Center for Probing the Nanoscale - NSF NSEC Grant 0830228

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About the Center for Probing the Nanoscale

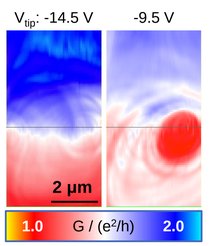
Stanford University and IBM Corporation, with funding from National Science Foundation, founded the Center for Probing the Nanoscale to achieve five principal goals:

- **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

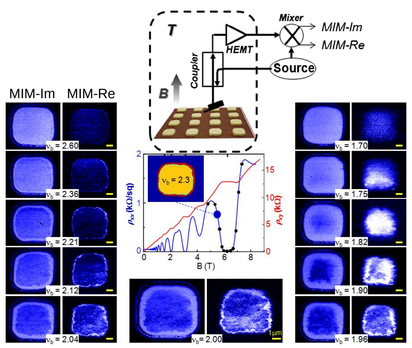
Nanoscale Electrical Imaging

Goldhaber-Gordon, Shen, Pruitt

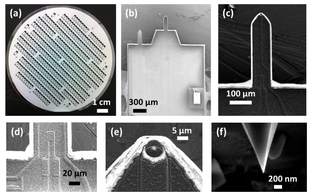
- **Measure electronic properties of materials at 10-nm resolution.**
- Tools under development:
  - **Scanning Gate Microscopy (SGM)**: Electrostatic coupling of a quasi-DC tip voltage to sample. Continuing studies on local charge transport in graphene, complex oxides, and topological insulators.
  - **Microwave Impedance Microscopy (MIM)**: 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.



SGM maps of the quantum spin Hall effect in HgTe quantum wells. The QW is etched away in the bottom half. Strong conductance modulation and full suppression of edge state transport are observed.



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 (ν_b = 2.6) to 7.3 T (ν_b = 1.7).

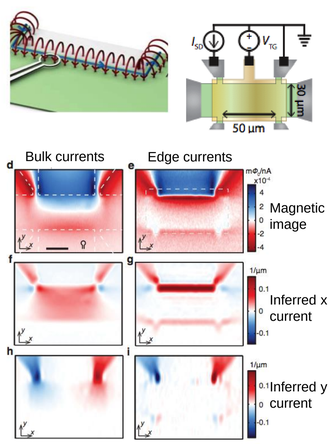


SEM images of novel batch-fabricated probes that integrate an electrical shield to reduce noise pickup and a piezoresistor for self-sensing of tip deflection. These probes have been used for simultaneous topographic and electrical imaging (MIM).

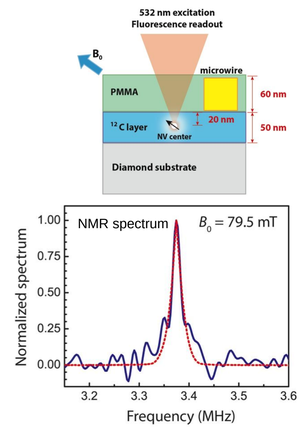
Individual Nanomagnet Characterization

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 transport coexist, providing input on how ballistic transport may be limited in the edge channels.

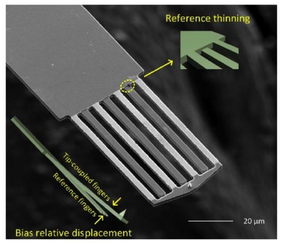


Single NV centers were used to detect nanotesla-field fluctuations from protons in a sample external to the diamond. The detection uses an electron spin – nuclear spin double resonance method with optical fluorescence readout.

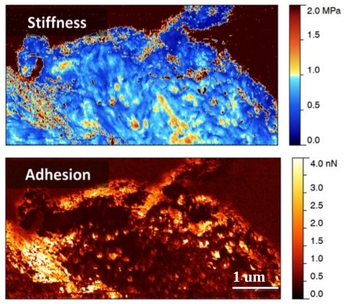
Bio-Probes

Melosh, Solgaard, Butte

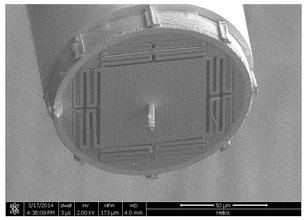
- **Measure the forces, mechanical properties, and dynamics of biological membranes** with critical resolutions of nanometers, microseconds, and pN by developing and using novel probes.
  - Combine ultrafast cantilevers with bio-functionalized stealth probes to insert into the membrane in order to gain 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.



