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Thermoelectric transport in topological insulator Bi_2Te_2Se bulk crystals

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ABSTRACT

Bi_2Te_2Se (BTS221) bulk crystals were recently discovered as an intrinsic 3D topological insulator. We have synthesized this material, and studied the transport properties of BTS221 from the thermoelectrics perspective. Temperature (T) dependent resistivity measurement indicates surface dominant transports in our sample at low T. We also report Seebeck measurement between 50K to room T.

INTRODUCTION

There dimensional (3D) Topological insulator (TI), a new state of quantum matter, has attracted considerable attention mostly because of its unique topological protected surface states (TSS). On the surface of 3D TI materials, there exist non-trivial gapless surface states protected by time-reversal symmetry (TRS), whereas the bulk of TI resembles a normal band insulator. The TSS give rise to 2D helical Dirac fermions with linear energy momentum (E-k) dispersion. Due to the helical nature (resulting in spin-momentum locking) of the Dirac cone(s) on TSS, the topological protection reduces backscattering which requires spin flip (breaking the TRS), and is thus unlikely without magnetic impurities. Therefore, the TSS channels are largely immune to (nonmagnetic) structural imperfection. Because of the characteristic properties, TSS are promising for not only novel physics, but also nano-electronics[1],[2],[3],[4],[5]. Among other applications, TI materials are also expected to offer opportunities to enhance energy efficiency of thermoelectric (TE) devices[6][7]. We note that most of the current heavily studied TI materials, such as Bi_2Se_3 and Bi_2Te_3, are also widely-commercialized TE materials with high figure of merit (ZT~1, at ordinary temperatures, ~270 to 400 K). However, both Bi_2Se_3 and Bi_2Te_3 have substantial bulk conduction due to a significant amount of unintentional doping in the bulk. This has been one major challenge for the transport and device studies of TI, as a highly conducting bulk would “short-out” the TSS conduction and mask the transport features associated with TSS.

Recently, a new TI material, Bi_2Te_2Se (BTS221) has been synthesized and demonstrated to have a dominant surface transport at low temperature (T) [8][9]. Here we report our preliminary thermal power (Seebeck coefficient) measurements on bulk BTS221 crystals. Since our BTS221 has been shown to be an intrinsic TI, with bulk insulating and surface conduction dominating at low T [10], studying the Seebeck coefficient of BTS221 at various temperatures (tuning from bulk dominated transport to surface dominated transport as T lowers) will likely provide much insights about thermoelectric transport of TSS and distinguish surface from bulk contributions.

EXPERIMENT

We have synthesized high quality BTS221 crystals by Bridgman method from highly purified (99.9999%) elemental starting materials (Bi, Te and Se). Small pieces of single crystals were cleaved by razor blades, and then fabricated into quasi-Hall bar type devices by attaching contact leads with indium for various transport experiments. In order to perform Seebeck measurements in our cryostat, we built a home-made Seebeck stage. An optical image of the stage is shown in Fig. 1a, and Fig. 1b shows the schematic diagram. On our Seebeck stage, a piece of BTS221 crystal was suspended by two glass substrates. On each substrate, a platinum (Pt) stripe (thickness ~100 nm), serving as a thermometer, was deposited by e-beam evaporation. Temperature dependent four-terminal resistances of each Pt stripe were later measured individually. A pair of thermometers was used to probe temperature gradient ΔT cross the BTS221 crystal by monitoring the resistance change in the Pt stripes. Finally, a film heater was attached to one end of the crystal across which a temperature gradient can be generated by passing electrical current through the heater. After tuning on the heater, we measure voltage difference caused by ΔT, and then calculate S by $\Delta V/\Delta T$. Here we present a representative result measured in a BTS221 crystal (L×W×T ~ 10mm×3mm×200μm).

RESULTS AND DISCUSSION

Figure 1c shows a 4-terminal longitudinal resistance as a function of T from 1.8K to 220K by slowly warming up the sample. The resistivity increases as temperature decreases, indicating an insulating behavior. Our data can be fitted to Arrhenius law ($R_{xx} \sim e^{\Delta/kT}$, where k is the Boltzmann constant, and Δ is an activation energy gap used as the only fitting parameter) very well with Δ ~35meV from 88 K to 220 K as shown in the inset of Fig. 1c. Below 20K, the resistivity begins to saturate. It suggests a surface conduction dominated region. At base temperature, the resistivity reaches ~6 Ω*cm which is comparable to the largest bulk resistivity values have ever been reported in this material[9].

