Center of Integrated Nanomechanical Systems (COINS)

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The mission of COINS is to enable interdisciplinary invention, understanding, and construction of nanomechanical systems for environmental monitoring and national security applications. We focus on two major applications: (i) portable, sensitive, low-cost Personal And Community-based environmental MONitors (PACMON), and (ii) wireless, low-power, sub-millimeter tacking, tracking and locating (TTL) devices.

To realize efficiently the goals of COINS, a carefully designed and integrated plan combining the talents of 31 investigators spanning 10 different disciplines (applied physics, bioengineering, chemical engineering, chemistry, economics, electrical engineering and computer science, materials science and engineering, mechanical engineering, molecular and cell biology, and physics) has been established and set into motion. Six major thrusts couple the three naturally divided technology tiers of System Integration, Enabling Technology, and Fundamental Knowledge Base, all necessary to support PACMON and TTL. The cornerstone for the realization of our vision is the development of a new nanomechanical detection system that integrates sensing, power, electronics, wireless communication, and mobility onto a single platform.

During its first year, COINS made significant advances in fundamental knowledge, technology, education, and industrial collaborations. These early achievements place the Center on the right track towards realizing its goals.

Advances in Fundamental Knowledge

We are working on ways to improve nanodetection selectivity and sensitivity, increase and control carrier mobility and energy conversion in nanoscale materials for power generation, develop new, nanoscale actuation mechanisms for switching and mobility, and improve fabrication techniques for integration and heat dissipation.

- Created a tetrapod with CdTe nanorods and quantum dots, and successfully measured the electrical current through the branch point. A vertical arm pointing away from the substrate served as a nanomechanical lever to tune electrical properties.
- Built a synthetic NEMS actuator powered by surface tension. With only two liquid indium drops on a carbon nanotube surface, this nanoelectromechanical relaxation oscillator achieves a power density 100 million times larger than in typical sports cars.

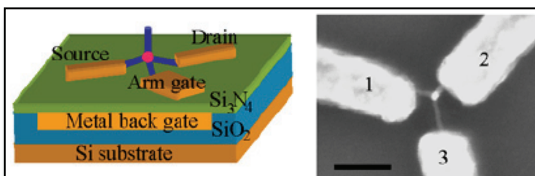

Fig. 1 Scheme of tetrapod single electron transistor. *left*: the device schematic structure, in which three arms of a tetrapod are contacted with small metal electrodes and the fourth arm points vertically away from the substrate. The fourth arm serves as a mechanical lever acting on the

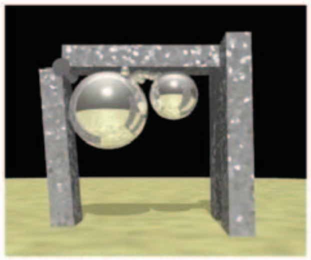

Fig. 2 Liquid metal droplets powering a NEMS walker.

- Simulated the instantaneous friction force between two carbon nanotubes in a double-wall configuration. Molecular dynamics calculations demonstrated a strong and nonlinear dependence of the friction force on the relative velocities of the tubes.
- Predicted the dependence of the optical properties of silicon nanowires on both their size and growth direction, using highly accurate *ab initio* techniques.
- Developed a technique for charge-doping individual molecules in an atom-by-atom fashion.
- Characterized the surface contamination, contact annealing, and sequential wall removal of a full multiwall carbon nanotube device with high resolution TEM.
- Measured the deflection profiles of clamped silicon nanowires grown in microtrenches. The results demonstrated the rigidity of the starting and ending base of the nanowires and the beam-like elastic behavior of the fabricated nanowire-in-trench structures.
- Applied nanocavity-based dielectric relaxation spectroscopy towards understanding protein folding/unfolding mechanisms.

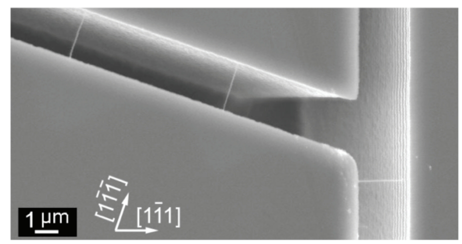

Fig. 3 Scanning electron micrograph showing rationally-synthesized silicon nanowires bridging microfabricated trenches.

