

Tuesday Afternoon Poster Sessions

Nanometer-scale Science and Technology

Room: Hall 3 - Session NS-TuP

Nanometer-scale Science and Technology Poster Session

NS-TuP1 Capture and Characterization of Nanoparticles at Trace Levels in Semiconductor Process Gases, J. Feng, M. Raynor, D. Davia, A. Seymour, R. Torres, Matheson TriGas Inc.

Particulate contamination in process gases used in semiconductor fabrication can have harmful effects on device morphology, performance, reliability and yield. There are significant challenges in the measurement of particles in process gases, especially trace level nanoparticles <50 nm in reactive and corrosive gases. Optical particle counters and condensation nucleus counters are frequently used in inert gases to provide real time data on particle levels and size distributions. However these devices may not provide accurate size measurement or be compatible with reactive gases. Further, they don't give any information on the composition of the particles, which may be important for determining the contamination source. An alternative method is to capture the particulate contamination on sampling filters and perform post microscopic analysis. This approach has been previously used for environmental particulate sampling but has not been widely applied to reactive semiconductor gases. In this work, a sampling system with nanopore-sized (NPS) membrane filter for capturing particles from difficult-to-measure gases is described, initially tested with a nanoparticle source in nitrogen and then applied to reactive process gases such as HBr. Feasibility of capturing iron oxide nanoparticles (30-50 nm) introduced into purified nitrogen via a particle shaker inert gas was demonstrated on NPS alumina filter. Sampling with HBr required compatibility testing of the filter membrane. Results indicated that the NPS alumina filter is capable of withstanding the corrosive effects of HBr, provided the sampling system and gas are properly dried. Membranes were analyzed using various surface analysis techniques such as AFM and SEM. Before collecting samples, blanks were collected to ensure that the delivery system was clear of any contamination. Typical results of contaminant particles from reactive gases such as HBr are presented. These data provide information on the particle content and form in the source container and delivery lines and efficiency of filters in removing particles from the flowing gas. SEM images of particles captured from a filtered gas sources via a delivery system show the presence of clusters of small particles, indicating that the particles may have an affinity for one another in the gas phase. SEM-EDS provides compositional data of the particles detected. The data show that in the case of HBr, the particles are mainly mixed metal bromides. The elements detected compare well to those detected by hydrolysis metal sampling with ICP-MS. Such information can assist in locating the source of particles and eliminating such sources

NS-TuP4 Large area Room-Temperature Nanoimprint using Liquid-phase HSQ Resin with PDMS Mold, Y. Kang, M. Okada, Y. Haruyama, K. Kanda, S. Matsui, University of Hyogo, Japan

Nanoimprint lithography (NIL) is a very useful technique to make nanostructure devices with low cost and high throughput. So far, we reported room-temperature NIL (RT-NIL) using hydrogen silsesquioxane (HSQ) as a resin. However, the issue of a higher imprinting pressure than those of thermal NIL and UV NIL still remain to be addressed in NIL using spin-coated HSQ as the replication material. We attribute these disadvantages to evaporation of the solvent contained into HSQ during the spin-coating.

To overcome the above problem, we reported a Nanoimprint technique using liquid-phase HSQ as a replication material alternative to HSQ resin formed by conventional spin-coating. A low imprinting pressure and HSQ residual layer with less than 10 nm thick were achieved by using liquid-phase HSQ. But the HSQ-coated substrate is required to heat up around 90 °C to evaporate the solvent contained in the HSQ resin while the pressure was held. And a large area imprinting was difficult because the organic solvent in the HSQ evaporated only through the side-gap between SiO₂/Si mold and HSQ coated Si substrate. To address these problems, we used Poly(dimethyl siloxane) (PDMS) mold instead of SiO₂/Si mold. Because PDMS is a porous gel, the organic solvent in the HSQ solution can be evaporated through PDMS mold.

The new imprint technique using liquid-phase HSQ with PDMS mold is as follows. First, the PDMS mold was fabricated by spin-coating a mixture of base resin and hardener resin (Dow Corning Co. Sylgard 184) on the SiO₂/Si master mold. Following, PDMS coated substrate was baked at 70 °C for 15 min to cure the PDMS. After curing of the PDMS, the PDMS mold was demolded from the SiO₂/Si master mold. Next, HSQ solution was

dropped onto a Si substrate. Following, the PDMS was pressed onto the Si substrate with 1MPa pressure. And then, the organic solvent in the HSQ solution was evaporated through the pores of PDMS. The imprinting temperature, pressure and time were RT, 1MPa, and 10 min, respectively. In this experiment, we used two kinds of HSQ, one is the caged HSQ (Dow Corning Co. Fox-16) and another is the ladder HSQ (Tokyo Ohka Kogyo Co. OCD T-12). Finally, the PDMS mold was removed from the Si substrate, and then HSQ patterns were successfully replicated on a 4 inch wafer in full area.

