Thickness-dependent conductance in Sb_2SeTe_2 topological insulator nanosheets

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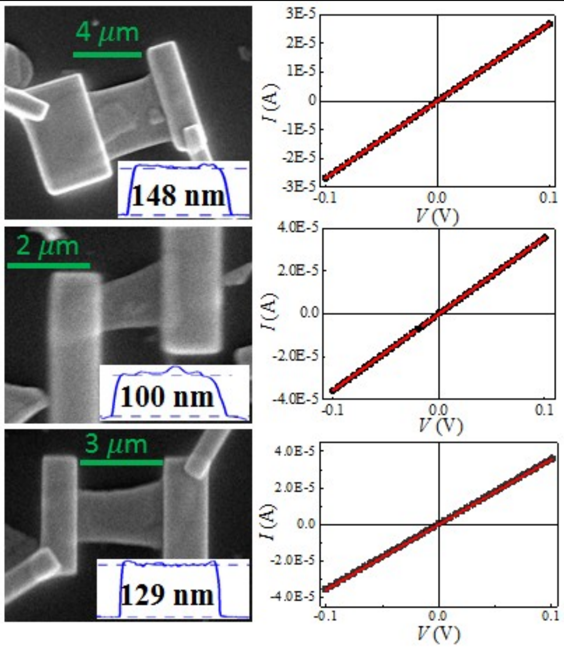
Motivation:

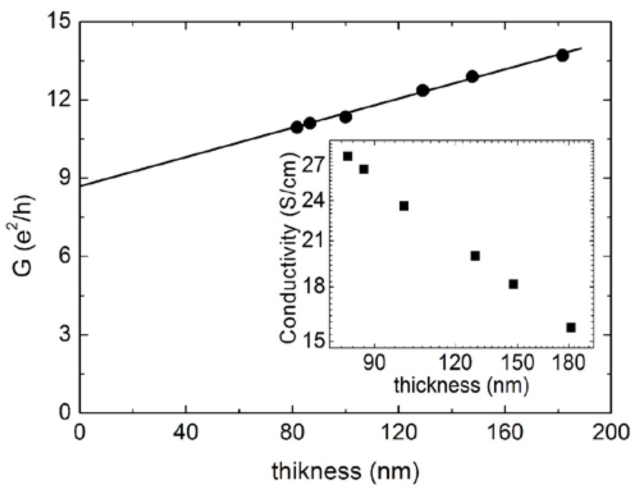
- The carrier transport properties of 3D topological insulators are contributed from both bulk and surface states. The bulk carriers transport in whole system and surface state carrier only transport in system surface.
- The effective detected transport characteristics should be thickness dependence, but rare reports on this effect and the reported results are inconsistent.

Sample Preparation:

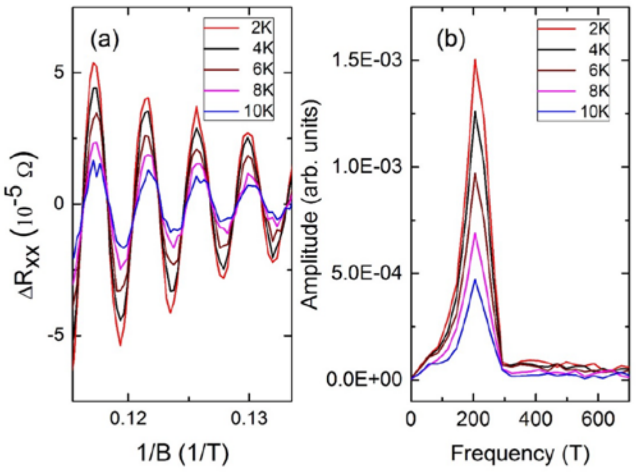
- The Sb_2SeTe_2 single crystals were grown with a homemade resistance-heated floating zone furnace (RHFZ). The as-grown crystal were cleaved along the basal plane.
- The cleaved Sb_2SeTe_2 single crystals were dispersed on the insulating SiO_2/n-Si templates. The ohmic Pt contacts were fabricated using Focused-ion beam deposition. The thickness of the Pt contacts was roughly sub-mirco meter.



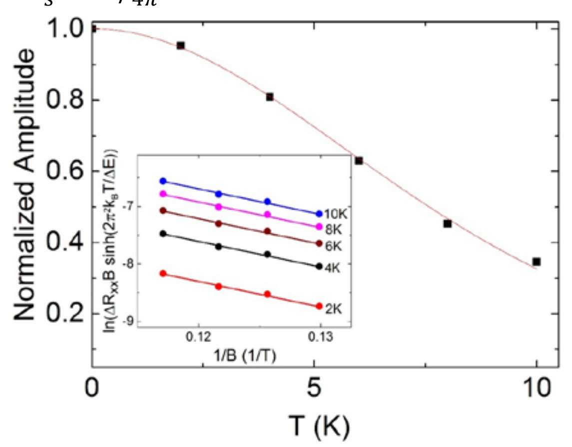
- The SEM image of Sb_2SeTe_2 nanosheets.
- The current-voltage shows the linear relation that supports the ohmic contact of these samples. The conductance is determined by the slope of the current-voltage slope at room temperature.



