3D-Nanoprinting of Magnetic Force Microscopy Tips

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Introduction

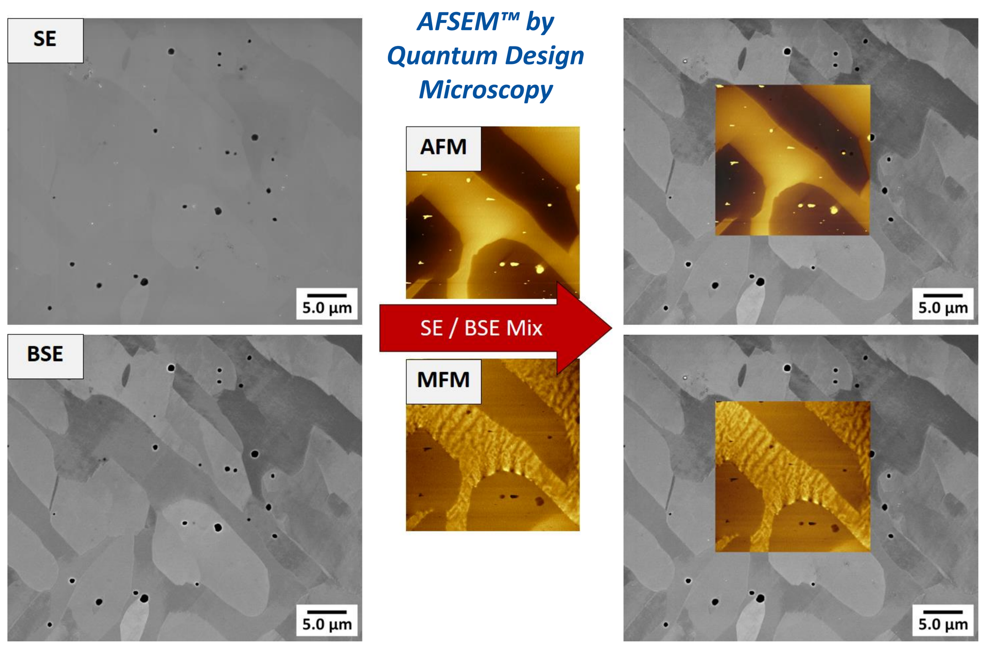

Figure 1: Correlative microscopy studies using SEM and AFM based techniques provide complementary and comprehensive material insights beyond single techniques.[1]

Magnetic devices play an important role in modern electronics, sensing or data storage. To analyze related materials in a comprehensive way, combined SEM-AFM studies are often not optional but essential. Fig.1 shows such an example where SE, BSE, AFM and MFM information complement each other in an ideal way. MFM benefits in particular from vacuum conditions, as Q-factors and by that magnetic sensitivities strongly increase (Fig.2). To exploit the full potential, high-resolution MFM tips are needed for such instrumentation, which are the topic of this study.

