# Nanograting–Mediated Growth of Bismuth Selenide Topological Insulator Nanoribbons

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Topological Insulators (TIs) are a group of emerging materials that exhibit unusual electronic properties.[1, 2] The ballistic transport of carriers *via* these conductive surface states can be topologically protected against the scattering by nonmagnetic defects.[1, 2] Therefore, TIs could be implemented to make low-dissipation electronic channels for applications in spintronics, thermoelectrics, and magnetoelectronics.[2] One of the most critical challenges for the practical applications of TI is the residual bulk conductivity that can seriously degenerate the contribution of the surface states.[2] To suppress the bulk conductivity, a great deal of effort has been invested to create and characterize topological insulator nanoribbons (TNRs) that have been demonstrated to be able to manifest the surface conduction states due to their large surface-to-volume ratio and have significant potentials to be integrated into state-of-the-art device configurations.[3-5] The nanoparticle (NP) – catalyzed vapor-liquid-solid (VLS) process has been widely employed as a low-cost approach to create TNRs for the purpose of fundamental research.[3, 4, 6, 7] However, additional research is needed to significantly improve the yield of sub-100 nm wide TNRs and also obtain a high uniformity of the ribbon widths.

In this work, we present a nanostructure-mediated growth process specifically for producing bismuth selenide ($Bi_2Se_3$) TNRs with a high yield. In this process, TI nanostructures are grown on nanograting templates by using the NP-catalyzed VLS mechanism. As demonstrated in Fig. 1, in comparison with the growth processes on flat (Fig. 1a) and randomly rough (Fig. 1b) substrates, such a nanograting-mediated growth process (Fig. 1c) produces TNRs with a dramatically higher yield (~15,000/mm$^2$), a narrower average ribbon width ($w_{avg}$ < 60 nm), and a higher uniformity in width ($\sigma$ < 30 nm); effectively suppresses the formation of other unwanted morphologies; and also results in the axial growth of nanoribbons along specific in-plane directions relative to pre-structured gratings (Fig. 2). The TEM characterization shows that the produced nanoribbons are single crystals with atomically smooth edges (Fig. 3). Finally, Aharonov–Borm (AB) oscillations[4] in the magnetoresistance were observed and clearly demonstrated the coherent transport of electrons through topological surface states of $Bi_2Se_3$ nanoribbons (Fig. 4).

This work could serve as an important foundation for nanomanufacturing topological insulator nanoribbons with controllable feature size, large-area uniformity and ordering suitable for future applications in low-dissipation nanoelectronics and magnetoelectronic sensors.

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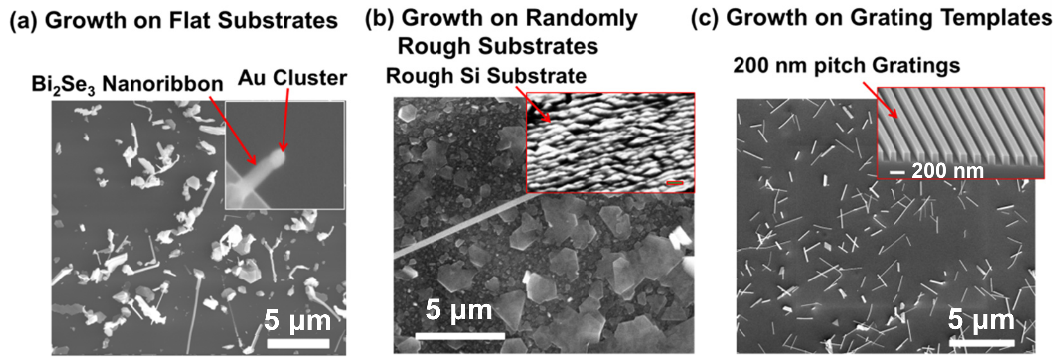


Fig. 1 SEM images of TI nanostructures grown on (a) a flat Si substrate (the inset shows a TNR with one end capped with a Au cluster), (b) a randomly rough Si substrate (the inset: tilted-view SEM of the rough substrate before the growth), and (c) a Si template bearing 200 nm period gratings (the inset: tilted-view SEM of 200 nm pitch gratings pre-structured on the growth substrate).

