## Nanomaterials
## Room Naupaka Salon 1-3 - Session NM-WeP
## Nanomaterials Poster Session

**NM-WeP-1 Array of Freestanding Graphene Variable Capacitors on 100 mm Silicon Wafers for Vibration-Based Energy Harvesting Applications**, ***Paul Thibado***, *F. Harerimana, J. Mangum,* University of Arkansas

Highly flexible, electrically conductive freestanding graphene membranes hold great promise for vibration-based applications. This study focuses on their integration into mainstream semiconductor manufacturing methods. We designed a two-mask lithography process that creates an array of freestanding graphene-based variable capacitors on 100 mm silicon wafers. The first mask forms long trenches terminated by square wells featuring cone-shaped tips at their centers. The second mask fabricates metal traces from each tip to its contact pad along the trench and a second contact pad opposite the square well. A graphene membrane is then suspended over the square well to form a variable capacitor. The same capacitor structures were also built on 5 mm by 5 mm bare dies containing an integrated circuit underneath. We used atomic force microscopy, optical microscopy, and capacitance measurements in time to characterize the samples.

**NM-WeP-2 On the Theory of the Energetic Spectrum of Lateral Superlattices (lsl) on Vicinal Planes: The Role of Crystal Potential**, ***Victor Petrov,*** Institute of Radio Engineering and Electronics Russian Academy of Sciences, Russian Federation

As is known, the existence of superlattice effects in quantum wells (QWs) on vicinal planes predicted [1] and discoveredindependently in 1977 [2] initiated with the appearance inthese systems of a new crystallographictranslationperiod in the plane of quantum wells $A >> a$ ( $a$ - lattice constant). The emergence in these LSL of the periodic system of atomic steps allows to explain the appearance of minigaps (MG) in the energetic spectrum of particles in QWs by the scattering of electrons on such steps. At the same time it is evident that the contribution to the MG formation should also be made by all crystallographic planes in the area oflocalization of the particle wave function.

This paper theoretically shows that the consideration of only crystal potential and of the potential locating the particle in LSL on vicinal planes results in the appearance ofMG even without taking into account of the step structure of the QW boundaries. A method has been developed that makes it possible to calculate the energetic spectrum of these systems for the arbitrary localizing potential by leaving the effective mass approximation in single-valleysemiconductors of the GaAs type.

For the cases of the rectangular QW and inversion layer analytical expressions have been obtained for MG magnitudes which depend on the parameters of the crystal and localizing potentials as well as on angles that define the orientation of the QW planes in the crystal. It has been shown that for LSL of the GaAs type the magnitudes of MGs approximate several meV.

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**NM-WeP-3 Fabrication and Physicochemical Analyses of Core-Shell $Fe_3O_4$–$TiO_2$ Particles Applicable to Plasmid DNA Purification**, ***Gye Seok An,*** *J. Kim,* Kyonggi University, Republic of Korea*; J. Shin,* Hanyang University, Republic of Korea

Magnetite ($Fe_3O_4$) and titanium dioxide ($TiO_2$) composites with core-shell structures have been applied in various applications owing to the advantages afforded by their combined characteristics. In this study, $TiO_2$ was adsorbed onto $Fe_3O_4$ by an aqueous process under reflux conditions using titanium(IV) isopropoxide as the $TiO_2$ precursor. In order to increase the adsorption efficiency of $TiO_2$ particles, the surface of $Fe_3O_4$ was treated using a reagent having a hydroxyl group, a carboxyl group, and a citric acid bond. The functional group formed on the $Fe_3O_4$ surface was expected to act as a site where $TiO_2$ particles were adsorbed through electrostatic interaction. After the $Fe_3O_4$-$TiO_2$ fabrication step, the analyses identified functional groups most suitable for $TiO_2$ adsorption. In addition, various physicochemical analyses analyzed the characteristics of $Fe_3O_4$-$TiO_2$ particles prepared using the particles with the optimal functional group. The surface functional groups and $TiO_2$ particles on $Fe_3O_4$ were observed by Fourier transform infrared spectroscopy and adsorbed $TiO_2$ particles were observed by electron microscopy and elemental composition analysis. Additionally, agarose gel electrophoresis tests confirmed the suitability of the $Fe_3O_4$–$TiO_2$ particles for plasmid DNA purification.

