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Center for Nanoscale Systems in Information Technologies

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The Center for Nanoscale Systems (CNS) has assembled interdisciplinary teams to execute an aggressive and wide-ranging nanoscale science and engineering (NSE) research program [1]. The CNS research mission is to substantially advance the impact of nanotechnology in future, high-performance, information technology systems. CNS teams are working in three focused research thrusts – nanoelectronics, nanophotonics, and nanomagnetics – with the collective purpose of understanding and controlling the electronic properties of materials at the nanoscale and of exploiting these material systems and associated nanoscale phenomena in technologically significant applications. The Center's central objective is to develop effective nanoscale devices and systems that have the potential of being revolutionary solutions for the ever-more demanding requirements of future computational, sensing, information storage and communication systems. CNS also seeks to develop and advance effective NSE research tools and techniques to support and further advance these information technology efforts. Illustrative examples of current CNS research efforts include the following:

Nanoelectronics: To enable an effective post-CMOS transition in high performance Si electronics, we will develop and demonstrate a new, practical architecture within which the physics of charge confinement in Si nanostructures can provide unique benefits for dense information-processing systems that employ *embedded memory elements* as logic. This is being developed in a functionally dense architecture that employs nanostructures to provide the means to *software configure* interconnects to correct for unavoidable variability in nanoscale systems due to imperfect fabrication and defects. An important milestone in this Si nanoelectronics effort has been the implementation of two aligned gates on opposite sides of a planar silicon channel [2]. This device structure provides adaptive variation of the operational control of the device with one of the gate voltages and demonstrates that the techniques for fabricating transistors with extremely thin channels (10's of nm) and for placing gates of 10's of nm length are at hand. The device geometry also allows one gate to float, making the structure a memory. Simulations show that the geometry allows memories to be scaled in silicon to 10's of nm's with excellent on-off control and speed. The key is the ability to overlap the control gate with the bottom, floating gate so that hot carrier injection is enhanced.

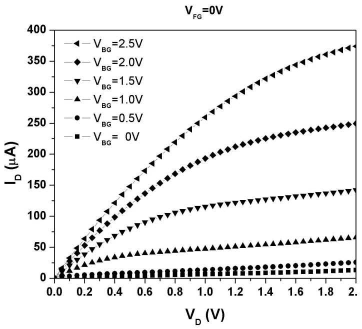

Fig.1. Example of the electrical characteristics of the dual-gate Si transistors

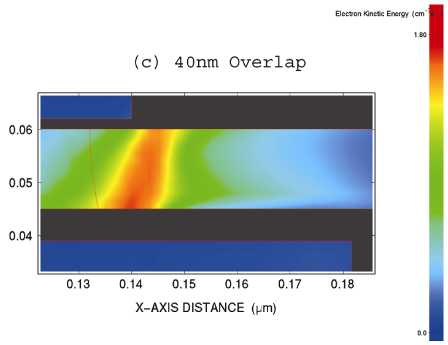

Fig. 2: Injection of charge in the underlying floating gate region of a dual gate Si transistor.

In a parallel nanoelectronics effort, we combine methods developed separately in the fields of microelectronics, polymer chemistry, solid-state physics, and inorganic chemical synthesis to create and probe carbon-based nanoscale electronic devices. The potential outcome is a future generation of nanoscale devices with new capability, such as interfacing with chemical or biological systems. Previous work by CNS researchers and others has shown that semiconducting C nanotubes have intrinsic properties, such as the carrier mobility, that are superior to Si. For useful applications, it is critical to optimize the device geometry to make use of these intrinsic characteristics. One key issue is maximizing the gate capacitance. We have used an electrolyte as a gate for a nanotube transistor (NT) to explore the ultimate limits of device operation [3]. We have also made use of high-κ dielectrics in collaboration with groups at Stanford [4]. We have built NT transistors with an 8nm thickness ZrO_2 gate insulator. These devices have characteristics comparable to those found in our electrolyte gating experiments and are significantly better than those previously obtained in all-solid state nanotube transistors.

