Improved Instrumentation and Patterning Strategies for Extended and Continuous FIB Nanofabrication

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Focused ion beam (FIB) systems are applied to an increasing number of applications in R&D nanofabrication. As a result, more advanced and sophisticated patterning approaches also become increasingly important [1,2]. FIB nanofabrication provides direct, resistless, and three-dimensional patterning and is partnered due to these complementary strengths with other lithography techniques. There are also opportunities to transfer instrument solutions and patterning strategies from one discipline to the other, for instance, apply EBL techniques to FIB nanofabrication. We show that with a lithography-centric instrument design in architecture and components it has been possible to employ write field stitching as well as truly continuous, i.e. stitch-free, writing to FIB nanofabrication, after optimization of parameters that are unique to milling as compared to resist-based EBL.

Besides investigation, patterning optimization and application examples for stitching with FIB milling we report on a patterning methodology with a truly continuous stage movement while milling/ cutting with an ion beam. This allows for the creation of continuous structures which can extend for mm or even cm. A high speed pattern generator is synchronized to the movements of the laser-interferometer stage while the beam movement is optimized, e.g. in order to prevent re-deposition. We tested different beam strategies and found that simple beam patterns (which are suitable for EBL) result in V shaped grooves with a lot of re-deposited material (Figure 1), but an improved beam pattern needs to mimic the looping strategy of conventional milling. Optimal patterns are calculated with respect to stage speed, beam current, desired depth, and looping strategy. The result is shown in Figure 2 for grooves with defined depth and steep walls keeping re-deposition to a minimum.

Finally, the same instrumentation can be employed for continuous stripe-like patterning over larger areas with various more sophisticated, repetitive, beam movements (Figure 3). As FIB milling is a quite slow patterning technique compared to EBL, this approach is better-suited for resist, functionalization and implantation applications. Examples for hard masking with Ga in diamond [3] or silicon samples and especially with ions like Au or Si [4,5] will be presented and discussed. In general, the results show that with instrument optimization stitching as well as continuous writing strategies can be successfully applied to direct FIB milling as well as FIB masking and functionalization applications. This will bring advances in optical or fluidic applications which are exceeding a single write field [3].

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[1] A. Imre et al., JVST B 28(2) (2010) 304.
[2] E. Palacios et al., JVST B 28(6) (2010) C6I1.
[3] S. K. Tripathi et al., J. Micromech. Microeng. 22 (2012) 055005.
[4] S. Bauerdick et al., JVST B 31 (2013) 06F404.
[5] S. Tongay et al., Appl. Phys. Lett. 100, 073501 (2012).

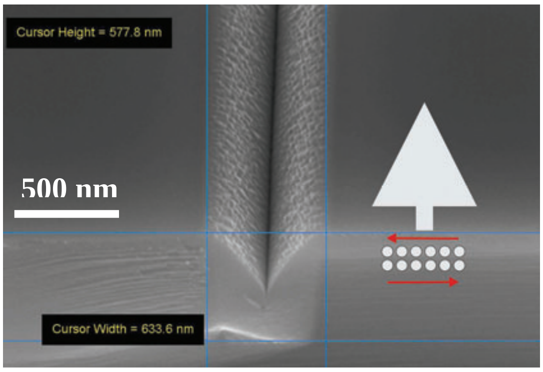

Figure 1: X-sectional view (SEM) of a stage driven FIB cut in silicon with a simple 2 line beam pattern.

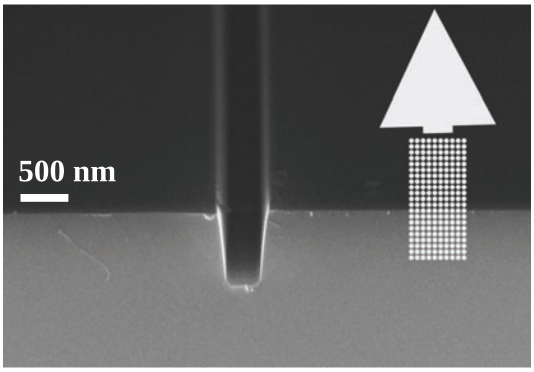

Figure 2: X-sectional view (SEM) of a steep and clean cut in silicon with a FIB adapted repetitive beam pattern during continuous stage movement.

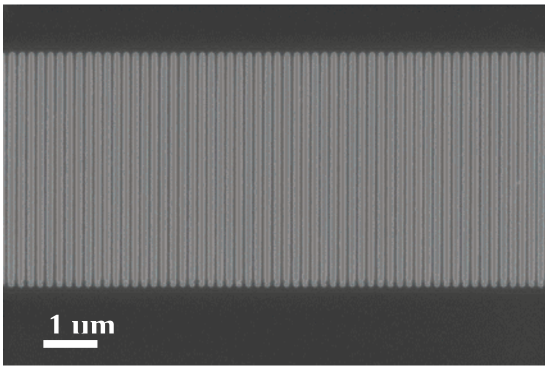

Figure 3: SEM image of a mm long pattern written with a repetitively scanning beam during continuous stage drive. This grating is exposed in PMMA by Si++, whereas this mode has also been applied to various implantation applications.