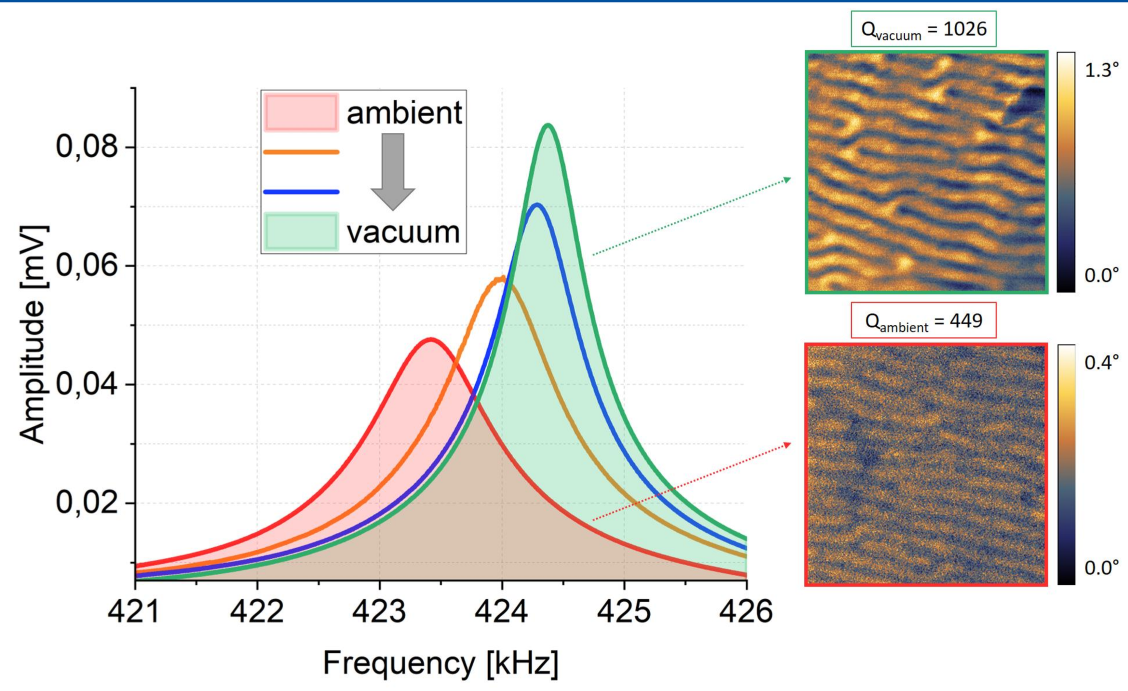

Figure 2: Implications of environmental pressure on AFM amplitudes, which increase quality-factors (Q) under vacuum conditions.

Morphology, Chemistry, and Structure

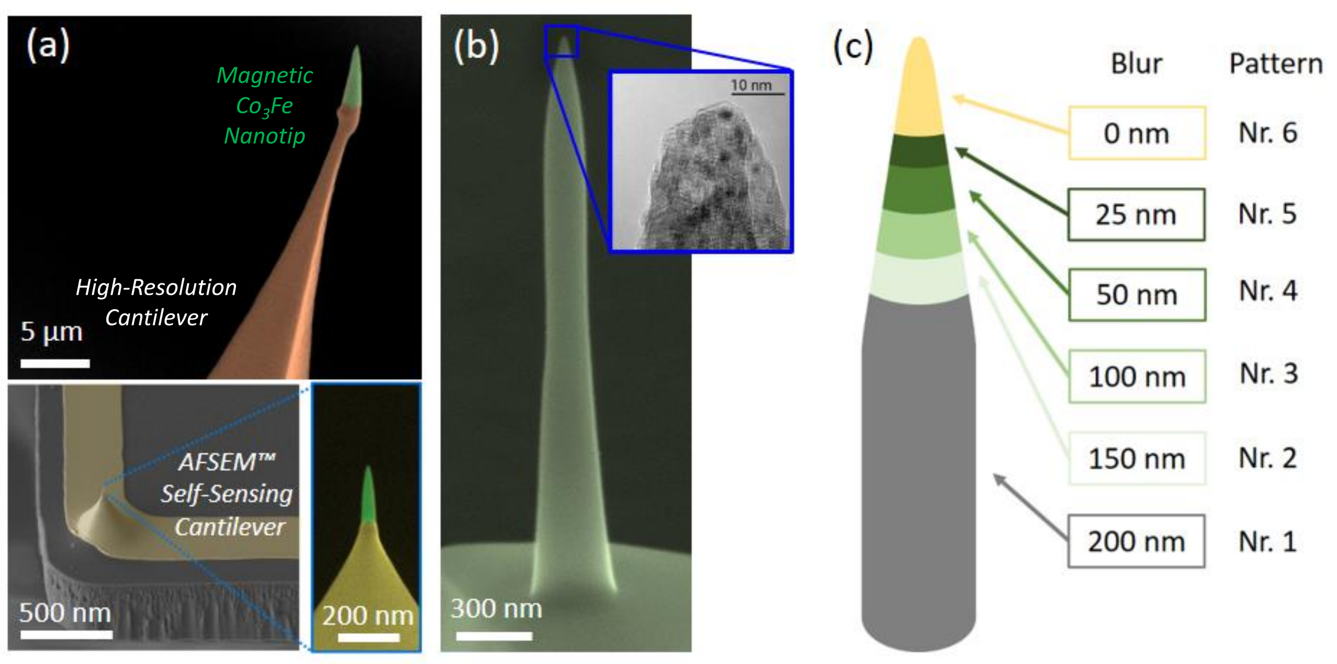

Figure 3: (a) FEBID-based MFM nanoprobe modification on different cantilevers.[3] (b) fully grown Co_3Fe nanoprobe for tipless cantilever platforms with a TEM image of the tip region, revealing the apexes around 10 nm. (c) Dynamic patterning sequence for full pillar growth as shown in (b) via decreasing beam blurs.[4]

A Co_3Fe based precursor was used for FEBID-based modification or full growth of MFM nanoprobes via advanced patterning sequences (Fig.3).[2] Upfront, a wide range of growth parameters and their implications on morphology (Fig.4), structure and chemistry (Fig.5) were studied. By that, the ideal FEBIP process windows were identified for fabrication of AFM compatible MFM nanoprobes.

