A Study of Microsensor Substrates

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Abstract

The goal of this project was to investigate the surfaces of microsensor substrates using atomic force microscopy. The effort was intended to observe if there exists a pattern of damage caused by stiction, and to find differences between samples that become stuck and those that do not.

Procedure

- Divided samples into three groups
  - Group I: Samples that exhibited stiction during g-testing
  - Group II: Samples that were manufactured in the same lot as Group I, but were not g-tested for stiction
  - Group III: Samples that did not exhibit stiction
- Determined optimal cantilever stiffness
- Obtained topographic images
  - Investigated roughness
- Obtained force curves
  - Investigated pull-off force
- Validated data

Determining Optimal Cantilever Stiffness

It was necessary to determine the optimal cantilever stiffness for investigating the substrate surfaces before valid data could be gathered. We defined the optimal stiffness value as the value at which both imaging and force curve acquisition could be carried out reliably without damaging the surface.

A force curve is obtained when the probe tip is brought into contact with the sample surface at a single point and then pulled back in a controlled manner. The forces governing the process are tracked by recording the cantilever position with respect to the surface. The force applied on the sample by the cantilever is shown on the vertical axis. Negative values represent attractive forces and positive values represent repulsive forces as dominant forces in the system. The horizontal axis is the separation between the probe tip and the surface. Positive separation indicates indentation.

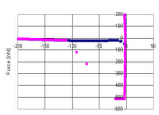

Figure 1

If the cantilever is too compliant, then the pull-off force shown on force curves will not be valid. The minimum point of the curve occurs beyond the saturation point of the position sensitive photo-detector (PSPD).

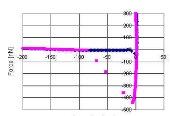

Figure 2

An example of a cantilever of acceptable stiffness is shown in the figure above. The minimum point on the curve is clearly visible and within the linear operation range of the PSPD.

If the cantilever is too stiff, the surface and the probe tip may be damaged when brought into contact. Damage on the surface may be in forms of scratches during imaging, or holes. Damage to the tip results in larger tips. The choice of cantilever stiffness is therefore a trade-off between accuracy of data and protection of samples and probe tips. 6N/m was experimentally determined to be the most suitable cantilever stiffness.

Data Validation

In order to ensure that the collected data were reliable, an image of the tip was acquired before and after each sample was examined.

Figure 10 shows the topographic image of a new tip. Figure 11 shows that of a worn-out tip. The difference in the contrast in these two figures reveals the difference between the shapes of the two tips.

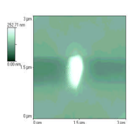

Figure 10

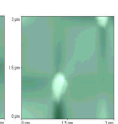

Figure 11

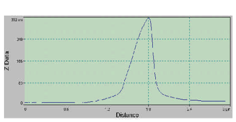

Figure 12

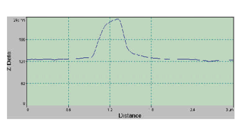

Figure 13

Figure 12 shows the cross-section of a new tip. The tip extends narrowly in the z-axis and its peak is triangular.

Figure 13 shows the cross section of a worn out tip. The tip is not as high as the new tip and the peak is now a rough semi-circle.

Why wearing out degrades data validity:

- The tip radius becomes larger, therefore small surface features cannot be detected correctly on a topographic scan.
- Larger tip area means more atoms will be adhering to each other while a force curve is being acquired. Therefore the pull-off force becomes artificially larger.

Methods

There was circuitry built on top of the substrate surfaces that we wanted to examine. In order to expose the sample surfaces, the circuitry was removed through exfoliation using tape. Exfoliation was more difficult on Group I than in either of the other groups. In order to fully expose the substrate, exfoliation was repeated three or four times. Samples in Groups II and III were much easier to exfoliate.

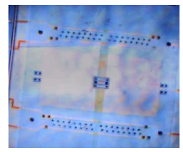

Figure 9

Figure 9 shows one sample after exfoliation, as seen using an optical microscope. The white area is the substrate. The arrays of holes running parallel to each other on the top and the bottom of the substrate are left when the components of the device built on top of this substrate were removed.

Observations

Topographic images were the first tool we used to compare samples from the three different groups. Figure 3 shows an image of the substrate of a sample from Group I. Similarly, Figures 4 and 5 show images from Groups II and III respectively.

Through the topographic images, we observed the microstructure. The microstructure did not vary noticeably from one group to the next. We were also able to obtain surface area roughness estimates, which were within 0.6 nm for all groups.

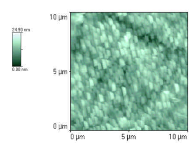

Figure 3

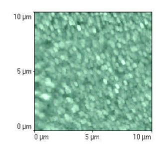

Figure 4

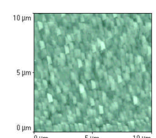

Figure 5

We used force curves as a measure of how much stiction each surface exhibited. We used the pull-off force, the force necessary to separate the tip and the surface, as a means to determine stiction. Figures 6, 7, and 8 show force curves acquired on samples from Groups I, II, and III respectively.

The resulting pull-off force values were 279.3 nN for Group I, 26.9 nN for Group II, and 45.8 nN for Group III. These values are the average pull-off force obtained after acquiring approximately 30 force curves on samples from each group.

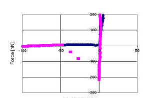

Figure 6

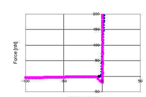

Figure 7

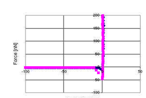

Figure 8

Summary

	Group I (Bad lot, tested)	Group II (Bad lot, not tested)	Group III (Good lot, tested)
Area RMS (nm)	2.94	2.70	3.23
Microstructure radius (nm)	258	297	268
Average pull-off force (nN)	279.3	26.9	45.8
Standard deviation (of pull-off force) (nN)	162.8	15.2	14.2
Standard deviation / average (pull-off)	58.3%	50.1%	31%
Exfoliation	Difficult	Easy	Easy

Resources

- *A Practical Guide to Scanning Probe Microscopy*, copyright Thermomicroscopes, www.thermomicro.com
- *Surface Forces and Adhesion*, N.A. Burnham and A.J. Kulik, in "Handbook of Micro/Nanotribology", pp. 247-71, B. Bhushan, ed., CRC Press, Boca Raton, FL, USA (1999).
- Samples generously provided by Analog Devices, Inc. Cambridge, MA 02139