# Center for Probing the Nanoscale - NSF NSEC Grant 0830228


## PI: David Goldhaber-Gordon, Co-PI: Nicholas Melosh

## Stanford University, Stanford, CA 94305


## About the Center for Probing the Nanoscale

Stanford University and IBM Corporation, with funding from National Science Foundation, founded the Center for Probing the Nanoscale to achieve five principal goals:

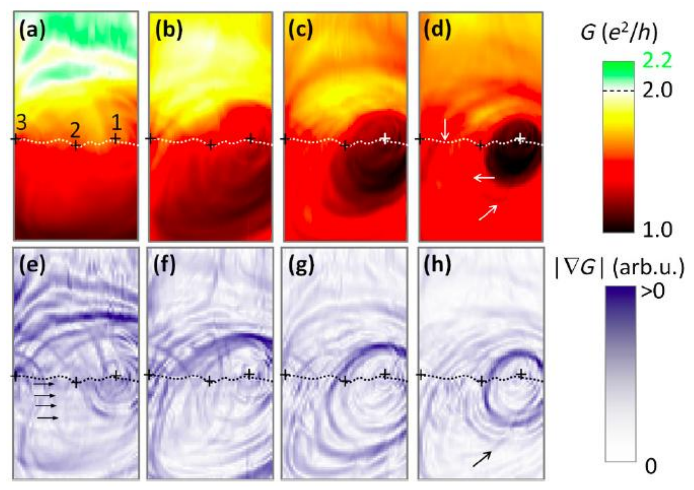
- **develop novel probes** that dramatically improve our capability to observe, manipulate, and control nanoscale objects and phenomena
- **educate the next generation of scientists and engineers** regarding the theory and practice of these probes
- **apply these novel probes** to answer fundamental questions in science and technology
- **transfer our technology** to industry in order to make these novel probes widely available
- **inspire** students, teachers and the public about nanotechnology

## Nanoscale Electrical Imaging

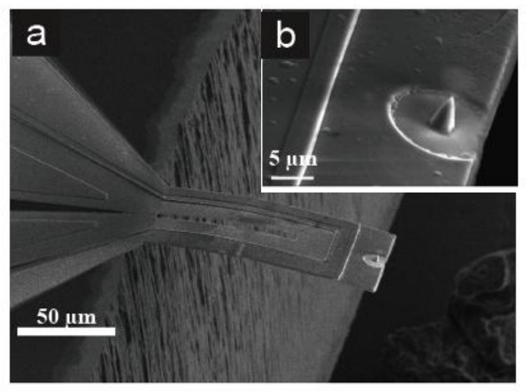
**Goldhaber-Gordon**, Shen, Pruitt

- **Measure electronic properties of materials at 10-nm resolution.**
- Tools under development:
  - **Scanning Gate Microscopy (SGM)**: Electrostatic coupling of a quasi-DC tip voltage to sample. Continuing studies on local charge transport in graphene, complex oxides, and topological insulators.
  - **Near-field Scanning Microwave Microscopy (NSMM)**: Electric or magnetic coupling of a microwave signal from a tip to a sample. Continuing studies on electronic phase transitions in manganites, 2DEG systems, topological insulators, and ferroelectrics.


*NSMM on a static random access memory sample reveals a thin layer of the dopant ions penetrating through the protective layers during the heavy-ion implantation steps.*




*SGM conductance and gradient maps in the quantum spin Hall regime at different applied tip voltages. The dotted lines indicate the edge of the HgTe device. Scattering sites, identified by sets of concentric rings, likely limit the expected non-dissipative transport in the helical edge channels.*

