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Characterization and topological properties of Bi2Se3 thin film grown by using physical vapor deposition

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Abstract

Physical vapor deposition (PVD) method was used to grow large area Bi_2Se_3 thin films with size of 1×1 cm^2 on sapphire (Al_2O_3) substrates. The samples are found to have the right composition and are of high quality. Weak anti-localization effect is observed in the electric measurement for the sample placed at low temperature and in a magnetic field which indicates that the thin film has a topological surface state.

1. Introduction

Topological insulators (TI) have attracted much attention recently because they are a new kind of quantum materials which possess very unique properties and are very promising for making spin polarized devices. TI is characterized by having a combination of a gapped bulk band structure and a gapless, linearly dispersed, surface band structure. In addition, the surface state is metallic and is protected by the time reversal symmetry [1] The V-VI semiconductor Bi_2Se_3 has been known as a thermoelectric material for a long time. Recently Bi_2Se_3 has been discovered to have a unique topological surface states. There are many different methods to grow Bi_2Se_3 nanostructures and thin films. Bi_2Se_3 nanostructures such as nanowire, nanoplate or nanoribbon can be grown by using chemical vapor deposition (CVD) [2-6], chemical interaction [7] and molecular beam epitaxy (MBE) [8] . Bi_2Se_3 thin films can be grown by using thermal evaporation [9], pulsed laser deposition (PLD) [10] and MBE [11-12]. In this work, we developed the physical vapor deposition (PVD) method to grow Bi_2Se_3 thin films on the sapphire (Al_2O_3) substrate. The physical vapor deposition system is simple in design, it consists of only a furnace, a mechanic pump and a quartz tube, but it can produce large area (1×1 cm^2) high quality Bi_2Se_3 with high yield. We believe it is a very competitive method for the growth of high quality large area Bi_2Se_3.thin film for future spintronic application.

2. Sample preparation

Bi_2Se_3 thin films were grown by physical vapor deposition. Bi_2Se_3 powder was placed at the center of a quartz tube which is placed inside a furnace and Al_2O_3 substrates were placed 15 cm away from the source powder. The temperatures of the sample powder zone and the substrate zone are independently controlled by their own temperature controller. The quartz tube is connected to a mechanical pump to keep the pressure in the quartz tube at 5×10^{-3} during the growth of the thin film.

3. Sample Characterization

Fig. 1 is the optical image of the sample we can see in

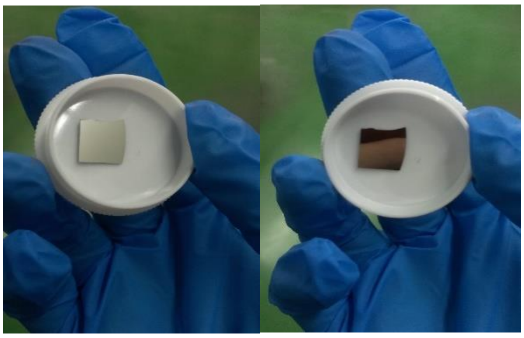

Fig. 1 Images of the Bi_2Se_3 thin film.

this figure that the size of the sample is about 1cm by 1 cm and it has a mirror-like.surface. AFM image and depth profile for Bi_2Se_3 thin film grown with source powder temperature set at 530 ℃ and the substrate temperature set at

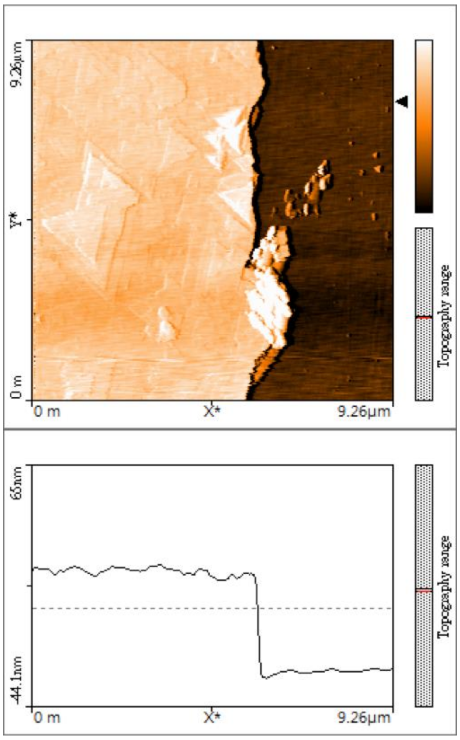

Fig. 2 AFM image and depth profile of Bi_2Se_3 thin film with thickness of 40 nm.

