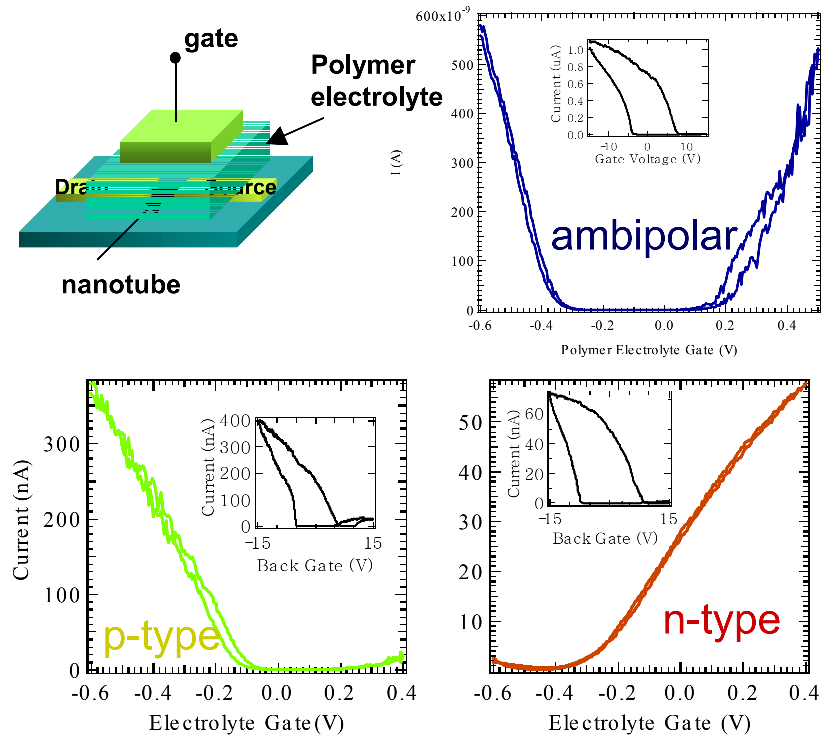
CAREER: Synthesis, surface functionalization and charge carrier injection in 1D nanostructures

Moonsub Shim, University of Illinois at Urbana-Champaign, DMR-0348585

This project aims to further understanding of synthesis and processing, including chemical functionalization, to control electronic properties of 1D nanostructures.

Due to inherently large surface-to-volume ratio, nanoscale materials are highly sensitive to external effects. Especially in single-walled carbon nanotubes (SWNTs) where all atoms are at the surface, adsorption of molecules even from the ambient can alter their electronic properties. One consequence of this sensitivity is that SWNTs almost always exhibit hole (p-channel) conduction only as shown in the transfer characteristics in the insets. By utilizing charge transfer from chemical groups of polymers, p-, n- and ambipolar characteristics have been achieved. Addition of electrolytes in polymers allows screening of other external effects and elimination of hysteresis. Furthermore, the highest efficiency gating of SWNT transistors can be achieved by directly applying a potential to the polymer electrolytes.



Polymer electrolyte gated nanotube transistors. By varying polymer chemical groups, carrier type and doping level can be controlled. Extremely short Debye lengths leads the highest efficiency electrostatic gating and screening of other external effects.

Nano Lett. **4**, 927 (2004).

The aims of this project are 1) to elucidate how external factors (from inevitable exposure to ambient molecules to intentionally introduced chemical groups) alter the electronic properties of 1 dimensional materials and 2) to exploit that understanding to vary/improve synthesis and processing conditions to achieve desired electronic properties. Single-walled carbon nanotubes (SWNTs) are utilized as prototypical system due to their all surface atom structure which leads to extreme sensitivity to external factors.

In the example shown, chemical groups of the adsorbed polymers are exploited to alter the electron transport properties of SWNTs. Electron-withdrawing poly(acrylic acid) leads to hole conduction only, while electron-donating polyethylenimine results in electron conduction only. On the other hand, when relatively inert polymer, poly(ethylene oxide), is used, both electron and hole conduction are observed. Directly applying gate potential to the polymers (with electrolytes in them) leads to additional advantages such as low voltage operation of transistors, elimination of uncontrolled hysteresis caused by charge trapping on substrates, and highest gate efficiency achieved to date for SWNT transistors. This approach also provides a very simple method of studying transport characteristics of nanoscale semiconductors by exploiting high capacitance of electric double layer which is ~3 orders of magnitude larger than those of commonly employed electrostatic gate for individual nanostructures. Further studies that elucidate electronic interaction between polymer chemical groups and SWNTs (e.g. combined spectroscopic and transport measurements to observe potential chemical bonds and/or electron transfer complexes between polymers and nanotubes both at the ensemble and individual nanotube levels) are planned for near future.

Other fundamental issues are also currently being examined in two parallel approaches: 1) liquid electrolyte gating measurements on individual SWNT transistors where varied solutions (e.g. concentration, pH, and types of solute) are used to probe chemical composition of nanotubes (e.g. are there defects along the sidewalls that influence SWNTs transport characteristics and if so what is the chemical composition of such defects?) and 2) UV-induced desorption in controlled environment to elucidate how molecules from the ambient influence electronic properties of nanotubes. One of the most important parameters in both of these studies is synthesis conditions. Different methods of nanotube growth are utilized to control, for example, diameter and density as well as to minimize/eliminate amorphous carbon content. Processing/fabrication conditions are also carefully examined as they allow possibility of isolating different contributions to observed properties (e.g. variations in choice of metal contacts to isolate effects arising at the contacts as opposed to those inherent to nanotubes, fabrication of suspended nanotubes to isolate out substrate effects).

The results of these studies should lead to better understanding of chemical composition and structure of nanotubes and synthetic/processing routes with which we can control these features (which will in turn allow us to better control properties of nanotubes).

CAREER: Synthesis, surface functionalization and charge carrier injection in 1D nanostructures

Moonsub Shim, University of Illinois at Urbana-Champaign, DMR-0348585

Education:

Through this program, two graduate and two undergraduate students have been trained and have become familiar with synthesis, characterization and device fabrication of nanoscale materials. Graduate students, Ju Hee Back and Taner Ozel, have also had the opportunity to mentor undergraduate researchers (Samantha Cruz and Zai Chang). In addition, the PI has also developed and delivered several lectures on carbon nanotubes and other nanoscale materials and is currently developing a new course on nanotechnology for lower division undergraduates to expose students at an early stage to one of the most exciting fields of materials science.

REU student (Samantha Cruz) growing single-walled carbon nanotubes via catalytic chemical vapor deposition .

Outreach:

The PI is currently developing lecture materials for an introductory materials science course which will be used to record and deliver on-line lectures. This on-line course will be made available to historically black/minority-serving institutions.