**NM-WeP-4 Synergistic Effects of Carbon Nanotube and Modified Reduced Graphene Oxide Covalently Bonded Hybrid and 3d-Foam on Electromagnetic Interference Shielding Properties of Polymer Composites**, ***Keun-Byoung Yoon,*** *S. Lee, J. Kang, D. Lee,* Kyungpook National University, Republic of Korea

Exploring light-weight electromagnetic interference (EMI) shielding material with high EMI shielding effectiveness (SE) is of great significance to alleviate the growing EMI pollution problem, prevent electronic instruments from the EMI, and protect human health. Hence, several methods are being explored to efficiently restrain EM pollution. Among these studies, carbon nanotubes (CNT) and graphene nanoplates are of particular favor on account of their unique structures and remarkable conductivities.

In the frame of this work, hybrid reduced graphene oxide (rGO) and multi-walled carbon nanotube (MWCNT) nanofiller were designed and covalently bonded through an amide bond. A hybrid nanofiller was prepared through the reaction of modified GO with ethylenediamine and oxidized MWCNT and reduced to hydrogen iodide. Another design is 3D-foam of modified GO and oxidized MWCNT, which is mixed, and 3D-foam is manufactured using various surfactants and used as a nanofiller of the epoxy and polydimethylsiloxane (PDMS) matrix.

The chemical and electrical properties of the hybrid and 3D-foam nanofillers are characterized to establish the correlation between the material characteristics and the EMI shielding performance of the nanocomposites. The mechanical and electrical properties and EMI shielding effectiveness of nanocomposites as functions of hybrid and 3D-foam nanofillers types and contents were investigated in detail.

The addition of rGO significantly increases the electrical conductivity, because CNTs can fill the gaps between rGOsheets [https://www.sciencedirect.com/topics/engineering/graphene-sheet], and bridge the neighbor graphene sheets to form a preferable conductive network. In a low areal density 3D-foamed MWCNT/rGO aerogel, vein-structured MWCNT expands the conductive network of mesophyll-structured rGO, which promotes reflection and absorption of electromagnetic waves inside the materials, resulting in excellent EMI shielding effectiveness of 65dB in C-band and absorption-dominate shielding mechanism.

This study not only put forward a facile and effective approach to fabricating epoxy nanocomposites with excellent electrical conductivity and EMI shielding effectiveness but also provided a framework to study the interfacial interaction in rGO/MWCNT hybrid and 3D-foam nanofillers.

**NM-WeP-5 Synthesis of Vertically Aligned Carbon Nanotubes Using Carbon Monoxide as a Carbon Source**, ***Kosuke Homma,*** *S. Mori, M. Endo,* Tokyo Institute of Technology, Japan*; H. Nakamura,* Tokyo Institute of Technology / Yaskawa Electric Corporation, Japan*; S. Tanaka,* Yaskawa Electric Corporation, Japan

Recently, vertically aligned carbon nanotubes (VACNT) grown vertically from substrates have been attracting attention in fields such as Through Silicon Via (TSV). Although hydrocarbons such as ethylene and acetylene have been mainly used as carbon sources for the synthesis of VACNT, there have been few reports of VACNT growth using carbon monoxide as a carbon source. This study is aimed at searching for and modeling the optimum conditions for aligned growth of CNTs from carbon monoxide. As the catalyst preparation method, we use the dip-coating method, which has been reported for the aligned growth of CNTs from carbon monoxide. The sputtering method, which has been used in many reports on the aligned growth of CNTs from hydrocarbons, was also investigated.

In the dip coating method, cobalt and molybdenum were used as catalysts. Cobalt acetate was used as the source of cobalt and molybdenum acetate as the source of molybdenum, and ethanol was used as the solvent. The optimum conditions for dip coating were investigated using the lifting speed of the dip-coating and the concentration of the solution as parameters. Experiments were conducted in the range of 0.03~0.9 cm/s as the lifting speed of the dip-coating. The concentrations of cobalt and molybdenum in the solution were 0.01~1.2 wt%. Quartz substrates were dipped in a mixed solution of cobalt and molybdenum and pulled up to coat the surface with cobalt and molybdenum. Subsequently, calcination

was performed at 400°C for 5 minutes in an atmosphere. The substrate after calcination was inserted into a quartz tube reactor, and after being evacuated with a vacuum pump, a mixture of Ar and H2 flowed into the reactor for reduction treatment at 700°C for 10 minutes under atmospheric pressure. After that, the feed gas was switched to CO and synthesis was performed at 700°C for 60 minutes under atmospheric pressure. The surface and cross-section of the substrate after synthesis was observed by SEM. The crystallinity of the CNTs was evaluated using Raman spectroscopy. The results showed that CNTs grew randomly on the surface of the substrate in most conditions; the Raman spectroscopy analysis indicated that single-walled CNTs were synthesized since the strong RBM peak was observed. VACNT was observed when the lifting speed was 0.9 cm/s and the concentrations of cobalt and molybdenum were 0.2 wt%. Based on the results, the conditions necessary for aligned growth and the model were discussed. We also tried to specify the conditions for aligned growth of CNTs using the sputtering method and its optimum condition and growth model are discussed.

