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Evolution of Surface Morphology during Focused Ion Beam Sputtering and Gas-assisted Sputtering Processes

D.P. Adams

Sandia National Laboratories, MS 0959, Albuquerque, NM, 87185.

Currently focused ion beam (FIB) sputtering and gas-assisted sputtering processes are of interest for sample preparation, head trimming, reverse engineering / failure analysis and microfabrication. For most applications, control of nanometer-scale feature surface morphology is desirable. Sample preparation for transmission electron microscopy requires formation of smooth sputtered surfaces. This is particularly important when cross sectioning thin film device heterostructures. On the other hand, a FIB-sputtered surface that has nanoscale ripples, facets, cones or other features provides an interesting template for subsequent thin film growth.

In order to realize the many benefits of FIB systems, we have investigated the development of surface morphology during sputtering and gas-assisted sputtering processes. In particular, we investigate changes in morphology during ion milling of hard, low sputter yield materials such as diamond, cubic boron nitride and aluminum oxide. We show how the developed morphology depends on ion beam incidence angle[1], ion dose, chemical environment (through the introduction of certain reactive gases) and initial surface roughness. For example, the feature surface roughness created during high dose (10^{18} ions/cm^2) FIB sputtering and H_2O – assisted FIB sputtering [2] is contrasted in Figure 1 for a range of ion beam incidence angles. We demonstrate that certain yield-enhancing gases can lead to different ripple amplitudes, ripple wavelengths and facet heights. The atomistic mechanisms underlying changes in morphology are discussed in terms of recently developed theories of evolving ion induced morphology [1,3]. Of interest to sample preparation, we focus on the changes in morphology during FIB sputtering at large angles ($\theta > 80^{o}$) - approaching a grazing incidence geometry. At these high angles, surfaces are often composed of nanoscale steps and terraces. Direct evidence of a ripple-to-microfacet morphology transition is shown with increasing ion dose.

Evolving surface morphology will be discussed in the context of emerging applications of focused ion beam sputtering. Three-dimensional FIB milling of predetermined curved shapes, such as hemispheres and parabolas, into initially flat surfaces will be discussed [4]. Also FIB shaping of micron-scale cutting tools having complex three-dimensional geometries will be highlighted. Examples of these two techniques are shown in Figure 2.

References:
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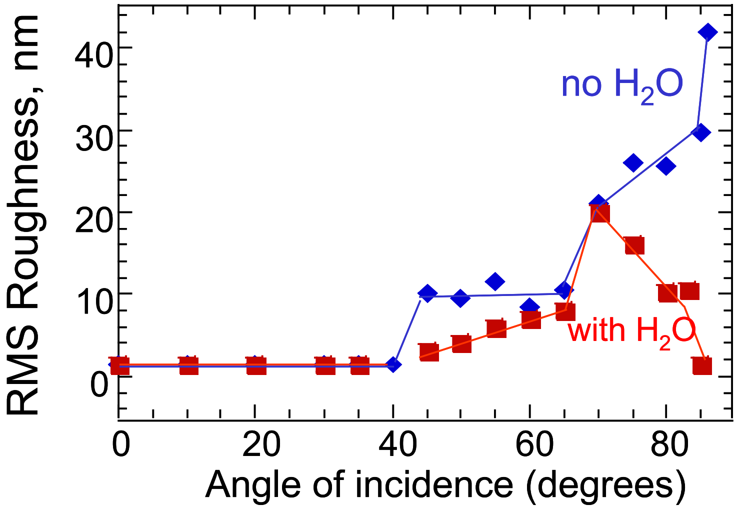

Figure 1: Plot of RMS roughness versus ion beam angle of incidence for FIB sputtering of diamond (diamonds) and water-assisted sputtering processes (squares). Experiments involved high dose (~ 10^{18} ions/cm^2), 20 keV gallium ion bombardment.

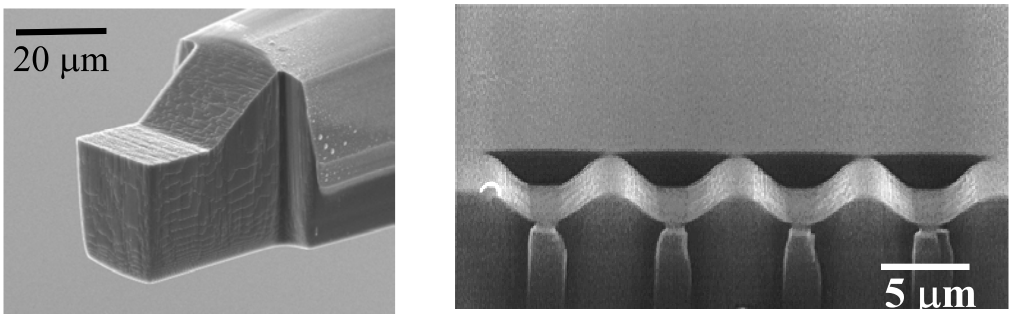

Figure 2: Image on left is a FIB shaped micro-cutting tool used for ultra-precision lathe machining. It was sculpted from a single crystal diamond tool blank. Image on right is a sinusoidal feature FIB machined into Si using 3-d ion milling software.