NS-TuP5 Electron Microscopy Characterization of Hexagonal Molybdenum Trioxide (MoO₃) Nano-Rods, I.B. Troitskaia, V. Atuchin, Institute of Semiconductor Physics, Russia, G.C. Franco, University of Texas at El Paso, D.A. Ferrer, University of Texas at Austin, M.A. Ramos, C.V. Ramana, University of Texas at El Paso

MoO is an interesting material for application in solid state microbatteries, electronic information displays, and optical memory and sensor devices. MoO₃ exhibits several polymorphs and, hence, the controlled growth and structure of MoO₃ are highly important. The successful efforts to synthesize metastable hexagonal phase (*h*-MoO₃) have been very limited, partly due to the complications in stabilizing the metastable-phase as compared to the thermodynamically stable *a*-MoO₃. As such, the physicochemical properties of the metastable *h*-MoO₃ phase are largely unknown, in spite of the fact that metastable structures often demonstrate new or enhanced activity when compared to thermodynamically stable phases. Here, we demonstrate a simple low-temperature chemical method to produce metastable *h*-MoO₃ nanorods and their excellent structural characteristics. Hexagonal MoO₃ samples were prepared via the precipitation of molybdenum oxide from an ammonium paramolybdate solution, by the addition of nitric acid. The structure of *h*-MoO₃ nano-rods was examined in detail using high-resolution scanning electron microscopy (HR-SEM) and high-resolution transmission electron microscopy (HR-TEM). A drop of the nanorods diluted in ethanol was added onto a carbon-coated TEM grid, and allowed to evaporate for analysis on a FEI Tecnai TF20 (200kV) equipped with a STEM unit, high-angle annular dark-field (HAADF) detector and X-Twin lenses. The SEM data reveal that the nano-rod *h*-MoO₃ crystals have the shape of straight hexagonal rods with an aspect ratio ~60. The HR-TEM results confirm the hexagonal structure of the MoO₃ nanocrystals. Computations of the observed TEM data along with x-ray diffraction pattern further confirm the stability of the nano-structure of *h*-MoO₃ rods. The results obtained are presented and discussed.

NS-TuP6 A Photochemically Initiated Chemistry for Coupling Underivatized Carbohydrates to Gold Nanoparticles, X. Wang, Portland State University, O. Ramström, KTH - Royal Institute of Technology, Sweden, M. Yan, Portland State University

Biofunctionalized metal nanoparticles provide a sensitive platform for the analysis and detection of molecular recognitions in biological system. The remarkably sensitive optoelectronic properties of metal nanoparticles make nanoparticle-based materials a powerful tool to study fundamental biorecognition processes. Here we present a new and versatile method for coupling underivatized carbohydrates to gold nanoparticles (Au NPs) via the photochemically induced reaction of perfluorophenylazide (PFPA). A colorimetric model system based on the carbohydrate-modified Au NPs was furthermore constructed for the sensitive detection of carbohydrate-protein interactions. Treating mono-, and di-mannose-modified Au NPs with Concanavalin A (Con A) lead to a distinct color change of the Au NP solution, which was directly associated with the surface plasmon resonance shift upon nanoparticle aggregation. The coupling chemistry is highly efficient and is applicable to a wide range of carbohydrate structures.

NS-TuP7 Fabrication of Quantum Dots Utilizing Multi-Coated Self-Assembled Monolayer, N.Y. Kwon, K.H. Kim, I.S. Chung, Sungkyunkwan University, Korea

We have created various nano-gaps by controlling the number of self-assembled molecular coating. The generated nano-gaps were used to yield quantum dots with a precise size and placement. First, Au electrodes with an unique shape were obtained using a conventional lithography. Then, self-assembled multilayer, composed of alternating layers of α , ω - mercaptoalkanoic acids (~2 nm) and copper (II) ions, were deposited on Au electrode patterns to form the controllable gap between adjacent Au electrodes. After reaching to nanometer-scale gap, the secondary Au was deposited again and lift-off both ZEP420A (E-beam resist) and molecular resist, thereby resulting in quantum dot with nano-gap between gold electrodes. Ellipsometry and cyclic voltammetry (CV) were used to analyze the number of self-assembled molecular layer. Also, contact angle and X-

ray photoelectron spectroscopy (XPS) were used to analyze chemical properties between gold and self-assembled multilayer. Additionally, Scanning probe microscopy (SPM) and field emission secondary electron microscopy (FE-SEM) were used for characterization on shape of nano-gap and quantum dots.

NS-TuP8 The Efficient Film Growth Method for Active Layer of Polymer Solar Cells, K.W. Kim, H.J. Kim, B.Y. Hong, Sungkyunkwan University, Korea

Polymer based organic solar cells have made rapid progress after the advent of bulk-heterojunction concept consisting of an interpenetrating network of electron donor and acceptor material. Since slow growth of active layer allows to improve the cell performance, some approaches have been already used to reduce the film growth rate such as boiling point modification using solvent mixture, slow drying or solvent annealing by reducing spin coating time which controls the solvent annealing time.

In this work, we investigate the role of spin coating frequency combined with solution concentration at fixed active layer thickness on performance of polymer solar cells based on regioregular poly(3-hexylthiophene) (RR-P3HT):[6,6]-phenyl-C₆₁-butyric acid methyl ester(PCBM) system. The thickness of active layer is standardized by controlling the solution viscosity with solution concentration. It is found that the spin coating frequency is associated with solvent evaporation time and highly affects the degree of interpenetration of the crystalline P3HT and the highest power conversion efficiency was obtained with the combination of the possible lowest spin coating frequency and solution concentration under AM 1.5 G spectral illumination of 100 mWcm⁻². The structural and optical properties of active layer are characterized by various analysis methods such as X-ray diffraction (XRD), ultraviolet-visible absorption spectroscopy and atomic force microscopy (AFM).

NS-TuP9 Study on Inverted Hybrid Solar Cell with ZnO Thin Film for Stability Improvement, J.W. Park, Y.S. Park, B.Y. Hong, Sungkyunkwan University, South Korea

Recently, the organic solar cell has been receiving lots of attention as a clean and safe energy source instead of the fossil fuel due to its lower manufacturing cost and environment-friendly energy conversion capability. Several research groups have claimed the organic solar cells with ~5 % conversion efficiency. However, they still have low efficiency and the unstable because organic materials are easily oxidized by humidity and UV light under the atmosphere environment.

