Resonant Probe AFM:
Uses and Advantages

RESONANT PROBE ATOMIC FORCE MICROSCOPES' UNIQUE CONSTRUCTION AND FUNCTIONALITY ENABLE THEM TO SERVE IN APPLICATIONS DEMANDING SPOT-ON ACCURACY, ADAPTABILITY, AND EXCEPTIONALLY HIGH DEFINITION

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A resonant probe atomic force microscope (AFM) offers capabilities and benefits not found in commonly used optical deflection AFMs in the measurement of physical constants, physical properties, and surface morphology.

However, resonant probe AFMs' functionality and potential remain misunderstood, even though resonant probe technology and its methodology are decades old. This article discusses resonant probe AFM construction, functionality, and typical applications, as well as introduces readers to Mad City Labs' custom AFM solutions.

Resonant Probe Construction And Functionality

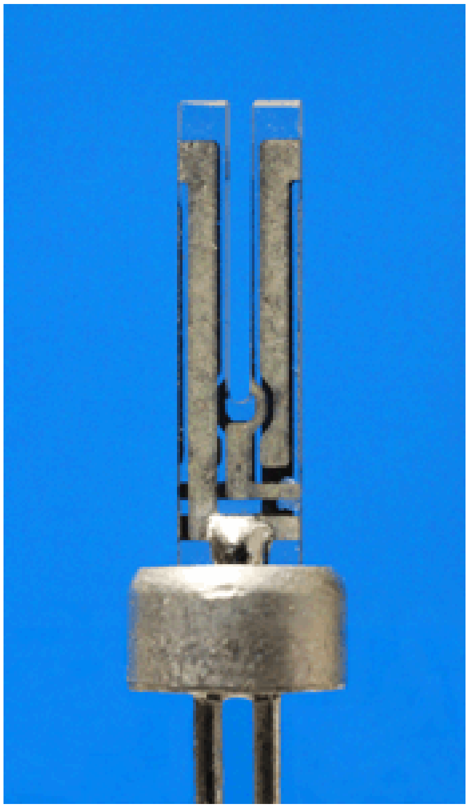
The basis for resonant probe microscopy — and its key differentiator from optical deflection apparatus — is a piece of quartz crystal shaped like a tuning fork.

The technology was developed and leveraged by Seiko in the 1960s as an oscillator that would vibrate at a specified frequency, very accurately. The technology was applied by Seiko to timepieces, and later it was integrated into microprocessors to guide their "time of day" counters.

In the 1990s, IBM Research developed resonant probe microscopy using these crystal quartz tuning forks at its Almaden innovation lab in Silicon Valley. Under this technique, the tuning fork — with tips made of various materials applied to the end, depending on the application — is used as a force sensor.

The fundamental difference between the optical deflection technique and the resonant probe technique is that the resonant probe always is oscillating; when operating, it is always in intermittent contact with the surface. Optical deflection systems were initially envisioned only as constant contact probes, wherein you drag the probe across a surface, absent any oscillation, and you can measure how it moves (e.g., measuring frictional forces on a surface). That said, intermittent contact probing was developed later for optical deflection AFMs.

Because of the extent to which resonant probe microscopy allows experimenters to modify and functionalize probe tips, it tends to attract individuals and teams who require customization and the flexibility to make their own tips.



At the advent of commercial AFM microscopy (early 1990s), vendors raced to produce standardized micro-machined tips — essentially, small cantilevers wherein you shine a laser onto the back of the tip, place that on a position sensor detector, and then measure the deflection of that tip. While this methodology has dominated the market since, the tuning fork has emerged as a valuable, agile microscopy tool.

For example, attaching a standard commercial optical deflection tip to the tuning fork allows it to be used for both optical deflection and resonant probe microscopy. A wire glued to the end of the probe could be used in one of two ways: as a conductive metal for direct imaging, and the wire tip could be used as a near-field probe; or, one could apply a bias voltage to the tip.