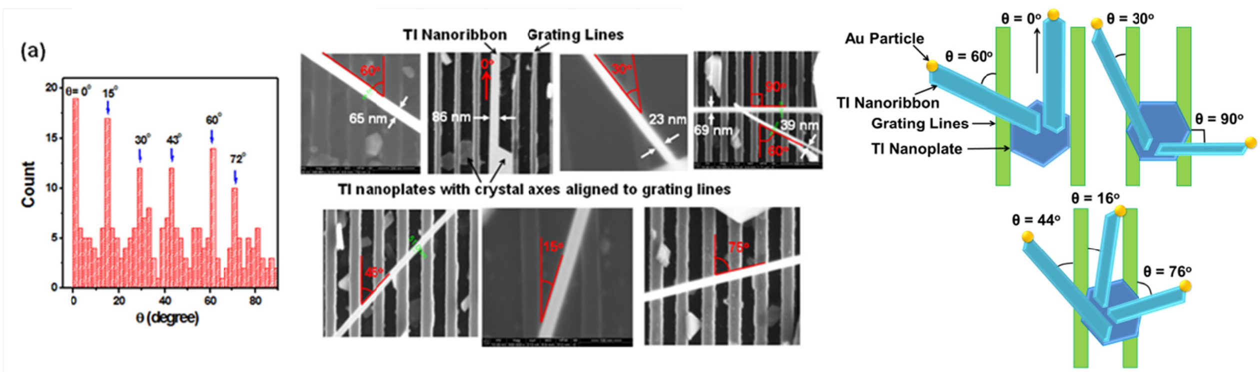


Fig. 2 (a) Statistics of nanoribbons orientation angles relative to gratings. The SEMs display exemplary nanoribbons with various preferential orientation angles. (b) Schematic illustration of nanograting-mediated growth of nanoribbons.

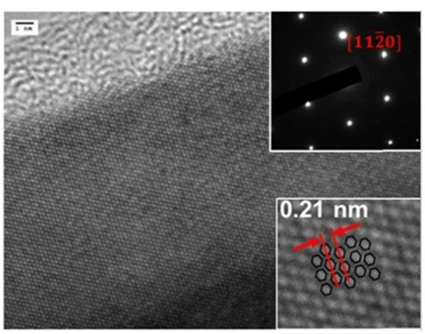


Fig. 3 High-resolution TEM of the edge of an as-grown $Bi_2Se_3$ nanoribbons and its selected area electron diffraction pattern indicates that the nanoribbons is single-crystalline and the growth of the nanoribbons is along [11-20].

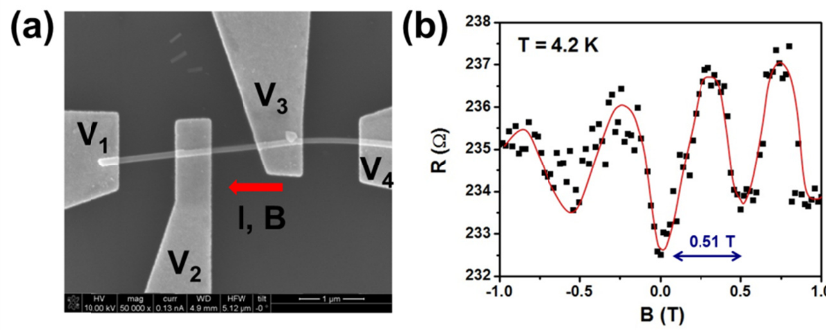


Fig. 4 (a) SEM image of a four-terminal device consisting of a $Bi_2Se_3$ nanoribbon with width of 119 nm and thickness of 68 nm. (b) Magnetoresistance (R) of the nanoribbons plotted as a function of magnetic field magnitude (B), which was measured at 4.2 K. Aharonov–Bohm interference oscillations with a period of 0.55 T were observed, corresponding to one flux quantum (h/e) through the cross-section of the nanoribbons.



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