Nanometer-scale Science and Technology
Room 2020 - Session NS-WeA

Nanotube Devices and Processes
Moderator: D. Carr, Sandia National Lab

2:00pm **NS-WeA1 2006 AVS Peter Mark Award Lecture - Biofunctionalized Single-Walled Carbon Nanotubes: Purification, Properties, and Devices***,* ***M.C. Hersam***[1]*,* Northwestern University **INVITED**

The utilization of single-walled carbon nanotubes (SWNTs) in large quantities for electronics, optoelectronics, biosensors, and medical applications will require SWNTs of the same physical structure, electronic type, and band gap. Since current methods of synthesis produce SWNTs with polydisperse structure and properties, post-production purification is highly desirable. Here, we demonstrate a scalable method for enriching SWNTs by diameter and electronic structure using density gradient centrifugation. Importantly, this technique does not require covalent modification of the SWNTs, which can significantly degrade their outstanding electronic, optical, and mechanical properties. Furthermore, density gradient centrifugation is compatible with SWNTs of arbitrary length. To date, we have demonstrated purification in aqueous density gradients using a variety of noncovalent biofunctionalizations including sodium cholate, sodium dodecyl sulfate, and DNA. Atomic force microscopy analysis confirms enrichment by diameter and reveals SWNTs of various lengths between 0.1 and 1 micron. Furthermore, optical absorption and photoluminescence spectroscopy verify improvements in the monodispersity of SWNT optical properties. Finally, thin film field effect transistors (FETs) have been fabricated using SWNTs that are enriched by metal or semiconducting electronic type. The purified semiconducting SWNT thin films yield FET on/off ratios that are 10,000 times higher than their metallic counterparts. Overall, this non-destructive and scalable separation strategy is expected to impact a variety of applications for SWNTs where monodisperse structure and electronic properties are essential.

2:40pm **NS-WeA3 Recent Advance on the Synthesis and Device Applications of Aligned Carbon Nanotubes***,* ***C. Zhou****,* University of Southern California **INVITED**

We present a novel nanotube-on-insulator (NOI) approach to produce high-yield nanotube devices based on aligned single-walled carbon nanotubes. First, we managed to grow aligned nanotube arrays with controlled density on crystalline, insulating sapphire substrates, which bear analogy to industry-adopted silicon-on-insulator substrates. Based on the nanotube arrays, we demonstrated registration-free fabrication of both top-gated and polymer-electrolyte-gated field-effect transistors with minimized parasitic capacitance. In addition, we have successfully developed a way to transfer these aligned nanotube arrays to flexible substrates. Our approach has great potential for high-density, large-scale integrated systems based on carbon nanotubes for both micro- and flexible electronics.

3:20pm **NS-WeA5 Size Effects on Electrical Contacts to Nanotubes and Nanowires***,* ***F. Leonard****,* Sandia National Laboratories*; A.A. Talin,* Sandia National Laboratories, 94550

Metal-semiconductor contacts play a key role in electronics. Here we show that for quasi-one-dimensional structures such as nanotubes and nanowires, side contact with the metal only leads to weak band re-alignement, in contrast to bulk metal-semiconductor contacts. Schottky barriers are much reduced compared with the bulk limit, and should facilitate the formation of good contacts. However, the conventional strategy of heavily doping the semiconductor to obtain ohmic contacts breaks down as the nanowire diameter is reduced. The issue of Fermi level pinning is also discussed, and it is demonstrated that the unique density of states of quasi-one-dimensional structures makes them less sensitive to this effect. Our results agree with recent experimental work, and should apply to a broad range of quasi-one-dimensional materials.

3:40pm **NS-WeA6 Electrical Contact Metallization to Self-Assembled Large-Scale Carbon Nanotube Arrays***,* ***J.H. Bak****, B.Y. Lee, S.S. Hong, S. Hong, Y.D. Park,* Seoul National University, Korea

We report on the investigation of various metallization schemes to electronically probe self-assembled large-scale carbon nanotube arrays. Reliable and highly reproducible metallization scheme to realize ohmic contacts to single wall carbon nanotubes (swCNT) by Palladium and Gold metallic thin films is an important technological step for the realization of swCNT-based nanoelectronics and their applications as well as self assembled large scale CNT arrays being technological attractive for mass-production of swCNT-based devices. Although electrical contacts to individual swCNT by Cr, Ti and Pd have enabled the observations of ballistic electron transport in swCNTs,@footnote1@ the systematic study of metallization to self assembled large scale CNT arrays and the elucidation of its electrical properties have been limited. Large-scale CNT arrays are selectively patterned via directed-assembly strategy on areas defined by self-assembled monolayer patterns.@footnote 2@ Metallization and electrical properties of resulting contacts are studied by patterning submicron contact electrode on 2µm wide CNT array elements by e-beam lithography followed by the e-beam evaporation of contact metals of which contact spacing is varied from 300nm to 2µm. Contact spacings greater than 2µm represent mixed nanotube junctions properties. We found Pd contacts show both ohmic and nonhomic contact behavior whereas Cr and Ti metallization result in nonohmic contacts. @FootnoteText@ @footnote 1@ D. Mann et al., Nano Letter 3, 1541 (2003).@footnote 2@ S. Rao et al., Nature 425, 36 (2003).

4:00pm **NS-WeA7 Devices Based on Individual Carbon Nanotubes***, S. Roth,* ***J. Meyer****, D. Obergfell, S. Sahakalkan, M. Kaempgen,* Max Planck Institute for Solid State Research, Germany **INVITED**

Combining advanced semiconductor technology, synthetic organic chemistry, and high resolution transmission electron spectroscopy it is possible to prepare electronic and electromechanical devices based on individual single-walled carbon nanotubes and to fully characterize these devices by electrical and mechanical investigations and electron diffraction. We present examples of ultrafine electrochemical electrodes, T-junction transistors, peapod transistors, electromechanical acceleration sensors, and a torsional pendulum. The state of the art of industrial applications is reviewed.

4:40pm **NS-WeA9 Damage-free Surface Modification of Carbon Nanotubes using Advanced Neutral Beam***,* ***K. Okumura****, Y. Sato, K. Tohji, S. Samukawa,* Tohoku University, Japan

In an effort to realize carbon nanotube (CNT) FET, it is necessary to modify electric characteristic of grown CNTs by using plasma process. However, the conventional plasma process damages CNTs because charged particles and ultraviolet photons are irradiated to the CNTs. As a result, the CNT FET could not be practically fabricated using conventional plasma processes. Here, we have proposed damage free surface modification by using our developed neural beam to resolve the problems and to practically fabricate the CNT FET without any damages. Neutral beam can almost eliminate irradiation of charged particles and ultraviolet photons to CNTs. In this study, we irradiated Ar plasma and Ar neutral beam to single-walled carbon nanotubes (SWCNTs). Raman spectra confirmed that the intensity ratio of D-band/G-band in SWCNTs irradiated by neutral beam was still kept at the same as that with no beam irradiation. Conversely, the intensity ratio of D-band/G-band was drastically increased by conventional plasma irradiation. Transmission electron microscopy could also confirm that SWCNTs did not have any damages after the neutral beam irradiation, whereas SWCNTs was destroyed by conventional plasma irradiation. Neutral beam process is very promising candidate for future CNT FET fabrication processes.

[1] **Peter Mark Memorial Award Winner**

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