CENTER FOR PROBING THE NANOSCALE
An NSF Nanoscale Science and Engineering Center

About the CPN

Stanford University and IBM Corporation, with funding from the National Science Foundation, founded the Center for Probing the Nanoscale to achieve five principal 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 which have economic importance for industry.
- To *educate the next generation of scientists and engineers* regarding the theory and practice of these probes.
- To *transfer our technology to industry* so that corporations can manufacture and market our novel probes worldwide.
- To *inspire thousands of middle school students* by training their teachers at a Summer Institute for Middle School Teachers.

Director: Kathryn Moler (kmoler@stanford.edu)
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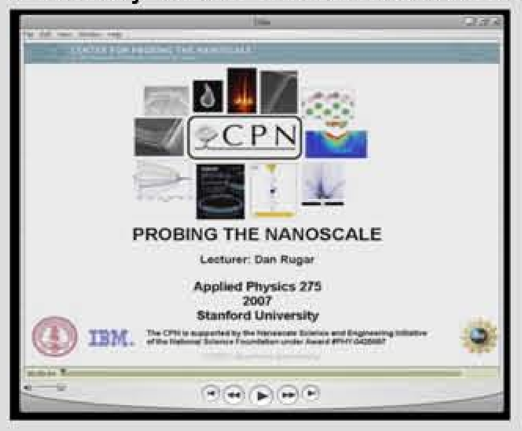
CPN Education Programs

The Summer Institute for Middle School Teachers (SIMST)

In June of 2007 the CPN offered the second annual Summer Institute for Middle School Teachers (SIMST) to 16 teachers from California.
Our goal was to excite teachers about nanoscale science while increasing their knowledge of physical science and providing them with ready-to-use learning modules. Teachers worked closely with CPN scientists on inquiry-based modules that address California's 8th grade science content standards. Alumni of the program have access to the CPN nanoprobe lending-library. For information contact Kyle Cole (kylecole@stanford.edu, 650-723-4490)

On-line Nanoprobe Videos

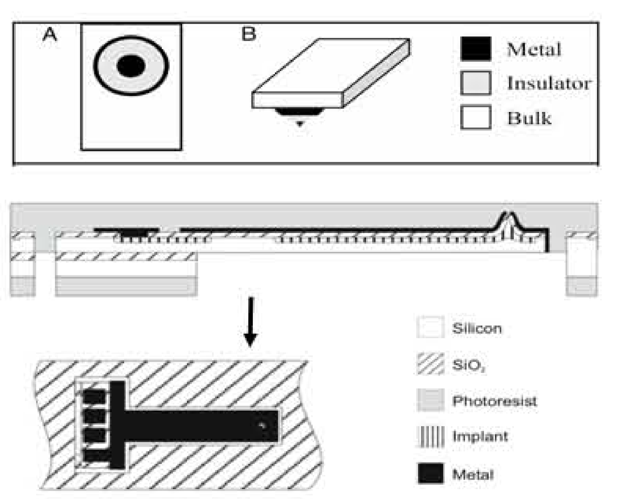
The CPN is deeply committed to educating the next generation of scientists and engineers and offers a variety of on-line educational videos. Videos of the course "Probing the Nanoscale" (Applied Physics 275) overviews the principles and practice of various scanning probes and includes seminar-type lectures on the applications being pursued by CPN researchers.



- Video lectures on nanoprobe theory, operation and research.
- Available with English captions
- Term-searchable database links to multiple videos containing your search term
- See website for details: http://www.stanford.edu/group/cpn/