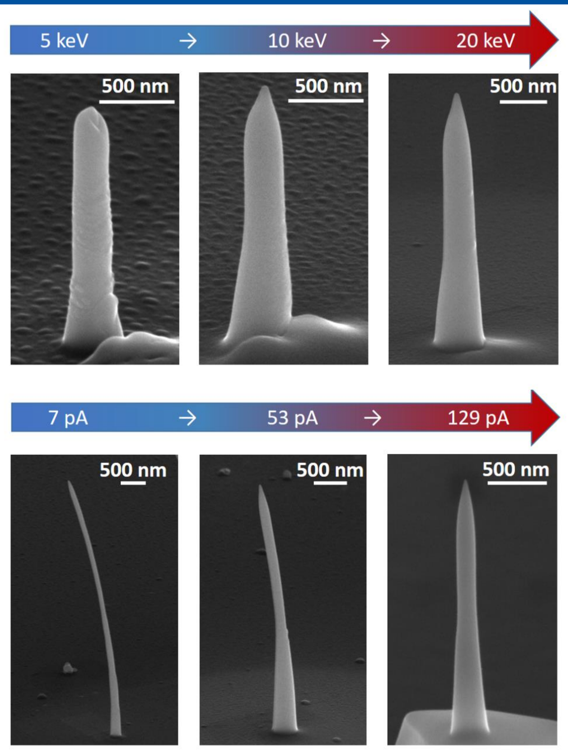

Figure 4: Selected implications of electron energies (top) and beam currents (bottom) on morphologies.

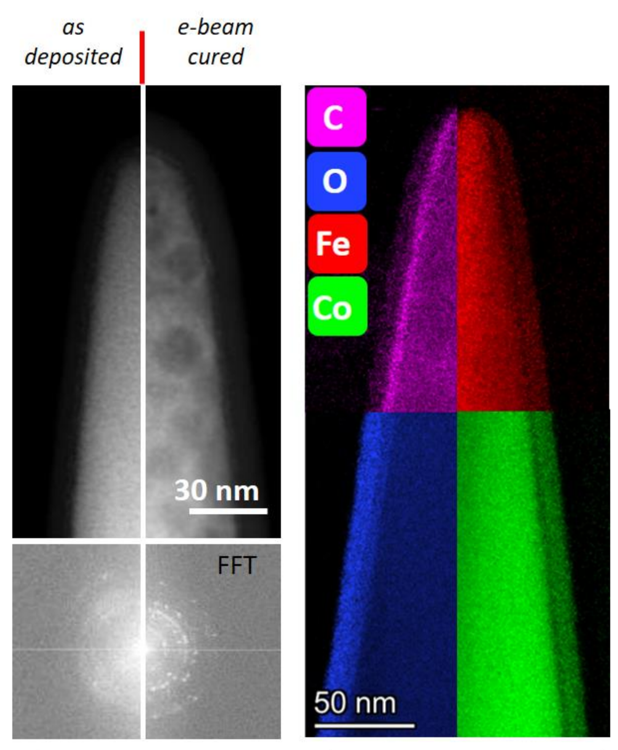

Figure 5: HAADF images, FFT and EDXS analysis of differently prepared / treated Co_3Fe 3D nanoprobes.

