Advanced nanofabrication of nanosuperconductors, and devices using focused ion beam technologies

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Superconducting materials, known for their dissipationless electrical transport and macroscopic quantum coherence, are fundamental to a wide range of applications, from magnetic sensing to quantum electronics. Their miniaturization into the nanoscale not only enables integration into advanced device architectures but also reveals novel phenomena arising from confinement and geometry. Among these, the transition to three-dimensional (3D) superconducting nanostructures opens exciting possibilities for manipulating quantum states and enhancing functionality.

In this contribution, we present a direct-write, additive nanofabrication strategy based on focused ion beam (FIB) technologies to construct complex 3D superconducting architectures with nanoscale precision. This approach allows for the controlled growth of free-form geometries, such as nanohelices, whose physical properties can be finely tuned through structural design. These nanohelices exhibit superconductivity with critical temperatures around 7 K, demonstrate resilience under high magnetic fields, up to 15 T, depending on the orientation of the field relative to the helical axis and a show non-trivial electronic response. Beyond their superconducting performance, these nanostructures exhibit rich and multifunctional behavior. Their chiral geometry enhances light-matter interaction, leading to pronounced circular dichroism and dissymmetry factors that surpass those observed in planar counterparts.

Moreover, we show that densely packed arrays of planar nanostructures exhibit enhanced vortex pinning capabilities, arising from their engineered spatial modulation. This effect is revealed by the appearance of multiple resistance minima at well-defined magnetic field values, indicating commensurability between the vortex lattice and the nanostructure geometry—an essential characteristic for the development of fluxonic circuits.

Finally, we demonstrate that the superconducting properties of nanowires can be actively modulated by applying external electric fields, opening new possibilities for designing tunable superconducting elements.

Altogether, this work underscores the potential of FIB-based direct-write nanofabrication as a platform for designing and realizing advanced nanosuperconductors. The ability to integrate superconductivity, geometry-induced functionalities, and field-tunability within a single nanostructure paves the way for future developments in quantum and nanoelectronic technologies.