Progress Report on the Multi-Species Focused Ion Beam Lithography System and Its Applications

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Focused Ion Beam Lithography (IBL) can have significant advantages over electron beam lithography (EBL), like direct, resistless, and three-dimensional patterning, while at the same time delivering the *in-situ* process control by cross-sectioning and inspection that a focused ion beam (FIB) instrument typically affords. Although an IBL-centric process can in many cases be slower than a resist-accelerated EBL-centric nanofabrication process, an increasing number of applications can be found over the last ten years mainly based on FIB systems and combined FIB-SEM microscopes upgraded with nanolithography add-on packages. In addition such IBL applications are motivated by the relative simplification of the overall nanofabrication process as compared to that of EBL, especially for the direct processing at the nanometer scale of novel materials for which EBL processes have yet to be developed, or any materials for which EBL processes do not exist or are otherwise difficult to access.

We have improved the IBL instrumentation specifically for nanometer scale patterning over large areas. This dedicated IBL tool utilizes true lithography architecture and an ion source and column optimized for high resolution and large area nanometer scale patterning. This includes in particular a laser interferometer stage, long-term beam to sample position stability, as well as enhanced beam current stability and true automation capabilities. These system features enable high resolution, large area patterning over long times for IBL applications such as X-ray zone plates [1], large area gratings [2] (see Figure 1), and wafer-level nanopore devices, tasks which are impossible with an analytical FIB-SEM microscope platform. As a result IBL is as powerful as, complementary to, and compatible with (mix & match) the other lithography techniques commonly found in nanoscale research and development facilities.

With the appreciation that the ion type has dramatic consequences on the physical and chemical nature of the resulting nanostructures, we have collaborated here to extend the Gallium IBL tool's unique ion column and source towards the long-term stable delivery of multiple species for a nanometer-scale focused ion beam employing a liquid metal alloy ion source (LMAIS). The IBL system is equipped with an ExB filter capable of selecting single and multiple charged ion species [3] (see Figure 2) and has, for example, produced the Au and Si focused ion beams utilized for the development of a novel graphene nanoribbon nanofabrication process [4]. We present a progress report demonstrating the capabilities (see Figure 3) and applications of the multiple-species IBL instrument.

[1] A. Nadzeyka et al., Microelectr. Engineering 98 (2012), 198-201.
[2] S. K. Tripathi et al., J. Micromech. Microeng. 22 (2012) 055005.
[3] B. R. Appleton et al., Nucl. Instrum. Methods B 272, 153 (2012).
[4] S. Tongay et al., Appl. Phys. Lett. 100, 073501 (2012).

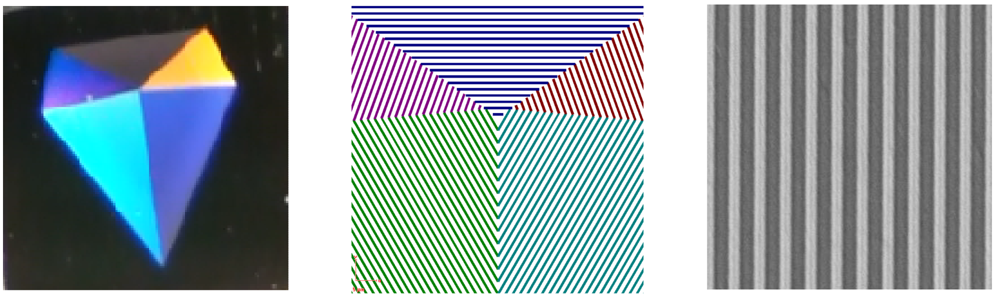

Figure 1: Large area (3x4 mm²) grating (400 nm) in a diamond layer fabricated by Ga IBL hard masking [2]: photograph, exposed pattern and SEM micrograph.

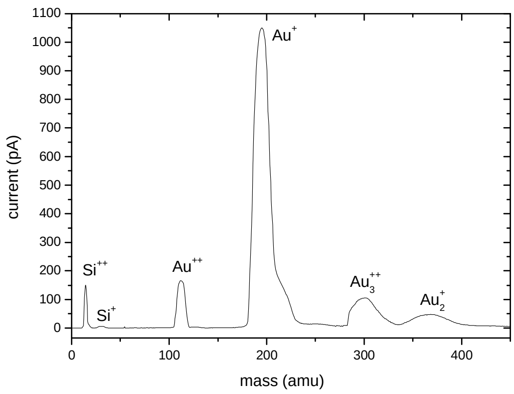

Figure 2: Mass spectrum of a AuSi ion source with various ion species.

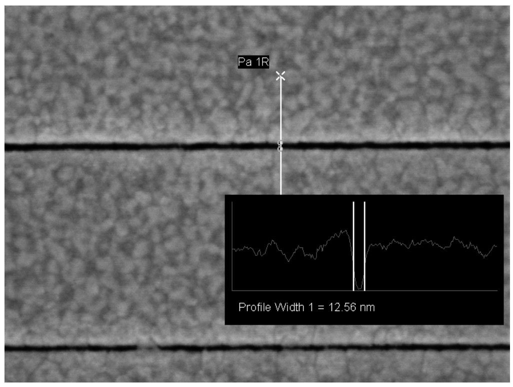

Figure 3: Lines (dose test) milled by a Si^{++} ion beam into a 20 nm Au layer.