Fabrication of Active Probe Structures for Atomic Force Microscopy

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Abstract

The atomic force microscope (AFM) launched a wide variety of applications ranging from life sciences to metrology after its invention in 1986. However, current applications are limited by several aspects of the conventional AFM technology, which uses a passive cantilever probe and typically slow and bulky piezoelectric actuators. The relatively slow piezoelectric actuators limit the attainable imaging speeds, and the complex cantilever dynamics makes the extraction of quantitative material property characterization difficult. This project addresses these issues by introducing a new probe structure for the AFM. This new probe has a sharp tip placed on an active, electrostatically actuated, micromachined membrane with an integrated displacement sensor. The membrane itself and the diffraction grating form a small phase sensitive optical interferometer for displacement detection. The project focuses on the fabrication of this probe and the experimental results obtained from the fabricated devices. Lift-off process and membrane deposition mainly involve lithography and metallization to fabricate the devices. The devices are then analyzed after being released in the critical point dryer. These results include applications such as fast tapping mode imaging, which utilizes the electrostatic actuator, and time resolving interaction force imaging, which utilizes the well-behaved dynamics of the device.

Introduction

Since its invention, the AFM has found a wide variety of applications ranging from life sciences to metrology. Moreover, AFM is one of the most widely used tools in nanotechnology. For example, applications in physics and chemistry are important for surface property characterization such as stiffness. In biology and life sciences, AFM also can be used in force spectroscopy for drug discovery and ***in vitro*** cell imaging. In engineering and nanosciences, sample information can be obtained by surface roughness analysis and process quality control.

Atomic Force Microscope

The various components of the AFM working together are what enable such diverse applications. A typical AFM has; 1) a micro-cantilever probe, 2) optical lever detection, 3) the piezoelectric tube, which is also the scanner, and 4) the controller. The probe acts as a force sensor, and the cantilever has a very sharp tip with diameter of 2-50 nm. The optical lever detection is used to determine the position of the probe by the photo detector sensing the laser reflected off the cantilever. The piezoelectric tube moves the sample or the probe in x-y-z direction. The controller keeps the cantilever deflection constant through feedback control while the probe scans the sample locally.

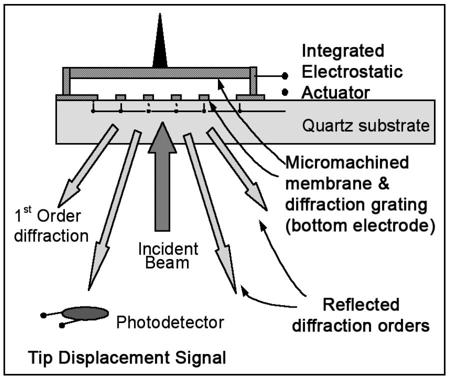

Figure 1: FIRAT probe structure and diffraction based optical interferometric detection.

Current applications are limited by some aspects of the conventional AFM technology, which uses a passive cantilever probe and typically slow and bulky piezoelectric actuators. The relatively slow piezoelectric actuators limit the attainable imaging speeds, and the complex cantilever dynamics makes the extraction of quantitative material property characterization difficult. To tackle this issue, a new probe structure called the force sensing integrated readout and active tip (FIRAT) was introduced.

This new probe has a sharp tip placed on an active, electrostatically actuated, micromachined membrane with an integrated displacement sensor as illustrated in Figure 1 [1]. The membrane itself and the diffraction grating form a small phase sensitive optical interferometer for displacement detection [1]. So the interferometric detection is more sensitive than the optical lever detection of conventional AFM, and the electrostatically actuated membrane is faster than the piezoelectric tube. In order to validate such functionalities of the FIRAT probe, it first has to be fabricated and then analyzed through various experiments.

Experimental Procedure

The fabrication of the FIRAT probe was carried out in the Microelectronics Research Center. We used a 4-inch quartz wafer on which to fabricate the probes. The process began with surface preparation of the wafer by ultra-sonication in acetone for 15 minutes and then in methanol for 15 minutes. Finally, the surface was ready after oxygen plasma cleaning using Plasmatherm reactive ion etching (RIE). Lithography, using the mask aligner,

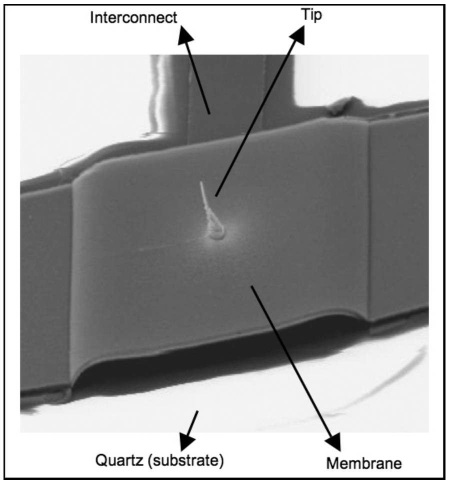

Figure 2: Image of fabricated FIRAT probe. Fingers, not shown, are under the membrane.

resulted in finger patterns. The lift-off process was then carried out to make 0.120 μm Al fingers, which were deposited using the e-beam evaporator. Next, through lithography, a sacrificial layer of about 2.5 μm thick was formed over the Al fingers in order to deposit the Al membrane.

The membrane, which had a thickness of approximately 0.8 μm, was deposited using the DC sputterer. Lithography was carried out again to perform wet etching using aluminum etchant to define the structure. After the ME dicing machine cut the wafer into several probe devices, they were released under photoresist stripper and then in the critical point dryer. A sharp tip, with a diameter of about 50-100 nm, was installed on the membrane of one of the devices using the focused ion beam tool. The final product of such a device is shown in Figure 2.

Results and Conclusions

We were able to successfully fabricate the FIRAT probes. We checked and confirmed the progress of the fabrication by taking images using a digital microscope, and gathering data using a non-optical profilometer at different intervals during the process. Similar probe devices were analyzed using the Wyko optical profilometer to confirm the fabrication of the completed structures. Using the experimental setup in Figure 3, several experiments were conducted on earlier probes, which are similar to the devices that we fabricated [1]. The time resolved integrated force (TRIF) imaging experiment demonstrated that the FIRAT probe was able to characterize stiffness and stickiness of selected samples [2].

The experimental data showed that the membrane only deflected when the probe contacted a hard material sample. However, for a soft material sample, both the membrane and the sample deflected. Thus, the softer material took more time to achieve peak contact force compared to the harder material. The amount of force required for the probe to retract from the sample determined the stickiness. In Figure 4, the fast tapping mode imaging experiment showed that the FIRAT probe was able to track the sample better than a typical cantilever at higher imaging speeds – line scan rates of up to 60 Hz [1]. These results along with other experimental data have shown great promise for the new probe, and were used to explore the extent of its functionalities.

Future Work

Although the current fabrication process does make the production of the probes simple, the probes still cannot not be commercially reproduced. The next step of this project is to design a process to enable mass installment of tips on the probes. This would make the mass production of such probes possible and facilitate the start of commercial production.

Acknowledgments

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References

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Figure 3, right: Experimental setup integrating the FIRAT probe with commercial AFM system.

Figure 4, below: Line scans of sample at different imaging speeds for each probe.