Advances in Technology

We are working on novel characterization approaches that allow high-resolution of the entire device in real-time, new nanoelectromechanical integration approaches, low-power nano- and microscale propulsion, ultra-strong adhesives for on-chip integration and mobility applications, and overall robustness, manufacturability, and controlled fabrication issues.

- Developed nanotextured surface made from silicon nanowires that has the necessary flexibility for optimal adhesion. By adding kinks to the nanowire tips, good surface contact was obtained without bending.
- Developed a mechanically switched transistor based on silicon nanowires that does not suffer from cross-coupling deficiencies.
- Integrated nanowire synthesis directly into device fabrication using microfabricated trenches and gold cluster-catylized SiCl4 CVD synthesis.
- Demonstrated nano-micro integration of both silicon nanowires and carbon nanotubes using the localized synthesis and assembly method.
- Developed a piezoresistive on-chip detection technique. This technique, which overcomes earlier signal attenuation problems, achieving mechanical detection sensitivities of 40 aN/sqrt(Hz) and $2X10^{-14}$ m/sqrt(Hz) at low T.

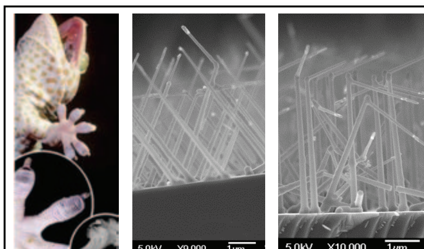

Fig. 4 *left*: Gecko feet shown at progressively greater magnification, culminating in an image of the nanoscopic setae (lowermost inset). *middle*: Kinked silicon nanowires grown on (111) oriented substrate. *right*: Kinked silicon nanowires grown on (110) oriented substrate.

- Fabricated and characterized polyimide nanohair arrays for adhesion applications with reduced inter-hair adhesion and higher hair packing densities.

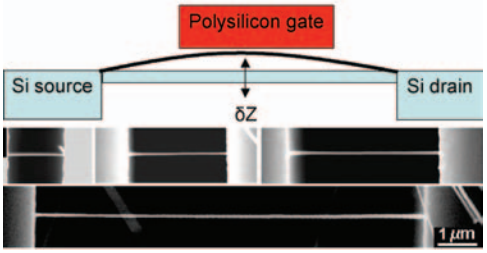

Fig. 5 *top* Schematic geometry of a mechanically active silicon nanowire transistor. *bottom* Scanning electron micrograph of silicon nanowires grown over microfabricated trenches. Scale bar is 1 micron.

- Built a nanofluidic transistor and demonstrated electrostatic control of ion transport in the nanochannels. The ability to tune the ionic and electrostatic environments makes nanofluidic transistors capable of femtoliter sensitivity.
- Developed process procedures for a displacement measurement testbed for medical sensors.

Advances in Education

The COINS NSEC is already making major contributions to and having a substantial impact in the realm of education. Several examples of our progress in this area include new nanoscience and technology exhibits at the Lawrence Hall of Science, a new UC Berkeley nanotechnology club with 400 members, high school students learning about nanotechnology at UC Merced, and a new course on the intersection of nanotechnology and business to be offered at UC Berkeley.


Fig. 6 Annual Berkeley Nanotechnology Club Nanotechnology event (2004).

Advances in Industrial Collaborations

The COINS research program, with its multi-disciplinary scope ranging from nanostructure synthesis, property characterization, theoretical simulation, instrumentation development to system integration, requires strong collaboration and active industrial interaction to achieve substantial scientific advancement and technology breakthrough. There are clearly market forces driving mechanical devices and systems towards further miniaturization to the nanometer scale. However, before any such commercial products can be realized using nanomechanical systems, fundamental research as proposed in COINS is required. Our significant partnership with industry and national laboratories will enable our students to take advantages of opportunities to perform research outside academia during their training, and will enable industry personnel to gain expertise and technical know-how in the emerging nanomechanical science and engineering. Several leading U.S. companies (HP, Nanosys, Nanomix, IBM, GE, Intel, Honeywell, ChevronTexaco) with active programs in nanotechnology have expressed strong interest in expanding their collaboration with Berkeley. Many of these companies have strong in-house research and development efforts in the micro- and nano-mechanical research areas. The industrial collaboration takes a number of forms, including participation on the COINS Industrial Advisory Board, support for joint research projects, student internships, access to fabrication facilities that are not available on the campus, and visiting industrial researchers.

For further information about this project link to http://nano.berkeley.edu/coins or email azettl@berkeley.edu.