NANOELECTRONIC THEME

Coaxial Tip Piezoresistive Probes

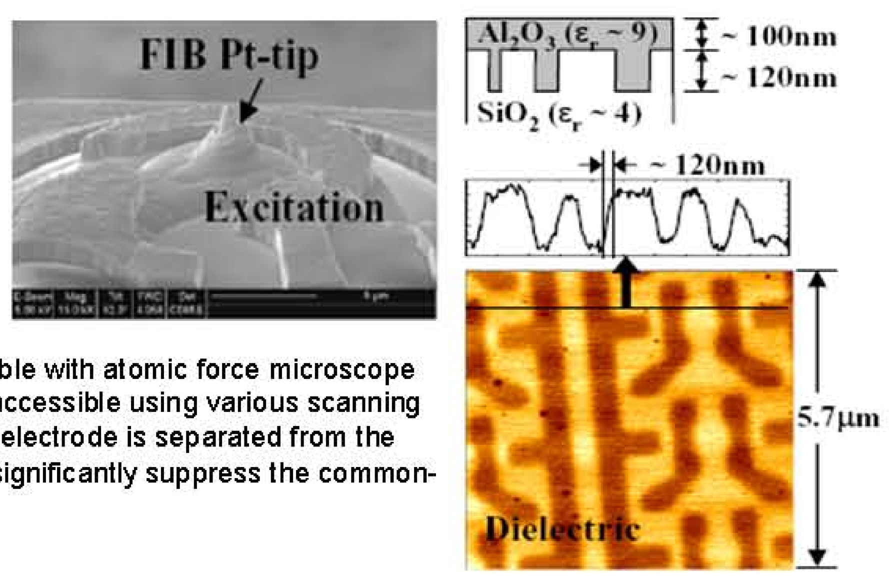


GOAL: to design, fabricate and characterize a novel probe consisting of a cantilever with an integrated coaxial tip capable of producing a highly-localized electromagnetic perturbation.

FIGURES: Top AB: Schematic of the proposed cantilever with coaxial tip. A. Bottom view and B. Side view. The outer conductor and insulator are shown etched back for illustration purposes. **Middle:** Fabrication process for the coaxial tip (shown in cross-section). **Bottom**: top view of piezoresistive probes. (Pruitt, Goldhaber-Gordon, Nahid Harjee)

Scanning Microwave Microscope

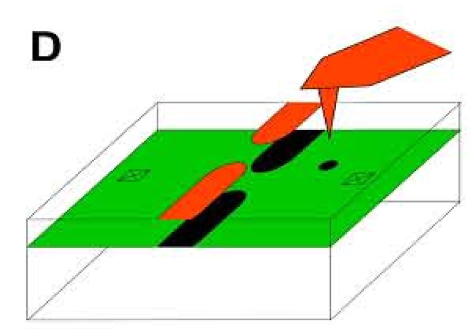
GOAL: to develop a near-field scanning microwave microscope (NSMM) with transmission lines and the sensor unit patterned on a silicon nitride cantilever interchangeable with atomic force microscope (AFM) tips, and easily accessible using various scanning platforms. The sensing electrode is separated from the excitation electrode to significantly suppress the common-mode signal.

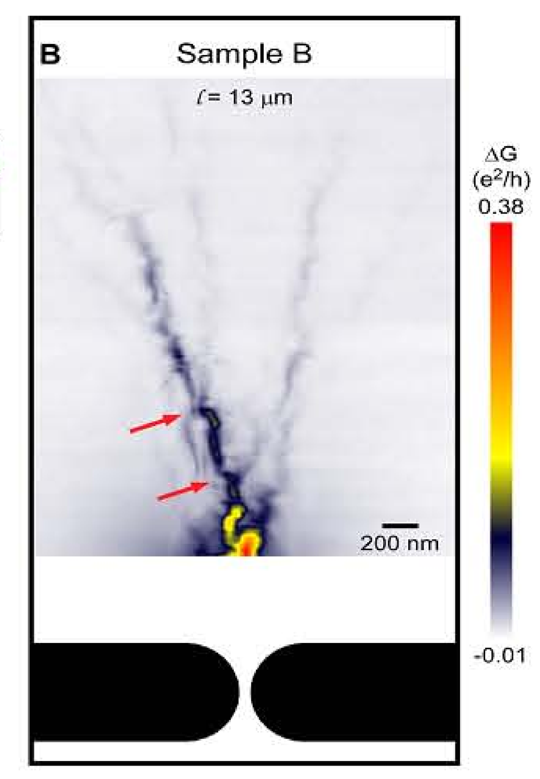


FIGURES: SEM image of the probe end, showing the excitation electrode and the Pt-tip deposited by FIB. Flat sample with sub-surface dielectric contrast. The NSMM image shows clear contrast in the dielectric channel with ~120nm spatial resolution. (Shen, Kelly, Lai)

Scanning Gate Microscopy

GOAL: advance scanning gate microscopy (SGM) probes and techniques to map electron organization in semiconductor quantum dots.





