Optimized growth condition and quantum oscillation of topological semimetal Sb

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Sb, a common element in III-V semiconductors, has been known to be topologically nontrivial since the early studies on topological materials [1]. To fully utilize its spintronic properties of topological surface states, high-quality epitaxial films are essential. Sb has a rhombohedral A7 crystal structure and can be epitaxially grown on the nearly lattice matched (111) surface of semiconductors whose lattice constant is close to 6.1 Å such as GaSb(111)A [2][3] and InAs(111)B [4] by molecular beam epitaxy (MBE). Recently we have developed epitaxial growth of Sb on GaSb(111)A [5], but the Sb thin films grown by this procedure have in-plane twin structures which degrade their transport properties. Here in this work, we optimize the MBE growth conditions for Sb on GaSb(111)A and observe Shubnikov-de Haas (SdH) oscillations originating from a hole pocket of the Sb Fermi surface, which is a signature of coherent quantum transport of the bulk carrier.

The studied sample structure consists of Sb (1 μm) / GaSb (100 nm) / GaSb(111)A substrate. The growth procedure for the GaSb buffer is the same as our previous report [5]. We varied the substrate temperature (T_{sub}) for Sb layer. When T_{sub} = 30°C, Sb becomes amorphous [5]. When $T_{sub} \geq$ 100°C, Sb grows as one-dimensional nanowires, which is consistent with the previous result [6]. When we grew Sb at T_{sub} = 60°C, reflection high energy electron diffraction (RHEED) patterns showed asymmetric streaks [upper panel of Fig. 1(a)], indicating epitaxial growth without twin structures. After the growth of 5-nm-thick Sb, the sample was annealed at T_{sub} = 260°C for 30 minutes. Finally, we grew 1-μm-thick Sb at T_{sub} = 200°C. RHEED patterns became much brighter with Kikuchi lines [lower panel of Fig. 1(a)], indicating successful epitaxial growth. We confirmed epitaxial relation of Sb(0003) // GaSb(111) from the out-of-plane X-ray diffraction (XRD) measurement [Fig. 1(b)], as expected.

At 300 K, magnetic-field-dependence of Hall resistance of our sample showed *p*-type conduction with a hole concentration of 1.02×10^{21} cm^{-3} and mobility of 205 cm^2/Vs, indicating that the Fermi level is located at a hole pocket. At 2 K, we observed giant positive magnetoresistance of about 100,000% and clear SdH oscillations [Fig. 1(c)]. Analysis of the SdH oscillations following the Lifshitz-Kosevich theory allows us to estimate the effective mass of $0.125m_0$, Berry phase of 0.825, and quantum mobility of 4460 cm^2/Vs of the observed Fermi surface. Frequency of the SdH oscillations becomes minimum when the magnetic field is tilted at about 60 degrees from perpendicular to the plane, which is consistent with the *k*-space structure of the Sb hole pocket [7]. These results demonstrate the high quality of our Sb thin film thanks to the optimized growth conditions and method.

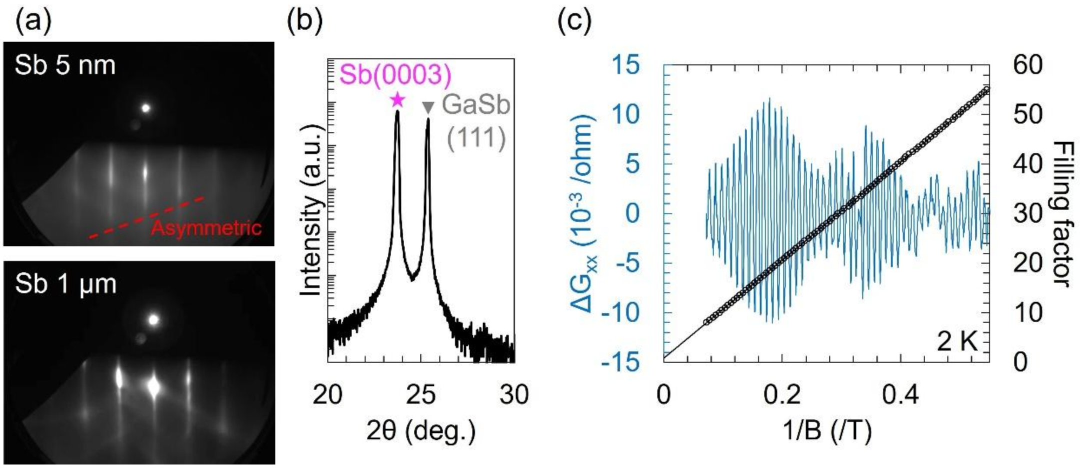

Figure 1 (a) RHEED patterns of a Sb thin film during the MBE growth. (b) Out-of-plane XRD spectrum of our Sb thin film sample. (c) Extracted SdH oscillatory component of longitudinal conductance ΔG_{xx} against inverse magnetic field (1/*B*) at 2 K. Black points are the filling factors at extrema of the oscillation.

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