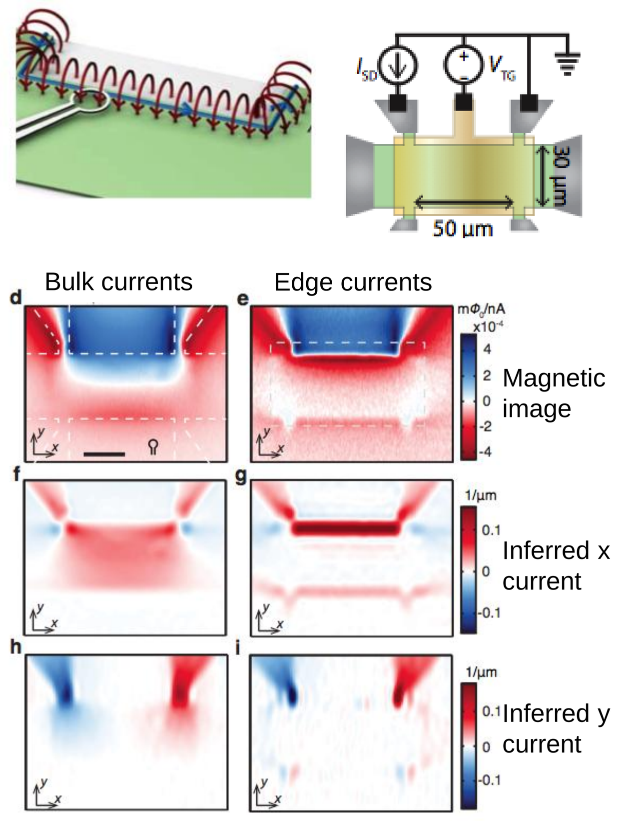



*SEM images of novel probes that integrate a coaxial tip to produce a highly-localized electric field and a piezoresistor for self-sensing tip deflection. These probes have been batch-fabricated and can be used for both SGM and NSMM.*

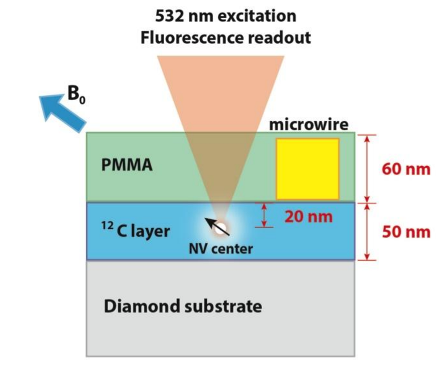
## Individual Nanomagnet Characterization

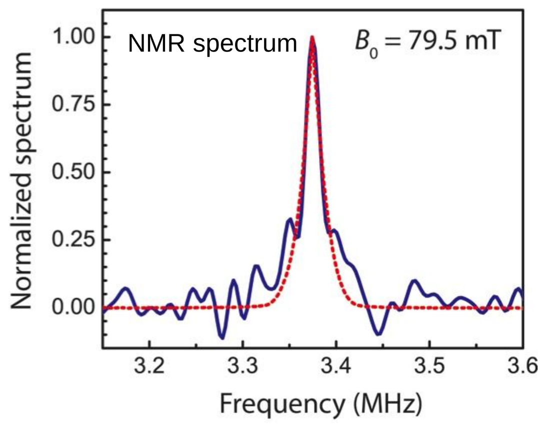
**Moler**, Kirtley, Kapitulnik, Rugar

- **Develop and demonstrate techniques with the magnetic sensitivity and spatial resolution to characterize individual nanomagnets.**
- Advancing development of **Nanoscale Magnetic Resonance Imaging** toward a molecular structure microscope.
- Tools under development:
  - **Scanning Superconducting Interference Device (SQUID) Microscopy:** Extremely sensitive instrument for imaging local magnetic fields.
  - **Scanning Sagnac Microscopy:** Interferometric technique for magneto-optic imaging based on the polar Kerr Effect.
  - **nanoMRI:** Chemically specific 3D imaging of molecular structures using magnetic resonance force microscopy and nitrogen-vacancy (NV) centers in diamond.