- Different from the conventional materials for which the conductivity is independent of the thickness. The measured conductivity decreases as the thickness increases, which implies the transport characteristic of layer carriers.
- The conductivity, σ, is inversely proportional to the thickness, $\sigma \propto t^{-1}$, in a system with layer carrier.
- Our experimental data reveals $\sigma \propto t^{-0.72}$, which implies other carrier contributions in the system.
- The sheet conductance, G, which is defined as σt, is a characteristic of layer transport characteristics, and it is thickness-independent in a layer transport system.
- We proposed the total conductance G of a topological insulator nanosheet with a thickness could be expressed as
- $G = G_s + G_b = G_s + \sigma_b t$
  G_s : sheet conductance of the surface state.
  G_b : sheet conductance of the bulk state.
  σ_b : conductivity of the bulk state.
- The measured sheet conductance is proportional to the thickness. The extracted $G_s = 8.7\left(e^2/h\right)$ and $\sigma_b = 2.67 \times 10^{-2}\left(e^2/h\right)$.



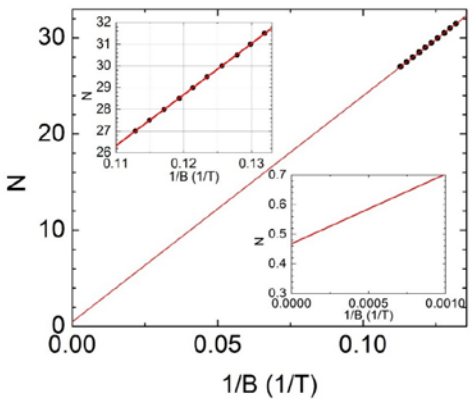
- To confirm the thickness-dependent sheet conductance originates from the surface state. The Shubnikov-de Haas (SdH) oscillations were performed at low temperatures.
- (a) The Rxx as a function of inverse magnetic fields. It shows periodic oscillations.
  (b) The Fourier transform shows that the oscillations are the same. The oscillation frequency is $F \approx 205$ T. Onsager relation $F = \left(\frac{c}{2e}\right) k_F^2$, and $k_F = 7.8 \times 10^6$cm^{-1}, which is consistent with the 7.3×10^6cm^{-1} form ARPES.
- The surface density of state
  $n_s = {k_F^2}/{4\pi} = 4.95 \times 10^{12}$cm^{-2}



The temperature dependence of the normalized amplitude of the SdH oscillation at B=8.8 T follows the Lifshitz-Kosevich (LK) theory well:

$$R(T,B) \propto \frac{\left({2\pi^2 k_B T}/{\Delta E_N(B)}\right) e^{-\left(2\pi^2 k_B T_D\right)/\Delta E_N(B)}}{\sinh\left(\left(2\pi^2 k_B T\right)/\Delta E_N(B)\right)}$$

Landau level spacing, $\Delta E_N(B) = {heB}/{m_c}$, is determined by the oscillation amplitude damping, and leads to $m_c = 0.17 m_0$
Fermi velocity of surface state $v_F = 5.26 \times 10^7$cm/s.
The Dingle temperature $T_D = 17$K.
Carrier life time $\tau = 7.1 \times 10^{-14}$s.
Mean free path $l_s = v_F \tau = 37.3$nm.
Carrier mobility $\mu_s = {(e l_s)}/{(h k_F)} = 718$cm²/Vs
The surface state conductance $G_s = n_s e \mu_s = 5.7 \times 10^{-4}\ 1/\Omega$ (from SdH oscillations)
The surface state conductance $G_s = 8.7\left(e^2/h\right) = 3.3 \times 10^{-4}\ 1/\Omega$ (from thickness-dependent sheet conductance)



- fan diagram $2\pi N = {F}/{B_N} + \varphi$
- N : N^{th} Landau level.
- F : SdH oscillation period
- B_N : magnetic field of oscillation peaks.
- φ : Berry phase.
  (φ =0 : normal fermion with parabolic dispersion
  φ =π : Dirac fermion with linear dispersion)
- Oscillation peak: N+0.5; oscillation deep: N
- $n = 0.47 \mp 0.01$
- This supports detected SdH oscillations are from the topological surface state.

Conclusions:

- The electrical transport characteristic was investigated in a series of Sb_2SeTe_2 topological insulator nanosheets with the thickness ranging from 80 to 200 nm.
- The conductance increases as the thickness decreases, and the sheet conductance is proportional to the thickness. The corresponding sheet conductance of the surface state is 8.7e2/h.
- The SdH oscillation was observed at high magnetic fields and low temperatures. The oscillation frequency is 205 T that is corresponding to the $k_F = 7.8 \times 106$ cm^{-1} . This extracted Fermi momentum is the same as the results from the value of ARPES, and the Berry phase is π.
- Following the L-K theory, the transport characteristics of the surface state is qualitatively determined. The surface state conductance is consistent with the determined value from the thickness-dependence sheet conductance.
- These support that the thickness-dependent sheet conductance originates from the combination of the surface state and the bulk state.