



Multi-Ion FIBID for 3D Direct-Write Nanomanufacturing and Functional Imprinting

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Focused Ion Beam Induced Deposition (FIBID) combines localized material synthesis with the intrinsic flexibility of Focused Ion Beam (FIB) processing. While Ga-based FIBs are mostly used in the field, the emergence of multi-ion plasma-FIB platforms now substantially expands this concept: different ion species can potentially be selected not only for imaging, milling, and deposition, but also for locally modifying the composition and functionality of previously deposited materials. This creates a unified environment for additive, subtractive, and transformative nanomanufacturing within a single instrument.

In this context, we here explore these possibilities using a Helios 5 HYDRA multi-ion platform equipped with several precursor chemistries. Initial experiments systematically evaluate fundamental FIBID characteristics, including deposition rates, accessible beam-current regimes, morphological evolution, chemistry, and process stability for C, W, mixed C-W, Nb, and Au-based materials. Beyond planar deposits, free-standing three-dimensional structures were fabricated demonstrating the broad material and geometrical flexibility of plasma-FIB-based 3D direct writing. The resulting material portfolio spans across structurally supporting, metallic, optical active and potentially electronically functional deposits and thereby provides a basis for heterogeneous 3D nanoarchitectures.

Going beyond direct synthesis, ongoing work investigates whether the different ion species available on the same platform can be used to locally transform FIBID materials after deposition. Of particular interest is oxygen-ion-based functional imprinting in Au-C matrices. Here, localized O-FIB irradiation is explored as a pathway toward carbon removal and the formation of Au-enriched functional domains. The decisive challenge is to identify process conditions under which ion-induced chemical conversion can be balanced against sputtering, implantation, structural damage, and morphology changes. Such experiments will clarify whether oxygen ions can act as spatially confined chemical processing tools rather than exclusively as milling species.

The combination of multi-material 3D FIBID and ion-selective post-growth transformation establishes a new perspective for FIB-based (3D) nanomanufacturing. Instead of using individual ion species for isolated processing tasks, multi-ion platforms could enable sequential workflows in which three-dimensional structures are directly written, locally reshaped, compositionally transformed, and functionally programmed. This opens a pathway toward heterogeneous nanoarchitectures whose geometry, material composition, and local electronic, optical, or mechanical response are defined within a single beam-based manufacturing platform.