3D-Nanoprinting of advanced high-resolution Magnetic Force Microscopy Tips

M. Brugger-Hatzl[1], R. Winkler[2], L. M. Seewald[2], D. Kuhness[2], M. Huth[3], S. Barth[3], H. Plank[1,2,4]

1. Graz Centre for Electron Microscopy, Steyrergasse 17, 8010 Graz, Austria
2. Christian Doppler Laboratory DEFINE, Graz University of Technology, 8010 Graz, Austria
3. Institute of Physics, Goethe University, Max-von-Laue-Strasse 1, 60438 Frankfurt am Main, Germany
4. Institute of Electron Microscopy and Nanoanalysis, Graz University of Technology, Steyrergasse 17, 8010 Graz, Austria

Introduction

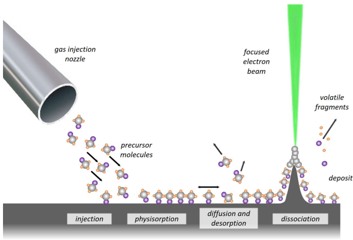

Figure 1: Focused Electron Beam Induced Deposition (FEBID) is a mask-less, direct-write, additive manufacturing technology.

Magnetic devices are used in a various fields, ranging from sensing to data storage. The ongoing trend towards smaller feature sizes raises demand of analyzing magnetic features at the nanoscale. This examination can be conducted using Magnetic Force Microscopy (MFM), which has evolved into a powerful characterization technology that requires high-resolution MFM tips. In industry, magnetic sensitivity of AFM tips is achieved by additional coating which limits the resolution and brings the risk of local delamination. To overcome these limitations, the additive direct-write fabrication of magnetic nano-cones via focused electron beam induced deposition (FEBID) is introduced (Fig. 1).[1] FEBID allows the modification or even full growth of functional AFM tips (Fig. 2).

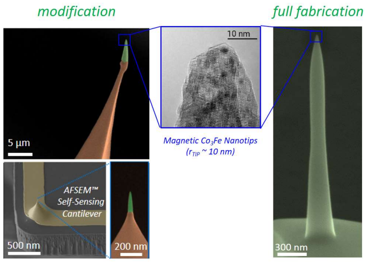

Figure 2: Direct-write fabrication of functional AFM tips from on-demand modification to full growth of functional tips.[2]

Morphology, Chemistry and Structure

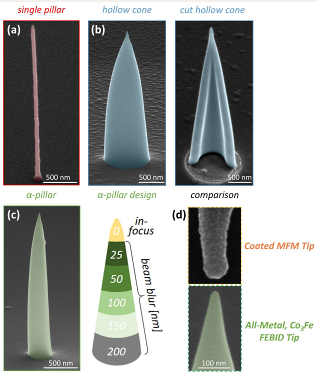

Figure 3: Different patterning designs are shown. (a) single pillar deposited using a stationary e-beam. (b) Hollow cone design is printed in a circular pattern. (c) For the α-pillar a subsequent beam blur is applied to the static e-beam. (d) The MFM α-pillar is compared with a commercial coated MFM tip.[4],[5]

A $HCo_3Fe(CO)_{12}$ precursor was used for the full growth of MFM tips.[3] First, different patterning designs (Fig. 3) were explored to fulfill the strong demands for stable MFM operation. Then morphology, chemistry and structure were investigated over a wide range of patterning parameters. Co_3Fe α-pillars deposited at higher primary electron energies are

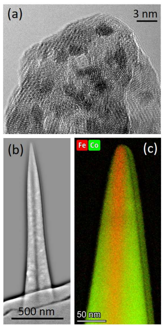

Figure 4: TEM characterization of Co_3Fe pillars. (a) TEM image, (b) high-pass filtered TEM-HAADF image 20 keV/81 pA α-pillar, (c) Scanning-TEM EDX map.[5]

taller, whereas a higher beam current results in shorter but clearly wider cones (Fig. 5). TEM characterization of the tip region (Fig. 4) was carried out, revealing a high degree of crystallinity and a sharp apex. Direct comparison with a commercial MFM tip shows the reduced apex radius for the FEBID MFM tip (Fig. 3d).