Seebeck coefficient of the BTS221 crystal measured in a mediate T range (between 50 K and 290 K) was shown in Fig. 1d. The positive S indicates a p-type carrier, consistent with the Hall measurement in this sample (data not shown here). As T increases up to room T, S slightly increases. The values of our measured S are found to be comparable to previous measurements [11]. We believe the Seebeck coefficient measured in the mediate T range still involve substantial contribution from the bulk. Interestingly, the value of S at 50 K is notable, and only ~30% lower than that at room T. Future measurements at lower T may be helpful to resolve the surface contribution.

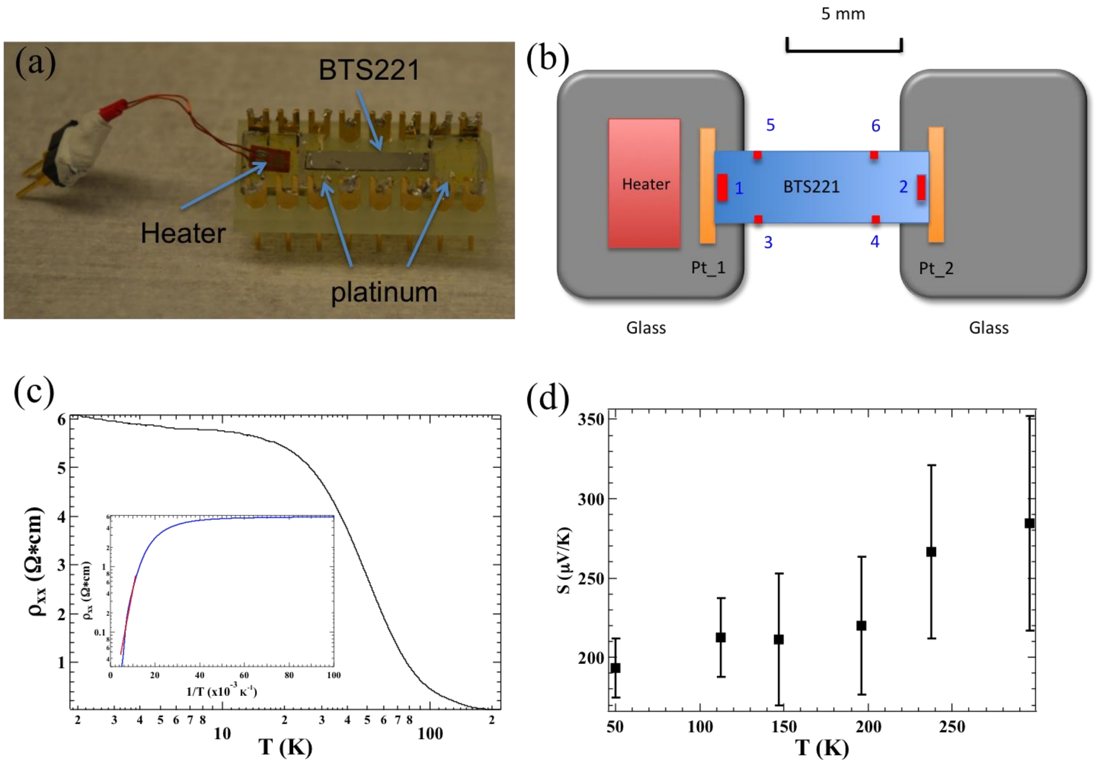

Fig.1. (a) An optical image of one Bi_2Te_2Se single crystal sample mounted on a home-made Seebeck measurement stage. (b) Schematic diagram. (c) Four-terminal R_{xx} (also resistivity) as a function of temperature. An excitation energy ~ 35 meV was extracted by fitting the data to Arrhenius law (as shown in the inset with blue line showing the experimental data and red line the fitting curve). (d) Seebeck coefficient measured in the sample between 50 K and 290 K.

CONCLUSIONS

We have synthesized BT221 crystal. The bulk of the sample is found to be very insulating with a resistivity of ~ 6 Ω*cm at 1.8 K. A home-made Seebeck measurement stage was used to measure the Seebeck coefficient in cryostat. The Seebeck coefficient of our crystal was found to be p-type above 50 K, and can be useful for thermoelectric applications.

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