Development of a Three Degrees of Freedom Atomic Force Microscope

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Abstract

An atomic force microscope (AFM) easily measures forces in one direction. It can be adapted to measure force in the other directions, but it is time intensive and challenging. In this paper, a three degrees of freedom atomic force microscope (3DOF AFM) is presented. Microfabrication techniques are used to design, fabricate, and test a miniature system that can measure forces in three directions with high resolution. Typical applications for the 3DOF AFM are probing nanostructures and studying hard disk drive interactions with the reading head.

Introduction

Atomic force microscopes are used to measure surface topographies. They consist of a cantilever with a tip at the end. A laser beam deflects off the end of the cantilever and into a detector. The detector measures the deflection of the laser beam to find the displacement of the tip as it moves across different surface topographies [1, p. 1614]. AFMs typically measure forces with one degree of freedom, which is in the x direction. The y and z directions are obtainable; however it is time intensive and challenging. A three degree of freedom atomic force microscope can measure forces in all directions.

In order for this to occur, the 3DOF AFM device has to be compliant in all three directions. Compliancy is measured by a low κ value, which is calculated using a finite element simulation software called ANSYS. Figure 1 is depicting the movement of one of the devices in the x direction. This device is made of one vertical thick vertical beam (20 μm) and two thin cross beams (varying between 2 μm or 3 μm). Applications of a 3DOF AFM would be the manipulation and probing of nanostructures, studying hard disk drive interfaces, and understanding nanoscale friction and adhesion forces.

The main objective of this research was to use current microfabrication techniques to design a fabrication process by optimizing both the lithography and process steps in order to fabricate a free standing miniature system that can measure forces with three degrees of freedom.

Experimental Methods

In this research, we developed a fabrication process for free standing micro machines, specifically a three degrees of freedom atomic force microscope. The devices varied from having two cross beams to one beam, the beam thickness varied from 2 μm to 3μm, and the angle between the beams varied from 4° to 10°. Various techniques were used throughout the fabrication process.

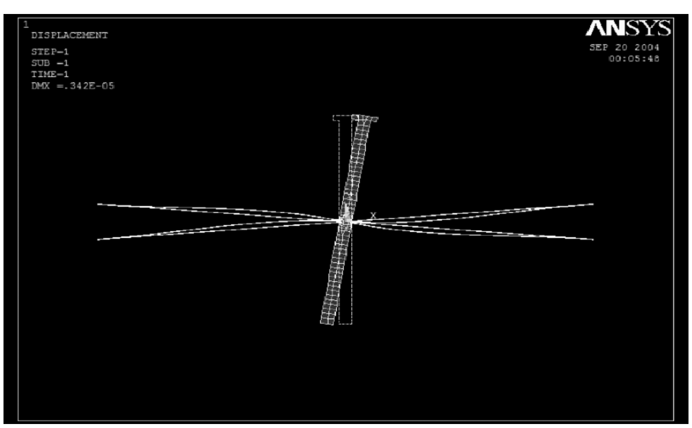

Figure 1: Depiction of the device movement in the x direction from ANSYS.

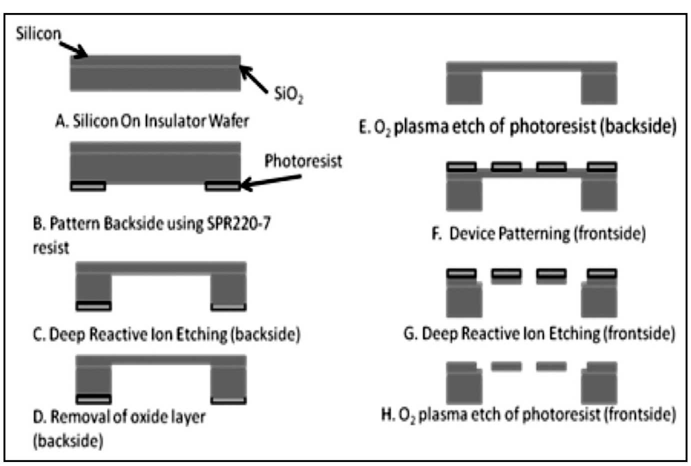

Figure 2: Schematic of the fabrication steps used to fabricate the free standing devices.

