Carbon nanodevices for sensors, actuators, and electronics

E H Yang, Stefan Strauf, Frank Fisher, and Daniel Choi

Progress in the fabrication, assembly, and manipulation of nanotubes and graphene-based materials promises many technological advances.

The electrical properties of carbon nanotubes (CNTs) and graphene make them exceptional candidates for developing novel devices with functionality and efficiency that is orders-of-magnitude better than state-of-the-art technologies. These next-generation electronics will significantly increase the capabilities of high-throughput information systems while simultaneously decreasing their size, weight, cost, and assembly complexity.

Despite the promise of vastly superior performance of CNT and graphene-based devices, several fabrication issues need to be resolved to realize their full potential. Our research focuses on nanodevices based on CNT and graphene nanostructures for use in nanoelectronic devices, nanoactuator systems, and nanosensors.

For example, we are developing nano-segmented, in-plane CNT structures and investigating their quantized electron energy properties. In-plane CNTs are formed using chemical vapor deposition between catalyst patterns. Then they are segmented using a voltage-applied atomic force microscope (AFM) process to form CNT-based quantum dots (QDs). During segmentation, an AFM tip applies a negative voltage (approximately 5V) to create defects at specified locations along the multiwall nanotube (MWNT).

Other researchers are also pursuing the development of CNT-based QDs, but our fabrication technique is compatible with forming CNT-QD arrays, which will enable single-electron memory states with high electron charging energies that are stable up to room temperature. This type of device is critical for high-speed, ultra-low-power electronics as well as highly sensitive nanosensor applications. An example is shown in Figure 1, where four sets of CNT-QDs could combine to yield a memory cell.

The quantized electronic energy levels of CNT-QDs depend strongly on the dimensions, chirality, and electron charging energy $E_c$ of the QD (i.e. single electron confinement). Detailed knowledge of such properties is necessary to understand the single electron transport and storage properties of CNT-QDs, particularly as a function of the CNT growth and segmentation parameters.

We have found that MWNTs display a room temperature photocurrent that is slightly dependent on excitation wavelength. Conductance measurements of a MWNT sample (as a function of source-drain and back-gate voltage) carried out at 80K showed a nonlinear response, suggesting a MWNT 1D density of states.

We are in the process of characterizing the conductance of individual CNTs at temperatures from 4 to 300K, as a function of bias and gate voltage. Photoconductivity will also be measured at low temperatures to characterize the transport behavior of MWNT samples before and after segmentation.

In other work, we are investigating the field emission properties of graphene nanostructures for vacuum electronics applications. Graphene is a two-dimensional carbon honeycomb-structured single crystal showing ballistic transport, zero band gap, and electric spin transport characteristics. To measure field emission from graphene, we prepared sheets...
Our future work will pursue the fabrication, assembly, and manipulation of CNT and graphene nanostructures for nanosensors, actuators, and nanoelectronic device applications. Overcoming the technical challenges of working with these materials will enable wider exploitation of their outstanding electrical properties. This will lead to next-generation devices with unrivaled functionality in sensor, detector, system-on-a-chip, and system-in-a-package applications, as well as programmable logic controls and energy storage systems.

*Part of this work was supported by the Air Force Office for Scientific Research.*

**Author Information**

E H Yang, Stefan Strauf, and Frank Fisher  
Department of Mechanical Engineering  
Stevens Institute of Technology  
Hoboken, NJ  
http://personal.stevens.edu/~eyang/  
http://personal.stevens.edu/~eyang/nmdl.html

EH Yang is director of the Micro Devices Laboratory and was previously a recipient of the Lew Allen Award for Excellence at NASA’s Jet Propulsion Laboratory (JPL), where he was a senior engineering staff member. He is currently associate editor of the IEEE Sensors Journal.

Stefan Strauf received the Harvey Davis Memorial Award for Research Excellence in 2008, and his current research includes single electron transport, photocurrents, shot-noise characterization of carbon nanotube and graphene devices, and quantum key distribution using single photon sources.

Frank Fisher is co-director of the Nanotechnology Graduate Program at the Stevens Institute of Technology. His current research interests include micro and nanomechanics, processing-structure-properties of polymer nanocomposites, and piezoelectric approaches for energy harvesting applications.
Daniel Choi
University of Idaho
Moscow,

Daniel Choi is an associate professor at the University of Idaho and associate director of the University of Idaho cleanroom facilities. He has received awards including the Aerospace Outstanding Invention Award in 1997 and the Spot Award at NASA’s JPL in 2005.

References