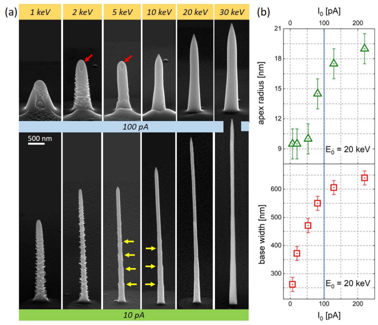

Figure 5: (a) SEM images of Co_3Fe α-pillars deposited at different primary electron energies and beam currents (at high beam currents in upper row and low beam currents in lower row). (b) shows measured apex radii (top) and base widths (bottom) of α-pillars for different beam currents at a primary electron energy of 20 keV.[5]

MFM Performance

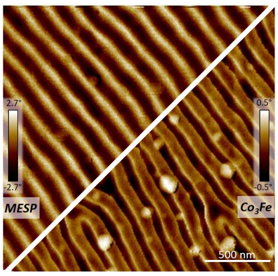

Figure 6: Comparison of MFM-Phase images of a CoPt multilayer sample executed using a well-estab-lished commercial MFM tip (MESP, Bruker) and a FEBID Co_3Fe α-pillar.[5],[6]

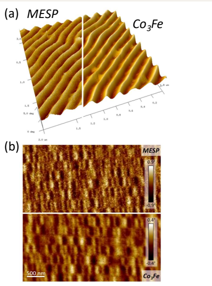

Figure 7: Comparison of MFM-Phase images of (a) a CoPt multilayer sample and (b) a magnetic hard disc drive.[5],[6]

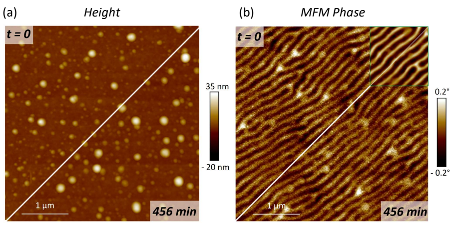

Figure 8: Wear test experiments of the Co_3Fe α-pillars were carried out continuously for almost 8 hours using a CoPt multilayer sample, which corresponds to a scanning distance of 46 cm. A comparison of the first and the last (a) height and (b) MFM phase images is shown. High-quality MFM phase images (see green-framed box) were taken at lower scanning speed.[5],[6]

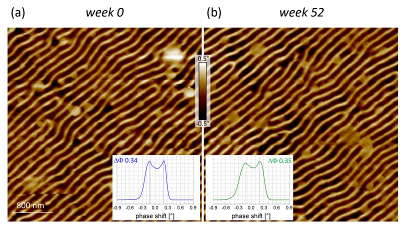

Figure 9: The long term durability of Co_3Fe α-pillars was examined after 52-weeks of storage in ambient conditions. As can be seen, there is practically no loss of signal strength, image quality, or noise, which proves the chemical long-time stability of such 3D nano-probes. The insets show the corresponding average phase shifts.[5],[6]

The MFM Phase images recorded with a well-established commercial MFM tip were compared with a FEBID Co_3Fe α-pillar for a CoPt multilayer sample[6] (Fig. 6) and a hard disk drive (Fig. 7), revealing a superior AFM/MFM performance of the FEBID tip. Additionally, the wear resistance (Fig. 8) and the long term durability (Fig. 9) were tested, demonstrating a high wear resistance and practically no signal loss after 1 year of storage.

Conclusion

This work introduces all-metal Co_3Fe nano-probes for AFM-based magnetic force microscopy, fabricated by focused electron beam induced deposition. To provide mechanical rigidity, a special conical design is introduced, which is realized by gradual electron beam blurring. In comparison with well-established commercial products, optimized Co_3Fe α-pillars reveal slightly lower absolute phase shifts, however, with very low noise and high lateral resolution for clear imaging of magnetic nano-features, which cannot be observed with commercial MFM probes.

References

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Contact

michele.brugger-hatzl@felmi-zfe.at
harald.plank@felmi-zfe.at

www.felmi-zfe.at
(FEBID QR-Code, 3D-AFM height image)