doi:10.1017/S1431927610062872
Microsc. Microanal. 16 (Suppl 2), 2010

Direct-Write Focused Ion-Beam Lithography

A. Joshi-Imre,* L. E. Ocola,* J. Klingfus,**

* Center for Nanoscale Materials, Argonne National Laboratory, Argonne, IL 60439
** Raith USA, Ronkonkoma, NY 11779

Direct-write focused ion-beam lithography (IBL) on a large area (covering several square millimeters) may be applied in the R&D for nanofabrication tasks such as efficiently producing nanostructures for electronic, magnetic, photonic and microfluidic applications. Although efficiency in this case is very much dependent on the actual device geometry and materials, yet for some of these applications IBL is likely to outscore other patterning methods due to the following reasons: 1) direct physical milling may be the only known way to pattern some materials at the nanoscale, and 2) IBL is capable of producing intricate 3D surfaces in a single processing step and thus saving time (as compared to performing multiple lithography and etch steps to produce a similar result).

In the first part of this presentation, we will show IBL patterning examples for various applications. Details of the patterning methods including surface coatings, ion beam condition and writing techniques will be discussed. The fabrication of sub-micrometer ferroelectric capacitor structures in bismuth ferrite (BFO) thin films [1] and tunable photonic crystals milled in barium titanate thin films [2] will be shown as examples of direct-write IBL on complex oxides. Figure 1 illustrates the method we employed for BFO patterning. As another example we will highlight the patterning of magnetic multi-layer thin films, in particular the fabrication of disks in bi-layer CoFe-IrMn films used to study the behavior of magnetic vorteces [3]. Finally, we will discuss the advantages of using IBL for the patterning of microfluidic channels as we described in [4].

In the second part of the presentation we will introduce evaluation results on large-area FIB lithography performed with an FEI Nova NanoLab 600 Dual Beam microscope [4]. Our system is configured with a 100 nm resolution X-Y stage and a Raith Elphy Plus Lithography control interface, with integrated 16-bit DAC pattern generator and software. Characterization of pattern placement accuracy, pattern repeatability and drift were performed. Offset lithography (multiple exposures with offset write-fields) and pattern overlay using in-field registration marks were evaluated for correcting stitching errors. We find that by using a combination of offset lithography and in-field registration mark correction methods the pattern placement accuracy may be reduced from over a micrometer (1.3 μm ± 1.2 μm) to better than 100 nm (74 nm ± 147 nm). While our results indicate that pattern placement would be a serious concern in high-resolution patterning (such as in the fabrication of large-area photonic crystals or waveguide structures), a number of other applications (such as the fabrication of large-area microfluidic channels) are viable on a dual beam microscope. We also find that due to higher beam deflection speed provided by the electrostatic scanning in FIB systems versus the electromagnetic scanning found in majority of electron-beam systems, FIB lithography can be just as fast as electron beam lithography for typical mill depths down to about 200 - 500 nm (material dependent) [5].

References

[1] Structures studied by R. Nath et al., *Appl. Phys. Lett.* 96 (2010) in print; abstract regarding the fabrication submitted to EIPBN 2010
[2] Conference paper by P. T. Lin et al., IPNRA 2008
[3] Presented by A. Imre et al. at EIPBN 2008

[4] Presented at EIPBN 2009; A. Imre, L. E. Ocola, L. Rich, and J. Klingfus, *Journ. Vac. Sci. Techn. B.* (2010) in print
[5] The use of the Center for Nanoscale Materials was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357. The BFO capacitor structures were fabricated in collaboration with Orlando Auciello and his group, the BTO photonic crystals were fabricated in collaboration with Bruce Wessels and his group, the ferromagnetic thin films were patterned in collaboration with Amanda Petford-Long and her group, and the microfluidic channels were fabricated with the help of Edgar Palacios. Discussions with Oliver Wilhelmi, Laurent Roussel and Lucille Gianuzzi of FEI, Brian Whitehead of Raith USA, and Sven Bauerdick, Matthias Berse, and Lloyd Peto of Raith Gmbh are gratefully acknowledged.