Figure 2 is a schematic showing the steps of the fabrication process. The process begins with a silicon-on-insulator (SOI) wafer. 10 m thick SPR220-7 photoresist is used to pattern the backside of the wafer. The first step of the process was to optimize lithography techniques. In order to optimize the lithography process, modifications had to be made due to the resist thickness. The first modification was to use the multiple exposure feature on the Karl Suss MA6 to prevent resist bubbling. The second modification was to skip the post exposure bake to prevent resist cracking. Deep reactive ion etching (DRIE) was used to etch the backside up until the oxide layer. The oxide layer was wet etched using a buffered oxide etch. The frontside mask was then aligned with the backside mask using the MJB3 for device patterning. DRIE is used to etch the frontside the whole way through the wafer. This resulted in free standing devices that were approximately 20 μm thick.

Future Work

We will further develop and modify the fabrication process in order to obtain a higher yield. After the devices are successfully fabricated, they will be mounted to a probe and tested in a FIB SEM. The displacement will be measured and multiplied by the spring constant, κ, (which was previously calculated in ANSYS) to find forces with three degrees of freedom of nanostructures, specifically nanowires on a silicon substrate.

Conclusions

Lithography techniques were optimized and a fabrication process was developed, but not to 100% accuracy. All of the 3DOF AFMs broke during the fabrication process; however we were able to fabricate some 2DOF AFMs. This shows that the fabrication process was successful but had a low yield. Minor modifications have to be made to the fabrication process in order to obtain a higher yield. Figure 3 is one of the 3DOF AFM devices etched 10 μm into a silicon wafer. Figure 4 shows an SEM image of one of the free standing 2DOF AFM devices that were fabricated using the proposed fabrication process.

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References

[1] Colton, Richard J. Nanoscale Measurements and Manipulation. Review Article. P. 1609-1635. 30 June 2004.

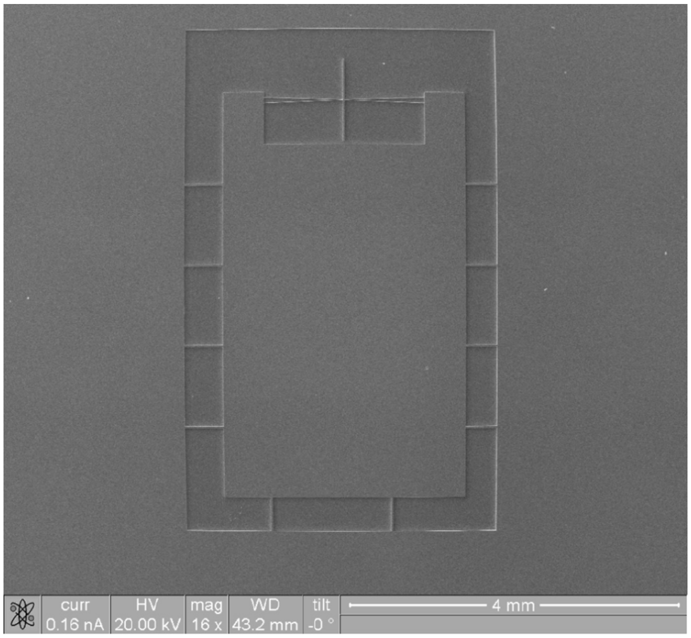

Figure 3: SEM image of a 3DOF AFM (not free standing).

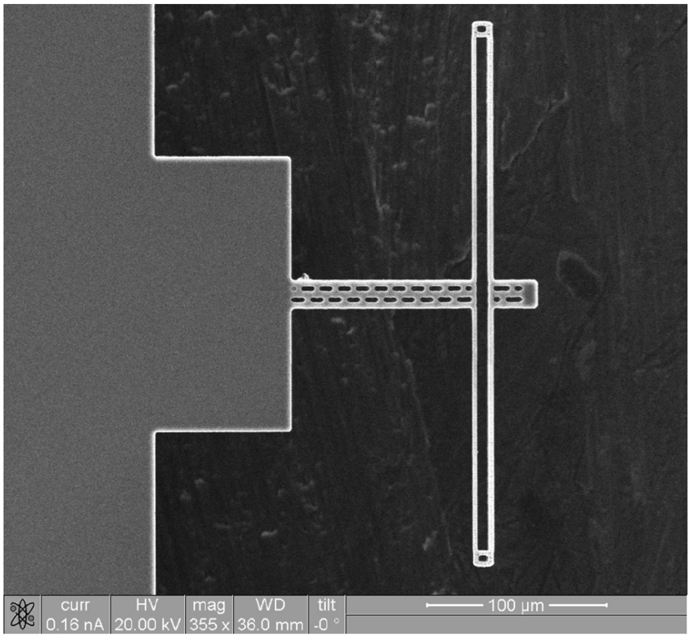

Figure 4: SEM image of a free standing 2DOF AFM fabricated using this fabrication process.