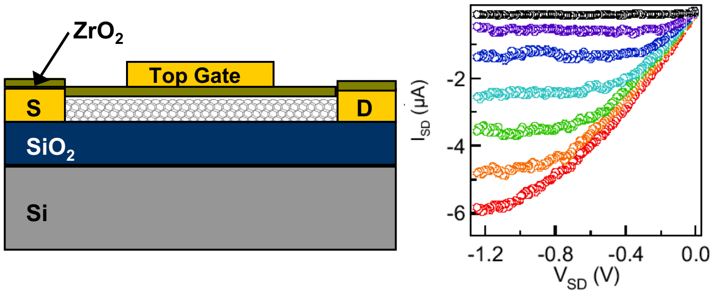

Fig. 3. C nanotube transistor schematic and electrical characteristics

Nanophotonics: The development of photonic system components that exploit nanoscale phenomena to provide functionality could satisfy the full-spectrum of requirements for the future implementation of *all-optical* circuits and networks for telecommunications. The CNS approach is to tailor and manipulate the optical properties of materials by the utilization of nanostructures [e.g., quantum dots (QDs)], and through the control and variation of composite materials at the nanoscale level. Lead-salt QDs are among the few semiconductor materials that allow size-quantized optical transitions at technologically-important infrared wavelengths. With a colloidal synthesis technique, we have produced PbSe dots with controllable diameters between 3 and 8 nm and find they offer several desirable properties:

- Highly monodisperse without processing after synthesis;
- Lowest-energy optical transitions between 1 and 2 µm;
- Fluorescence quantum yield of 80% despite the lack of a capping layer.

The PbSe QDs exhibit a surprisingly-long luminescence lifetime: 300 ns, which is two orders of magnitude longer than that calculated from the transition dipole. The slow spontaneous emission rate may help achieve gain and lasing in these structures. [5]

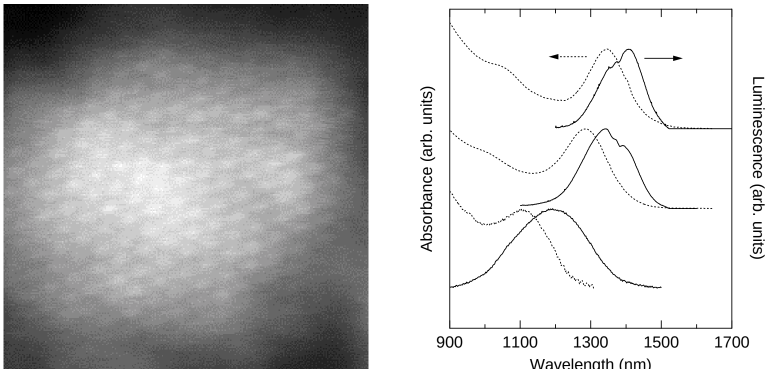

Fig. 4. High resolution electron micrograph (full scale = 6.4 nm) of PbSe QD showing single atom columns, and absorption (dotted) and luminescence (solid) spectra of PbSe QDs of different mean diameters

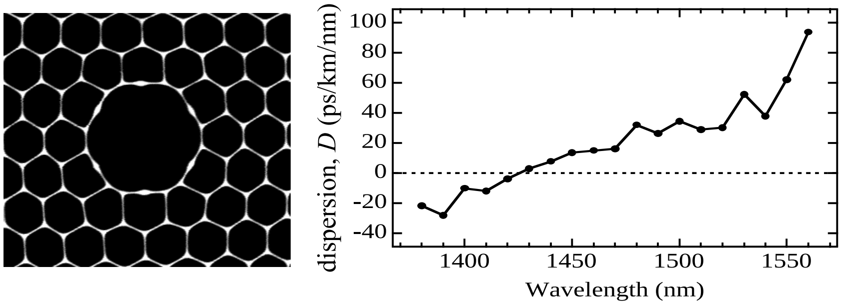

Fig.5. (a) Micrograph of an air-core fiber. The widths of the silica glass "bridges" (white) are ~ 50 nm. (b) At > 1425 nm, the fiber exhibits anomalous dispersion that is 3 times larger than conventional fiber.

