

Stanford University Center for Probing the Nanoscale

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The Center for Probing the Nanoscale (CPN) at Stanford University is an NSF-supported Nanoscale Science and Engineering Center (NSEC) focused on the development of new measurement tools for nanoscale research. Such tools are an urgent priority to enable nanoscale science and engineering: as the National Research Council pointed out,¹ “One must be able to measure and quantify phenomena in order to understand and use them, which is true also for nanoscale phenomena.” Our NSEC addresses five overriding goals:

- *To develop novel probes* that dramatically improve our capability to observe, manipulate, and control nanoscale objects and phenomena.
- *To educate* the next generation of scientists and engineers regarding the theory and practice of these probes.
- *To apply these novel probes* to answer fundamental questions and to shed light on technologically relevant issues.
- *To disseminate* our knowledge and to transfer our technology so that other research scientists and engineers can make use of our advances, and so that corporations can manufacture and market our novel probes.
- *To inspire* thousands of middle school students by training their teachers at a Summer Institute.

Stanford and IBM have distinguished histories and programs in nanoprobe research, and formed the Center for Probing the Nanoscale to propagate this legacy into the next generation. CPN currently includes ten core investigators, over twenty affiliated faculty members and dozens of students and postdocs from nine academic departments and one industry research campus. Research at CPN is now organized into three tightly knit theme groups.

1) Nanoscale Electrical Imaging

With the rapid advancement in electronic devices, lithographically-patterned structures such as transistors now commonly have electronic properties that vary on scales of a few to tens of nanometers. Novel materials also exhibit local electronic variations, due to patterns in the underlying atomic structure,

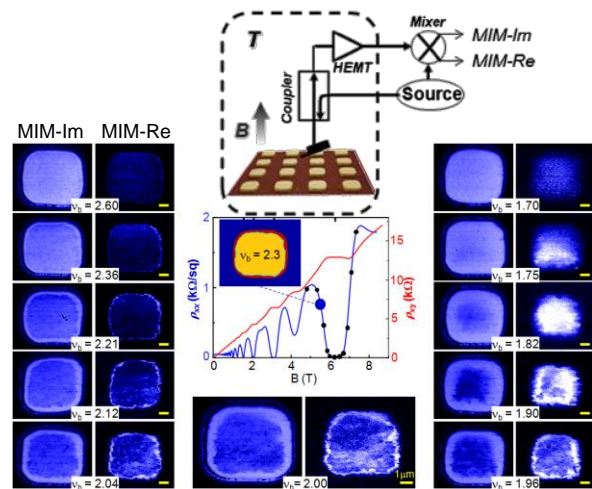


Figure 1. Microwave Impedance Microscopy of Coulomb-driven quantum Hall edge states in a GaAs/AlGaAs 2DEG. Counterclockwise from top left to top right, MIM images at $T = 2.3$ K as the B field increases from 4.8 T ($\nu_b = 2.6$) to 7.3 T ($\nu_b = 1.7$).

Adapted from K. Lai, et al., "Imaging of Coulomb-driven quantum Hall edge states." *Physical Review Letters* **2011**, 107 (17), 176809.

¹ “Small Wonders, Endless Frontiers: Review of the National Nanotechnology Initiative,” report from the National Research Council, June 2002.

inhomogeneity in structure or doping, or spontaneous organization of electrons. These local variations have important implications for the behavior of the materials or structures and ultimately determine the properties and performance of advanced electronic devices. CPN is developing Scanning Gate Microscopy and Scanning Microwave Microscopy in order to measure electrical properties at the nanoscale (Fig. 1). Both developments are enabled by Center-developed design and production of specialized scanning probe cantilevers that integrate a coaxial tip to produce a highly localized electric field and a piezoresistor for self-sensing tip deflection.

2) *Individual Nanomagnet Characterization*

Magnetic nanoparticles have a number of present and proposed applications spanning various areas in information technology, biology and medicine. For example, magnetic nanoparticles are crucial in increasing the density of information storage, have been clinically approved for use as MRI contrast agents, and have the potential to be successfully used for treatment and removal of cancer cells. The properties of magnetic nanoparticles are inherently sensitive to small variations in volume, shape, and structure, and therefore it is vital to characterize them individually. Our theme group develops and advances a variety of nanoprobes, such as Magnetic Force Microscopy, Scanning Sagnac Microscopy and Scanning SQUID Microscopy, with the spatial resolution and magnetic sensitivity to detect and characterize individual nanomagnets for nanobiotechnology applications. Furthermore, in conjunction with IBM Research, we are developing Nanoscale Magnetic Resonance Imaging tools with the goal of extending the sensitivity of magnetic resonance imaging to the level of individual nuclear spins. This would enable the development of a “molecular structure microscope” capable of imaging the atomic structure of molecules in three dimensions. Recent work sponsored by CPN has proven that magnetic resonance force microscopy (MRFM) can achieve three-dimensional imaging with spatial resolution of about 4 nm. We are currently focusing our efforts on extending MRFM resolution to below 1 nm – or roughly an order of magnitude improvement over today’s capability. Current work focuses on using nitrogen-vacancy centers in diamond as localized magnetometers for nanoMRI.

