Unintended Consequences of Focused Ion Beam Milling on Nanostencil Lithography

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Abstract

Sub-micron device features may be fabricated using standard lift-off techniques including electron beam lithography, interference lithography, extreme UV and x-ray lithography. An alternative to these fabrication techniques is nanostencil lithography. Nanostencil lithography avoids possible contamination sources such as resist coatings, solvents and etching and also has the possibility of fabrication and measurement being performed while maintaining ultra high vacuum (UHV) conditions. Stencil lithography can be used in static [1] or dynamic mode [2] and is used for a variety of different applications such as magnetic nanostructures [2], fabrication of in situ interconnects [3], molecular beam epitaxial deposition through a stencil mask [4] and defining clean metal patterns [5].

Focused ion beam (FIB) milling, a common fabrication technique to make nanostencil masks, has the unintended consequence of gallium ion implantation surrounding milled features in silicon nitride membranes [6]. In this work, we demonstrate that FIB-milled nanostencils can lead to a substantial change in structure and chemical composition of resulting nanostructures deposited by electron beam evaporation when compared to the starting material. We present characterization with transmission electron microscopy (TEM), electron energy loss spectroscopy, energy dispersive x-ray spectroscopy, magnetic force microscopy (MFM) and Kelvin probe force microscopy (KPFM) to demonstrate the surprising influence of FIB-milled nanostencils on deposited nanostructures. This effect is attributed to implanted gallium ions in the nanostencil surrounding milled features, and could provide a means for tuneable control over the growth of magnetic nanostructures with varying iron content and film morphologies. The effect may also be mitigated by thinning the nanostencil using a reactive ion etch which may remove the gallium ions.

References

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Figures

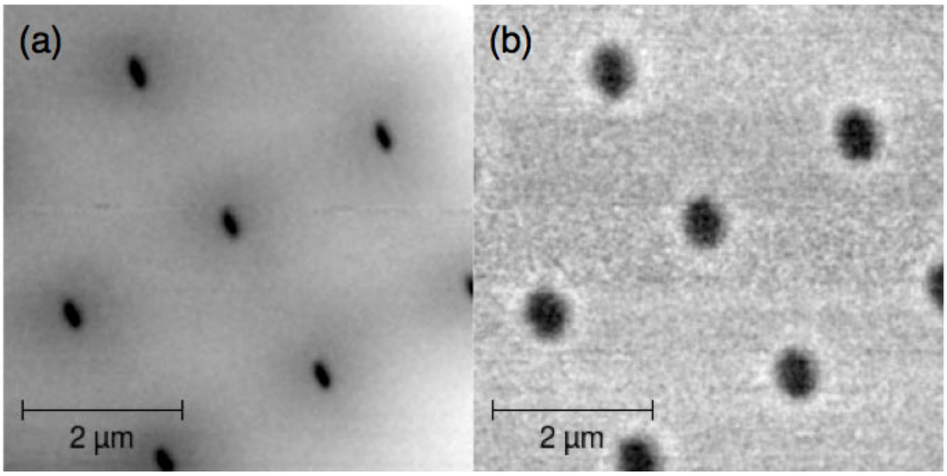

Figure 1. Simultaneously acquired non-contact frequency shift topography (a) and Kelvin probe microscopy images (b) of nanostencil fabricated using FIB milling. Charged regions around FIB milled holes are observed and attributed to gallium implanted from the FIB processing.

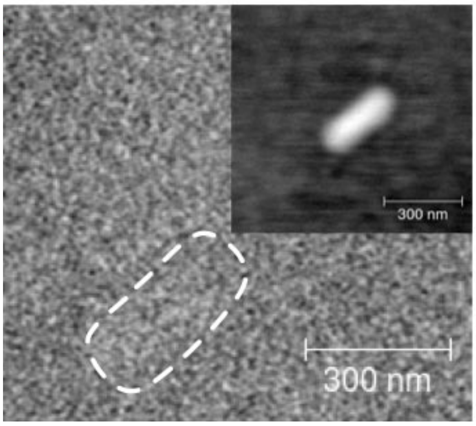

Figure 2. MFM image of a permalloy nanostructure made using a FIB milled nanostencil. Image was taken in a 60 mT in-plane applied field at a lift height of 70 nm. White dotted line indicates location of nanostructure. Inset is a non-contact atomic force microscopy topography image of the nanostructure with a z-scale of 25 nm.

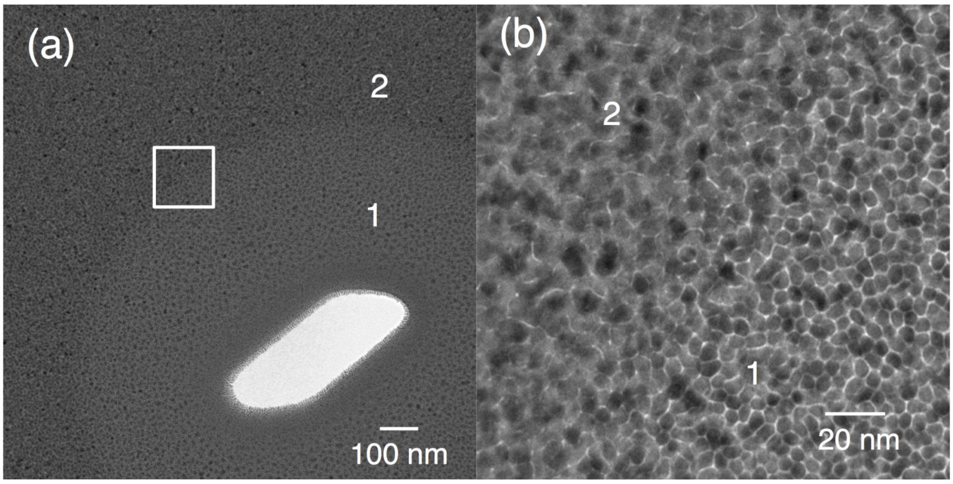

Figure 3. (a) Bright field TEM image of stencil used to make nanostructures. Two regions of permalloy growth are observed. Columnar growth is observed near the FIB milled holes (zone 1), and normal permalloy growth is observed far from the FIB milled holes (zone 3).