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Novel FIB nanofabrication strategies facilitated by light and heavy ions from GaBiLi Liquid Metal Alloy Ion Sources

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Focused Ion Beam (FIB) direct nano-patterning has become established as versatile, and precise fabrication method of smallest features at the nanoscale [1]. Applications in nanoscale science are manifold and require high resolution fabrication techniques at high fidelity, accuracy, and reproducibility. As a result, high demands concerning sputter yield, beam stability and patterning resolution are made on the ion beam for direct FIB nano-patterning. Liquid Metal Alloy Ion Source (LMAIS) is an emerging FIB source technology that provides a versatile solution to deliver light or heavy and fast or slow ions from a single source for FIB nanofabrication [2]. We present unique direct nano-patterning results and a novel workflow using GaBiLi LMAIS. This workflow allows taking advantage of the benefits of the different beams. Gallium, Bismuth and Lithium ions are emitted simultaneously with subsequent ion separation in an ExB filter.

A Lithium-ion beam has the smallest beam diameter and enables highest patterning resolution as well as imaging resolution of all ions available from LMAIS [3] whereas Bismuth ion beam provides higher sputter yield at higher depth resolution [4].

To overcome challenges during patterning of sub-10nm metallic nanogaps, we present a 2-step fabrication process for bowtie nano-antennas. This approach takes advantage of large volume material milling with a Bismuth ion beam at high sputter yield to speed up the entire fabrication process and subsequent lateral fine shaping using a Lithium beam from the same ion source.

Beyond direct nanopatterning, Lithium as the lightest ion available from LMAIS provides excellent ion beam imaging capabilities. Latest results of 3D milling and ion imaging with Bismuth and Lithium ions for 3D sample tomography and reconstruction will be presented.

[1] P. Li, S. Chen, W. Peng, W. Shan, and H. Duan, Recent advances in focused ion beam nanofabrication for nanostructures and devices: fundamentals and applications, Nanoscale 13, 1529 (2021).

[2] J. Gierak, P. Mazarov, L. Bruchhaus, R. Jede, L. Bischoff, Review of electrohydrodynamical ion sources and their applications to focused ion beam technology, JVSTB 36, 06J101 (2018).

[3] N. Klingner, G. Hlawacek, P. Mazarov, W. Pilz, F. Meyer, and L. Bischoff, Imaging and milling resolution of light ion beams from helium ion microscopy and FIBs driven by liquid metal alloy ion sources, Beilstein J. Nanotechnol. 11, 1742 (2020).

[4] A. Tolstogouzov, P. Mazarov, A.E. Ieshkin, S.F. Belykh, N.G. Korobeishchikov, V.O. Pelenovich, D.J. Fu, Sputtering of silicon by atomic and cluster bismuth ions: An influence of projectile nuclearity and specific kinetic energy on the sputter yield Vacuum 188 110188 (2021).

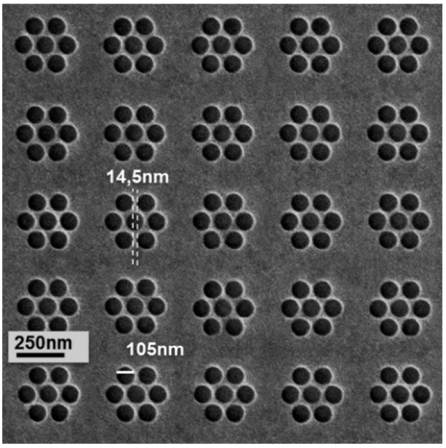

Fig. 1: *Li FIB patterning of heptamer-arranged nanohole (HNH) arrays in 50nm Au film on SiO_2 and subsequent Li ion beam imaging.*

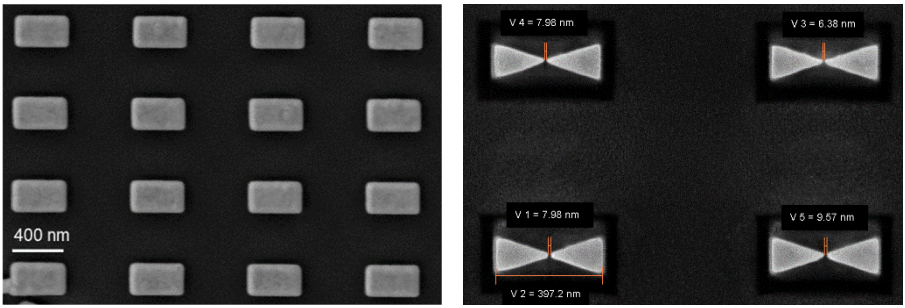

Fig. 2: *Stepwise fabrication of nano bowties in 50nm Au film on Si: a) Bi FIB for large volume milling to excavate rectangular boxes, b) Li FIB for fine shaping bowties structures at highest resolution.*

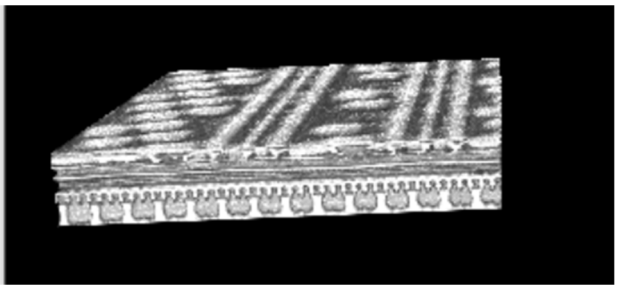

Fig. 3: *3D reconstruction (5µm x 5µm x 0.85µm) of semiconductor chip layers by Bi milling and Li imaging.*