

Helium-Ion-Beam Direct Writing of a 3D Superconducting Nanohelix with Angle-Dependent Magnetotransport

Rosa Córdoba,*^a Devi Anitha,^a Ana Galet,^a Gregor Hlawacek^b

^a *Institute of Molecular Science (ICMol), Universitat de València, Catedrático José Beltrán Martínez, 2, 46980 Paterna (València), Spain;*

^b *Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany*

Focused electron and ion beams offer maskless, site-specific routes to functional three-dimensional (3D) nanoarchitectures. Here, helium-ion-beam-induced deposition (He⁺-FIBID) is used to direct-write a tungsten-carbon (W-C) superconducting nanohelix from W(CO)₆ precursor gas, and angle-dependent magnetotransport is employed to probe the functional consequences of its curvilinear geometry. The beam parameters were tuned to produce a nanohelix approximately 125 nm in diameter with 9.5 turns. A single structure was transferred to a Si/SiO₂ substrate and electrically connected to pre-patterned Ti pads using Pt-FIBID contacts.

Four-terminal resistance-versus-field, $R(B)$, measurements were performed in a Physical Property Measurement System. The field was swept over 0–8 T in both sweep directions while its orientation remained fixed; the sample was rotated in 10° increments, thereby changing the orientation of the 3D helix relative to the field. Because the local wire direction varies continuously along a helix, this rotation modifies the distribution of local field components experienced by the structure.

Angle-resolved dR/dB maps reveal a pronounced dependence of the superconducting transition on field orientation, with a particularly strong feature near $\theta \approx 90^\circ$. Selected orientations exhibit multi-step transitions and multiple derivative peaks, with characteristic fields spanning approximately 3.0–4.25 T. Complementary angular pairs (0°/180°, 10°/170° and 30°/150°) show approximately symmetric peak positions. The observations are consistent with different parts of the nanohelix experiencing distinct local electromagnetic conditions and geometry-dependent vortex-related dissipation. These results demonstrate how a beam-written 3D form can be reflected in the superconducting response, highlighting He⁺-FIBID as a route to functional 3D beam-based nanomanufacturing.



Figure 1. Left: Schematic of direct-write growth of a 3D W-C nanohelix by He⁺-FIBID. Right: Representative angle-dependent $R(B)$ curves of a nanohelix. The inset shows a sketch of the measured nanohelix geometry and mounting orientation.

Acknowledgements

The authors wish to acknowledge the financial support from Generalitat Valenciana (SEJIGENT/2021/012T), grant RYC2020-029075-I funded by MCIN/AEI/10.13039/501100011033, COST Action CA19140 (Fit4Nano), the Excellence Unit María de Maeztu and MICIU (PID2023-149494NB-C31). Part of this work was carried out at the HZDR Ion Beam Center, a member of the Helmholtz Association.

References

- [2] R. Córdoba et al., Nano Lett. 19, 8597–8604 (2019). <https://doi.org/10.1021/acs.nanolett.9b03153>
- [3] E. Zhakina et al., Adv. Funct. Mater. 36, 2506057 (2026). <https://doi.org/10.1002/adfm.202506057>

* Corresponding author: rosa.cordoba@uv.es; phone: +34 96 35 44275