In this work, we propose an inverted-type organic/inorganic hybrid solar cell using ITO/ZnO/P3HT:PCBM/Au (indium tin oxide/zinc oxide/poly(3-hexylthiophene) : [6,6]-phenyl C₆₁ butyric acid methyl ester/Au) structure to enhance the efficiency and the stability of the organic solar cell. ZnO thin film is used as buffer layer to prevent the interface of organic layer by UV light from the oxidation and to reduce the energy barrier for easily transferring electron between ITO electrode and the LUMO level of the organic acceptor. Also, ZnO film blocks the injection of the hole from the P3HT to ITO for no charge carrier recombination. It is observed that the power conversion efficiency is significantly dependent on the thickness of ZnO thin film, which is deposited with magnetron sputtering system. The power conversion efficiency of 2.6 % under AM 1.5 G spectral illumination of 100 mWcm⁻² is obtained when the thickness of ZnO thin film and P3HT:PCBM is optimized. In addition, Au used as back electrode to solve the problem of Al, which is susceptible to reactions with oxygen and water, and to control the work function between HOMO level of P3HT and the energy level of metal electrode. From the periodically testing result for long days, we proved that our solar cell which isn't encapsulated has a longer stability than typical organic solar cell fabricated by the same condition under ambient.

NS-TuP10 Growth of Vertical Si Nanowires Using Square Matrix Anodic Aluminum Oxide Template, J.K. Hong, K.H. Kim, J.H. Heo, I.S. Jung, Sungkyunkwan University, Korea

The vertical Si nanowires were grown on Si(100) substrate using a low-pressure chemical vapor deposition(LPCVD) system. The square pattern of AAO was obtained by combining pre-patterning Al thin film surface using focused ion beam (FIB) with anodizing process. The pore size and its period of the square matrix were approximately 50nm and 100nm, respectively. To determine the role of the indent depth on Al surface in AAO formation, FIB doses were varied from 1x10¹⁷ ions/point to 8x10¹⁷ ions/points. We found that a minimum indent depth is about 16nm. The minimum indent depth seems to be required to localize electric fields in a downward direction thereby yielding an indented pattern after AAO formation. In addition, we found that the higher voltage in anodizing process yields better uniformity in pore shapes. The Au nanoparticles as the catalyst for epitaxial growth of Si nanowires were deposited at the bottom of the AAO template on Si substrate using an electroless deposition with a mixture of a solution

containing Au ions and 1% HF. The average diameter of Au nanoparticles in each pore was 65nm.

The physical properties were analyzed using secondary electron microscope (SEM), transmission electron microscopy (TEM), and X-ray diffraction. Additionally, the detailed analysis including pore diameter and pore depth were made using scanning probe microscope (SPM).

NS-TuP12 Nanostructuring by Ion Beam: The Role of Surface Active Elements, B. Setina Batic, M. Jenko, Institute of Metals and Technology, Slovenia

Ion bombardment has recently attracted much attention as a tool for inducing self-organized patterns on various metal, semiconductor and amorphous surfaces. Depending on the conditions imposed upon the ion beam as well as on the properties of the material, different surface morphologies can form. The most common surface topography that forms under the ion beam influence is ripple-like morphology, which is prevalent in the case of amorphous materials, but in the case of semiconductors and single crystalline metal materials observations of dots, pits, mounds and pyramidal structures have also been documented.

Polycrystalline Fe-3%Si alloy was chosen as a model system for studying sputter induced topography modulations due to its properties: each grain, ranging few μm in size and of different crystalline orientation, behaves as a single-crystal surface that sputters independently of the surrounding grains. Thus, it is possible to experimentally include a large amount of grains of different crystallographic orientations in the same experimental run. Additionally, the samples were doped with a small amount of surface active elements to verify their role on the formation of self-assembled structures.

Samples of Fe-3%Si alloy were polished to achieve a smooth starting surface and subjected to Ar⁺ ion beam irradiation of different energy, angle and ion dose to obtain a complete set of experimental data on ion induced morphology changes. Results show that the surface exhibits grain-orientation dependent patterns, ranging from well-defined ripple structures to terraces, pits, or pyramidal structures. The characteristic length of these structures is in the order of a few hundred nanometres. Preliminary results show that surface active elements, such as Se or Sn, have a determining role on the formation of ripple-like patterns, causing the ripples to develop facet-like characteristics.

The samples were characterized using a multitechnique approach: Field Emission Scanning Electron Microscope (FE-SEM, Jeol JSM 6500-F) was used for the determination of different structures that formed in individual grains and to visualize a larger area of the sample, while Atomic Force Microscope (AFM, Veeco) gave detailed information on corrugation, individual ripple wavelengths, facet angles, pit depths and other morphological details.

NS-TuP13 Photo-patterning of Nitrophenyl-Terminated Self-Assembled Monolayers by using Localized Surface Plasmon, S. Uenishi, T. Ichii, K. Murase, H. Sugimura, Kyoto University, Japan

Patterning of self-assembled monolayers (SAMs) has attracted much attention owing to its potential applications to various microdevices fabrication processes. In particular, photochemical micropatterning of SAMs is of special interest, since it can be adopted into photolithography which has been the most successful microprocessing technology with high productivities. Recently, photoinduced reduction of nitrophenyl-terminated SAMs on silver surfaces has been reported [1], where nitrophenyl groups were converted to phenylamine groups by visible light irradiation. This must be prominently useful technique in the field of biotechnology and photochemistry, because some biomolecules and nanoobjects of noble metals can be adsorbed on amino-terminated surfaces. However, visible light irradiation is difficult to be applied to nanoscale patterning owing to diffraction limit. This can be overcome by using localized surface plasmon with nanoobjects of noble metals. Electromagnetic field relative to the surface plasmon is localized in a few tens of nanometer, which is independent of light wavelength. In this study, we demonstrated photoinduced reduction from nitrophenyl groups to phenylamine groups by using direct light irradiation and localized surface plasmon.

