

# Spin-orbit torque driven by interfacial chemistry in topological BiSb/NiFe bilayers with Ti insertion

Talluri Manoj<sup>a,b</sup>, Zhenchao Wen<sup>a</sup>, Jun Uzuhashi<sup>a</sup>, Tadakatsu Ohkubo<sup>a</sup>, Hiroaki Sukegawa<sup>a</sup>, Chandrasekhar Murapaka<sup>b</sup>, Brian York<sup>c</sup>, Xiaoyong Liu<sup>d</sup>, Quang Le<sup>d</sup>, and Seiji Mitani<sup>a</sup>

<sup>a</sup>National Institute for Materials Science, Tsukuba 305-0047, Japan

<sup>b</sup>Department of Materials Science and Metallurgical Engineering, Indian Institute of Technology-Hyderabad, 502284, Telangana, India

<sup>c</sup> Formerly with Western Digital, San Jose, CA 95119, USA

<sup>d</sup>Western Digital, San Jose, CA 95119, USA

Topological insulators (TIs), particularly BiSb, have garnered significant attention in spintronics due to their unique electronic properties for large spin-orbit torque (SOT) efficiency. [1,2] However, TI thin films face challenges in their low melting point, high diffusivities, low bulk conductivity, and degraded topological surface states when combined with a ferromagnetic layer, which impedes the widespread applications of TIs. In this work, BiSb thin films with a NiFe ferromagnetic layer were prepared for exploring the impact of Ti spacer insertion on SOT efficiency. Remarkably, the Ti spacer layer enhanced SOT efficiency, persisting after aging and annealing, offering insights into interfacial interdiffusion for improved spintronics applications.

All the thin films were grown on sapphire c-plane Al<sub>2</sub>O<sub>3</sub>(0001) substrates by magnetron sputtering at room temperature. Structural properties were characterized by reflection high energy electron diffraction (RHEED), X-ray diffraction (XRD), atomic force microscopy (AFM), and high-angle annular dark-field scanning transmission electron microscopy (STEM). Two samples, BiSb/NiFe and BiSb/Ti/NiFe, were compared under different conditions, i.e., as-deposited, room temperature aged for 45 days, and annealed at 400 K for 1 h. Conventional UV lithography was employed to fabricate coplanar waveguide devices to evaluate SOT efficiency through the spin-torque ferromagnetic resonance (ST-FMR) method. After deposition of BiSb, RHEED patterns revealed semi-polycrystalline growth, with improved crystallinity observed after annealing. The AFM image displayed a remarkably flat surface with an average roughness of 0.7 nm for the as-deposited 8-nm-thick BiSb thin film. Thickness-dependent resistivity measurements for the BiSb thin films illustrated the emergence of topological surface states, with increased resistivity in thicker films. XRD spectra confirmed the existence of a robust (001)-texture of the BiSb thin films, particularly in films thicker than 8 nm. Subsequently, ST-FMR measurements demonstrated an enhanced SOT efficiency of 1.2, achieved in the sample with a Ti spacer layer, which is around 4 times higher than in the sample without the Ti layer. The enhancement of SOT efficiency could be attributed to protecting topological surface states and preventing interdiffusion due to the Ti insertion. Microstructural analysis from cross-sectional STEM indicated an improved crystallinity in the Ti-inserted sample after annealing. Elemental analysis revealed the role of Ti in suppressing interdiffusion and preserving topological properties, contributing to the substantial increase in the SOT efficiency.

These results provide crucial insights into the complex interfacial microstructures, emphasizing the pivotal role of the Ti spacer layer in enhancing SOT efficiency in BiSb/NiFe structures, potentially paving the path for practical applications of BiSb-based topological materials in spintronics.

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[1] N. H. D. Khang *et al.*, Nat. Mater. 17 (2018) 808–813.

[2] H. H. Huy *et al.*, Appl. Phys. Lett. 122 (2023) 052401.