Quantum transport of surface and bulk states with high mobility in elemental topological insulator α-Sn

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Topological insulators (TIs), whose band structure consists of gapped bulk bands and linear-dispersion metallic surface states, are among the most celebrated topological materials. Among them, strained α-Sn, one of the firstly known three-dimensional TIs [1], possesses surface states with a very high Fermi velocity (~ 7×10^5 m/s) [2]. Moreover, being a single-element material, the band structure and topological properties of α-Sn are robust against material control problems such as deviation from stoichiometry, which is severe in other compound TIs such as the Bi_2Se_3 families. These features of α-Sn are promising in the perspective of spintronic device applications. However, studies on transport properties of α-Sn have been scarcely reported thus far [3], largely due to difficulties in material preparation.

In this study, we grew high quality single-crystal α-Sn thin films and study their quantum transport properties. α-Sn thin films (thickness of 56 monolayers or 9.2 nm) are epitaxially grown on InSb(001) substrates by molecular beam epitaxy (MBE). High-quality single-crystal α-Sn with a diamond crystal structure was confirmed by scanning transmission electron microscopy (STEM), as shown in Fig. 1(a). In a wide range of temperature (2 - 20 K), we observed strong Shubnikov-de Hass (SdH) oscillations even in a low magnetic field range as low as 3 kOe. The SdH oscillations revealed three components, all of which show two-dimensional transport: i) We observed a surface state of α-Sn with a light cyclotron mass (~ 0.035 m_0) and nontrivial Berry phase (~ -0.62π) [Fig. 1(b)]. The quantum mobility of the surface state reaches about 24000 cm^2/Vs, which is ten-times higher than that in previous reports [3]. ii) A heavy-hole-like state of α-Sn with a relatively heavy cyclotron mass (~ 0.12 m_0) was observed for the first time in quantum transport, whose nontrivial Berry phase (~ 0.54π) suggests its hybridization with the surface state, as reported in ref. [1]. iii) We saw a trivial oscillation with a light cyclotron mass (~ 0.035 m_0) which is attributed to the conduction band of InSb or α-Sn. We also studied thickness-dependence of the α-Sn band structure, which will be discussed in the meeting. Our results provide insights into the nontrivial band structure of elemental topological insulator α-Sn.

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References: [1] Y. Ohtsubo, *et al.*, PRL **111**, 216401 (2013). [2] R. A. Carrasco, *et al.*, APL **113**, 232104 (2018). [3] Q. Barbedienne, *et al.*, PRB **98**, 195445 (2018). [4] D. Shoenberg, *Magnetic Oscillations in Metals* (Cambridge University Press, New York, 2009).

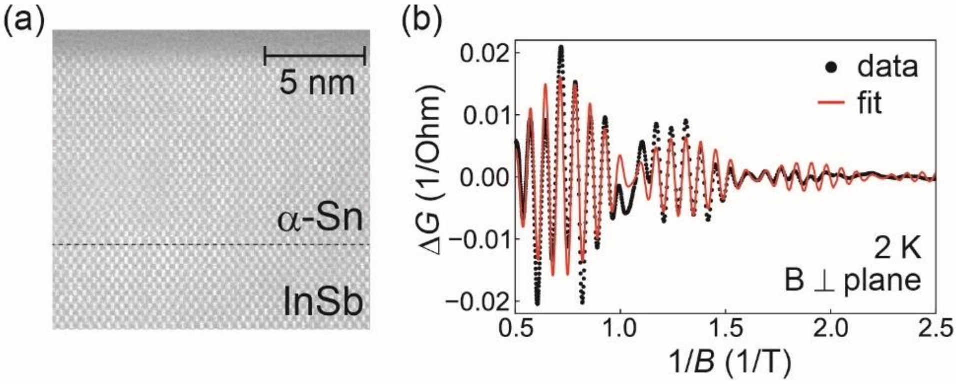

FIG. 1. (a) STEM lattice image of α-Sn. (b) SdH oscillation of α-Sn at 2 K with a magnetic field perpendicular to plane. Background is subtracted by polynomial fitting. Experimental data, which contains two components of SdH oscillation in this region (< 2 T), are fitted by the standard Lifshitz–Kosevich theory [4].