First, 4-nitrobenzenethiol (NBT) SAMs were irradiated with visible light through photomask. The SAMs were formed on gold substrates by immersing the substrate in ethanol solution of NBT (1 mM) at room temperature for 24 hours. Photochemical changes were detected as surface potential shift using Kelvin-probe force microscopy. The surface potential of the irradiated regions was positively shifted by approximately 10 mV. This potential change suggests some photochemical changes induced by the light irradiation on the SAM. Water contact angle measurement and X-ray photoelectron spectroscopy (XPS) were also applied to the SAMs which are irradiated with the light through plain glass plate in these cases. Water contact angle increased from about 45 degrees to about 50 degrees after visible light irradiation. Proof of the photoinduced reduction was not detected by the XPS measurement probably because X-ray irradiation also

promoted reduction of the nitrophenyl groups. These results suggest some changes induced on the surfaces by the light irradiation.

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NS-TuP14 Enhanced Thermal Stability and Nanoparticle-mediated Surface Patterning: Pt/TiO₂(110), *F. Behafarid, A. Naitabdi, B. Roldan Cuenya*, University of Central Florida

Size-selected Pt nanoparticles were synthesized by inverse micelle encapsulation on PS-PVP diblock copolymers. The thermal stability of these Pt nanoparticles deposited on TiO₂(110) has been investigated by scanning tunneling microscopy. Our micelle-based nanoparticles were found to be very stable against agglomeration and they preserved their initial size (~3.2 nm) and hexagonal arrangement up to an annealing temperature of at least 1000°C [1]. Furthermore, the original spherical shape of these particles was found to change upon annealing above 1000°C, leading to the formation of 3D faceted particles. Atomic desorption and cluster coarsening was observed at 1060°C. Our study also revealed that strong nanoparticle/support interactions are present in this system, resulting in the formation of TiO₂ nanostripes at high temperature with widths and a 2D spatial arrangement pre-determined by the presence and distribution of the Pt nanoparticles on the substrate.

Further insight into the mechanisms underlying the enhanced thermal stability of our micellar nanoparticles was obtained via a comparative study with UHV-evaporated Pt nanoparticles supported on pristine and polymer-coated TiO₂(110) surfaces.

NS-TuP15 STM Measurements at mK Temperatures for Higher Energy Resolution, *Y.J. Song, A.F. Otte*, NIST and University of Maryland, College Park, *Y. Kuk*, NIST and Seoul National University, Korea, *J.A. Stroscio*, National Institute of Standards and Technology

Since the invention of scanning tunneling microscopy (STM) in early 1980's, STM and STM-based measurement techniques have been used in a variety of fields for their atomic resolution. With the advent of cryogenic microscopes operating around 4K, the high resolution spectroscopic capabilities of the STM have had significant impact. In this poster, we describe our efforts to make STM measurements at even lower temperatures approaching 10 mK to gain further energy resolution in spectroscopic measurements. To realize this enhanced energy resolution, we constructed an ultra high vacuum (UHV) Dilution Refrigerator (DR) based STM system. The DR was constructed very rigidly in order to have a high resonance frequency. Furthermore, it has two independent modes of He3-He4 mixture gas condensation: a traditional 1K pot condenser, and a Joule-Thomson condenser for possible lower noise operation. For STM measurements, we custom-designed and built an STM module suitable for operation at mK temperatures. The whole STM module can be transferred from the upper, room-temperature chamber where the sample and tip can be easily exchanged. The sample holder has five isolated electrical contacts which are also used for kinematic mounting of the sample. This allows four-probe electrical measurements to be performed simultaneously with STM measurements. A cryogenic current amplifier has been constructed and is mounted in the DR for low noise tunneling measurements. We describe the current progress and performance of this new system.

NS-TuP16 A Probe Characterizer for Atomic Force Microscope Fabricated from Si/SiO₂ Multilayers, *H. Itoh*, AIST, Japan

A method to fabricate accurate nanostructures was developed using superlattices and selective etching technique [1]. A probe shape characterizer for atomic force microscope (AFM) was developed for reliable measurement of AFM image and ISO standardization [2]. Comb-shape lines and spaces (10 nm to 50 nm) were fabricated using Si/SiO₂ superlattice. Line width and space distances were determined from the cross-sectional image of transmission electron microscope. Edge radii of these structures were less than 1.5 nm, and line width and line distance were fabricated in the accuracy less than 1.5 nm. The comb-shape lines and spaces were used to determine the aspect ratios of the AFM probe shape [1]. Aspect ratios of cone-like probe from tip apex to the bottom can be determined from apparent depth in the AFM image obtained from 8 kinds of different space widths. In case of the CNT probe, diameter of cylinder-like probe can be estimated from trajectory of the AFM probe on space structure. Advantage of characterizing probe shape using comb-shape pattern is that uncertainty can be defined from the shape of the reference material. Thus, reconstructed AFM image is reliable and applicable to characterize the precise morphology of nano-materials [3] and nano-structures.