300 ℃ is depicted in Fig, 2. The thickness of the sample is 40 nm and we can see in this figure that the sample is very flat.

The results of the x-ray diffraction measurement performed on the same sample is shown in Fig. 3. We can identified the diffraction are from (003), (006), (009), etc. and this indicates the growth is an epitaxy grow with (0001) Bi_2Se_3 ∥ (0001) Al_2O_3.

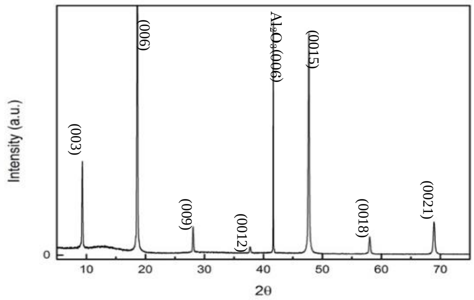

Fig. 3 X-ray diffraction data of the Bi_2Se_3 thin film. The diffraction peaks are originated from (003),(006), (009), planes as are marked in the figure.

4. Magneto-resistance measurements

For the electric measurement, the sample is made into Hall bar geometry with length of 0.8 mm and width of 0.2 mm. The device is then placed in a PPMS system with which the sample temperature can be varied between room temperature and 2K and the applied magnetic filed can be varied between 0 to 9T. We found from the electric measurement that the electric conduction is by electron conduction (n-type), and the carrier concentration in the sample is insensitive to the temperature variation and is around 1.1×10^{18} cm^{-3} between T=2k to T=300K. On the other hand, mobility of electron in the sample increases from μ=400 cm2/V for T=300 K to μ=954 cm2/Vs for T=2 K., and this carrier mobility is about 18 times higher than the carrier mobility in Bi_2Se_3 thin film grown by using pulsed laser deposition. The magneto-resistance measurement taken at T= 2K, 5K, 15K, 30 K, and B between 0 and 9T are shown in Fig. 4. We can see in the figure that there is a cusp feature originated from the weak antilocalization effect at low magnetic field and we can also find that the magneo-resistance is linear, non saturating at high field. These results suggest topological surface states exist in the Bi_2Se_3 thin film grown by using simple PVD method.

5. Conclusions

A simple, easy to implement physical vapor deposition system was developed to grow Bi_2Se_3 thin film. We demonstrate that large area Bi_2Se_3 thin film with high crystalline quality and very flat surface can be grown quite efficiently by using this simple method. Electric measurement indicate that the carrier type is n-type, the mobility of the sample is high as compared to other method. Both Cusp features near zero magnetic field and linear non-saturating behavior were

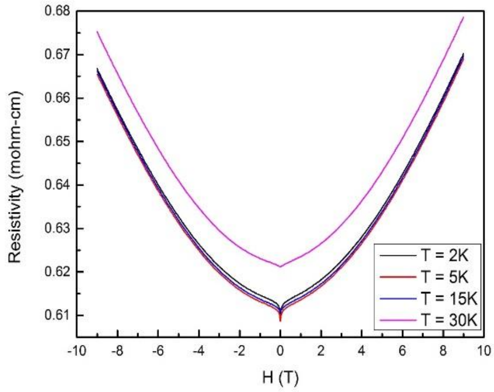

Fig. 4 MR at T= 2 K, 5 K, 15 K and 30 K. We can find there exist a cusap feature near B=0 and in high magnetic field MR is linear, non-saturating.

observed in the MR measurement and these results indicate there are topological surface states in the Bi_2Se_3 film grown by using our simple PVD method.

Acknowledgements

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