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Optical Interferometer Microscope for Monitoring and Control of Focused Ion Beam Processes

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Focused ion beam (FIB) techniques have a wide range of applications including lithographic mask repair, specimen preparation, head trimming, circuit modification, failure analysis, reverse engineering and device prototyping [1]. Although FIB systems offer excellent in-plane spatial resolution, control of feature depth and shape is limited [2]. Most often, sputter rates determined through independent measurements are used along with beam current to estimate the time required to erode into a target to a given depth. This approach, however, can be adversely affected by many factors including: ejecta deposition, ion reflection, secondary phase formation incorporating implanted ions, ion channeling, target swelling, evolution of surface morphology and its impact on yield and gallium cluster formation.

In order to enhance the capabilities of modern FIB systems, we have designed, fabricated and tested a custom optical interferometer microscope suitable for operation during ion beam processing. This Michelson interferometer is intended for real-time monitoring and feedback control of focused ion beam processes including sputtering and, potentially, ion stimulated deposition. The apparatus is fabricated with low outgassing rate components for operation in an ultra-high vacuum environment, and the optics are retractable providing ample space when removed for other commonly-used diagnostic tools and gasjet assemblies. The interferometer is external to the FEI, Co. Magnum focused ion column used for experiments but contained within the target chamber. The optical path and ion beam vector are designed to be co-incident at a sample as indicated in Fig. 1. This is made possible through use of a pinhole mirror that is positioned above a specimen. A secondary electron detector is positioned with line-of-sight to the irradiated areas on a specimen.

Tests with FIB-milled Si(100) demonstrate 1.0 μm optical in-plane resolution and an optical field of view equal to 175 μm. A FIB-milled test pattern is shown in Fig. 2. Figure 2.a. shows the test pattern as imaged by scanning electron microscopy (SEM). Figure 2.b. shows the same features using the custom-built Michelson interferometer microscope. Features are ~ 100 nm deep and spaced by varying amounts. The pattern indicated by an '*' has a 2.0 μm pitch (i.e., 1.0 μm-wide features). In addition, we find that the out-of-plane resolution is $\leq$ 5 nm. This is indicated in Fig. 3 which shows images of four features sputtered to different depths. The actual depths listed in the figure are measured independently by atomic force microscopy (AFM).

References:
[1.] J. Orloff, M. Utlaut, and L. Swanson, in *High Resolution Focused Ion Beams: FIB and Its Applications* (Kluwer Academic/Plenum, New York, 2003).
[2.] P. Gnauck and P. Hoffrogge, Proc. of SPIE, 4980 (2003) 106 – 113.

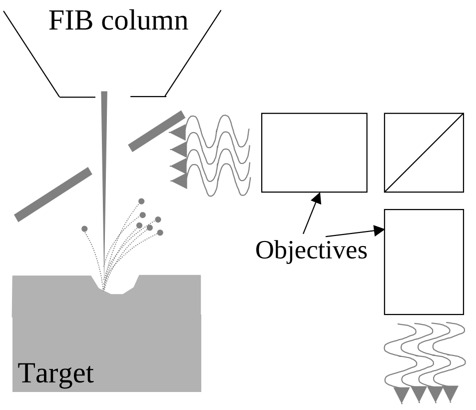

Figure 1. Schematic of focused ion beam system and interferometer microscope.

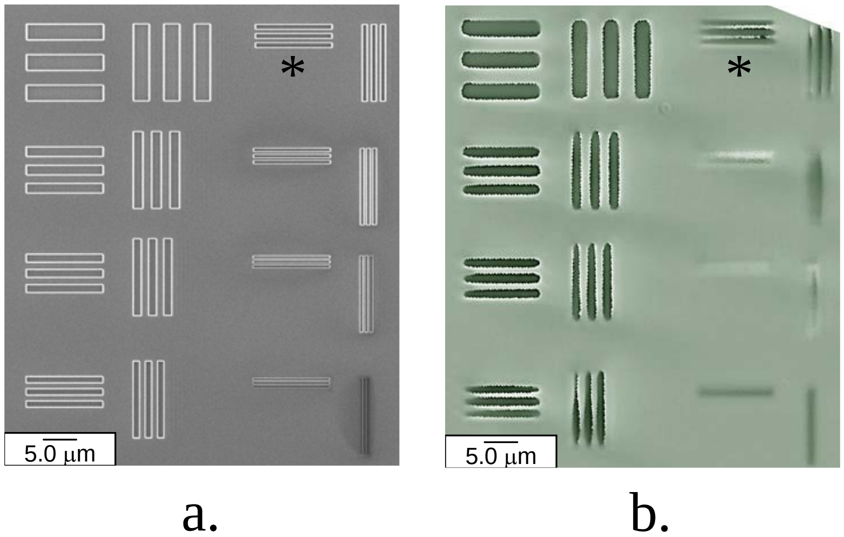

Figure 2. FIB-milled test pattern in Si(100) used to determine in-plane resolution of interferometer microscope. Image in a.) is obtained using SEM. Reconstructed image in b.) is obtained using the custom-built Michelson interferometer.

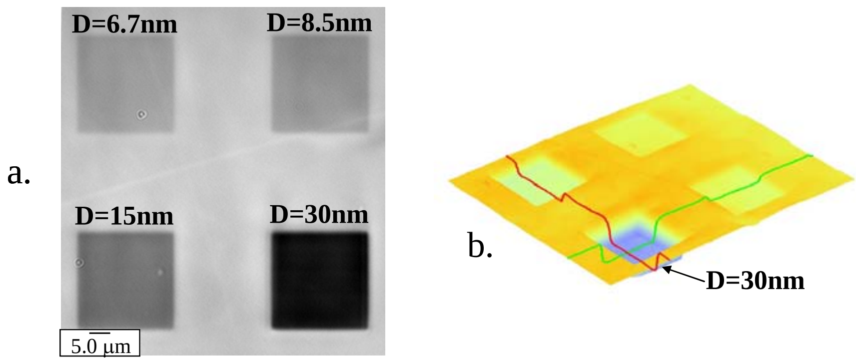

Figure 3. FIB-milled features of different depths, D. Actual depths (listed) are determined by independent AFM measurements. Plan view reconstructed image is shown in a. and tilted view in b.