References

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NS-TuP17 Growth and Optical Properties of ZnO Fern-like Nanoleaves, *H. Ji*, Jilin University, P.R. China, *H. Gao*, Harbin Normal University, P.R. China, *Y. Zhao*, Northeast Forestry University, P.R. China
Zinc oxide is a very widely studied nanomaterial due to its potential applications in nanoscale optoelectronic and photovoltaic devices. A variety of ZnO quasi-one-dimensional morphologies have been synthesized by different methods. Often applications of the ZnO nanostructures are closed related to their morphology providing motivation to study the relationship between the morphology and growth technique.

Using a mixture of ZnO, Eu₂O₃ and C powder as source material, ZnO with a novel morphology referred to as nanoleaves was fabricated using thermal evaporation. The structures and morphologies of the as-synthesized samples were characterized by x-ray diffraction, field-emission scanning electron microscopy, high-resolution transmission electron microscopy and energy dispersive x-ray spectroscopy. The ZnO nanoleaves are wurtzite single crystals that have an appearance of fern-like leaves with symmetrical paired teeth on opposite sides. For some of the nanoleaves, there are long needles that grow from the end of some of the teeth and forming parallel arrays. The growth mechanism, kinetically driven process and photoluminescence of the ZnO nanoleaves will be discussed.

NS-TuP18 Characteristics of Al-doped ZnO Film and its Application to the Electrode for Inverted Organic Solar Cell, *D.H. Lee, S.U. Lee, B.Y. Hong*, Sungkyunkwan University, Korea

High-quality Al-doped zinc oxide (ZnO:Al; AZO) films are very attractive materials due to relatively low cost, non toxicity and stability at high temperature, and also they are being extensively investigated to apply to various fields such as solar cells, flat panel displays and organic light emitting diodes.

In this work, we investigated the electrical, optical and structural properties of AZO film grown on the glass by RF magnetron sputtering method with zinc oxide target doped Al₂O₃(2 wt%). AZO films were synthesized at the pressure of 1mTorr with RF power varied from 100 W to 175 W. The optimized AZO film had the transmittance above 85% at visible region and the resistivity of 1.5×10^{-3} ohm-cm at room temperature. The characteristics of AZO film were investigated by X-ray diffraction (XRD), Hall measurement system, UV-visible spectroscopy, and atomic force microscopy (AFM).

In addition, the optimized AZO film in this work was applied to a transparent electrode for an inverted organic solar cells (AZO/P3HT:PCBM/PEDOT:PSS/Au) which was compared with the organic solar cell with the standard structure using indium tin oxide (ITO) as the electrode.

NS-TuP19 Comparison of Oxidation Behaviors of Si_{1-x}Ge_x Nanowires, *S.Y. Kim, S.W. Kim, D.-H. Ko*, Yonsei University, Korea

Conventional devices came to have issues as scaling down. One of the methods to overcome the limit of scaling down is semiconductor nanowires and because of their potential application for nano-scale devices they have received considerable attention during the past years. Compared to other semiconductor nanowires, Si & Si_{1-x}Ge_x nanowires are more important as for the base-materials of future nano-scale device because of their special merit of being compatible with current silicon device fabrication processes. In addition to this, Si & Si_{1-x}Ge_x nanowires are suitable candidates for investigating characteristics associated with quantum size effects. Among the conventional Si-compatible processes, the oxidation properties are of great interests so we investigated the oxidation of Si_{1-x}Ge_x nanowires at the point of Ge behaviors during oxidation. Si_{1-x}Ge_x nanowires were grown in a LPCVD by VLS method. Source gases of SiH₄ and GeH₄ were used for growing Si_{1-x}Ge_x nanowires on Si (111) substrates. Thin gold layer was deposited as catalyst, and Ge contents of Si_{1-x}Ge_x nanowires were controlled to 15% and 30%. Grown nanowires were thermally oxidized in the vertical furnace with the various temperature and time. After oxidation, grown oxide thicknesses were measured by TEM methods and compositions of oxide and remain nanowires were analyzed by TEM and EDS methods. Comparing the oxidation characteristics of the Si_{1-x}Ge_x nanowire with those of Si nanowires and (100) Si wafer, it is concluded that Ge plays a significant role in deciding an oxidation characteristics and oxidation characteristics of Si_{1-x}Ge_x nanowires can be affected by Ge contents as well as nanowire size.

NS-TuP20 Carbon Nanotube Embedded Three Dimensional (3-D) Carbon Microelectrodes for Rechargeable Microbatteries, G.H. Kim, E. Kozarsky, H.S. Jee, K.T. Kim, J. Kim, E. Takeuchi, Y.-K. Yoon, University at Buffalo

Lithium ion rechargeable batteries power a wide range of electronic devices including cell phones, laptop computers, digital cameras, and medical devices because of the high energy density. However, the technological development of the battery has been held back by the limited range of available electrode materials. Desirable battery electrodes are to have a large surface area for high energy density and device compactness, and a fast charging/recharging property for high power demand. Recently, three dimensional (3-D) carbon electrodes have been successfully demonstrated using the polymer carbonization process with lithographically defined high aspect ratio microstructures [1]. The advantages of this approach include the accurate definition of 3-D microstructures using ultraviolet (UV) lithography and converting them into the carbon electrode by pyrolysis, resulting in chemically and mechanically stable, low cost electrodes. However, the carbon electrodes from polymer pyrolysis show relatively high electrical resistivity resulting in slow charging/discharging response. On the other hand, carbon nanotubes (CNT) are known to provide outstanding electrical, mechanical and chemical performance.

