P28: 3D Nanoprinting of advanced AFM nanoprobes

L. M. Seewald[1], R. Winkler[1], M. Brugger-Hatzl[2], and H. Plank[1,2,3]

[1] Christian Doppler Laboratory - DEFINE, Graz University of Technology, 8010 Graz, Austria
[2] Graz Centre for Electron Microscopy, 8010 Graz, Austria
[3] Institute of Electron Microscopy, Graz University of Technology, 8010 Graz, Austria
E-Mail: lukas.seewald@felmi-zfe.at

Aside of electron / ion beam microscopes, scanning probe techniques have evolved into an indispensable technology pool for surface characterization in diverse research areas from materials science over biotechnology towards life sciences. In that context, atomic force microscopy (AFM) plays a central role due to its low demands on surfaces and the compatibility with various environments. At the same time, lateral resolution in the lowest nanometer range can be achieved for conventional setups, while advanced operation modes provide access to functional surface properties, including electrical, magnetic, thermal, optical or mechanical properties. The latter possibilities, however, require functional nanoprobes, which are mostly achieved by either coating of conventional nanoprobes or by fabrication of a solid functional nanoprobe tip, which not only increases the achievable resolution due to sharper apexes but also eliminates the risk of delamination, which renders such probes useless. Related fabrication approaches include the mounting of specifically grown crystals on pre-structured cantilevers or the application of particle beam induced deposition techniques for direct growth of functional nanoprobes. In that context, focused electron beam induced deposition (FEBID) has evolved into a reliable, additive direct-write manufacturing technique at the nanoscale. Aside controlled fabrication of 3D (nano-)designs, material properties are naturally the decisive element when advanced operation modes are targeted. Aside of specifically designed precursor compounds, post-growth treatments, such as the exposure to temperatures / gases / electron beams in different environments, have considerably expanded the functional tunability towards the intended properties [1].

In this contribution, FEBID-based 3D nanoprinting will be revisited in the context of the here relevant fabrication of advanced AFM nanoprobes. Process aspects to achieve high-fidelity geometrical replication and post-treatment processes to specifically tune materials properties are also included for further discussions of 3D nanoprobe concepts, which are developed in our workgroup in collaboration with industry. We will focus on thermal [2], electrical [3] and magnetic [4] nanoprobes, where we not only highlight the advantages but also demonstrate the superior performance in comparison to alternative, commercially available products. We conclude the contribution with a view on ongoing activities but also discuss remaining challenges, to provide a comprehensive picture of the current status of FEBID-based, 3D nano-printing of advanced AFM nanoprobes.

References

[1] Plank, H., *et al. Micromachines.* 11, 48. (2019).
[2] Sattelkow, J., *et al. ACS Appl. Mater. Interfaces.* 11, 22655–22667. (2019).
[3] Seewald, L.M., *et al*. *Nanomaterials.* 12, 4477. (2022).
[4] Winkler, R., *et al. Nanomater.* 13, 1217 (2023).

materials, such us: charge carriers and phonon mean free path. Presented study opens a way towards electrical rectifier metamaterials, frequency multipliers in THz range, phononic crystals and thermal rectifiers.

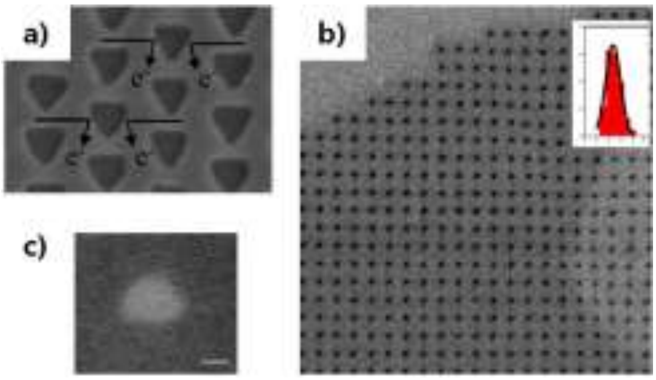

Figure 1. a) Scanning electron microscope image of an artificial functional material. The arrows indicate the typical electron trajectories. The devices operate similar to a bridge rectifier [2]. Triangles base is 200 nm large. B) Helium ion microscope image of perforated graphene membrane with He-FIB, period is 30 nm. Inset shows a typical pore diameter distribution in nm. C) Triangular pore in graphene by He-FIB. Scale is 10 nm.

References

[1] Shorubalko, I., *et al. Appl. Phys. Lett*. 79, 1384-1386. (2001).
[2] Song, A.M., *et al. Appl. Phys. Lett*.,79, 1357-1359. (2001).
[3] Jacobsen, A., *et al*. *Appl. Phys. Lett*. 97, 032110. (2010).
[4] Butti, P., *et al. Appl. Phys. Lett*. 112, 133501. (2018).
[5] Shorubalko, I., *et al*. *Book chapter in Helium Ion Microscopy*. Ch.15. (2016).
[6] Scholder, O., *et al*. *Nanotechnology*. 24, 395301. (2013).
[7] Buchheim, J., *et al*. *Nanoscale*. 8, 8345-8354. (2016).
[8] Shorubalko, I., *et al*. *Beilstein J. Nanotechnol*. 8, 682–687. (2017).
[9] Celebi, K., *et al. Science*. 344, 289-292. (2014).