Nanoscale Cantilevers for Ultrasonics and Nanoscale Folding

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Abstract:

This project utilizes the charge storing property of oxide-nitride dielectric to fabricate cantilevers for actuation. We propose to achieve this by depositing charge on oxide-nitride cantilever, then releasing the cantilever thus freeing it to bend with electrostatic force. Charge deposition was attempted with both Atomic Force Microscopy (AFM) and exposure of samples to radioactive sources. Lift-mode was verified with AFM to detect long range magnetic and electric forces. The release of thin oxide-nitride layers was also demonstrated by wet etch in TMAH.

Introduction:

Memory devices such as EEPROM/NROM utilize oxide-nitride and oxide-nitride-oxide dielectrics to store bits. Si_3N_4 contains a large number of traps thus providing a low-potential site for storing charge [1]. In this paper, we explore the usage of charge storage capability of oxide-nitride for cantilever actuation. With 10-40 nm of oxide/nitride, the electric-field between AFM tip and sample should be adequate to exceed the breakdown voltage of dielectric layers and deposit charge.

Procedure:

To test charge writing/reading with AFM, a single mask process was used to fabricate oxide-nitride-oxide samples. First oxide layer was ~10 nm, nitride was Si-rich LPCVD ~6-20 nm, final oxide layer was thermal oxidation of nitride at 900°C. We were unable to obtain a good thickness measurement of the third oxide layer.

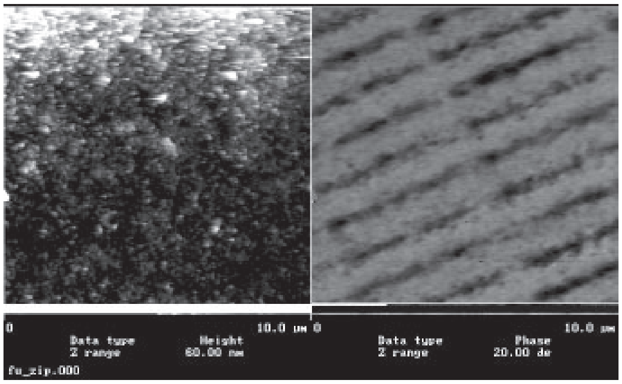

Figure 1: MFM scan of 250 MB zip disk.

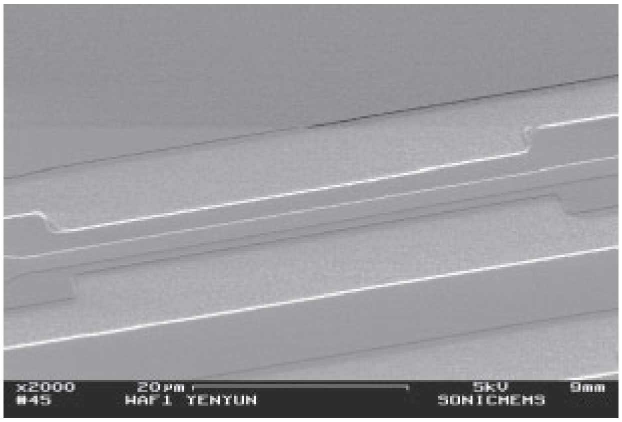

Figure 2: Cantilevers with thinner folding region ~ 2 µm.

MikroMasch NSC36/Ti-Pt tips were used in tapping/contact mode on a JSPM-4210 AFM/STM. Conduction was verified between the Ti-Pt tip and silicon samples by ramping I-V characteristics. However, by applying a sample bias 10-100V in AC/contact modes, charge was not detected. At large biases, the tip becomes damaged and cannot be used for charge detection after being used for charge writing. Charge deposition possibly failed due to low retention time of Si-rich nitride or the final oxidation removed most of the nitride.

Charge writing was attempted on our final oxide-nitride-poly-nitride cantilever with Dimension 3100 in tapping/contact modes. Bias was applied by connecting an external voltage source to the sample. Tip scan rates were varied from 0.02-1 µm/s while scanning a 50 nm x 50 nm region and applying a voltage of 10-100V. Electric force microscopy (EFM) was performed by applying a 3-5V bias and lifting the tip by 10-150 nm while scanning. However, no contrast in phase signal was observed at the region of interest. The experiment was repeated on a 10 nm SiO_2 sample to decrease the breakdown field, however no phase contrast was observed for biases up to 70V in contact mode. During charge writes with Dimension AFM, tip damage was less of an issue at high biases.