Both uses allow the experimenter to modulate the effect to both images and observe near-field optical effects in many samples.

Applying a voltage to the tuning fork force sensor/probe will cause it to oscillate at a set frequency. As you bring the probe close to a surface, its oscillation frequency changes, the amplitude of the oscillation changes, and its phase changes. These changes are carefully monitored, and you can tune on either signal with the correct electronics.

The wire material chosen depends on what the experimenter hopes to accomplish. A tip made from a magnetic material, for example, would interact with any magnetism or magnetic field on the surface, altering the magnetic field of the tip when it is brought close to the material under test.

A light shined on the resonant probe tip also changes the interaction between the tip and the electric field of the light at the surface. It is important to note that this is done for effect, rather than out of necessity (i.e., one can use light in resonant probe microscopy, but it's not required, as it is in optical deflection).

An optical fiber also can be attached to the resonant probe tip, creating what is known as a near-field scanning optical microscope (NSOM). Before the fiber is attached to the tuning fork, it is etched to whittle its tip down to a 50 nm aperture. The experimenter then can bring the tip close to the surface and maintain a fixed force on that surface, enabling experiments with, essentially, a 50 nm pinhole.

Note that the tip on a resonant probe system usually comprises a very hard material, versus the softer cantilevers used in optical deflection. However — even in biological materials, polymers, and other liquids — the impact often is negligible because the amplitude of oscillation is small.

Application Areas and Advantages

The various tips that can be applied to the probe, the different ways in which those tips can be manipulated, and the ability to apply light for effect (rather than out of necessity) grant resonant probe microscopy unmatched utility.

In some scenarios, this capability makes resonant probe systems the best tool for the task; in others, resonant probe microscopy is the only feasible solution. Consider the following examples:

- Resonant probe microscopy can be used to measure excitations from micro-machined optical antennas. One of the earliest resonant probe applications, this is accomplished by shining a light on the surface under test and analyzing the interaction between the light and the antenna.

- Resonant probe microscopy can be used to study surface plasmons by inducing excitation of the electrons inside of a metal or semiconductor. This technique is used in semiconductor analysis, using terahertz (THz) waves to probe the device's inner workings.

- Resonant probes known as nitrogen vacancy (NV) centers create a magnetic loop on the tip. By applying light to this area, experimenters can create an excitation not much bigger than a single atom, allowing them to measure incredibly small magnetic fields.

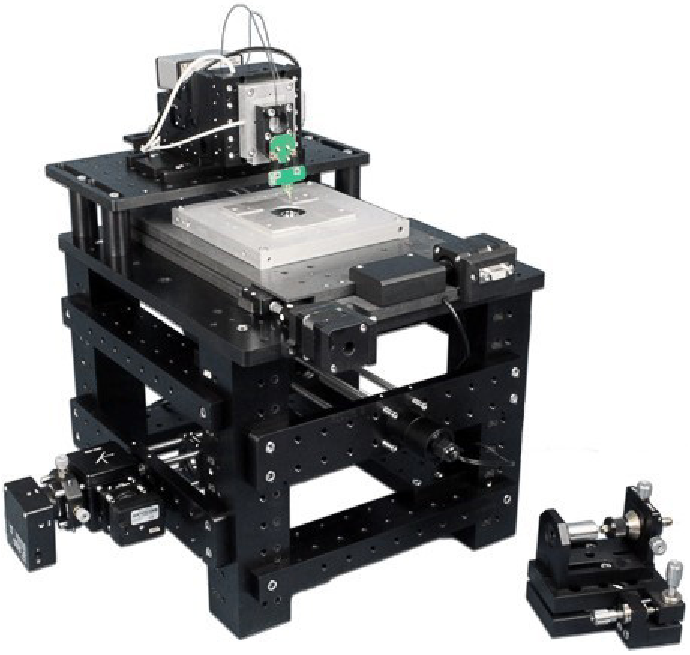
- Additionally, while both optical deflection and resonant probe systems can be used to interact light with the probe tip and an electric field, a tuning fork system offers more space to apply that light.

