Center for Probing the Nanoscale

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Stanford and IBM have a distinguished legacy in nanoprobe technology. The goal of the Center for Probing the Nanoscale (CPN) is to continue this legacy and broaden its impact. CPN aims to develop the nanoprobes that will become the standard equipment of the future, enabling the nanotechnology community to measure, image, and control nanoscale phenomena [1].

Government Nanotechnology Funding: An International Outlook, published by the National Science Foundation, predicts that worldwide annual industrial production in the nanotechnology sectors will account for a $1 trillion annual market and employ 2 million people within 10 to 15 years [2]. All the scientists and engineers working to realize this vast economic potential have something in common: they all need better tools for probing the nanoscale.

The NSF-Stanford-IBM NSEC, Center for Probing the Nanoscale (CPN), has five goals:

- *To develop novel probes* that dramatically improve our capability to observe, manipulate, and control nanoscale objects and phenomena.
- *To apply these novel probes* to answer fundamental questions in science and to shed light on materials issues that have economic importance for industry.
- *To educate the next generation of scientists and engineers* on the theory and practice of nanoprobes.
- *To transfer our technology to industry* so that corporations can manufacture and market our novel probes.
- *To inspire tens of thousands of middle school students* by training their teachers at a Summer Institute.

We intend to develop a toolbox of nanoprobes with revolutionary capabilities, including:

- Scanning Tunneling Potentiometry (STP) that can image and measure electrical transport on 10-nm length scales.
- Scanning Tunneling Microscopy (STM) that can not only image and manipulate single atoms, but can also conduct Electron Spin Resonance experiments with single-spin sensitivity.
- Magnetic Force Microscopy (MFM) probes with magnetic metal-coated carbon-nanotube tips that can image, measure, and manipulate magnetic structures on 5-nm length scales.
- Near-field Scanning Optical Microscopy (NSOM) to measure optical properties and focus light to 30-nm length scales, with a thousandfold improvement in photon throughput compared to present NSOM throughputs.
- Scanning Hall Probe Microscopy (SHPM) that can non-invasively image and quantitatively measure weak magnetic fields with 30-nm spatial resolution.
- Scanning SQUID Microscopy (SSM), and scanning SQUID susceptometry, with sub-micron spatial resolution and with magnetic sensitivity approaching the quantum limit, with the ability to detect the spin of a few electrons.
- Magnetic Resonance Force Microscopy (MRFM) that can detect the spin of a single electron, specify the location of the electron in three dimensions with nanometer resolution, and measure the quantum mechanical state of the spin.

To facilitate the commercialization of our instruments and to elucidate critical materials isssues in joint research with industry, we have initially formed collaborations and partnerships with IBM, Veeco, Asylum Research, WITec, NanoMagnetics, Superconductor Technologies Inc., Seagate, and American Superconductor Corporation.

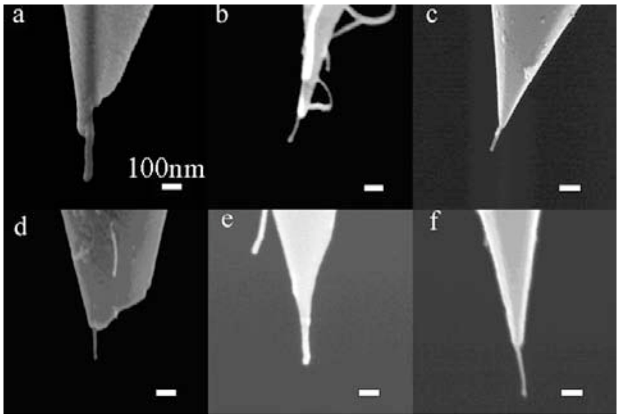

Figure: A nanoprobe improvement invented by CPN investigators [3]. The Scanning Electron Microscope images show magnetic metal-coated carbon nanotube tips for use in Magnetic Force Microscopy. The nanotube tips are as small as 5 nm in radius, enabling great improvement in the spatial resolution of magnetic imaging with MFM compared to the conventional pyramid tips on which they are grown. Each image shows a 100 nm scalebar.