SEM image of an AFM probe assembled onto an optical fiber. With their micron-size form factor, fiber facet AFM systems open up new applications of the technique, such as in vivo imaging of live cells. The device uses a Fabry-Pérot Cavity made of photonic crystal mirrors where the cavity doubles as the release structure of the device. In the image shown, the tip was made on a separate wafer and welded onto the final device using a focused ion beam.

Selected Recent Publications

[1] A.G.F. Garcia, M. Koenig, D. Goldhaber-Gordon, K. Todd, "Scanning gate microscopy of localized states in wide graphene constrictions." *Physical Review B* **2013,** *87* (8), [doi:10.1103/PhysRevB.87.085446].

[2] A. Gellineau, Y.P. Wong, O. Solgaard, "Engineering-reflected phase in Fabry-Perot sensors with resonant mirrors." *Opt. Lett.* **2013,** *38* (23), [doi:10.1364/ol.38.004992].

[3] K.K. Hu, M.A. Bruce, M.J. Butte, "Spatiotemporally and mechanically controlled triggering of mast cells using atomic force microscopy." *Immunol. Res.* **2014,** *58* (2-3), [doi:10.1007/s12026-014-8510-7].

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

[5] 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**].

[6] H.J. Mamin, M.H. Sherwood, M. Kim, C.T. Rettner, K. Ohno, D.D. Awschalom, D. Rugar, "Multipulse Double-Quantum Magnetometry with Near-Surface Nitrogen-Vacancy Centers." *Physical Review Letters* **2014,** *113* (3), [doi:10.1103/PhysRevLett.113.030803].

[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] M. Pelliccione, A. Sciambi, J. Bartel, A.J. Keller, D. Goldhaber-Gordon, "Design of a scanning gate microscope for mesoscopic electron systems in a cryogen-free dilution refrigerator." *Review of Scientific Instruments* **2013,** *84* (3), [doi:10.1063/1.4794767].

[9] E.R. Schemm, W.J. Gannon, C.M. Wishne, W.P. Halperin, A. Kapitulnik, "Observation of broken time-reversal symmetry in the heavy-fermion superconductor UPt3." *Science* **2014,** *345* (6193), [doi:10.1126/science.1248552].

[10] 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." *Applied Physics Letters* **2013,** *102* (10), [doi:10.1063/1.4795598].

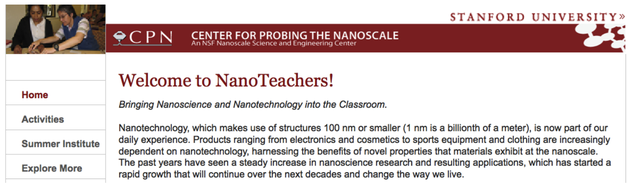
[11] A. Wang, M.J. Butte, "Customized atomic force microscopy probe by focused-ion-beam-assisted tip transfer." *Applied Physics Letters* **2014,** *105* (5), [doi:http://dx.doi.org/10.1063/1.4892075].

[12] Y. Yang, E.Y. Ma, Y.-T. Cui, A. Haemmerli, K. Lai, W. Kundhikanjana, N. Harjee, B.L. Pruitt, M. Kelly, Z.-X. Shen, "Shielded piezoresistive cantilever probes for nanoscale topography and electrical imaging." *J. Micromech. Microeng.* **2014,** *24* (4), [doi:10.1088/0960-1317/24/4/045026].

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 Network, Techbridge.
- **Public outreach events**: Girl Scouts Bridging, Bay Area Science Festival, NanoDays, etc.

- **Annual Nanoprobes Workshop**
  - Interactions between academic and industrial scientists to exchange knowledge and ideas.
  - Forum for disseminating exciting nanoprobe discoveries to the broader scientific community.

10th Annual Nanoprobes Workshop
May 2, 2014

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

Center Management

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