Stanford University Center for Probing the Nanoscale

NSF NSEC Grant 0830228
Director: David Goldhaber-Gordon, Deputy Director: Nicholas Melosh
Stanford University

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.

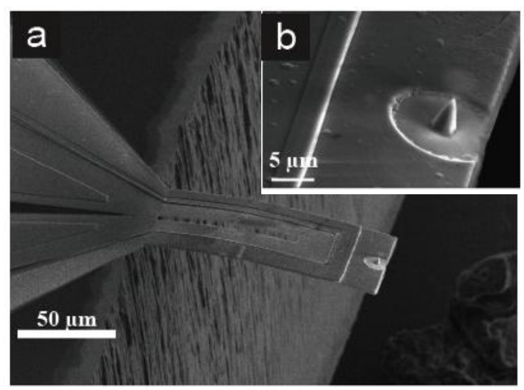

Figure 1. SEM images of novel probes that integrate a coaxial tip to produce a highly-localized electric field and a piezoresistor for self-sensing of tip deflection. These probes have been batch-fabricated and can be used for both Scanning Gate Microscopy and Scanning Microwave Microscopy. Ref. [1]

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, inhomogeneity in structure or doping, or spontaneous organization of electrons. These local variations have important

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

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. Both techniques 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 of tip deflection (Fig. 1).

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. We are currently focusing our efforts on extending magnetic resonance force microscopy 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 (Fig. 2).

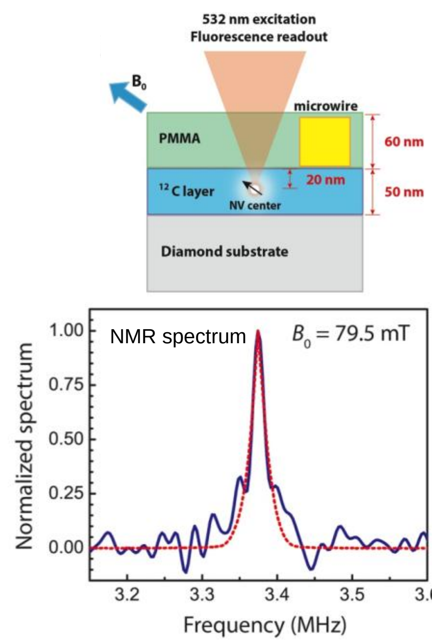

Figure 2. Single nitrogen-vacancy centers were used to detect nanotesla-field fluctuations from protons in a sample external to the diamond. The detection uses an electron spin – nuclear spin double resonance method with optical fluorescence readout. Ref. [2]

3) BioProbes

Understanding the principles 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

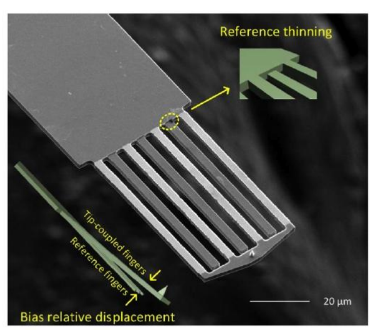

Figure 3. SEM image of ultrafast cantilevers for dynamic force measurement in liquids. The relative displacement between two sets of fingers (measured interferometrically) is a measure of the tip-sample interaction force. Ref. [3]

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 biological samples (Fig. 3). 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. 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 their interest and excitement about science. A successful approach for reaching middle school students has been through their teachers in the Summer Institute for Middle School Teachers. Middle school teachers participate in an intensive week-long program of content lectures, hands-on activities and curriculum development exercises. CPN helps teachers 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, which distributes ready-to-use, low-cost classroom kits to Bay Area Teachers.

CPN also organizes a range of educational workshops and partners with formal and informal educational organizations (K-12 schools, science museums, NISE Network, etc.) in the pursuit of creating a diverse and science-literate workforce. An Annual Nanoprobes 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. CPN's Industrial Affiliates program offers companies an opportunity to engage with Center participants to collaborate on research programs and 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] A.J. Haemmerli, R.T. Nielsen, W. Kundhikanjana, N. Harjee, D. Goldhaber-Gordon, Z.X. Shen, B.L. Pruitt, "Low-impedance shielded tip piezoresistive probe enables portable microwave impedance microscopy." *Micro & Nano Letters* **2012,** *7* (4), [doi:10.1049/mnl.2011.0679].
[2] H.J. Mamin, M. Kim, M.H. Sherwood, C.T. Rettner, K. Ohno, D.D. Awschalom, D. Rugar, "Nanoscale nuclear magnetic resonance with a nitrogen-vacancy spin sensor." *Science* **2013**, *339* (6119), [doi:10.1126/science.1231540].
[3] K. Vijayraghavan, A. Wang, O. Solgaard, M.J. Butte, N.A. Melosh, "Measurement of elastic properties in fluid using high bandwidth atomic force microscope probes." *Appl. Phys. Lett.* **2013,** *102* (10), [doi:10.1063/1.4795598].
For further information about this project, visit http://cpn.stanford.edu
For a list of publications, visit http://cpn.stanford.edu/research/pubs.html