3) *BioProbes*

Understanding the principle and processes that govern the functions of cell membranes will help us tailor drugs to effectively penetrate the membrane for efficient treatment. The novel BioProbes will directly study the membrane and measure the forces, mechanical stiffness, electrostatics, and sequence of biological processes to replace and complement more traditional remote sensing techniques. Our theme adapts unique cantilever designs for aqueous solution, based on recently invented torsional and dual-cantilever AFM probes that have extremely high force sensitivity together with kHz sampling frequencies, ideal for

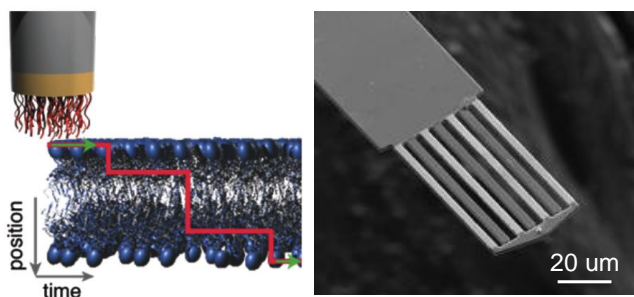


Figure 2. (left) Schematic of cell-penetrating peptides attached to the end of a cylindrical AFM tip and their trajectory during lipid bilayer penetration. (right) SEM image of ultrafast cantilevers for dynamic force measurement. The relative displacement between these two sets of fingers (measured interferometrically) is a measure of the tip-sample interaction force.

biological samples. Functionalized probe tips on the cantilevers provide specific biomolecular functionality, enabling us to attack the biologically important processes of viral peptide penetration and ion channel activity (Fig. 2). These metrologies will unlock the real time mechanical and electronic processes at and within biological membranes that are currently inaccessible by any other technique.

Outreach and Education

Nanotechnology is being increasingly adopted by industry, and current and future generations will encounter a significant amount of nanotechnology in their day-to-day products. Educating the public about nanotechnology is therefore at the core of CPN's outreach activities with the goal of creating a diverse science literate workforce.

It is known that middle school students lose interest in science and therefore CPN's outreach program is targeting this particular age group to retain and foster students' interest and excitement about nanotechnology and nanoscience. A successful approach for reaching middle school students has been the Summer Institute for Middle School Teachers (SIMST). Middle school teachers participate in an intensive week-long program of content lectures, hands-on activities and curriculum development exercises (Fig. 3). CPN helps the teachers to apply their new knowledge by having them create nanoscience lessons that are shared among participants for use during the school year. Activities are available through CPN's teacher website (<http://teachers.stanford.edu>) as well as through CPN's partner organization, Resource Area for Teachers (RAFT), which distributes ready-to-use, low-cost classroom kits of the developed nanoactivities to Bay Area Teachers.



Figure 3. Teachers from SIMST 2012 in front of Stanford's Memorial Church.

CPN also organizes a range of educational workshops, partners with formal and informal educational organizations (K-12 schools, science museums, NISE Network, etc.) in the pursuit of creating a diverse and scientific literate workforce to benefit current and future generations. An Annual Nanoprobe Workshop, which features 8-10 world-class nanoscience researchers as speakers, provides an excellent opportunity for academic and industrial scientists to exchange knowledge and ideas and to broaden the horizons of our students. The 8th workshop was held in May 2012 and attracted about 180 participants from academia and industry. CPN's Industrial Affiliates program offers companies an opportunity to engage with Center participants to collaborate on research programs or just stay informed on Center developments through newsletters. CPN is engaged with companies such as Agilent Technologies, Applied Materials, Asylum Research, IBM, FormFactor, Park Systems, Veeco Instruments, among others.

References

- [1] For further information about this project, visit <http://cpn.stanford.edu>
- [2] For a list of publications, visit <http://cpn.stanford.edu/research/pubs.html>