***Puseletso Mokoena***, University of the Free State, South Africa, *L. Chithambo,* Rhodes University, South Africa, *H.C. Swart, O.M. Ntwaeaborwa*, University of the Free State, South Africa

Luminescent properties of calcium phosphate phosphors are being investigated today for many applications in different types of light emitting devices. We have investigated the photoluminescent (PL), cathodoluminescent (CL) and thermoluminescent (TL) properties of hydroxyapatite or $Ca_5(PO_4)_3OH:Gd^{3+},Pr^{3+}$ phosphor for application in phototherapy lamps, information displays and TL dosimetry, respectively.. This phosphor was prepared by co-precipitation method and the concentrations of Gd^{3+} and Pr^{3+} in the $Ca_5(PO_4)_3OH$ host were varied. The PL data were recorded in air under excitation by a monochromotaized xenon lamp, the CL was measured in vacuum with a Gatan MonoCL4 attached to Jeol JSM-7800F field emission scanning microscope and the TL glow curves were recorded using a Riso TL/OSL reader (model TL/OSL-DA-20) system. In addition, the structure, particle morphology, and chemical states and composition of the phosphor were analyzed by x-ray diffraction, scanning electron microscopy and x-ray photoelectron spectroscopy respectively. The phosphor exhibited a narrowband ultraviolet B (UVB) emission located at 313 nm when excited with the xenon lamp or high energy electrons. This emission was attributed to the $^6P_{7/2} \rightarrow {}^8S_{7/2}$ transition of Gd^{3+} and was shown to improve considerably by incorporation of Pr^{3+} suggesting that there was energy transfer from Pr^{3+} to Gd^{3+}. The TL glow curves were measured in order to investigate the nature of the electron trapping centers and to determine the related activation energy. A single prominent peak was observed at 347 K at a constant heating rate of 5 $K.s^{-1}$. The TL kinetic parameter (activation energy) was deduced by the initial rise method, peak shape method and variable heating rates method.

2D-ThP8 Influence of the Deposition Time in Optical and Electric Characteristics of Ge Nanoparticles Grown in SiO_2 by LPCVD Technique, ***Melissa Mederos Vidal***, *S.N. Mestanza Muñoz,* Federal University of ABC, Brazil, *I. Doi, J.A. Diniz*, University of Campina, Brazil

Germanium nanoparticles (Ge-nps) have potential applications for electronic flash memories and light emitters in visible and near infrared wavelengths, with the main advantage of being compatible with actual device technology. It is know that, in floating gate devices, semiconductors nanoparticles are the charge-storage nodes placed in the gate oxide between the gate and de channel. Thus, as a result of the smaller bandgap, superior carries mobilities, and higher excitonic Borh radius compared to Silicon (Si), quantum confinement effects are much more obvious in Ge-nps, making this compound more ideal for memory devices. On the other hand, efficient light emission from Ge-nps in SiO_2 matrix has been already demonstrated being that this can be tuned by changing the size of the nanoparticle and their existence is attributed to the presence of oxide defects, nanoparticles interface, quantum effects, Ge oxygen deficient centers, etc. So, in this context, the present wok proposes the study of the influence that the improvement of the Ge-nps quality grown in SiO_2 by LPCVD under different time of deposition, have on their photoluminescence and memory characteristics. For that, measurements as Raman Spectroscopy (RS), Atomic Force Microscopy (AFM) and photoluminescence spectroscopy (PL) were carried out. All samples were made on p-type Si (100) wafer covered by a 8 nm-SiO_2-thermal-layer, using a vertical CVD reactor PMC 200 Phoenix Materials Corporation. The synthesis method was realized following a two-steps process: a first step, where took place the functionalization of SiO_2 surface by the deposition of Si nuclei from the SiH_4 pyrolysis, and a second step, where the selective growth of Ge nps over Si nuclei happens from GeH_4 pyrolysis. Fig 1 shows the Normalized PL spectra for different Ge-nps size where a shift in the PL

peak position towards longer wavelengths is observed with the increase of nanoparticle-size and, a raise in the intensity of the peak can be note with the enhance of the density of nanoparticle. For the memory characterization, circular MOS capacitors with 200 μm of diameter were fabricated containing these Ge-nps. Fig 2 shows the schematic of the MOS device (a) and the C-V curve comparison between a standard MOS capacitor and one containing the Ge NPs (b). According to this Fig., can be assumed that the major contribution to the memory property of the device comes from the nanoparticles in the gate dielectric since, for the capacitor without nanoparticles hardly hysteresis is observed.

