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The patterning toolbox FIB-o-mat: Exploiting the full potential of focused ion beams for nanofabrication

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Future breakthroughs in nanotechnology will rely on the ability to fabricate materials and devices by design, i.e. to tailor both material properties and device geometries according to a sophisticated blueprint. Direct writing using focused beams of ions or electrons is a powerful technique not only for rapid-prototyping of novel device components but also for mask-less processing of delicate nanostructures and local modification of materials. To achieve an optimal result in the patterning process, a full control over the beam path including its rasterization is necessary. Here, we present the open-source Python toolbox FIB-o-mat [1] for automated pattern creation and optimization (cf. Fig. 1).

Patterning with an ion beam is a digital process in which the beam spot dwells for a defined time at a certain location and is then shifted by a defined distance ('pitch') to dwell again. This beam path can be created from a high-level geometry that is rasterized following a pre-defined routine. Therefore, FIB-o-mat provides various geometries including their Boolean combinations together with all possible rectangular and annular rasterization schemes. For complex geometries however, rasterization may lead to artifacts in narrow regions or for large curvatures. Here, FIB-o-mat offers a low-level approach where the beam path is generated by curve off-setting for any given input geometry to achieve the best patterning fidelity.

The functionalities of the Python-based toolbox FIB-o-mat are showcased for He ion beam processing of three different material systems. The magnetic properties of Co-based multilayers were locally modified using the high-level beam path generation combined with automation via stage control [2]. Plasmonic tetramer antennas were cut from single-crystalline gold on glass, demonstrating the ultimate patterning resolution of the focused He ion beam with gap sizes down to 3 nm (cf. Fig. 2). Apart from the low-level beam path generation, a local dose optimization had to be carried out. Finally, suspended single layer graphene was patterned into simple trampoline resonators but also complex phononic crystal structures [3] using the low-level beam path generation and automation via stage control.

[1] V. Deinhart, L.M. Kern, J.N. Kirchhof, S. Juergensen, J. Sturm, E. Krauss, Th. Feichtner, S. Kovalchuk, M. Schneider, D. Engel, B. Pfau, B. Hecht, K.I. Bolotin, S. Reich and K. Höflich; *The patterning toolbox FIB-o-mat: Exploiting the full potential of focused helium ions for nanofabrication*; Beilstein J. Nanotechnol. 12 (**2021**), 304.

[2] L.M. Kern, et al.; *Deterministic Generation and Guided Motion of Magnetic Skyrmions by Focused He⁺-Ion Irradiation*, Nano Lett. 22 (**2022**), 4028.

[3] J. N. Kirchhof, et al.; *Tunable Graphene Phononic Crystal*; Nano Lett. 21 (**2021**), 2174.

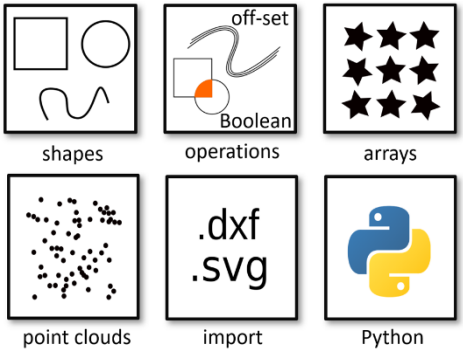

Fig. 1: FIB-o-mat tools

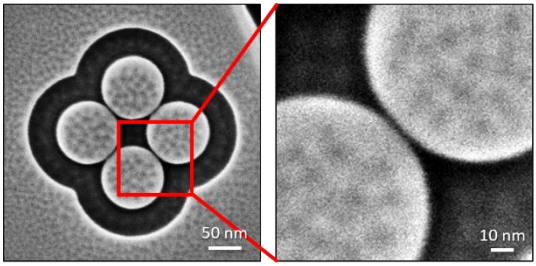

Fig. 2: Plasmonic tetramer antenna with ultimate gap resolution achieved by He ion beam patterning