AFM Tip Processing on Hinged Cantilevers

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Abstract

A method for atomic force microscopy (AFM) tip preparation is described that is amenable for integration onto a hinged cantilever, thereby achieving an exquisitely high-sensitive probe. Undercutting an etch mask with successive reactive ion etching, results in a quasi-pyramidal, high-aspect-ratio tip. Processing steps will be discussed, scanning electron microscopy (SEM) images will be shown, and a short narrative of how the tips are integrated onto the cantilevers will be described, including future directions of the work.

Summary

Few modern instruments can lay claim to the level of success enjoyed by the atomic force microscope (AFM). The ability to map surface topography with ~ nm resolution finds usefulness in almost every branch of science.

The original AFM employed a scanning tunneling microscope (STM) to monitor the motion of a diamond-tipped stylus supported on a gold foil cantilever [1].

Today’s AFM typically employs a silicon micromachined cantilever with a sharp tip on one side, and a reflective mirror surface on the other [2, 3]. When the tip interacts with the test surface, its deflection is measured by reflecting a laser beam off the back side of the cantilever onto a 4-segment position-sensitive photodetector (PSPD). Whereas the top and bottom segments of the detector indicate height variations in the position of the tip, the left and right segments can be used to indicate the amount of friction between the tip and sample surface [4]. However, because the same cantilever is used in the vertical bending mode (for topographical imaging) and the lateral bending mode (for frictional force imaging) these motions are inextricably coupled with mechanical crosstalk resulting.

Chui [5] was arguably the first to appreciate decoupling of the lateral and vertical sensitivities in an AFM cantilever. Later, Kageshima [6] was able to mill a trench into a commercial AFM cantilever with a focused ion beam (FIB), thereby enhancing both the lateral and vertical sensitivity.

Taking both of these concepts a step further, Beyder [7] was able to process silicon cantilevers with orthogonal (i.e. gimbaled) Si₃N₄ hinges of arbitrary thickness, thereby decoupling vertical and lateral sensitivities altogether. This allowed the geometry and stiffness to be separately optimized for each sensing direction. With arbitrary thickness hinges, Beyder is able to achieve exquisitely sensitive levers for the analysis of delicate soft-matter samples. Figure 1 exemplifies a dual-axis gimbaled lever with two tips (courtesy of Beyder).
In all of these cantilever arrangements, the tip that interacts with the test surface greatly influences the quality of the AFM image. Whereas the radius of curvature of the tip determines, in part, the imaging resolution of the cantilever, the shape of the tip can be more or less susceptible to image aliasing and artifacts that seriously degrade the final image [8].

At the CNF, silicon AFM tips are defined by a sequence of three reactive ion etch (RIE) processes: (1) isotropic etch to undercut the etch mask (O-Release), (2) anisotropic etch to lengthen the underlying pillar that results (O-Trench), and (3) a second isotropic etch to sharpen the pillar into a final quasi-pyramidal tip (O-Release).

A ~ 5 µm diameter circular etch mask comprising ~ 1.3 µm of S1813 (Shipley) photoresist, 30 nm of LPCVD nitride (low-stress, 800°C, 11 min) and 135 nm of thermal oxide (wet, no-HCL, 900°C, 65 min) is prepared.

For undercutting the etch mask, we utilize the default O-Release recipe in the Unaxis 770 ICP (inductively coupled plasma) tool. The O-Release program uses four etch steps of Ar (50 sccms) with increasing flowrates of SF₆ (20, 40, 60 and 70 sccms, respectively) at 850 watts of RF power. The duration of each of the four etch steps is 2, 2, 2 and 60 sec respectively. The resulting undercut etch mask is shown in Figure 2 with an underlying, partially-obscured pillar supporting the mask. On top of the mask, the resist is deformed into a 4-leaf clover-like formation.

To lengthen the pillar, we use the default O-Trench recipe on the Unaxis ICP tool. Each loop of the O-Trench program consists of a first polymer deposition step (70 sccms of CF₄, 2 sccms of SF₆, and 40 sccms of Ar, 5 sec at 850 watts RF-ICP) followed by a first etch step (2 sccms of CF₄, 70 sccms of SF₆ and 40 sccms of Ar, 2 sec at 850 watts RF-ICP) and a second etch step (2 sccms of CF₄, 100 sccms of SF₆ and 40 sccms of Ar, 5 sec at 850 watts RF-ICP). Five loops of the O-Trench recipe results in the pedestal/cap structure of Figure 3.

A final O-Release etch for 60 sec (in the last etch step) pinches-off the cap, and transforms the underlying pillar into a quasi-pyramidal tip, as shown in Figure 4.

Implementing one or more of these silicon AFM tips onto a single-axis or double-axis cantilever is done by lithographically defining the arms and hinged regions of the cantilever(s) after tip preparation.

Future work may include polarimetric encoding of the reflected optical signals from multiple, reflective regions on the back of a multi-axis, multi-tipped cantilever. Such encoding practices would allow a considerable increase in information content conveyed from the test surface.

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References