



Direct-Write Fabrication of Ultrathin Nb-Based Memristive Devices via FEBID

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Additive direct-write nanomanufacturing enables the localized synthesis of functional materials with spatial nanometer-scale precision and only very few constraints on substrate material, surface morphology, or device geometry. Over the past decades, focused electron beam induced deposition (FEBID) has evolved into a powerful approach for high-resolution fabrication, including complex three-dimensional nanoarchitectures [1]. Although functional electronic materials and device elements have already been demonstrated [2], their direct integration into planar and three-dimensional device architectures remains somehow underexplored. Combining material synthesis, geometric design freedom, and site-specific integration within a single beam-based workflow offers a pathway toward adaptive electronic architectures that can extend beyond conventional planar layouts.

Here, we demonstrate the direct-write fabrication of Nb-based memristive devices using a Nb(NMe₂)₃(N-t-Bu) precursor [3]. A systematic parameter study identifies process windows for the reproducible fabrication of laterally homogeneous Nb-based layers with sub-nanometer surface roughness. Lateral multi-electrode reference structures are used to evaluate the influence of electron-beam curing, H₂O-assisted purification, and ambient exposure. Although these treatments modify the absolute resistance, they do not produce reproducible high- and low-resistance-state switching, allowing material sensitivity to be distinguished from device-level memristive behavior.

Based on these findings, stacked Au-(Nb-C-N-O)-Co₃Fe devices are fabricated with active-layer thicknesses progressively reduced from tens of nanometers to ~4 nm. At 15 nm, pronounced nonlinear transport becomes evident without appreciable hysteresis, while further scaling to 7 nm produces first weak history dependencies. A decisive transition occurs at 4 nm: while no hysteresis is detected directly after fabrication, exposure to low-pressure H₂O vapor followed by a short conditioning phase induces pronounced, reproducible, and polarity-dependent hysteretic I-V characteristics. At ±10 V, high- to low-resistance-state ratios of 8.5 and 22.4 are obtained for positive and negative polarity, respectively. The thickness-dependent nonlinear response is consistent with field-assisted, trap-mediated transport, while the pronounced polarity asymmetry suggests an important contribution from oxygen redistribution and the chemically dissimilar electrode interfaces. The altered conductance state persists across short zero-bias interruptions; however, long-term retention remains to be established, indicating a metastable or volatile-like response.

These results establish FEBID as a viable route for directly writing ultrathin Nb-based memristive materials and nanoscale device stacks. By translating nanometer-scale thickness control and interface design into electronic functionality, this work extends FEBID beyond geometry-driven fabrication toward beam-written adaptive electronics and, ultimately, spatially integrated three-dimensional neuromorphic nanoarchitectures.

References

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