In this study, we report carbon nanotube (CNT) embedded 3-D carbon electrodes by using UV lithography on CNT embedded SU8 (photosensitive negative tone epoxy) and subsequent carbonization. Since the final electrodes consist of CNTs embedded in pyrolyzed carbon, they contain high electrical conductivity to contribute to increasing charging/discharging speed and chemical, mechanical stability in the electrolyte environment. Also, the small amount of CNTs in polymer does not interfere much with UV dose in the photolithography process, maintaining the high aspect ratio 3-D micropatterning capability.

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NS-TuP21 Silicidation Behaviors of Si_{1-x}Ge_x Nanowires for Future CMOS Device, S.W. Kim, S.Y. Kim, D.-H. Ko, Yonsei University, Korea

To overcome the scaling down issues in current semiconductor industry, scientists and engineers have been investigating the alternatives in the last few years. One of the methods is a semiconductor nanowires. They have been received remarkable attentions during the past years due to their potential application for future CMOS devices. Compared to other semiconductor nanowires, Si & Si_{1-x}Ge_x nanowires are more important as for the base-materials of future CMOS devices because of their special merits of being compatible with current silicon device fabrication processes. In addition, Si & Si_{1-x}Ge_x nanowires are suitable candidates for investigating characteristics associated with quantum size effects. For the application to the future nano-scale device process, we investigated the silicidation behavior of Si_{1-x}Ge_x nanowires. Si_{1-x}Ge_x nanowires were grown in a LPCVD by VLS method. SiH₄ and GeH₄ were used as a precursor sources for growing Si_{1-x}Ge_x nanowires on Si (111) substrates. Thin gold layer was deposited as a catalyst, and Ge contents of Si_{1-x}Ge_x nanowires were controlled to 15% and 30%. Ni layer was deposited on the as-grown nanowires by sputtering and RTP process was used for silicidation. The characteristics of Ni germanosilicide films on nanowires were investigated by using TEM and EDS methods. Also, electrical characteristics were measured by using patterned electrodes. Comparing the silicidation characteristics of Si_{1-x}Ge_x nanowires with those of Si nanowires, it is concluded that Ge plays a significant role to determine silicidation characteristics.

NS-TuP22 Electrospun ZnO Nanowire Based Ferroelectric Field-Effect Transistor using a Gate Dielectric Layer of Bi_{3.25}La_{0.75}Ti₃O₁₂ Thin Film, K.T. Kim, G.H. Kim, Y.-K. Yoon, University at Buffalo

Recently, ZnO nanowires (NWs) have been extensively studied for solar cell and field-effect transistor applications because of their intrinsic n-type semiconductor property with a wide band gap of 3.36 eV and a large exciton binding energy of 60 meV[1]. Specially, the nanowire architecture in field-effect transistors provides many advantages against the conventional bulk substrate approach such as device size reduction, isolated channel, reduced leakage current, reduced control voltage, and reduced power consumption even to several nJ[2]. The ZnO nanowire based transistor can be extended to a non-volatile memory device by adopting ferroelectric materials for the gate dielectric layer. While Bi-based perovskite Bi_{3.25}La_{0.75}Ti₃O₁₂ (BLT) and Pb(Zr,Ti)O₃ (PZT) thin films have been extensively investigated for non-volatile ferroelectric random access memory (FRAM) devices, BLT based devices are reported to offer better fatigue resistant characteristic, low processing temperature, and large remnant polarization.

In this study, we show a process to make ZnO nanowires using electrospinning with the polymer ZnO nanocomposite and subsequent sintering in various temperatures and characterize them. Also, BLT is prepared by the metal organic deposition (MOD) process and is spincoated on a Pt(150nm)/Ti(50nm)/SiO₂/Si substrate, followed by sintering in different temperatures (550°C, 600°C, 650°C, and 700°C) to form crystalline perovskite structures [3]. And the ZnO nanowires are formed on the BLT ferroelectric gate and the electrodes for source and drain are defined using a UV lithography followed by metallization. We show non-volatile switching in ZnO NWs with the BLT ferroelectric gate. We also evaluate the field dependent conduction of ZnO NWs with the remnant field of ferroelectric thin films and show fatigue and retention free performance. These devices are useful not only for non-volatile memory devices but also for various biosensors and nanoelectromechanical systems.

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NS-TuP23 Fabrication of n-ZnO Photonic Crystals by Nanosphere Lithography using Inductively-Coupled-Plasma Reactive Ion Etching with CH₄/H₂/Ar Plasma on the n-ZnO/GaN Heterojunction LEDs, S.J. Chen, National Tsing Hua University, Taiwan, C.-M. Chang, J.S. Kao, Instrument Technology Research Center, National Applied Research Laboratories, Taiwan, F.R. Chen, C.H. Tsai, National Tsing Hua University, Taiwan

Applying photonic crystals with Light Emitting Diodes (LEDs) to improve the light extraction efficiency have been demonstrated successfully. ZnO has been considered as a promising material for the development of next generation UV LEDs with high brightness due to its direct band gap (3.37eV) at room temperature and it has relatively large exciton binding energy. Recently, n-ZnO/p-GaN heterojunction LEDs have been fabricated by several groups. However there has not any experimental evidence yet to integrate photonic crystal with n-ZnO/p-GaN heterojunction LEDs. This paper reports fabrication of n-ZnO photonic crystal/p-GaN LED by nanosphere lithography to further booster the light efficiency.

