Nanoelectronics

Co-Organizers:
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The workshop addressed some of the fundamental issues concerning the incorporation of organic and inorganic building blocks as electronic, optical, and mechanical components into nano- and/or mesoscopic devices and systems and their electronic and structural characterization. The materials ranged from short organic molecules and monolayers of macromolecules, to carbon nanotubes, to semiconductors and superconductors.

In the keynote presentation, Surprio Datta (Purdue University) reviewed the modern conceptual framework for understanding quantum transport in nanodevices. Prof. Datta highlighted approaches applicable to both equilibrium systems, based on the Landauer approach, and non-equilibrium systems, based on the non-equilibrium Green function method. Prof. Datta described a simplified version of device that could be called an electronic "Maxwell's demon," one that lets electrons go preferentially in one direction over another. As an example Prof. Datta described a device based on selective spin scattering. The device operation emphasizes the interplay of reversible transport dynamics with irreversible thermodynamics.

Figure 1. Surprio Datta of Purdue University.

Organic materials can offer new electronic functionality not available in the inorganic devices. However, the integration of organics within nanoscale electronic circuitry poses new challenges for material physics, chemistry and nanofabrication. Paul Evans (University of Wisconsin) discussed the creation and the characterization of functional electronic interfaces, focusing on the molecular-scale formation of organic thin film transistors. Transport properties and photoinduced charge transfer were optimized using functional self-assembled monolayers at the interfaces between inorganic substrate and organic semiconductor. Nikolai Zhitenev (Bell Labs.) discussed applications of organic and inorganic materials as bistable switches. Resistive switching on the smallest length scale is not a purely electronic phenomenon. Rather, a motion of heavier constituents such as atoms or ions has to be involved that will in turn change the electronic properties. Nanodevices fabricated with monolayer of polyelectrolyte macromolecules demonstrate robust bistable switching and can be broadly modified by ion-exchange chemical reactions.

Carbon nanotubes (CNT) are tubes of rolled-up graphite with diameters as small as a nanometer and lengths up to a millimeter. The extraordinary sensitivity of electronic properties to the microscopic structure of CNT has been the blessing and the curse of the field for many years. As-synthesized CNT vary widely in their diameter, chirality, electronic and optical properties. For example, about one-third of all possible single-walled carbon nanotubes (SWNTs) exhibit metallic properties while the remaining two-thirds act as semiconductors. Their full potential will be limited until large quantities of SWNTs that are monodisperse in structure and properties become available. Mark Hersam's group (Northwestern University) has developed a technique for CNT purification by electronic structure via density differentiation. Employing selective surfactant encapsulation of SWNTs, density gradient ultracentrifugation and density separation, CNT can be purified to the point that large fractions of the material have a single, known chirality. Utilisation of this electronic type separation was demonstrated by construction of field effect transistors (FETs) employing percolating networks of the metallic or semiconducting SWNTs. Nadya Mason (University of Illinois at Urbana-Champaign) presented a variety of the quantum transport experiments with individual SWNT. Among devices discussed were single and the coupled quantum dots, quantum constrictions and wires defined using multiple electrostatic gates and/or intentional structural defects.

Traditional semiconductors offer vast research opportunities for design of novel quantum devices. An ability to manipulate spin of charge carriers in a controllable fashion is central to the developing field of spintronics. Usually, creation of spin-polarized current requires either injection from magnetic materials or the application of a strong Zeeman magnetic field. Leonid Rokhinson (Purdue University) has developed spin-filtering based on cyclotron motion in non-magnetic semiconductors. For holes in GaAs/AlGaAs heterostructures almost 100% bipolar spin filtering has been achieved in magnetic focusing geometry with spatial separation of polarized beams by 0.2 microns. Mark Eriksson (University of Wisconsin) discussed quantum devices in Si/SiGe heterostructures. Quantum phenomena such as the Kondo effect and the Fano effect can be now realized in Si/SiGe heterostructure-based quantum dots (QD). The size of the QD devices can be pushed down to a single electron.

Superconducting devices have been drawing significant attention as solid-state prototypes for quantum computation. Robert McDermott (University of Wisconsin) reviewed various quantum computing platforms. Recent advances in the materials and design of phase qubits have dramatically improved their coherence. Energy relaxation time as long as 500 ns has been measured. A factor that received little research attention in the past, but that is the most important for further improvement in qubit coherence, are losses in dielectric materials. Alexey Bezryadin (University of Illinois at Urbana-Champaign) has pushed superconducting circuitry into the few nanometer regime using carbon nanotubes and single DNA molecules as templates or scaffolds for superconducting wires. His nanowire superconducting quantum interference device can measure superconducting phase gradients generated by external magnetic fields or currents.

The workshop was concluded by Stephen Streiffer (Argonne National Laboratory) presenting the unique fabrication and characterization tools of the Center of Nanoscale Materials and describing the user program at the CNM.