Figures: D: SGM schematic showing metallic gates and tip, orange, creating depletion regions, black, in the 2DEG, green, buried below the surface of the sample. **B:** Electron flow originates from the QPC formed between two depletion regions (black). Red arrows denote branch points where one branch splits into two. (Goldhaber-Gordon, Jura, Sciambi)

Theme Leader: Mark Brongersma

Funded Projects and Participants

- **"Patterning Nano and Micro Metal Electrodes Using Dip-Pen Nanolithography"** Zhenan Bao and Maria Wang
- **"Scanning Tunneling Potentiometry"** Malcolm Beasley and Mike Rozler
- **"New optical probes for near-field optical microscopy in the visible and mid-infrared"** Mark Brongersma and Jon Schuller
- **"Carbon nanotube atomic force microscopy tip"** Hongjie Dai and Zhou Chen
- **"Scanning gate microscopy"** David Goldhaber-Gordon, Adam Sciambi and Michael Jura
- **"AFM-compatible near-field scanning microwave microscope"** Zhi-Xun Shen, Mike Kelly and Keji Lai
- **"Coaxial Tip Piezoresistive Probes for High-Resolution Scanning Gate Microscopy"** Beth Pruitt and Nahid Harjee

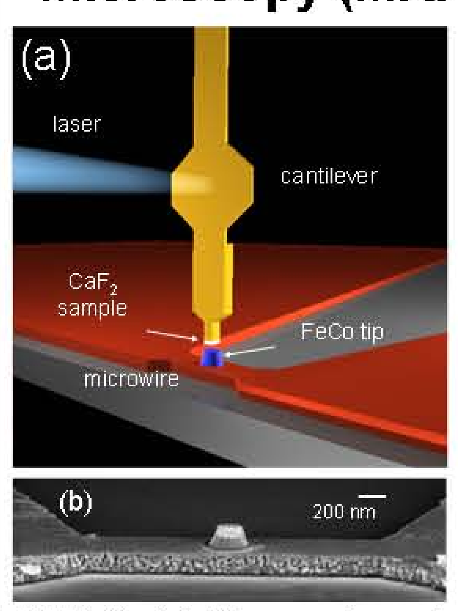
NANOMAGNETIC THEME

Theme Leader: John Kirtley

Funded Participants

- **"Development of Scanning M-O Sagnac probe"** Aharon Kapitulnik and Jing Xia
- **"First-principles calculations of atomic-scale STM-engineered surface spins"** Barbara Jones, Chiung-Yuan Lin
- **"High spatial resolution current imaging with the magnetic force microscope"** John Kirtley
- "**Quantum nanoprobes based on scanning tunneling microscopy**" Hari Manoharan, Brian Foster, Laila Mattos, Chris Moon and Jason Randel
- Kathryn Moler and Lan Luan
- **"Nano-SQUID Susceptometry with Single Electron Spin Sensitivity"** Kathryn Moler and Nick Koshnick
- **"Magnetic Resonance Force Microscopy"** Dan Rugar and Martino Poggio

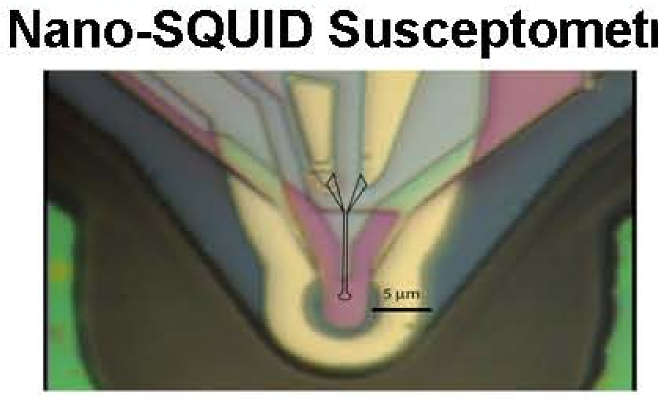
Magnetic Resonance Force Microscopy (MRFM)



GOAL: develop a microscope that can directly determine three-dimensional molecular structures based on ultrasensitive force detection of nuclear spins. Recent improvement to the magnetic resonance force microscope include the development of sharp magnetic tips that produce field gradients over 14 gauss per nanometer and a lithographically fabricated copper "microwire" that allows a 40 gauss rf field to be generated with less than 500 microwatts of heating. ("Nuclear magnetic resonance imaging with 90-nm resolution," Mamin, et al., Nat Nano 2:301 (2007)).

FIGURES: (a) Diagram of sample-on-cantilever MRFM with microwire rf field source and integrated FeCo tip.
(b) Scanning electron micrograph of copper microwire with integrated magnetic tip.