**NM-WeP-6 Electrical Characteristics of Multi-Layer Germanium Telluride Switching Device**, ***Chae Ho Lim***, *J. Park, S. Park, H. Kim,* Sungkyunkwan University (SKKU), Republic of Korea

**Abstract**

Various ovonic threshold switching (OTS) materials with unique insulator-metal transition (IMT) characteristics are being actively studied for applications in phase-change memories [1].Germanium telluride is one of the most actively studied materials and some variants, including germanium-antimony-telluride, are already in commercial use [2]. To improve the switching characteristics of germanium telluride, many approaches, such as stoichiometric control, doping, and process optimization, have been proposed [3,4].

In this presentation, we propose a multi-layer $GeTe_6$/GeTe structure to increase the on/off current ratio of OTS devices with a single $GeTe_6$ layer. The $GeTe_6$ layers with distinctive IMT characteristics were deposited by adjusting the power ratio during co-sputtering of GeTe and Te targets, and the GeTe layers were deposited in situ by sputtering the GeTe target. For fabrication of the switching device with a metal-insulator-metal structure, tungsten was used for both top and bottom electrodes having a crossbar shape. The on/off ratio of the multi-layer structure was increased compared to that of the single-layer structure ($GeTe_6$). Additionally, the threshold voltage was increased, and cycle stability was improved. The detailed origins for the improved characteristics will be discussed based on the experiments with various $GeTe_6$/GeTe stack numbers.

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**NM-WeP-7 Vertically Enhanced Ferroelectric α-$In_2Se_3$/GaN Heterostructure for Steep Switching High Electron Mobility Transistors**, *M. Yeom, J. Yang,* ***Geonwook Yoo***, Soongsil University, Republic of Korea

A highly crystalline two-dimensional (2D) ferroelectric material, $\alpha$-$In_2Se_3$ has been extensively studied for neuromorphic, ferroelectric tunnel junction devices, and phototransistors [1-3] because of its unique material characteristic, a ferroelectric semiconductor. Here, we demonstrate, for the first time, a ferroelectric $\alpha$-$In_2Se_3$/GaN HEMT van der waals heterostructure, in which the switchable ferroelectric polarization of $\alpha$-$In_2Se_3$ can induce steep subthreshold switching (SS) and large memory window. In-plane polarization within the $\alpha$-$In_2Se_3$ layer was successfully suppressed via self-aligned-gate etching process as analyzed by micro-Raman spectroscopy. On the other hand, out-of-plane polarization is strongly coupled to two-dimensional electron gas. Therefore, a record low *SS* of ~12 mV/dec with high on/off ratio of ~ $10^{10}$ was obtained. The transfer curve exhibits a counter-clockwise hysteretic behavior with a memory window of ~ 0.9 V, induced by the ferroelectric switching above the coercive field of $\alpha$-$In_2Se_3$.The results show that ferroelectric polarization and semiconductor characteristic of $\alpha$-$In_2Se_3$ is a promising for ferroelectric/III-V heterostructures, enabling emerging III-V based reconfigurable and neuromorphic applications.

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**NM-WeP-8 Electrochemical Powered Nano-Actuator from Carbon Nanoscroll**, ***Chae-Lin Park***, HYU-KITECH Joint Department, Republic of Korea; *K. Kim, S. Kim,* KITECH, Republic of Korea

Recently, nanobots are receiving great attention due to their high potential for use in various fields such as intelligent robots, biomedical devices, and drug delivery. Nanobots are realized through the use of nanomaterials and assembly of nanomaterials, and research on driving nanobots using electromagnetic fields, electrochemistry, and specificity of enzymes is in progress. Among them, studies on actuators of carbon nanotubes and graphene based structures driven by electrochemical power have been reported. Electrochemical-based actuators have the advantage of being operated with a low voltage and can be used in places made of electrolyte, such as the human body. However, a useful electrochemical power-based nanoactuator is driven by ion entry and exit, so it is difficult to drive it with a single nanomaterial rather than structures. The development of electrochemical-powered single nanomaterial-based nanoactuators remains a challenge. In this work, we implemented an electrochemical-powered actuator by using graphene as a carbon nanoscoll (CNS) structure with a diameter of 50 nm. Unlike carbon nanotubes and graphene, CNS has a scroll structure and is a material that can be driven independently based on electrochemical power through the input and output of ions between layers. We measured the actuation performance of CNS. When the voltage was applied to CNS on electrolytes, CNS charged and it let the apparent diameter of the scroll increase significantly. Changes of the CNS diameter were measured in real-time using atomic force microscope equipment. It was confirmed that the type of electrolyte and the magnitude of the applied voltage play an important role in controlling the performance of the CNS. Additionally, we have structured the CNS and confirmed that it operates electrochemically. It is expected to see the possibility of using it as a nanobot.