MFM Performance

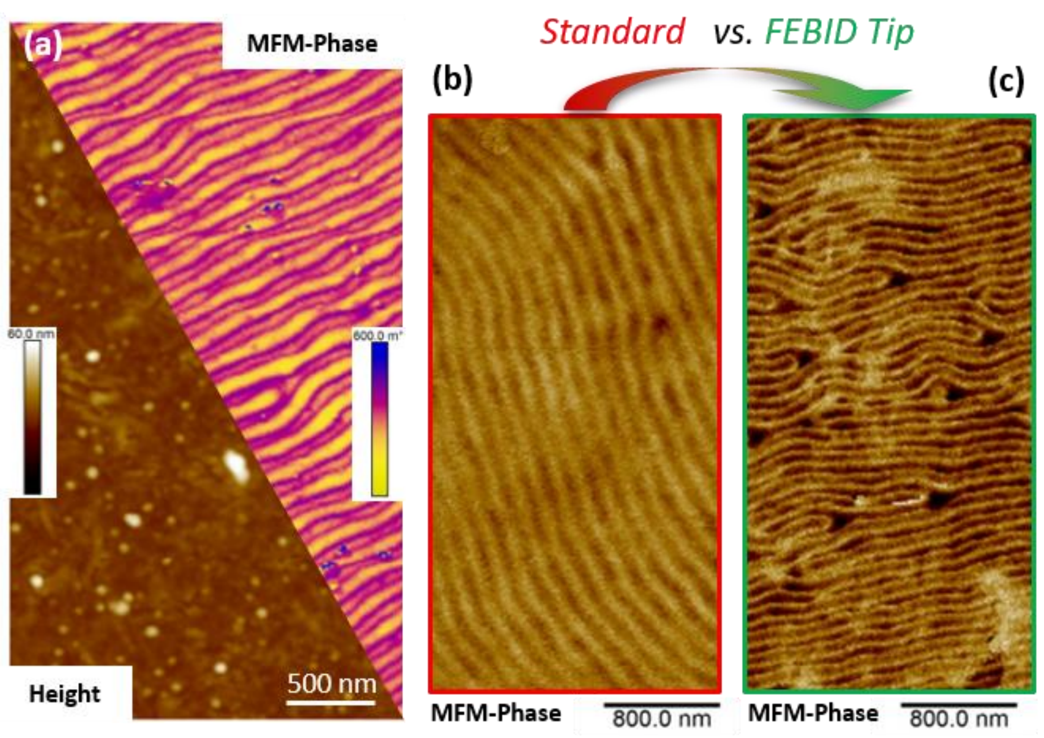

Figure 6: (a) height and magnetic phase of a CoPt multilayer system obtained with Co_3Fe FEBID-MFM tips.[5] (b) and (c) gives a direct MFM comparison between a commercial standard MFM tip and a FEBID tip, respectively, revealing the superior performance of the Co_3Fe nanoprobes.

The achievable performance of FEBID-MFM tips is demonstrated with special focus on lateral resolution, magnetic phase shift, signal-to-noise ratio, and wear resistance. Direct comparison of magnetic maps taken with a commercial and FEBID MFM-tips show the superior performance of the FEBID nanoprobe (Fig. 6). Also, wear resistance tests were conducted, as summarized in Fig. 7 by the first and last measurement after continuous operation for 3.7 h, where durability in height and stability in phase imaging is demonstrated. For further optimization, tip geometries were fine tuned (denoted as α-pillar) and subjected to electron beam curing for evaluation, which did not imply further improvements as fully summarized in Fig. 8.

