Signatures of two-dimensional topological insulator phase in BiSb ultrathin films

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Topological quantum computers using topological quantum (q)-bits are robust against errors which disrupt quantum coherency of the system. To realize topological q-bit, Majorana zero mode in topological superconductor vortex, superconductor / topological insulator or superconductor / semiconductor quantum wire Josephson junctions, and so on, have been proposed. Although most studies have been concentrated on superconductor/semiconductor quantum wire Josephson junctions, definite demonstration of Majorana zero mode have not yet been confirmed. In addition, fabrication of such Josephson junctions using nanowires is technically challenging. In contrast, superconductor / two-dimensional topological insulator (2D-TI) Josephson junctions are much easier to fabricate. Indeed, 4π-periodic Josephson supercurrent in 2D-TI HgTe-based topological Josephson junctions have been demonstrated as a signature of Majorana zero mode [1].

In this work, we evaluated the electrical properties of BiSb ultrathin films to explore the possibility of phase transition from 3D-TI to 2D-TI for use in topological q-bits. BiSb is promising because it is much easier to grow than HgTe and its Fermi level is always in the band gap, which is essential for electrical access to edge states in 2D-TI phase. For this purpose, we deposited $Bi_{0.85}Sb_{0.15}$ (thickness $t_{\mathrm{BiSb}} \leq 7$ nm) ultrathin film /NiO (1 nm) cap on sapphire substrates by magnetron sputtering. Figure 1(a) shows the BiSb electrical conductivity σ_{BiSb} at room temperature as a function of t_{BiSb} for ultrathin films (this work) and thick films reported before [2]. When t_{BiSb} was reduced from 54 nm to 7 nm, σ_{BiSb} increases due to dominant 2D surface conduction. However, when t_{BiSb} was further reduced to below 7 nm, σ_{BiSb} suddenly decreases, suggesting band gap opening in the 2D surfaces. Figure 1(b) shows the temperature dependence of resistivity ρ_{BiSb} for ultrathin BiSb. We observed that by reducing t_{BiSb} from 7 nm to 4 nm, temperature dependence of ρ_{BiSb} changed from metallic to nearly constant. This constant temperature dependence of resistivity is similar to those observed in the edge states of HgTe [3]. Thus, our results suggested that BiSb ultrathin films can transform from 3D-TI to 2D-TI when thin enough, and can be a new platform for topological quantum computers.

References: [1] J. Wiedenmann *et al.*, Nat. Commun. **7**, 10303 (2016). [2] B. York *et al.*, 2021 IEEE 32nd Magnetic Recording Conference (TMRC). [3] K.C.Nowack, *et al.*, Nat. Mater. **12**, 787 (2013).

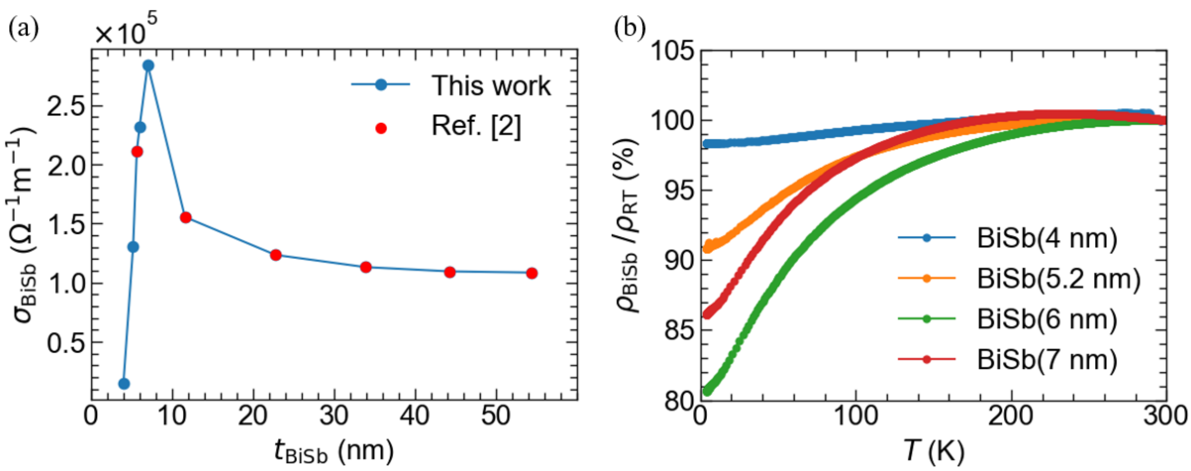

Figure 1. (a) t_{BiSb} dependence of σ_{BiSb} at room temperature. (b) Temperature dependence of resistivity ρ_{BiSb} with various t_{BiSb} from 7 nm to 4 nm.