*SQUID enables direct observation of edge currents in a quantum spin Hall regime of HgTe quantum wells. Edge channels and bulk currents coexist, providing input on how ballistic transport may be limited in the edge channels.*



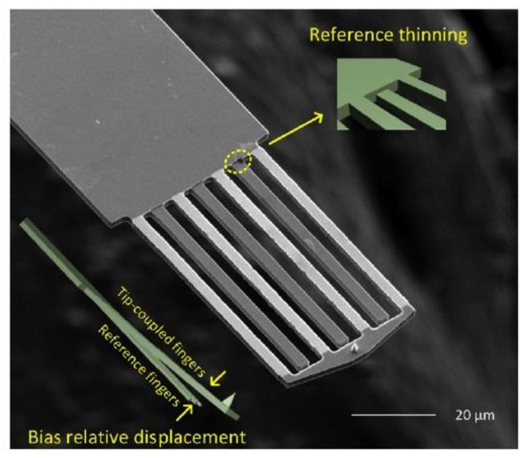




*Single NV centers were used to detect nanotesla-field fluctuations from protons in a sample external to the diamond. The detection uses an electron spin – nuclear spin double resonance method with optical fluorescence readout.*

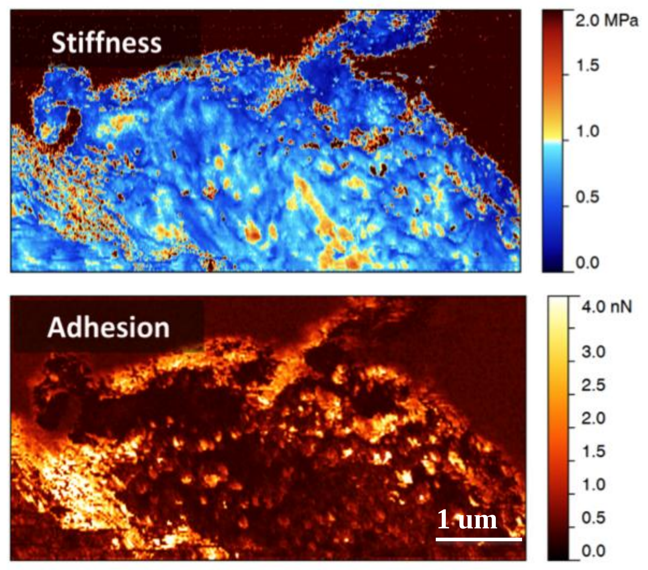
## Bio-Probes

**Melosh**, Solgaard, Butte

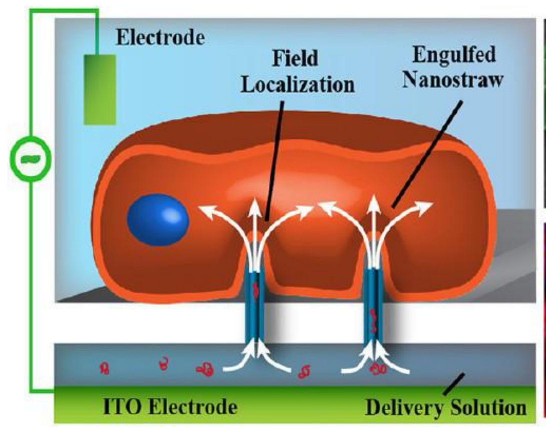
- **Measure the forces, mechanical properties, and dynamics of biological membranes** with critical resolutions of nanometers, microseconds, and pN by developing and using novel probes.
  - Combine ultrafast cantilevers with bio-functionalized stealth probes to insert into the membrane in order to gain insight on designing improved cell-entry agents.
  - Use probes to stimulate and characterize T-cells in order to understand immune activation.