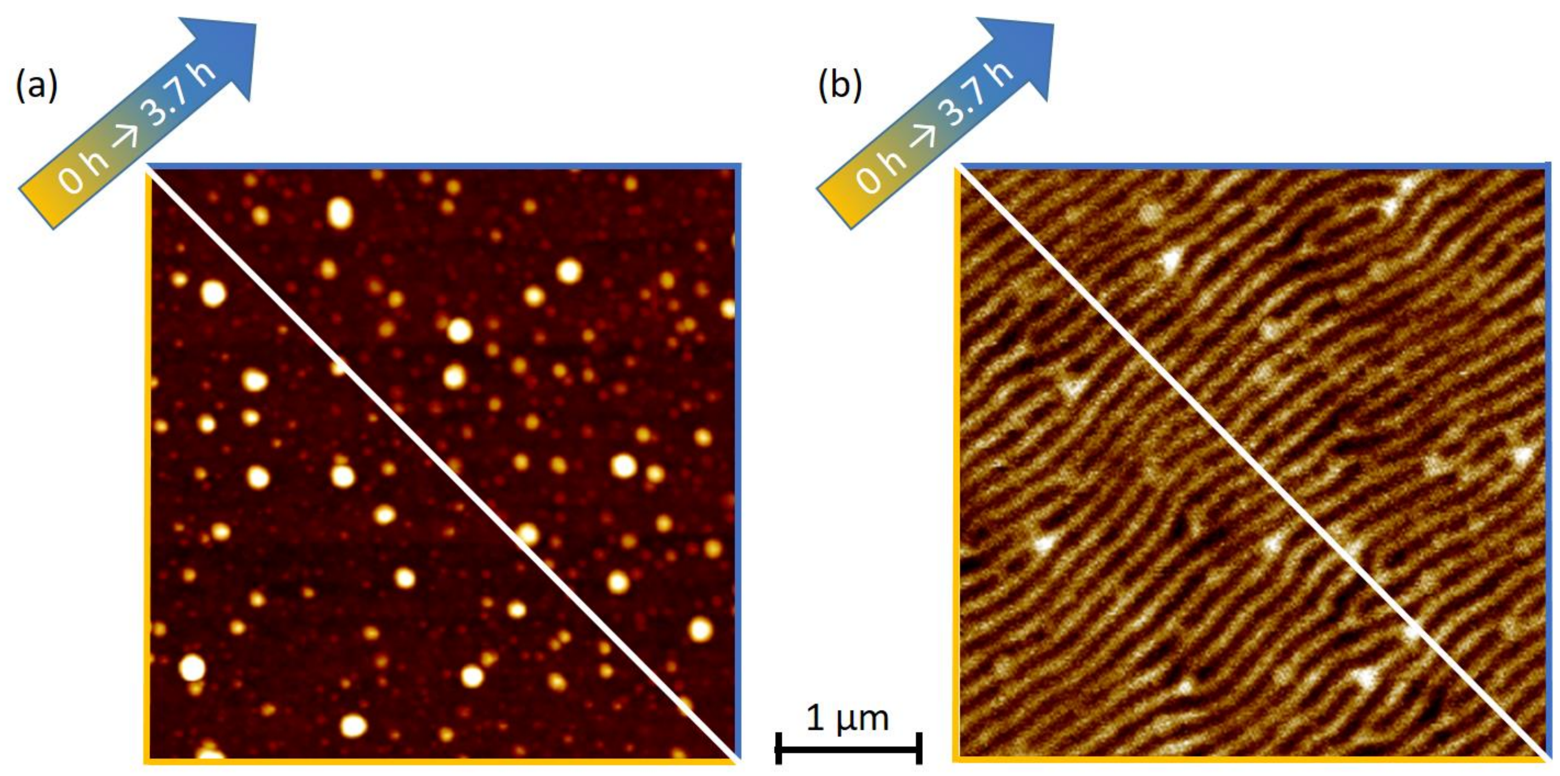

Figure 7: Wear resistance of a Co_3Fe nanoprobe. (a) topography and (b) magnetic phase image of a CoPt multilayer system are compared after a continuous measurement interval of 3.7 hours, revealing practically identical results in both signals.