**NM-WeP-9 Nanopattern Transferred Oxide and UV Curable Polymer Hybrid Films for Liquid Crystal Systems**, ***Da-Bin Yang***, *D. Seo,* Yonsei University, Korea

In the present study, nanopatterns were transferred using the UV-NIL method; in this method, the patterns are cured with UV radiation to produce the LC alignment layers. For high-quality LC alignment layers, transparent conducting oxides (TCOs) with excellent transmittances are mixed with a UV-cured polymer to prepare a hybrid solution.[1] In this study, we assessed whether high-quality nanopattern transitions can be obtained while reducing the steps of the NIL process by mixing these inorganic materials and polymers. The hybrid solution was coated on a glass substrate and cured by UV irradiation to prepare the nanopattern, and the nanopattern and LC alignment characteristics were analyzed by varying the UV curing time. The film surface was analyzed through X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM) analyses. The LC alignment characteristics were confirmed via polarized optical microscopy (POM) and pretilt angle measurements.

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**NM-WeP-10 Advanced Nanostructured Architectures via Nanoimprint Lithography on Hybrid Sol-Gel of SnGaO Thin Films**, ***Jin Young Oh***, *D. Seo,* Yonsei University, Korea

Line pattern replication process through nanoimprint lithography (NIL) method has been used in numerous of research fields. NIL technology is not yet utilized for displays industry, and we propose an alignment layer of

the sol-gel process using NIL. One-dimensionally nanopatterned by polydimethylsiloxane sheets cause surface changes in hybrid SnGaO thin films mixed in a 3:7 ratio, which aligns the liquid crystals (LCs) uniformly in the line pattern direction. These surface changes are confirmed through atomic force microscopy data analysis, and changes in surface shapes for different the curing temperatures in the furnace are analyzed. X-ray photoelectron spectroscopy (XPS) shows that the chemical composition of the thin films changes according to curing temperatures, and the intensities of SnO and GaO increase exponentially at 200°C compared to those at 50 °C. Through this, the van der Waals force increases between surface molecules, in the anisotropic direction to help align the LCs. Furthermore, we performed polarized optical microscopy and pre-tilt angle analysis confirm that the LCs are energized uniformly. Finally, the performance of an actual display device transmittance and electro-optical properties; the transmittance of SnGaO is 4.51p% higher than that of the currently commercialized PI-rubbing thin films, and the voltage-transmittance curve is a perfect graph. Thus, nanopatterned SnGaO thin films using NIL are expected to become the basis for next-generation displays.

Keywords: Nanoimprint lithography, Sol-gel method, Tin-gallium oxide, Atomic force microscopy, X-ray photoelectron spectroscopy

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**NM-WeP-11 First Demonstration of the Fully Euv Patterned Dram Capacitor***, **Seung Jin Kim**, J. Hong, B. Choi,* Sungkyunkwan University (SKKU), Republic of Korea

DRAM is continuously scaled down to improve productivity and low power operation. A DRAM cell consists of one transistor and one capacitor, and the pattern of the capacitor consists of storage poly (s-poly) and supporters. The s-poly is main body of capacitor, which is ultra-high aspect ratio structure with metal (Storage TiN)/dielectric/metal (Plate TiN) composition. The supporter prevents leaning or bending of the capacitor. To fabricate both s-poly and supporter, previous immersion-argon-fluorine (I-ArF) technology had been used up to 3rd generation 10 nm devices. In this process, a line-and-space simple double patterning technique (sDPT) was used to create a honeycomb array of highly integrated s-poly contacts. However, the sDPT method has significant problems such as multiple process steps and unit block s-poly not opening due to complex mask stacks and line-space asymmetry. The EUV technology simplifies mask stack and expose all s-poly cell by 1-set, which allow uniformity of contact. We believe that this work opening a feasibility of an inevitable EUV era to guarantee the extremely scaled sub-10nm patterning with high performance, high yield, and cost-effective process.

# Author Index

## Bold page numbers indicate presenter