2D-ThP9 Enhanced Electrical Conductivity of Transparent Carbon Nanotube Sheet by Acid Treatment, *J. Kim, **JinHong Kim***, University of Texas at Dallas

Enhanced electrical conductivity of transparent carbon nanotube sheet by acid treatment

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Considerable efforts were dedicated to fabricate flexible transparent conductive films (TCFs) with high transmittance and low resistance for utilizing in various applications. To date, the most commonly used material for TCFs is indium tin oxide (ITO) due to its high transparency and low electrical resistance. However, there are several disadvantages with using ITO films in future applications, such as the brittleness and problems with polymer substrates. Recently, researches focused on developments in flexible TCFs, either through optimized structural configuration or exploring new materials to replace ITO films.

Carbon nanotubes (CNTs) have received increasing attentions as ITO replacement due to their excellent mechanical, electrical, thermal properties. Our previous work produced transparent, conductive CNT sheets by using a simple spinning method [1-2]. These CNT sheets had sheet resistances of 0.75-1 kΩ/sq and transmittances of ~85-90 %. However, there was a trade-off effect between sheet resistance and transmittance of TCFs during transferring process of CNTs. An increasing number of CNT layers in the TCFs can decrease the sheet resistance as well as the transmittance, simultaneously. Therefore, key challenge is how to realize the highly conductive CNT sheet without a degrading of transmittance.

Simple acid treatment was conducted to improve the electrical conductivity of the CNT sheets. The transferring CNT sheets on glass substrates were immersed in 60 % nitric acid for 1 hour. After the acid treatment, highly conductive CNT sheets were obtained with slightly increased transmittance. The acid treatment leads further inter-connection between the individual CNTs to form continuous electrical pathway, result in high conductivity of the CNT sheet. These results lead us to believe that the CNT sheets with low sheet resistance (450 Ω/sq) and high optical transmittance (90%) can be potential candidate for flexible TCF applications.

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2D-ThP11 CVD Processes for the Growth of Single Layer Transition Metal Dichalcogenides and Alloys, ***Ariana Nguyen**, D. Barroso, E. Preciado, V. Klee, S. Bobek, C. Lee, S. Naghibi, I. Lu, G. Von Son Palacio, T. Empante, K. Brown, K. Yang, A. Nguyen, P. Rigas, W. Coley, L. Bartels*, University of California - Riverside

Transition metal dichalcogenides (TMD) present an exciting material system that provides tunable and direct –bandgap semiconducting properties at the single-layer limit. While monolayer TMD materials can be fabricated through exfoliation, we demonstrate single layer films and islands of MoS_2, $MoSe_2$, WS_2, etc. as well as their alloys that are grown in a CVD-like processes on SiO_2 and similar materials at process temperatures of ≤700°C. The resultant films can extend in a continuous fashion across cm-scale substrates and are composed of micron-scale rotational domains. By means of alloying, their band gaps can be tuned in a continuous fashion between 1.9 and 1.6 eV. We present how the use of organic chalcogen precursors allows more versatile alloying and homogeneous growth over extended areas. We also explore variations in the growth mode as a function of process pressure.