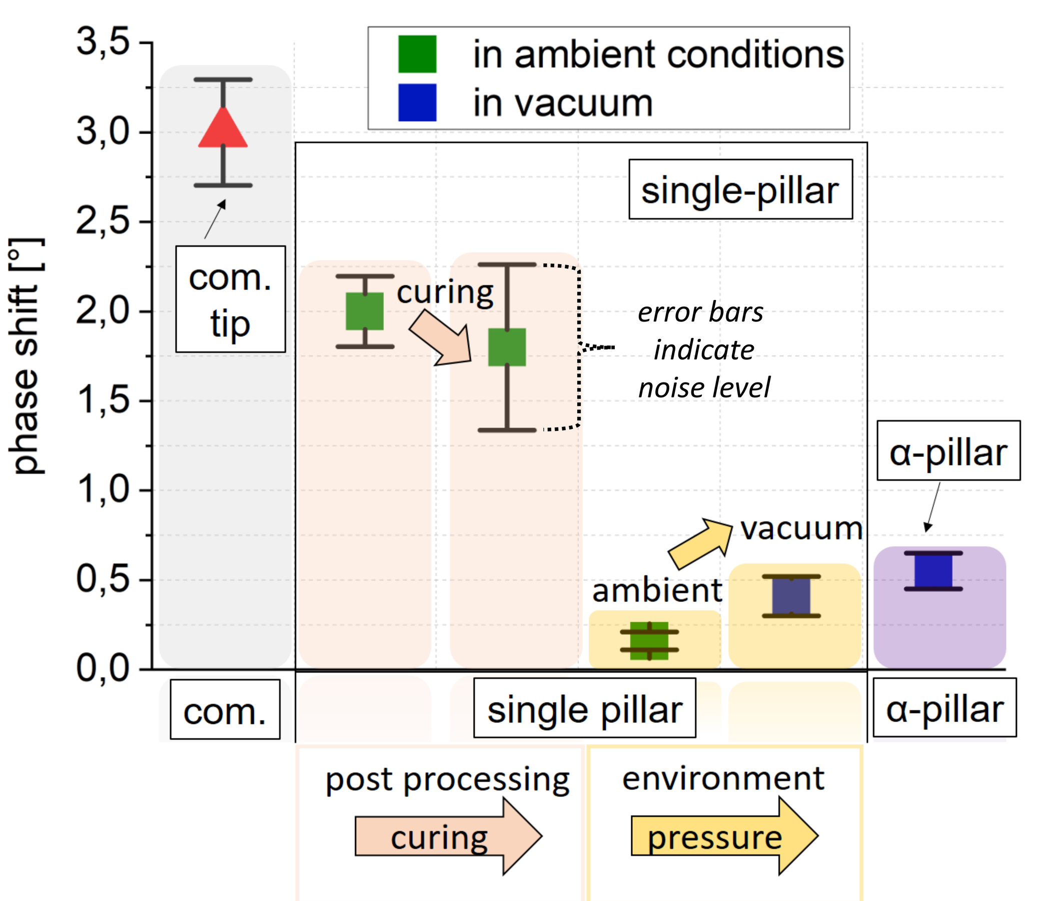

Figure 8: Full comparison of the magnetic phase shifts in different environments using commercial (red) and different FEBID tips.

Conclusion

FEBID was used for the fabrication of Co_3Fe-based, magnetic nanoprobes for MFM applications. The in-depth analyses revealed a superior performance compared to commercially available products concerning lateral resolution and magnetic sensitivity. Together with the fast direct-write manufacturing process, the absence of post-growth treatment and the high durability, the study demonstrates the industrial relevance currently being used in the field of correlative microscopy in collaboration with Quantum Design Microscopy.

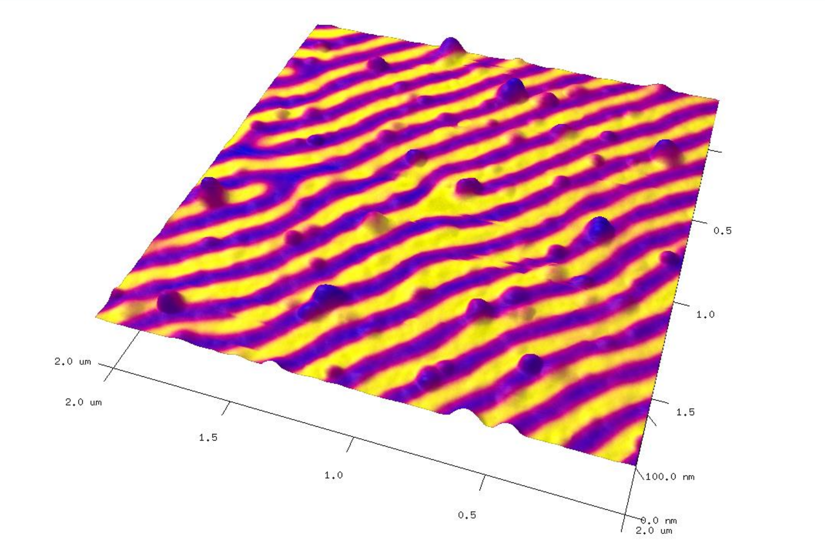

Figure 9: 3D height image with the magnetic phase contrast as colored overlay obtained by FEBID-based, Co_3Fe MFM tips.

References

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[5] Salikhov et al., *Phys. Rev. App.* **2021**, 16, 034016

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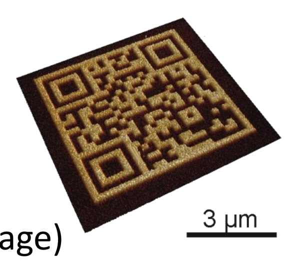

(FEBID QR-Code, 3D-AFM height image)