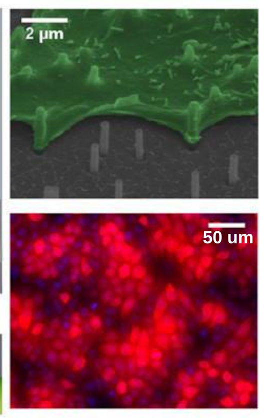



*SEM image of ultrafast cantilevers for dynamic force measurement. These interdigitated AFM probes are fabricated using standard MEMS processing techniques. The relative displacement between these two sets of fingers (measured interferometrically) is a measure of the tip-sample interaction force.*




*AFM images of fixed T-cells in fluid. The use of a high-bandwidth, diffraction-grating-based force sensor enables measurement of fast varying tip–sample interaction forces. Physical measurements of material properties of biological cells are acquired in minutes vs. days.*




*Left image: Schematic of nanostraw delivery mechanism. Nanoprobes formed on a porous substrate focus electric fields generated near the surface of a cell to create small holes in the cell wall, allowing delivery of compounds into the cell.*

*Right images: False color SEM image of cell membrane-nanostraw interfaces. Over 80% of cells were transfected to express a red fluorescent protein.*

## Selected Recent Publications


[1] J.C. Doll, A.W. Peng, A.J. Ricci, B.L. Pruitt, "Faster than the speed of hearing: nanomechanical force probes enable the electromechanical observation of cochlear hair cells." *Nano Lett.* **2012,** *12* (12), [doi:10.1021/nl3036349].

[2] J.R. Kirtley, B. Kalisky, J.A. Bert, C. Bell, M. Kim, Y. Hikita, H.Y. Hwang, J.H. Ngai, Y. Segal, F.J. Walker, C.H. Ahn, K.A. Moler, "Scanning SQUID susceptometry of a paramagnetic superconductor." *Phys. Rev. B* **2012,** *85* (22), [doi:10.1103/PhysRevB.85.224518].

[3] M. König, M. Baenninger, A.G.F. Garcia, N. Harjee, B.L. Pruitt, C. Ames, P. Leubner, C. Brüne, H. Buhmann, L.W. Molenkamp, D. Goldhaber-Gordon, "Spatially Resolved Study of Backscattering in the Quantum Spin Hall State." *Physical Review X* **2013,** *3* (2), [doi:10.1103/PhysRevX.3.021003].

[4] W. Kundhikanjana, Y. Yang, Q. Tanga, K. Zhang, K. Lai, Y. Ma, M.A. Kelly, X.X. Li, Z.-X. Shen, "Unexpected surface implanted layer in static random access memory devices observed by microwave impedance microscope." *Semiconductor Science and Technology* **2013,** *28* (2), [doi:10.1088/0268-1242/28/2/025010].

[5] J. Liu, M.J. Butte, "Single molecule labeling of an atomic force microscope cantilever tip." *Appl. Phys. Lett.* **2012,** *101* (16), [doi:10.1063/1.4760283].

[6] 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].

[7] K.C. Nowack, E.M. Spanton, M. Baenninger, M. Konig, J.R. Kirtley, B. Kalisky, C. Ames, P. Leubner, C. Brune, H. Buhmann, L.W. Molenkamp, D. Goldhaber-Gordon, K.A. Moler, "Imaging currents in HgTe quantum wells in the quantum spin Hall regime." *Nat. Mater.* **2013,** *12* (9), [doi:10.1038/nmat3682].

[8] I. Sochnikov, A.J. Bestwick, J.R. Williams, T.M. Lippman, I.R. Fisher, D. Goldhaber-Gordon, J.R. Kirtley, K.A. Moler, "Direct Measurement of Current-Phase Relations in Superconductor/Topological Insulator/Superconductor Junctions." *Nano Lett.* **2013**, [doi:10.1021/nl400997k].

[9] 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].