2D-ThP15 Studying Graphene & Other 2D Materials With A Multiprobe Cryogenic System That Provides For Simultaneous Raman & Other Optical Modalities With A Wide Variety of Functional SPM Probes, *J. Ernstoff,* Nanonics Imaging Ltd., Israel, ***Aaron Lewis***, Hebrew University of Jerusalem, Israel, *O. Zinoviev, A. Komissar, E. Maayan*, Nanonics Imaging Ltd., Israel

This presentation will address the revolution that is occurring in 2D materials such as Graphene, MoS_2, $WeSe_2$, etc., and the variety of measurement modalities that are needed to fully understand these materials at cryogenic temperatures.

It is a challenge to study such materials at temperatures down to 10^oK when one considers the wide variety of physical phenomena that have to be applied to get a full picture of the functionality of the material under study. This involves questions of structure, nanometric photoconductivity, electrical properties, thermal properties, near-field optical in the apertured and scattering modes, Kelvin probe, and of course Raman. All of these phenomena are common not only to 2D materials but also to carbon nanotubes.

Today's scientific challenges demand a system where one can image these phenomena and correlate such images with the nanometric structure of the material under study. This requires a multiprobe scanned probe microscopy system working at such extreme temperatures, which allows for multiple SPM on-line while maintaining complete optical accessibility. More specifically, the probes which can investigate near-field photoconductivity and Kelvin probe have to be capable of being on-line at the same time and also come into contact with one another to obtain overlapping images of nanometric spaces while still allowing for reflection Raman. This is necessary as many of these systems are incorporated into opaque devices. Such a system will be presented in this presentation with results on graphene.

2D-ThP17 Development of Low-k Dielectric for Graphene device, ***YoungGon Lee**, L. Cheng,* University of Texas at Dallas, *Y. Kim,* Gwangju Institute of Science and Technology, *G. Mordi,* Samsung, *HH. Hwang, A. Lucero,* University of Texas at Dallas, *BH. Lee,* Gwangju Institute of Science and Technology, *J. Kim*, University of Texas at Dallas

Graphene bilayer pseudo-spin field effect transistor (BiSFET) has been suggested as one of the most promising nanoelectronics since it has a lot of advantages such as low power operation and good scalability.[1] For graphene based 2D devices like BiSFET, it is preferable to have an extremely thin insulator layer with a low-k dielectric constant conformally deposited on the graphene surface. In this work, the transport behavior of non 2D crystalline low-k dielectrics, 3,4,9,10-parylene tetracarboxylic dianhydride (PTCDA), has been investigated to apply the graphene based device as an interlayer tunnel barrier for BiSFET. PTCDA thin films were evaporated on highly ordered pyrolytic graphite (HOPG) and Si surfaces using the molecular beam deposition. Then, Ru/Al was deposited using E-beam evaporator for electrical measurement.

PTCDA devices grown on Si substrate exhibit a rectifying behavior because Schottky can be formed at interface between PTCDA layer and Si substrate. The dielectric constants around ~1.6 - 2.2 were extracted from capacitance at built-in potential. These results are consistent with previous papers about organic-inorganic Schottky diode.[2] However, as the PTCDA film thickness is scaled down from 20 to 5 nm, the reverse currents increase up to six orders of magnitude possibly because of the tunneling current. In order to explore the tunneling behavior of PTCDA layer on the graphene, the current behaviors of PTCDA layer on HOPG has been investigated. Similar to the current behavior of thin PTCDA layer on Si substrate, PTCDA device on HOPG exhibit tunneling behavior; the current increase linearly with the applied bias in low bias region, whereas it changes exponentially as a function of applied bias in high bias region. The tunneling current of PTCDA layer shows thickness dependence. These behaviors can be modeled by direct tunneling equation. [3] Capacitances around ~9 and ~16 pF in 3 and 1 nm PTCDA layer on HOPG, respectively, were identified using a time domain reflectometry (TDR) measurement, which are coincide with the value of PTCDA on Si substrate. In addition, there is a weak temperature dependence in current of thin PTCDA device.

In summary, non-2D crystalline low-k dielectric has been developed for the tunnel barrier of graphene based device. The thickness of PTCDA film was successfully scaled down to a few layers. It has also demonstrated that the devices fabricated with thin PTCDA films on HOPG exhibit feasibility of direct tunneling behaviors.