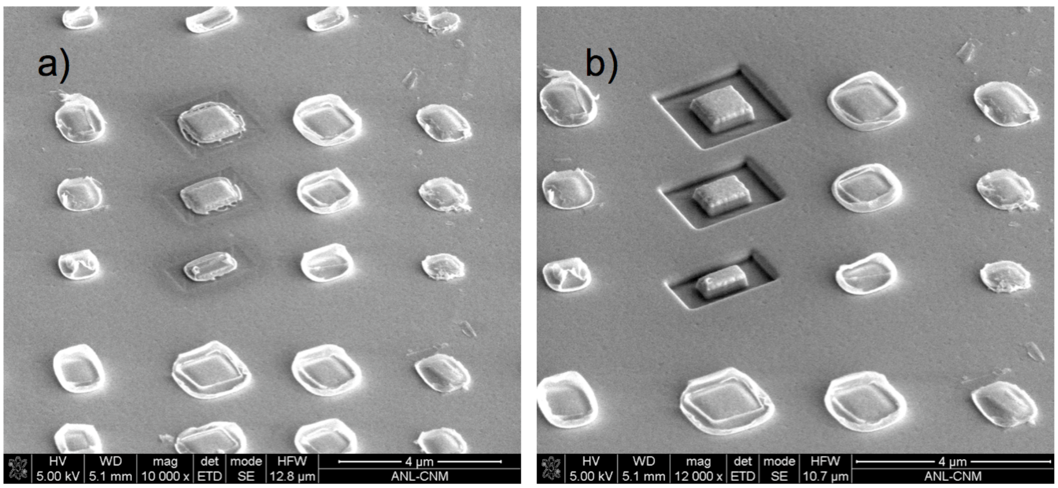

FIG 1. FIB lithography was overlaid onto patterned tungsten hard mask for the fabrication of BFO capacitor structures. The hard mask protects the underlying BFO film from potential damage caused by impacting ions, and can be removed with hydrogen peroxide wet etch at the end of the patterning. (a) Early, and (b) final milling stages of three isolated rectangular structures.

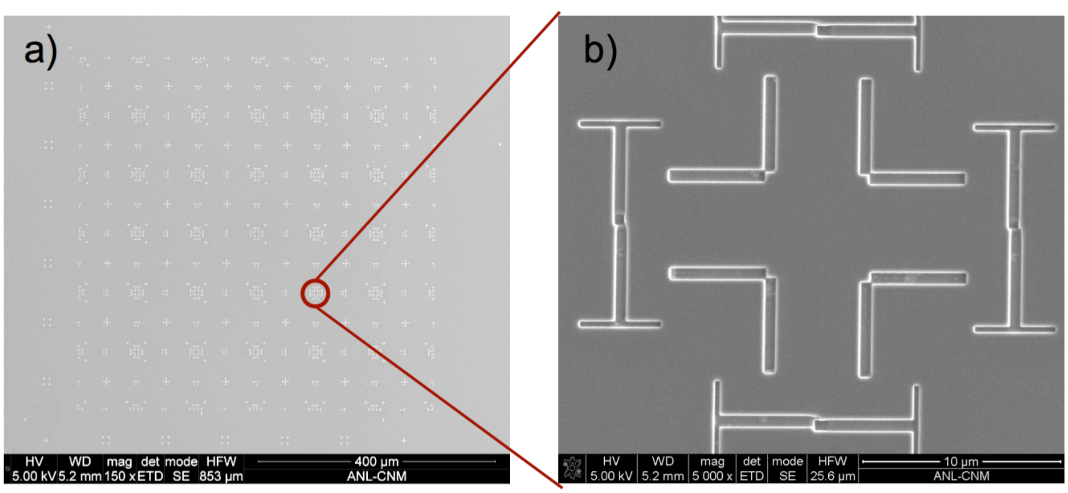

FIG 2. (a) Overview of a large area pattern, which was milled as a 7 by 7 array of 100 µm size write fields. (b) Stitching accuracy was measured at the corners of 4 neighboring write fields based on the matching horizontal and vertical location markers.

https://doi.org/10.1017/S1431927610062872 Published online by Cambridge University Press