

Focused Electron and Ion Beam Processing for High-Resolution AFM and MFM Probes

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Focused Electron Beam Induced Deposition (FEBID) is a versatile direct-write resist-free nanolithography technique that enables the precise growth of functional nanotips on conventional cantilevers (Fig. 1a) [1]. This approach provides a reliable route for tailoring probe geometry, aspect ratio, and composition to improve resolution in scanning probe microscopy [2-4]. In this contribution, we present recent results on the fabrication and application of non-magnetic and magnetic FEBID-grown nanotips designed to enhance imaging performance in Atomic Force Microscopy (AFM) and Magnetic Force Microscopy (MFM).

First, non-magnetic nanotips were grown (Fig. 1b,c) to optimize dynamic AFM experiments in challenging environments, demonstrating an excellent performance for high-resolution imaging of soft biological matter and operation in liquid media. Second, magnetic nanotips were fabricated to improve spatial resolution in MFM measurements. To further optimize these magnetic probes, post-processing by helium ion irradiation using a Helium Ion Microscope (HIM) was carried out for tip sharpening (Fig. 1d), successfully reducing the apex radius while preserving a suitable magnetic performance. The set of results presented highlights the advantages of combining FEBID nanolithography with ion beam post-processing for developing customized probes for high spatial resolution biological and nanomagnetic applications.

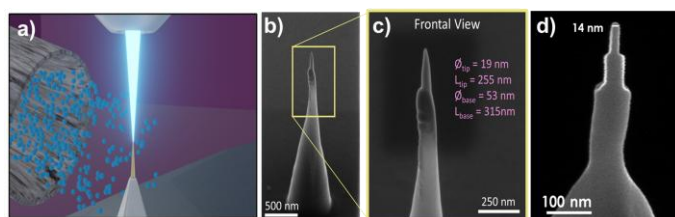


Figure 1. (a) Schematic illustration of the FEBID process for the localized growth of nanotips on cantilevers. (b) Electron microscopy image of a non-magnetic WC-based nanotip grown on a commercial AFM tip, and (c) detailed view showing the apex region. (d) Co-based magnetic nanotip after post-processing helium ion He^+ sharpening.

Acknowledgements

Authors would like to thank the Laboratory for Advanced Microscopies (LMA), from Universidad de Zaragoza, for providing access to their instruments and expertise. Additionally, the authors are grateful to the ELECMI network for granting free access through a competitive call to the Helios 600 system through project ELC648-2025. The authors acknowledge grants PID2023-146451OB-I00 and CEX2020-001038-M, funded by Spanish MCIN/AEI/10.13039/501100011033, grants E13_23R and PROY_E29_24, funded by Gobierno de Aragón and grant PIE 202660E127, funded by CSIC.

References

- [1] M. Huth, F. Poratti, O. V. Dobrovolskiy, *Microelectron. Eng.* 185–186, 9–28 (2018).
- [2] F. Allen, J.M. De Teresa, and B. Onoa, *ACS Appl. Mater. Interfaces*. 16, 4439 (2024).
- [3] Escalante-Quiceno, A.T.; Novotný, O.; Neuman, J.; Magén, C.; De Teresa, J.M. *Sensors*, 23(6), 2879 (2023).
- [4] Escalante-Quiceno, A.T.; Fernández, V.V.; Martín, J.I.; Hierro-Rodriguez, A.; Hlawacek, G.; Jaafar, M.; Asenjo, A.; Magén, C.; De Teresa, J.M. *Low Temp. Phys.* 50(10) 825-833 (2024).

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