Nano-SQUID Susceptometry

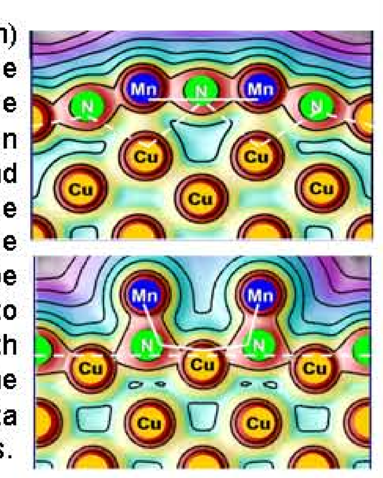


GOAL: develop an ultra-sensitive, high resolution Superconducting QUantum Interference Device (SQUID) Microscope to measure magnetic flux. Recent efforts have focused on defining a lithographic touch down point on the tip (lower purple tab). This point will bring the sensor within 100 nanometers of the sample. (Moler, Koshnick)

FIGURE: Image of a scanning SQUID tip, where an electron beam defined pickup loop (drawn in black) could have the sensitivity to magnetically detect a single electron spin.

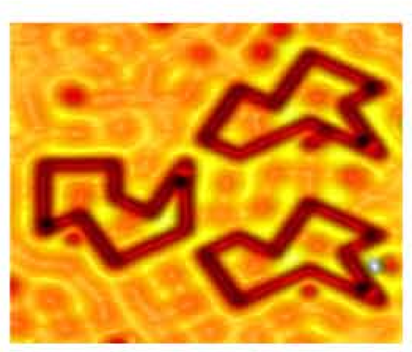
First-principles Calculations of Surface Spins

GOAL: Use magnetic atoms (Mn) placed on an insulating copper-nitride monolayer on top of a Cu(100) surface to answer how strong is the interaction between two spins on this surface and how can the interaction strength be tuned? What is the anisotropy of a single atomic spin and how can it be controlled? The first topic is related to fabricating atomic-scale structures with magnetization on a surface and the second relates to constructing data storage bits by aligning the atomic spins.



FIGURES: Charge density contours of Mn dimer in the CuN surface (left) at the Cu site (right) at the N site. The dash lines indicate how the CuN surface atoms in the presence of Mn displace differently in two cases. The solid lines show the coupling paths between Mn atoms. (Jones and Lin)

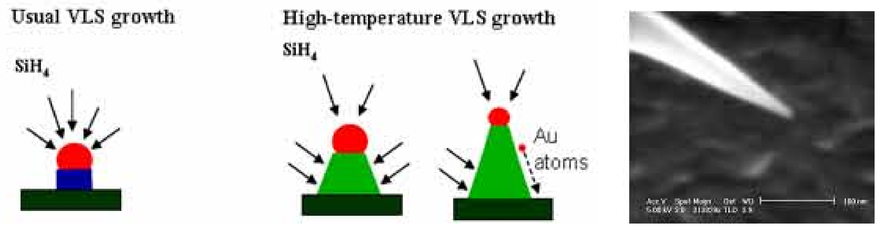
Quantum Isospectral Nanostructures



GOAL: Develop an ultasensitive scanning tunneling microscope (STM) to map electron wavefunctions in nanostructures. Two of these quantum mechanical resonators are isospectral – that is, all of their allowed energy levels are identical – and the third is not. Each assembly, which corrals the two-dimensional sea of electrons on a copper (111) surface, was created from 45 carbon monoxide molecules. Here, the STM's ability to build atomically precise nanostructures, measure their electronic energy levels, and map their wavefunctions sheds light on a problem in contemporary mathematics: "Can one hear the shape of a drum?" In the case of quantum mechanical drums, it seems, the answer is "No." *[Rendered 15 nm x 15 nm STM topograph. CO on Cu(111) with a few defects of unknown identity.] (Manoharan , Moon)*

MOLECULAR MECHANICS THEME

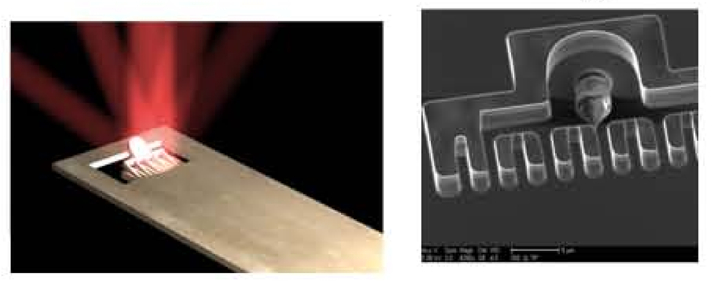
Nanowires as Novel Probe Tips



GOAL: to develop cone-shaped silicon and metal nanocones (NC) by vapor-liquid-solid (VLS) growth and using them as a new type of scanning electrochemical probe. These tips have a sub-5 nm end radius and offer both high spatial resolution and stable base support for the probe tips.