Mad City Labs' Expertise

Another distinct advantage offered by resonant probe microscopy systems — Mad City Labs' systems, specifically — is their ability to self-calibrate. There is no light to adjust (unless it is desired as part of the experiment), and Mad City Labs systems run a self-calibration routine, measuring the fundamental properties of the tuning fork. This includes finding the fork's resonant frequency and setting the desired resonant shift (i.e., what is the surface force?).

At this point, Mad City Labs systems' included software allows experimenters to measure the series resistance and the parallel capacitance, as well as adjust the oscillation — all with pinpoint accuracy and high resolution.

Such accuracy and resolution are made possible not by the resonant probe alone, but by the Mad City Labs system as a whole, which utilizes nanopositioners with embedded sensors to enable linear, repeatable, high-quality relative measurements. As a baseline example, consider a piece of silicon (Si) that has been annealed — creating one-atom-high steps on its surface — as a calibration tool. These single-step heights have been measured using X-ray scattering, producing a value close to 300 picometers (pm).



Commercial optical deflection systems typically can achieve 30 pm to 40 pm (RMS) accuracy (NOTE: this capability has been inferred from available data, but not demonstrated) in this same endeavor. In contrast, Mad City Labs resonant probe microscopy systems consistently measure displacements of 10 pm (Peak to Peak absolute displacement). This measurement is not inferred but comes from measurement of the system. It is not necessary to operate in a vacuum to achieve this accuracy and resolution.

Mad City Labs' customizable AFM and NSOM instruments are built to order, informed by customer specifications and in-house knowledge of the applications for which the systems are being used.

Generally, the first question asked is, "What range of motion/scan range do you need (i.e., along X, Y, and Z axes)?" A customer may want a very long-range system, a very short-range system, or a system meant to operate in a low-vacuum situation. Ultimately, the nanopositioners enabling this movement and experiment stability form the core of any AFM.

Fundamentally, a fully functional AFM system purchase would include an X, Y, Z nanopositioning system, a tuning fork, a coarse positioning system, and the electronics that interpret what's coming out of the tuning fork. All these products have been engineered not just to work together, but also to complement one another for optimal performance. While it is possible to buy separate components elsewhere and build some of these things in-house, these alternatives lack the functionality of a Mad City Labs system.

Further, when most companies sell you an AFM, they do it based on a single product or group of products. In general, Mad City Labs is unique in its approach of "You can build an AFM; here are your choices. You buy what you want. You can do as much as you want, or we'll do it." In most cases, even custom instrumentation is ready for delivery within 30 to 45 days.

Conversely, NSOM systems are much more difficult for customers to construct in-house, due mostly to the inverted optical microscope required. Thus, MCL sells these products as complete systems.

Finally, while cost ranks a distant second to capability in such specialized systems, it warrants mention that a resonant probe AFM from Mad City Labs — despite its advantages — costs a fraction of the price of a competing optical deflection product.

Conclusion

Resonant probe microscopy is a well-understood, established technique with numerous applications. Various tips can be applied to the probe and manipulated in different ways, light contamination is eliminated as a concern, and Mad City Labs' customized systems are able to self-calibrate.

These capabilities, combined with best-in-industry accuracy and resolution, make resonant probe microscopy a consideration even in applications where optical deflection or other analysis techniques may traditionally be used.

Additional Resources

- *Building A Do-It-Yourself Atomic Force Microscope*
- *Extreme Metrology: Big Science Requires A Nano-Perspective*

About The Author

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About Mad City Labs

Mad City Labs designs and manufactures a complete product line of high precision piezo nanopositioners, micropositioners, atomic force microscopes, and single molecule microscopes. We provide innovative instrument solutions from the micro- to pico-scale for leading industrial partners and academic researchers. Visit www.madcitylabs.com or email mclgen@madcitylabs.com for more information.

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