Usually, electron beam lithography is employed to fabricate the photonic crystals, however, it is a cost process and not suitable for large area production. In our paper, the fabrication of ZnO photonic crystals is carried out by nanosphere lithography (NSL) using inductively-coupled-plasma reactive ion etching (ICP-RIE) with CH₄/H₂/Ar plasma on the n-ZnO/p-GaN heterojunction LEDs. NSL is a simple and relatively cheaper technique and allows for large-area production. The CH₄/H₂/Ar mixed gas gives high etching rate of n-ZnO film which yields a better surface morphology and results less plasma-induced damages of the n-ZnO film.

The periodicity of n-ZnO photonic crystal is designed to fit the spectrum of n-ZnO/p-GaN LED by a Matlab code which suggests an optimum lattice parameter is 200 nm and the air-filling factor of the n-ZnO photonic crystal ranges from 0.35 to 0.65. In our paper we will show our recent result that a ZnO photonic-crystal cylinder has been fabricated by using polystyrene-nanosphere mask with lattice parameter of 200 nm and radius of hole around 80 nm. Experiment results were discussed in detail in terms of surface morphology, photonic-crystal nano-structure and plasma-induced damages which were measured by atomic force microscope, scanning electron microscope and photoluminescence spectrometer respectively.

NS-TuP24 Dielectrophoresis-assisted Deposition and Alignment of Single-Walled Carbon Nanotubes for Electronic Device Fabrication, Z. Xiao, Alabama A&M University

Single-walled carbon nanotubes (SWCNTs) have been considered as a promising nanostructured material for the realization of future nanoelectronic devices because of their unique electrical properties such as the ballistic transportation of electrons or holes in SWCNTs. In this paper, we report deposition and alignment of SWCNTs using the dielectrophoresis (DEP) method and fabrication of single-walled carbon nanotube field-effect transistors (CNTFETs) with semiconductor materials as the source and drain materials. Ultra-purified HiPCO-grown single-walled carbon nanotubes (SWCNTs) from Carbon Nanotechnologies, Inc. (CNI) were used for the fabrication of CNTFETs. N-Methyl Pyrrolidone (NMP) was used to disperse SWCNTs in solutions. The dispersion of SWCNTs in the solvent was ultrasonically assisted, and then centrifuged. The degree of dispersion was examined by SEM. Dielectrophoresis (DEP) method was used to deposit, align, and assemble carbon nanotubes (CNTs) across the source and drain of CNTFETs to form the channel. Microfabrication techniques such as UV lithography and e-beam lithography were used to fabricate the CNTFETs. The gap between the source and drain varied from 800 nm to 3 μm. Both metals such as gold and semiconductors such as

bismuth telluride (Bi_2Te_3) were used as the source and drain materials for the CNTFETs. The drain-source current (I_{DS}) versus drain-source voltage (V_{DS}) and gate voltage (V_{G}) was characterized for the fabricated CNTFETs. The fabricated devices and measured electrical results will be reported in the Conference.

NS-TuP25 Three-dimensionally Suspended Single-Walled Carbon Nanotubes Inside the Holes of Porous Silicon, W. Yi, D. Lee, J. Lee, Hanyang University, Korea

Carbon nanotubes (CNTs) were synthesized inside the holes of the porous silicon substrate by thermal decomposition of C_2H_2 . Secondary electron microscopy (SEM) and Raman analysis revealed that single-walled carbon nanotubes (SWNTs) were suspended with three-dimensional networks (3-dim suspended SWNTs). Field emission measurements of those samples showed the enhanced turn-on voltage and emission property compared with pristine SWNT film. We also measured the photoconductivity of 3-dim suspended SWNTs under irradiation of infrared light after making two electrodes on the sample surface. The on/off ratio of resistivity, i.e. the resistance ratio under and without IR irradiation reached up to ~600 enough to be used as commercial IR sensors.

NS-TuP26 System Evaluation and Optimization of the Measurement Uncertainty in the Nanoscale Step-height Inspection by Dynamic Mode Atomic Force Microscopy, C.Y. Su, Y.H. Lin, S.S. Pai, P.L. Chen, N.N. Chu, C.C. Yang, M.H. Shiao, Instrument Technology Research Center, National Applied Research Laboratories, Taiwan

Atomic Force Microscopy (AFM) has been extensively adopted in a variety of applications in nanotechnology. Due to the high sensitivity in z-axis, the capability of mapping height distribution from sample topography with the resolution in the sub-angstrom is achieved. In this study, a standard operation process (SOP) has been designed and implemented in order to optimize operational parameters such as scan rate, drive frequency, target amplitude, set-point, integral gain, proportional gain, look-ahead gain and so forth for the AFM dynamic mode inspection. The step-height standards are provided by the national metrology institute Physikalisch-Technische Bundesanstalt (PTB). System evaluation of the measurement uncertainty is accorded to ISO, Guide to the Expression of Uncertainty in Measurement and ISO 4287, Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters. Repeatability, non-linearity, straightness, noise, probe deformation error, numerical error, system long-term stability and sample uniformity have been included in this evaluation.

NS-TuP29 Surface Structure of Metal-Organic Framework Revealed by High-Resolution AFM, P. Cyganik, K. Szalagowska-Kunstman, M. Goryl, M. Szymanski, Jagiellonian University, Poland

Metal-organic frameworks (MOFs) which consist of organic ligands linked together by metal ions belong to a relatively new class of porous materials.¹ Due to their potential applications in storage, separation, and heterogeneous catalysis, MOFs have attracted increasing attention. So far MOF research has been mainly focused on bulk structure of the material prepared in the form of a powder. Only very recently a new, and radically different, approach was undertaken by exploring the possibilities of MOF growth on surfaces in the form of thin films.^{2,3} An important issue for further progress in optimizing growth of MOF crystals, and particularly MOF thin films, is control of their surface structure. Therefore, high-resolution imaging of MOF surfaces is of key importance, as has been previously recognized for zeolites which are analogous to MOFs.