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2D-ThP18 Charge Exchange and Energy Loss of Slow Highly Charged Ions Passing Through Carbon Nano Membranes, ***René Heller***, *R.A. Wilhelm,* Helmholtz-Zentrum Dresden - Rossendorf, Germany, *E. Gruber, R. Ritter,* TU Wien - Vienna University of Technology, Austria, *S. Facsko,* Helmholtz-Zentrum Dresden - Rossendorf, Germany, *F. Aumayr*, TU Wien - Vienna University of Technology, Austria

The interaction of slow highly charged ions (HCI) with solid surfaces has been excessively investigated within the recent past. Numerous systematic experiments on the nano structure creation by HCI impact have been carried out and revealed in a variety of different models describing phenomena as the creation of nano hillocks, mono atomic deep pits and etch pits on different kind of (bulk) materials [1-5].

Recently, we have investigated the interaction of slow HCI with one nanometer thin carbon nano sheets. We could show that HCIs can efficiently induce the creation of nm-sized pores in these membranes [6]. However, the extremely small thickness of this kind of target offered us a second opportunity - the observation of the projectile right after the interaction process in terms of its energy loss and charge exchange.

The results of those measurements show an unexpected two-fold ion charge sate distribution after passing the membrane comprising (a) ions with very high charge states (close to the initial one) that almost lost no kinetic energy as well as (b) very low charged ions that lost a significant amount of kinetic energy. The balance of both contributions was found to depend strongly on the initial ion charge state. From these findings we draw a microscopic picture of the interaction process that is presented in the present contribution.

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2D-ThP20 An Efficient Dry-Transfer Technique with Thermal Annealing for Enabling High-Performance Multilayer MoS_2 Transistors, ***Xuqian Zheng***, *R. Yang, Z. Wang, P.X.-L. Feng*, Case Western Reserve University

We report the first dry-transferred pristine molybdenum disulfide (MoS_2) field-effect transistors (FETs) fabricated without any post-transfer lithographical and chemical processes, by using a facile, completely-dry-transfer technique with high throughput and high alignment precision. We show that the device performance can be greatly boosted by thermal annealing.

MoS_2 FETs have shown significant potential for enabling 2D electronic devices [1], by demonstrating increasingly competitive performance including high mobility, contact quality, and excellent On/Off ratios. All the MoS_2 FETs reported to date, however, are fabricated using electron-beam- or photo-lithography on top of MoS_2 flakes, and/or polymer-assisted transfer of MoS_2 sheets followed by dissolving the polymer [2], both of which involve multiple wet processing steps. Such processes may contaminate or even degrade the MoS_2 surface, and adversely affect device performance[3].

Here, we demonstrate multilayer MoS_2 FETs fabricated by using a completely-dry transfer method, which not only obviates the undesirable wet chemistry steps, but also has high device yield and more scalable device geometry. Using the technique, we fabricate the electrodes at wafer scale, aligning each flake to the electrodes during the transfer, which significantly improves the efficiency and yield, achieving nearly 100% success rate in obtaining pristine MoS_2 FETs. This dry-transfer process is readily applicable to substrates with much thinner high-k dielectric layers to attain low-threshold-voltage, low-power operations. Also, the performance of as-transferred devices can be further improved through vacuum annealing treatments. While experiments suggest that annealing may lead to dissolving of graphene into metal and thus improve contact [4], annealing effect on MoS_2 devices remains to be systematically explored. We find that the devices' performance typically exhibit noticeable improvement after initial annealing, and further enhancement can often be achieved via additional annealing. With annealing treatments at increasing temperatures, reliable reduction in device resistance is observed, together with consistent increase in mobility up to μ=76cm^2/(V·s), improvement in On/Off ratio exceeding 10^7, and enhancement in transconductance. Furthermore, while sometimes annealing can even convert non-Ohmic contacts into Ohmic, occasionally such conversion may not be completed, but still clear improvement can be observed.

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