We will encourage and assist scientists and engineers who want to duplicate our probes. To educate them about our work and to elicit their feedback, we will give public presentations and publish papers on nanoprobe instrumentation in *Review of Scientific Instruments* as well as more specialized journals. We will organize an annual workshop on advanced nanoprobes and post descriptions of our probes on the Center website with contact information for people who want more details. The participating investigators will place a high priority on responding to inquiries.

We are deeply committed to educating the next generation of scientists and engineers regarding the theory, practice, and implications of our novel probes. The *CPN Fellows Program* will support graduate students, postdocs, and visitors engaged in nanoprobe research and education. CPN Fellows will present their work internally and receive constructive feedback from a friendly audience. CPN will organize courses for graduate students, for undergraduate science students, and for undergraduate non-science majors.

CPN courses for laypeople include “Probing the Nanoscale,” a course whose goal is to familiarize the students with Nanoscale Science and Engineering. The target audience includes non-technical majors, venture capitalists, lawyers, and managers and employees in technology-driven businesses. The course will fulfill a Stanford Distribution Requirement to make it attractive to Stanford students. The Stanford Center for Professional Development (SCPD), a national leader in the delivery of e-learning to technical professionals, will broadcast and record the course and will provide the course *free* to community colleges.

CPN courses for professional scientists and engineers include “Professional Ethics for Scientists” and “Advanced Nanoprobes”. Prof. Mac Beasley will lead the first CPN course, “Advanced Nanoprobes”, during the winter quarter of 04-05. Each participating investigator will teach one week of the course, reviewing his or her own area of expertise. The investigator will lecture during the first two classes and answer questions during the third class. This class will help us to achieve tight integration between research and education, and we anticipate that the course notes will become a seminal on-line reference.

The CPN Summer Institute for Middle School Teachers is a cornerstone of the Center. Middle school is a crucial time for students to form an interest in science, or conversely to lose interest in science [4]. It is the beginning of the science and engineering pipeline problem. But middle school is also an opportunity to fix a leak in the pipeline: students are ready for sophisticated concepts in middle school, according to National and California State standards [5]. For both of these reasons, middle school is the ideal time to share our enthusiasm and to give students a taste of cutting-edge research that is integrated with the curricular standards for their age level. The CPN Summer Institute will reach forty teachers per summer, eventually reaching tens of thousands of middle school students during the 5-year tenure of CPN.

An internal Executive Committee will administer CPN, allocate funding, evaluate the performance of the research groups, and decide annually which groups to renew and which new groups to fund. Final authority for continuing or sunsetting programs will rest with the PI, Kam Moler. Co-Directors Moler and Goldhaber-Gordon will otherwise share responsibility for running the Center. An External Advisory Board will monitor progress, explain problems of interest to industry, and advise on administrative issues. The Co-Directors will appoint an external Scientific Review Committee to review CPN twice during the term of the Center.

This is our vision for the Center for Probing the Nanoscale:

- The Center environment will challenge us, inform us, and stimulate us to develop better probes – and to develop them sooner than we could working individually. Our probes and our experiments will open the doors to new fields of science.
- The interdisciplinary Center will provide a broader and deeper education for students than graduate study in a single department can provide.
- Difficult problems which people from other organizations bring to the Center will inspire us and stimulate us to do outstanding science.
- Our probes and our experiments will solve materials problems that have restricted economic growth in the larger industrial community.
- Our experiments will not only demonstrate the capabilities of the probes, but also advance their development sufficiently so that industrial engineers can design commercial products based on our prototypes. We will transfer our probes to instrument manufacturers and share designs with other researchers so that people in all areas of nanoscale science and engineering can enjoy access to their capabilities.
- Our probes will help scientists and engineers to commercialize nanotechnologies.
- Our students will apply our probes to make discoveries that reveal deep truths of the nanoscopic world.
- Our students will be well educated and well positioned to make meaningful long-term contributions to nanoscale science ane engineering.

References

[1] For further information about this project link to http://www.stanford.edu/group/cpn/ or email <lietz@stanford.edu>.
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[4] Nat'l Science Teachers Association position statement: http://www.nsta.org/positionstatement&psid=20
[5] National Science Education Standards: http://www.nap.edu/readingroom/books/nses/html/6d.html