The talk focuses on the AFM study of a MOF single crystal surface.⁴ By performing analysis both in air and under ultra high vacuum conditions the high-resolution AFM imaging of a MOF surface is demonstrated. The surface structure of a MOF crystal grown directly on the functionalized substrate is revealed and, moreover, this information is further utilized to optimize growth conditions. Finally, our study clearly demonstrates a much higher structural quality of MOF crystals grown on the substrate in comparison to the conventional powder growth method.

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NS-TuP31 Enhanced Photovoltaic Performance of DSSC using Broccoli-Like TiO_2 Film with Surface Modification by Zinc Acetate Solution, G. Cai, Y. Chen, C. Huang, J. Liang, National Dong Hwa University, Taiwan

The broccoli-like TiO_2 film as working electrode for dye-sensitized solar cell (DSSC) was fabricated successfully by flat-flame chemical vapor deposition (FF-CVD) method we developed. The cell efficiency approaches 4.2% with the film thickness about 9~13 nm if the film was used without further surface modification. As we known, one source of the energy loss in DSSC is charge recombination occurring between electrolyte and working electrode. In order to reduce charge recombination, we supply a thin metal oxide coating on TiO_2 electrode by using surface modification with metal-containing salt solution as precursor. A higher band gap of the metal oxide semiconductor provides energy barrier to prevent electron transfer back to the oxidative species, and then reduce the charge recombination. However, although thicker metal oxide coating may reduce the rate of charge recombination, it may also reduce the rate of electron injection into the conduction band of TiO_2 working electrode and reduce the cell efficiency. Therefore, the thickness of the metal oxide coating needs to be optimized for the DSSC efficiency enhancement. In this research, we choose ZnO as coating oxide, since ZnO has slightly higher band gap (3.37eV) than TiO_2 (3.2eV). We vary the concentration of zinc acetate solution from 0.1 M to 0.001 M for coating different thicknesses of zinc oxide on TiO_2 working electrode. The crystalline quality and morphologies of surface modified TiO_2 electrodes were characterized by using XRD and FESEM. EDS and XPS were used to confirm the presence of zinc on the surface of TiO_2 electrode. The coating thicknesses were determined by high resolution transmission electron microscopy (HRTEM). The DSSCs using these working electrodes were measured under AM 1.5G 100 mW/cm^2 by Keithley 2400 sourcemeter. As a result, as the concentration of zinc oxide precursor solution decreases from 0.1 M to 0.001 M, the cell efficiency increases from 1.9% to 5.6%. The short circuit current density (J_{sc}) increases from 3.59 mA/cm^2 to 11.89 mA/cm^2 as the concentration decreases from 0.1 M to 0.001 M. Furthermore, we also found that the excess thickness of zinc oxide coating will block the electron injection, and results in lower efficiency after surface modification. The drop of efficiency from 4.2% to 1.9% is mainly attributed to the decrease of from 10.08 mA/cm^2 to 3.59 mA/cm^2 . It reveals that appropriate thin zinc oxide coating is necessary in reducing charge recombination, while maintaining the high rate of electron injection to the conduction band of TiO_2 working electrode.

NS-TuP32 Thickness Dependence of Thin Film Samaria Doped Ceria Oxygen Sensor, M. Nandasiri, Pacific Northwest National Laboratory, R. Sanghavi, Arizona State University, S.V.N.T. Kuchibhatla, P. Nachimuthu, M.H. Engelhard, V. Shutthanandan, W. Jiang, S. Thevuthasan, Pacific Northwest National Laboratory, S. Prasad, Arizona State University, A. Kayani, Western Michigan University

Resistive oxygen gas sensors stand out among various types of sensors due to their simplicity, low cost, portability, measurement circuit simplification, and low power consumption. Rare earth materials such as pure and doped ceria are potential candidates for resistive oxygen gas sensors due to their unique ability to lose or gain oxygen in response to ambient oxygen concentration. We have recently observed that 6 atom % Sm doping is optimum for obtaining better conductivity using samaria doped ceria (SDC) films. In order to develop oxygen gas sensors based on SDC thin films, it is important to understand the influence of film thickness on the electrical properties.

In order to achieve this goal, we have grown SDC thin films on sapphire, Al_2O_3 (0001) substrates by using oxygen plasma-assisted molecular beam epitaxy. The 6 atom% Sm doped SDC films with thickness ranging from 50 – 300nm have been grown and their conductivity was studied. The resistance of these films, obtained by two probe measurement capability under various oxygen pressures (1mTorr-100Torr) and temperatures (473K to 973K) at a fixed voltage of 2V, will be discussed. The differences in the electrical properties, thereby the oxygen ion conductivity, will be explained based on the chemical and structural characteristics of various films. Structural and chemical characteristics of the as grown films were analyzed by various *in situ* and *ex situ*, surface and bulk sensitive techniques.

In this study we observed that, overall conductivity increases with the film thickness at each temperature and oxygen pressure value. We also observed saturation in the conductivity at film thicknesses above 200nm. With the increasing interest for miniaturized oxygen sensors for high temperature uses, the nano-scale thin film doped ceria sensors may have a significant role to play in various future functional applications. In that sense it is vital to undertake fundamentals studies such as this.

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