Photonic band-gap fibers (PBGFs) are able to guide light via diffraction rather than by total internal reflection and offer promise of transmission losses and optical nonlinearities that are 1000 times smaller than those of conventional fibers. We have performed measurements of the dispersion and nonlinearity of a recently developed air-core fiber by our Corning collaborators. This fiber possesses an attenuation coefficient of 13 dB/km at a wavelength of 1500 nm – 200 times less than that of previously reported designs and an anomalous dispersion region for wavelengths greater than 1425 nm. The effective nonlinearity of the fiber is equal to that of air – 1000 times less than that of conventional glass fibers. These fibers support soliton pulses with powers greater than 2 MW in which the waveguide structure and the air provide the requisite anomalous dispersion and nonlinearity, respectively.

Nanomagnetics: We seek to advance the development of memory, logic, and sensor technologies that take advantage of the electron's intrinsic spin as well as its charge. A major focus is on the prospect of utilizing spin-polarized currents to reversibly switch and excite nanomagnetic moments for ultra-high density, non-volatile, on-chip memory applications. To develop a better understanding of these effects, we have made an extensive investigation of spin torque switching with Co-Cu-Co multilayers nanopillar devices [6]. This has established that the spin-transfer process is predominantly the result of spin-dependent scattering at the N-F interface and that the spin–polarized current exerts its effect on the nanomagnet in a manner orthogonal to that exerted by an applied field. This provides a basis for the "spin engineering" of nanostructures to further enhance the spin-transfer effect and to produce improved device structures for practical applications.

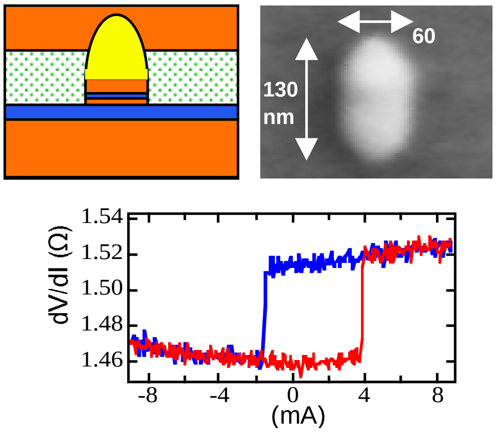

Fig. 6. (a) Cross-sectional schematic and (b) top SEM view of a spin-transfer nanopillar device. (c) R vs. I of a spin transfer device showing hysteretic switching by the spin polarized current.

References

[1] For further information about this NSEC, link to <**www.cns.cornell.edu**> or email <**cns@cornell.edu**>
[2] A. Kumar, et al., IEEE 2002 Silicon Nanoelectronics Workshop, 63 (2002)
[3] "High performance electrolyte-grated C nanotube transistors, " S. Rosenblatt, *et.al.*, Nano Lett. ***2***, 869 (2002).
[4] "High-k dielectrics for advanced C-nanotube transistors ...," Ali Javey, *et.al.*, Nature Materials, in press, (2002).
[5] "Optical properties of colloidal PbSe nanocrystals," H. Du, *et al*., Nano Lett. **2**, 1321 (2002).
[6] "Thermally activated magnetic reversal induced by a spin-polarized current," E.B. Myers *et al.*, PRL **89**, 196801 (2002); "Quantitative Study of Magnetization Reversal by Spin-Polarized Current in Magnetic Multilayer Nanopillars," F. J. Albert, *et al.*, PRL, **89**, 226802 (2002).