We then tried charge-reading by exposing samples to radioactive Ni-63/Po-210 beta/alpha source to eliminate

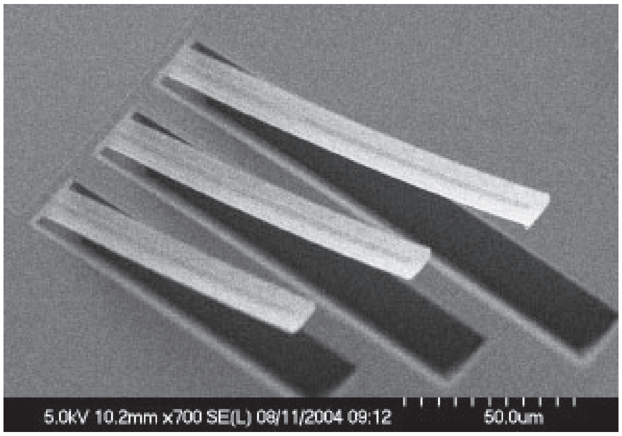

Figure 3: 2 μm wide cantilever.

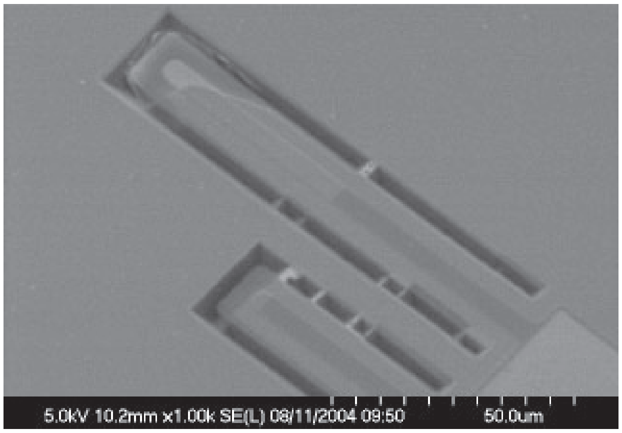

Figure 4: 10 μm cantilever - under-etched.

the factor of charge not being deposited. However, changes in the conductivity /topography of samples after exposure were undetected. This is because high energy electrons were accelerated through oxide-nitride-oxide instead of being retained.

To verify the ability of AFM to detect long-range forces, we imaged magnetic media with magnetic tips. MikroMasch NSC36/Co-Cr tips and Dimension 3100 were used. To detect long-range forces instead of atomic forces as in normal AFM operation, the tip is displaced 10-100 nm from samples. We were able to image magnetic patterns on a 250 MB zip disk at 10 nm lift height. In Figure 1, the left image is the topography of the zip disk; the right image is magnetic patterns of stored data.

Next, we proceeded to cantilever fabrication. The first layer was low-stress LPCVD nitride of 50 nm which served as protection for cantilever release. 50 nm of polysilicon was then deposited for conduction. Finally, oxide-nitride dielectrics were grown at 6/55 nm respectively.

The last task was to release cantilevers from the silicon substrate so that they could bend freely. TMAH was chosen over KOH due to selectivity over Si3N4 and SiO2. Etch rate of LPCVD nitride < 20 Å/hr and thermal oxide < 100 Å/hr while the etch rate of silicon is ~1-40 μm/hr depending on crystal orientation [2]. Since increased undercutting is desired in releasing cantilevers, cantilever structures were oriented 45° on silicon substrate because TMAH etch rate is greater in (100) than (111) plane [2]. From etch characterization on a sample without metal, we found that optimal etch time is approximately 1 hr for 70° 20% wt. TMAH. However, when we etched our final sample for 1 hr with 70° 20% wt. TMAH, all of the structures were underetched. It may be that the final sample had Au/Cr-contacts that reacted with TMAH solution causing final etch time to be > 1hr. In Figures 3 and 4, we see 2 μm cantilevers that are fully released and thicker 10 μm cantilevers that are underetched.

Results and Conclusions:

Fabrication of the cantilevers was successful; the minimum resolved features were 2 μm with stepper lithography. E-beam lithography is ideal to resolve smaller features and to fabricate smaller cantilevers that bend easier with electrostatic force. The process to release cantilevers worked well however etch rates need to be re-characterized with samples containing metal and for cantilevers of particular thicknesses.

We successfully verified the ability of AFM to detect long-range forces by detecting magnetic forces. It is more likely that charge is not being written rather than not detecting charge. During charge writes in contact mode, setpoint was increased to decrease potential tip damage. However in the future, setpoint should be decreased to increase contact with sample and decreasing tip scan speed.

Although EFM could be performed without applying bias, it is ideal to increase resolution of phase signal. Applying biases of opposite sign and observing phase signal can verify that the pattern is due to electric forces.

Acknowledgements:

Serhan Ardanuc, Prof Amit Lal, CNF staff, and Melanie-Claire Mallison.

References:

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[2] A, Merlos, "TMAH/IPA Anisotropic etching Characteristics," Sensors and Actuators, vol. 37-38 pp. 737-743, 1993.