

Electron Transport in Molecular Nanostructure

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The Columbia University Nanoscale Science and Engineering Center (NSEC) is dedicated to developing the highest level of fundamental understanding for many important phenomena of electron transport through single molecules, carbon nanotubes, graphene, and nanoscale molecular assemblies [1]. Our research program is exploring three broad scientific propositions:

- **Molecular Conduction:** The fundamental phenomena for electron transport through a single molecule represent an exciting opportunity for scientific discovery.
- **Molecular Assembly:** Through combination of “bottom up” creation of specific chemical systems and “top down” fabrication, we can explore transport properties of two dimensional nano-structures.
- **Nanoscale Characterization:** Characterization of nanoscale molecular assemblies closes the functional design loop linking molecular properties, pathways for assembly and electrical function.

Our interdisciplinary program pursues the synthesis, fabrication, and characterization of three different types of nanoscale molecular systems in intimate contact with electrical contacts: (1) single walled carbon nanotubes; (2) two-dimensional molecular systems including graphene, boron nitride, and molybdenum sulfide; and (3) single molecules. The Nanocenter program brings a common intellectual approach to create a fully integrated multidisciplinary program built upon these molecular systems.

Graphene and Other Two-Dimensional Molecular Nanostructures. The Columbia Nanocenter has been an instrumental force in the development and characterization of graphene, a seemingly simple one-atom thick sheet of covalently bonded carbon atoms [2]. In theory, the electrons in graphene do not move like normal particles with mass but rather they behave much more like photons, mass-less particles of light. As a result, electrons in graphene move more easily than in silicon providing for display of quantum mechanical behavior even at room temperature. In addition, graphene structures can display incredible structural flexibility and strength, high chemical stability, and controlled charge carrier concentration. This transformative new material has the potential to combine the high performance of the best semiconductors with the novel functionality of the best nanostructures, thus promising revolutionary new applications. We have been studying the fundamental aspects of graphene growth and structure both experimentally and theoretically [3]. We have carried out a number of basic studies of the novel electronic properties of graphene including quantum interference phenomena [4] and transport in graphene nanoribbons [5]. Through understanding of the mechanical properties of graphene sheets and membranes we have fabricated new electromechanical devices [6].

Single Molecule Conduction. The fundamental characterization of conduction phenomena in single molecules has proven to be a major scientific challenge. Our discovery of diamine-gold systems has allowed us for the first time to undertake systematic explorations of the influence of chemical structure on molecular conductance [7,8]. These experiments thus point the way toward a definition of chemical “design rules” for molecular conduction phenomena. Our demonstration of direct measurement of conductance for a single molecule covalently bonded

across a nanometer-scale carbon nanotube junction has created a new platform for single molecule conductance studies [9]. These experiments are already demonstrating a rich variety of behavior and should become a primary tool for explorations of molecular conductance. They also open new doors for sensitive single molecule detection techniques, potentially useful for DNA sequencing and related technologies.

Electronic Structure and Dynamics in Single Walled Carbon Nanotubes. We have made significant advances toward the characterization and understanding of isolated single walled carbon nanotubes. We have developed a unique form of Rayleigh Scattering Spectroscopy which provides rapid spectral signatures for individual nanotubes. This discovery has dramatically influenced how the entire scientific community explores the fascinating phenomena associated with carbon nanotubes. These capabilities are allowing us to explore the electronic properties of carbon nanotubes and carbon nanotube devices that have been structurally identified [10]. Based on these concepts we have explored in detail the properties of electronic devices fabricated from carbon nanotubes of known structure. These fundamental measurements will open up new perspectives in our understanding of the electronic transport properties of carbon nanotubes and corresponding devices.

New Paradigms for Multidisciplinary Research. Within the communities of Columbia University, Barnard College, City College of New York, and Rowan University, we have created a new paradigm for multidisciplinary research. This program has been extremely effective in generating excitement about nanoscale science and engineering and the rewards of interdisciplinary research.

References

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