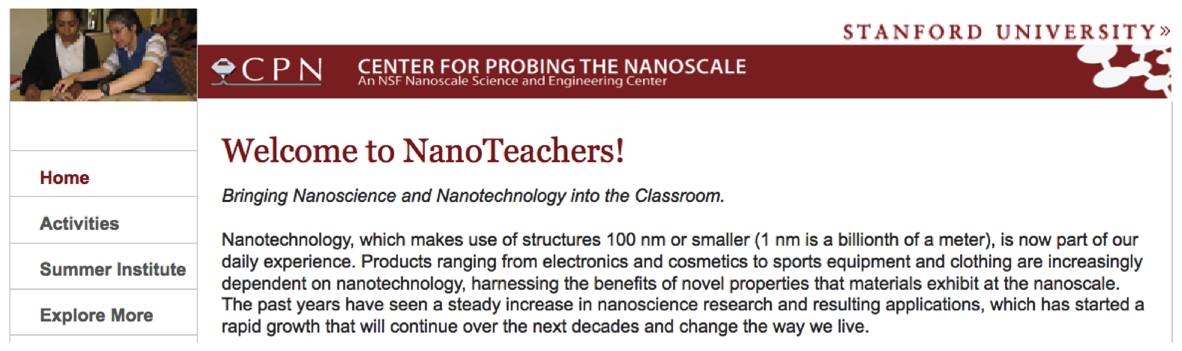
[10] X. Xie, A.M. Xu, S. Leal-Ortiz, Y. Cao, C.C. Garner, N.A. Melosh, "Nanostraw-electroporation system for highly efficient intracellular delivery and transfection." *ACS Nano* **2013,** *7* (5), [doi:10.1021/nn400874a].

[11] Y. Yang, K. Lai, Q. Tang, W. Kundhikanjana, M.A. Kelly, K. Zhang, Z.-X. Shen, X. Li, "Batch-fabricated cantilever probes with electrical shielding for nanoscale dielectric and conductivity imaging." *J. Micromech. Microeng.* **2012,** *22* (11), [doi:10.1088/0960-1317/22/11/115040].

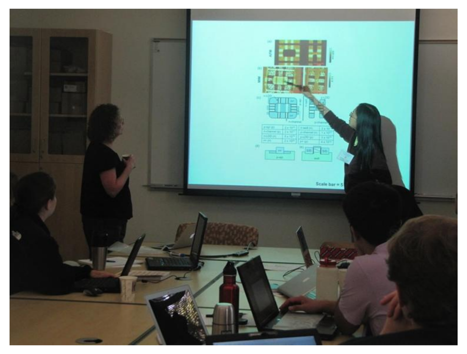

## Education and Outreach

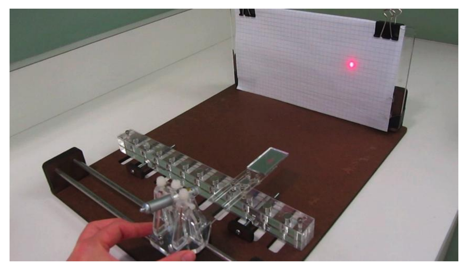
- **Summer Institute for Middle School Teachers**
  - Inspire middle school students by educating their teachers in nanoscale science and engineering during a weeklong training that includes hands-on activities and lab tours.

- Hands-on activities linked to CA Science Content Standards.
- Teacher preparation materials
- Nanoprobe models lending library
- Development of low-cost classroom activities with Bay Area distribution through Resource Area for Teachers (RAFT).




- **Workshops and seminars** for graduate students and postdocs: career paths, science communication, etc.
- Partnerships with formal and informal science education centers: K-12 schools, museums, NISE Net, Techbridge.
- **Public outreach events**: Girl Scouts Bridging, Bay Area Science Festival, NanoDays, etc.





- **Annual Nanoprobes Workshop**
  - Bring together academic and industrial scientists to exchange knowledge and ideas, form research collaborations.
  - Broaden the horizons of participants.
  - Encourage interaction between industry and graduating students.

*9th Annual Nanoprobes Workshop in conjunction with the 10th International Workshop on Nanomechanical Sensing*
*May 2, 2013*

- Industry field trips
- Industrial affiliates program
- Technology transfer through licensing and start-ups

## Center Management

**Director:**
David Goldhaber-Gordon
goldhaber-gordon@stanford.edu

**Deputy Director:**
Nicholas Melosh
nmelosh@stanford.edu

**Associate Director:**
W. Maria Wang
wmw@stanford.edu

**Program Manager:**
Laraine Lietz-Lucas
lietz@stanford.edu

**http://cpn.stanford.edu**
**http://teachers.stanford.edu**