Direct-Write 3D Nanoprinting of High-Resolution Magnetic Force Microscopy Nanoprobes

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Magnetic devices play an important role in modern electronic, sensing or data storage applications. To exploit their full potential, high-resolution Magnetic Force Microscopy (MFM) is established as standard characterization technology as part of the research and development loop. Due to the ongoing trend towards smaller and smaller active feature sizes, the demands on high-resolution MFM tips are also increasing. Based on that motivation, we here aim on the fabrication of MFM nanoprobes with functional apex radii in the sub-10 nm regime. Traditional products mostly base on additional magnetic coatings, which increases the apex radii and therefore limits the lateral resolution during Atomic Force Microscopy (AFM) based MFM measurements. Another disadvantage of a magnetic coating is local delamination, which can occur due to the mechanical stress during scanning and lead to a change (or even complete loss) in magnetic sensitivity. Therefore, it was the goal to fabricate fully magnetic nanoscale tips, that do not require additional coating. Focused Electron Beam Induced Deposition (FEBID) was used for additive, direct-write 3D-nanoprinting of such magnetic tips on pre-finished self-sensing AFM cantilevers.[1],[2] For that, a novel $HCo_3Fe(CO)_{12}$ precursor was used, which is one of the few precursors, providing metal contents above 90 at.% after initial FEBID fabrication.[3] To explore the possibilities, we comprehensively studied the parameter space and their implications on morphology, structure and chemistry in detail by using SEM, EDX, and TEM and STEM EELS (Figure 1.a). Next, the tip geometry was further optimized by an advanced, dynamic pattering sequence to fulfil the high demands for AFM operation.[4] Additionally, the fabricated tips were subjected to different post-processing procedures such as post-irradiation with electrons, thermal treatments and purification protocols to explore and identify the most promising fabrication window. The basic performance of such MFM tips is then demonstrated with special focus on lateral resolution, magnetic phase shift and signal-to-noise ratio. Fully optimized FEBID-MFM tips were then tested on various magnetic samples (magnetic multilayer system (Figure 1.b-e), hard disc drives, magnetic recording tapes) and benchmarked to commercially available MFM tips (Figure 1.b-c). Finally, the wear resistance of such MFM nanoprobes was evaluated during a continuous operation scan over a period of 3.7 hours, which revealed the high durability of the presented concept (Figure 1.d-e). By that, we demonstrate the successful 3D-nanoprinting of MFM tips on self-sensing cantilevers, which fulfils the high requirements when aiming on industrially relevant MFM tips using FEBID-based 3D nanoprinting.

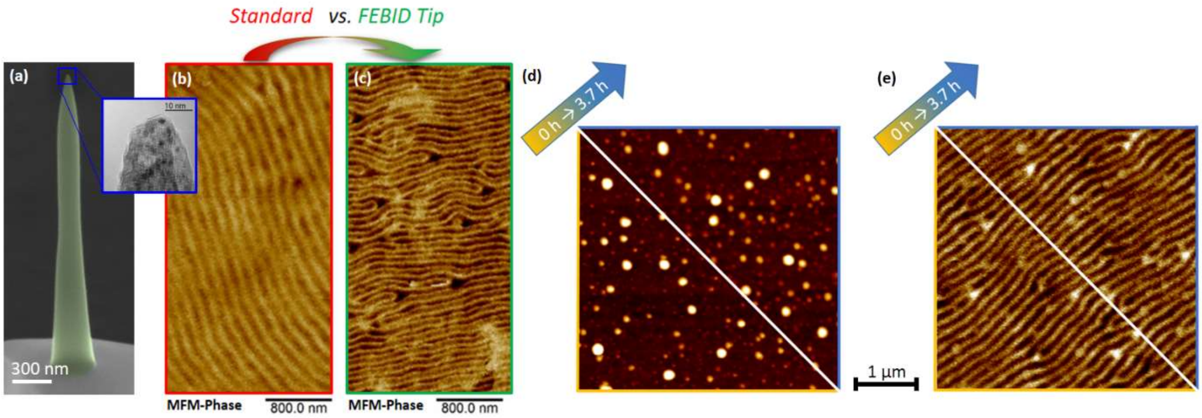

Figure 1: (a) SEM image of a specifically tailored, Co_3Fe 3D nanoprobe for Magnetic Force Microscopy (MFM). The inset shows a TEM image of the tip region, revealing a fully crystalline tip radius around 10 nm. (b) and (c) show a direct comparison of magnetic MFM maps, taken with a commercial and a FEBID-based MFM tip, respectively, which reveal the superior performance of the latter. (d) and (e) demonstrate the wear resistance of FEBID tips via topography and magnetic phase maps, respectively. The lower left parts (yellow) show the starting situation, while the upper right parts (blue) give the results after continuous AFM / MFM operation of 3.7 hours, revealing practically identical results, which underlines the durability of FEBID based MFM tips.

References

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