

E-Beam Lithography of Topological Insulators: Nanoscale Bismuth(III) Selenide Written Directly from a Single-Source Precursor

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Two-dimensional metal chalcogenides are promising materials for next-generation optoelectronic and quantum devices, yet scalable and deterministic integration at the nanoscale remains a key challenge. Here, we present a direct-write strategy for the fabrication of crystalline bismuth(III) selenide (Bi_2Se_3), a topological insulator.[1] A bismuth(III) selenourea precursor was designed to be solution-processable and to function as a negative-tone resist, enabling electron-beam lithography (EBL) patterning of Bi_2Se_3 with nanoscale precision.

Spin-coated films of the precursor can be directly patterned to define arbitrary geometries, which, following hydrogen-assisted annealing, is converted into polycrystalline Bi_2Se_3 whilst retaining the written form. Structural and compositional analysis confirms the formation of crystalline nanosheets and nanostructures with dimensions below 100 nm, exhibiting homogeneous elemental distribution and characteristic layered morphology.

High-resolution patterning with features down to ~16 nm was achieved, as well as grayscale lithography for three-dimensional structuring, enabling control over both lateral geometry and vertical topography. Dose-dependent studies reveal that electron exposure governs precursor decomposition and subsequent crystallization pathways, while annealing in a hydrogen atmosphere is critical for achieving phase-pure Bi_2Se_3 .

This work establishes a versatile platform for the direct writing of metal chalcogenide compound semiconductors, offering a route toward on-chip fabrication of complex architectures, including nanowires and three-dimensional features. Importantly, the approach unifies material deposition, patterning, and phase conversion in a single workflow, eliminating the need for conventional multistep lithographic processes. The ability to integrate synthesis and patterning at the nanoscale provides new opportunities for incorporating topological insulators into advanced devices.

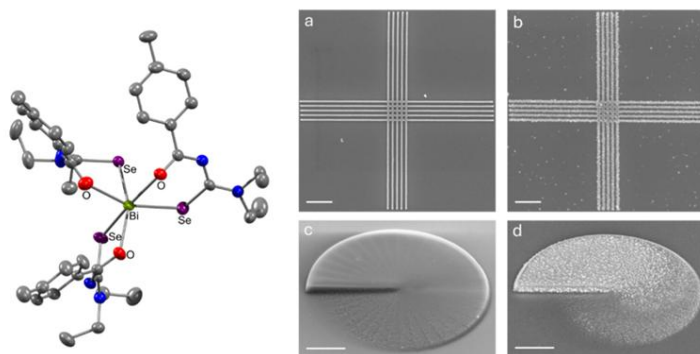


Figure 1. LHS: bismuth(III) selenourea single source precursor used for the study. RHS: (a) SEM image of high-resolution line patterns written by EBL, demonstrating negative-tone behavior and good linewidth control. (b) Corresponding SEM image of the line patterns after hydrogen-assisted annealing, showing preservation of pattern geometry with the emergence of crystalline contrast. (c) Grayscale lithography structure written by dose modulation, illustrating continuous height variation enabled by thickness-tunable precursor films. (d) SEM image of the grayscale structure after annealing under hydrogen, confirming retention of the three-dimensional profile and successful conversion into a crystalline phase. The scale bar for a and b is 400 nm and for c and d is 2 μm . [1]

References

- [1] Morell, J.; Nonahal, M.; ul Haq, A.; Timco, G. A.; Hasija, A.; Strashnov, I.; Lewis, D. J.; Winpenny, R. E. P. ‘ Direct Writing of Nanoscale Bismuth(III)Selenide from a Single-Source Precursor. *Chem. Mater.* **2026**, 37. DOI: [10.1021/acs.chemmater.6c00558](https://doi.org/10.1021/acs.chemmater.6c00558)

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