FIGURES: (Left) VLS growth: Au nanoparticles catalyze silane (SiH4) decomposition and define the diameter of Si NWs. To produce Si NCs, growth temperature is raised so that Au nanoparticles shrink by diffusion along substrate surface. (Upper right) SiN nanocone with ~5 nm end radius and high aspect ratio without any sharpening process. (Cui, Zhu)

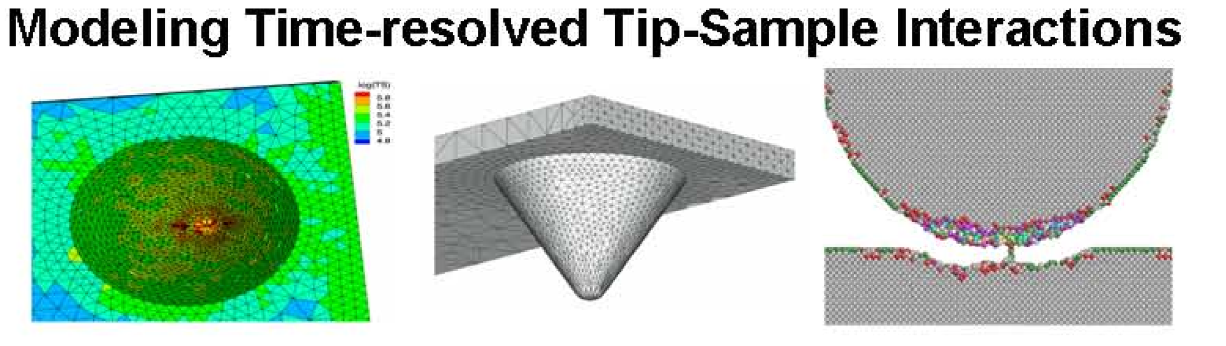
Time-Resolved Scanning Force Microscopy



GOAL: develop scanning probe microscopy (SPM) for quantitative measurements of mechanical and chemical surface properties at the nanoscale. Our method is based on measurement of time-resolved interaction forces between the atomic force microscope (AFM) tip and the sample surface by using a micro-machined cantilever with an integrated high-bandwidth force sensor. Traditional AFMs are only sensitive to the force impulse, or the average interaction force, limiting its use to topography measurements.

FIGURES: (Left) shows a drawing of our proposed cantilever structure for time-resolved force measurements. A mechanical resonator on the cantilever forms a diffraction grating that serves as a relative displacement sensor. During operation, the cantilever oscillates near its fundamental resonance frequency. During a fraction of oscillation cycle, the tip interacts with the sample. The high-bandwidth resonator responds to the interaction force, whereas the cantilever itself moves approximately as an harmonic oscillator because of its lower mechanical bandwidth. (Right) shows a scanning electron microscope (SEM) image of a fabricated cantilever.

Modeling Time-resolved Tip-Sample Interactions



GOAL: enabling the simulation and understanding of the interaction of an AFM tip with samples of different stiffness. We are exploring practical ways of utilizing time-resolved force information to expand the applicability of AFM as a measuring tool and enhance its reliability. The current focus is in exploring the reliability of local mechanical properties of the sample through continuum mechanics and atomistic models.

FIGURES: (Left and middle) Detail of the mesh used for the simulation of the dynamics of AFM with the parallel asynchronous variational integrators (PAVI) algorithm. Notice the fine discretization used at the tip. The number of time steps each element performs during the simulation is color coded on the left, in logarithmic scale. (Right) Quasi-2D atomistic model with periodic boundary conditions, silicon-like potentials in the tip and the sample, and a variable attractive interaction between them. The colors indicate the coordination number of each atom. Snapshots at very high values of adhesion show that the tip and sample exchange atoms, a highly unlikely situation to be observed.

Theme Leader: Olav Solgaard

Funded Participants

- **"Time-Resolved Scanning Force Microscopy"** Olav Solgaard and Fatih Sarioglu
- **"Interferometry for nanometer precision measurements in model membrane systems"** Steven Boxer and Prasad Ganesan,
- **"Nanowires as New Probes for Scanning Electrochemical Microscopy"** Yi Cui, Jia Zhu
- "**Modeling Time-resolved Interactions Between an AFM Tip and a Sample Surface**" Adrian Lew and Haneesh Kesari
- **"Interaction Forces and Mechanics of Cellular Membranes using Novel Atomic Force Microscopy Probes"** Nick Melosh and Ben Almquist
- **"Scanning Near-Field Optical Raman Microscope"** W.E. Moerner and Frank Jaeckel