New Ways of Seeing: Developing and Understanding Sensors for Scanning Probe Microscopy

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Scientific Thrust Area

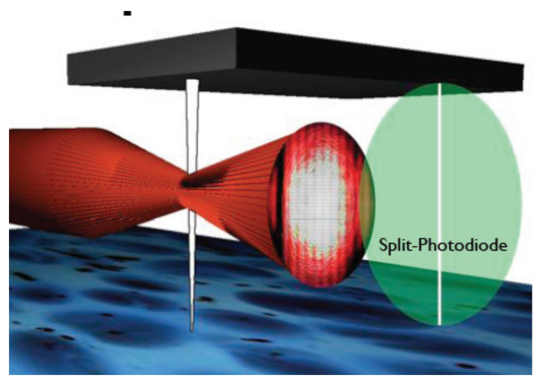
A main thrust of the Imaging and Manipulation Facility of the Molecular Foundry is to develop novel probes and extend the power of scanning probe microscopy to new areas.

- AFM studies of biological samples in fluid environments are limited by cantilever dissipation and noise. A novel "fiber force probe" is being developed to reduce the imaging noise floor by several orders of magnitude.
- A novel technique has been developed to fabricate optically-resonant plasmonic nano-antennas on AFM cantilever tips to perform near-field optical spectroscopy with ~ 20 nm resolution.
- Analytical transmission electron microscopy is being applied to study wear and failure mechanisms of AFM tips, and to explain the fundamental tribochemical wear processes that take place.
- Self-actuating self-sensing AFM cantilevers developed at the Technical University of Ilmenau are being applied to in-situ electron microscopy studies.

Research Achievements

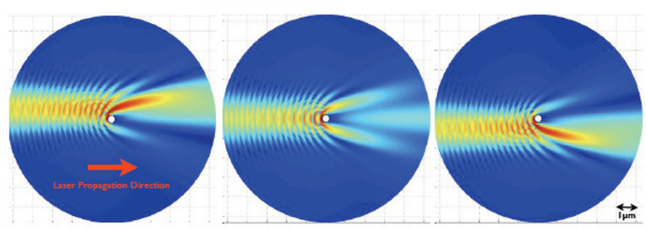
Fiber Force Probe

Imaging soft materials such as cell membranes and protein structures requires low forces to avoid sample deformation or damage. Cantilever thermal noise caused by coupling to the fluid environment (dissipation) places a fundamental lower limit on the forces that can be measured. Reducing the cross-section of the cantilever decreases the noise, but size reduction is limited by the AFM optical detection mechanisms. In the "fiber force probe" concept, shown at right, the deflection of a sub-wavelength nanowire cantilever is measured by forward scattering, similar to the methods used in "optical tweezers" experiments.



The "fiber force probe" concept

Detailed Mie-scattering calculations predict high force resolution for the fiber force probe, as shown in the simulated images at right. These predictions have been experimentally verified using 100 nm diameter $AgGa_2$ single-crystal nanowires and red laser light.

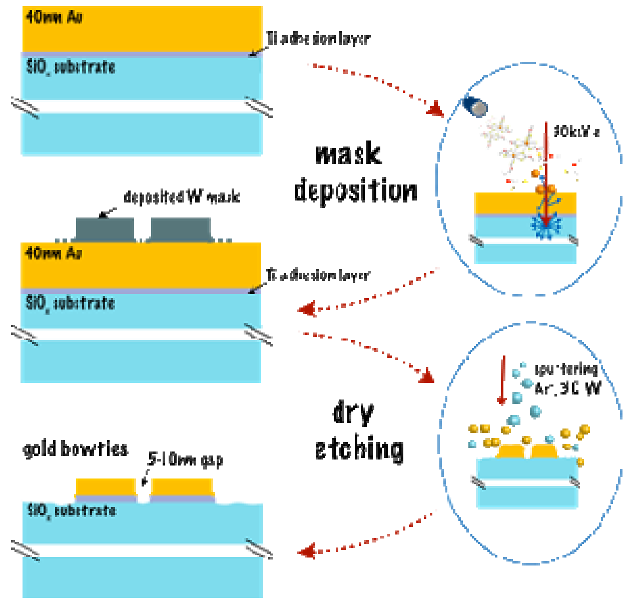


Mie scattering calculations showing nanometer displacement sensitivity for the fiber probe

Plasmonic Antenna Tips

Optical spectroscopy is normally limited by the wave-length of light, however scanning optical microscopy based on near-field scattering from metallic tip structures has demonstrated spatial resolution better than 20 nm. Resonant scattering from gold "bowtie" antennas[1] can generate significantly stronger optical fields than sharp metallic tips. We are constructing AFM cantilevers with plasmonic antennas fabricated at the tip apex in order to perform scanning near-field optical spectroscopy using Raman scattering or non-linear photoluminescence.

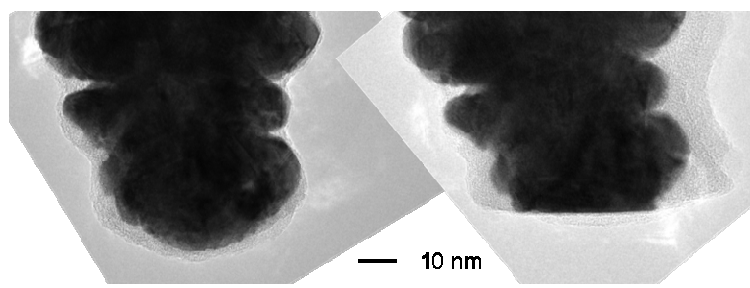
High-quality bowtie antennas can be produced on flat substrates by electron-beam lithography, but this method is not practical for cantilever tips, since it is difficult to align antennas with the required ~ 50 nm precision, and resist spin-coating is problematic. Antennas can also be produced with focused ion beam milling, but Ga ion contamination changes the Au plasmonic properties. A novel fabrication[2] method has been developed in the Nanofabrication facility to deposit a continuous 40 nm Au film, then use electron beam induced deposition (EBID) to make a high-resolution W mask, followed by low-energy Ar sputtering to remove the unmasked gold and the W mask, leaving a precision-aligned bowtie on the cantilever tip. Antenna tips have been successfully fabricated that show significant near-field Raman enhancement.



Fabrication Process for Bowtie Cantilever Tips

TEM investigation of AFM tip

As an AFM tip moves across a sample surface wear processes take place at the tip apex. This can change resolution in imaging experiments, and cause loss of signal in measurements such as local conductivity or work function. Analytical TEM studies reveal that the wear processes depend on the specific tribochemical system under study. In studies of organic monolayers on Si, the tips, terminated by single-crystal grains of Pt, showed atomic-scale wear without plastic deformation or dislocation formation. Once a flat facet was formed, an transfer film containing C, Si and Pt formed on the end of the tip, modifying the electrical properties.



Pt-coated AFM tip before and after imaging organic monolayers on Silicon substrates.

Future work

The fiber force probe, which has been validated in simulation and sensor tests, will be applied to biological systems for *in-situ* imaging of soft matter systems.

The plasmonic antenna tips will be used for near-field spectroscopic imaging of nanoscale samples.

Additional investigations are underway to determine the exact mechanisms of AFM tip wear as a function of substrate composition and imaging conditions.

References

1 P. J. Schuck, *et al*., "Improving the mismatch between light and nanoscale objects with gold bowtie nanoantennas." *Phys. Rev. Lett.* 94, 017402 (2005).

2 *A. Weber-Bargioni* et al., *in preparation.*