Hikami Larkin Nagaoka analysis of topological insulators

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Angle resolved photoemission spectroscopy study on electronic band structure of topological insulator Bi_2Se_3 in the presence of magnetic impurities

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LETTER

Crystal Growth and Basic Transport and Magnetic Properties of $MnBi_2Te_4$

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Abstract
We report successful growth of magnetic topological insulator (MTI) $MnBi_2Te_4$. The heating schedule basically deals with growth of the crystal from melt at 900^{0}C and very slow cooling (1^{0}C/hr) to around 600^{0}C with 24 hours hold time, followed by cooling to room temperature. Our detailed, PXRD Reitveld analysis showed that the resultant crystal is dominated mainly by $MnBi_2Te_4$ and minor phases of Bi_2Te_3 and MnTe. The transport measurements showed a step like behavior at around 150 K followed by cusp like structure in resistivity at around 25 K (T_P) due reported anti-ferromagnetic ordering of Mn. Both the resistivity transitions are seen clearly in dρ/dT measurements at 150 K and 20 K, respectively. The 25 K transition of the compound is also seen in magnetic susceptibility. Low temperature (5 K) magneto-resistance (MR) in applied field of up to 6 Tesla exhibited –ve MR below 3 Tesla and + ve for higher fields. Also, seen are steps in MR below 1 Tesla. The studied $MnBi_2Te_4$ MTI crystal could be a possible candidate for quantum anomalous Hall (QAH) effect.

Keywords Magnetic topological insulator · Crystal growth · Structural details · Surface morphology magnetism · Electrical transport

1 Introduction

Topological insulators (TIs) are dominating the quantum condensed matter for over a decade by now [1–3]. In this direction, one of the most happening new advancements had been the magnetic topological insulators (MTIs). In case of MTIs, a magnetic layer or element is inserted among the running TI unit cells of bulk 3D topological insulators such as 3d metal doped Bi_2Se_3, Bi_2Te_3, and Sb_2Te_3 [4–6]. The insertion of magnetic layer along running 3D bulk topological insulators shifts the Dirac position and thus alters the quantum transport properties of the parent system [7–10]. One of the most fascinating properties of the MTIs is the appearance of quantum anomalous Hall (QAH) effect [7–9].

QAH happens due to the finite Hall voltage created due to magnetic polarization and spin-orbit coupling, while the external magnetic field is absent. QAH is found to be in integer multiple of e^2/h which is called Landau level [9]. In principle, the inherent magnetism and topological electronic states are the necessary conditions for QAH. Though, ultra-thin films of TIs with enhanced surface area may exhibit QAH due to strong spin-orbit coupling (SOC), but is a rare possibility, and if at all, the same takes place at ultra-low temperatures [10]. Other possibility to realize QAH is to dope the 3D bulk topological material with transition metal elements, viz., Co, Cr, Eu, etc. [11, 12]. In this case as well because of randomly distributed 3d metal impurity to the realization of QAH is often difficult and if at all is at mK temperatures [10–13]. The best solution till date to observe QAH at higher temperatures is via the MTIs. A magnetic topological insulator having strong SOC exhibits quantized resistance and non-dissipative current at room temperature [14]. In case of MTIs, a 3d metal based magnetically ordered layer is inserted between the running 3D bulk topological insulator. An ideal example, being put forward by theoreticians [15–17] and very recently realized by experimentalists, is $MnBi_2Te_4$ [18–20].

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PAPER

Flux free single crystal growth and detailed physical property characterization of $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15) topological insulator

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Keywords: topological insulator, crystal growth, magneto resistance, transport properties

Abstract

Here, we report the crystal growth, physical and transport properties of $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15) topological insulator. Single crystals of $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15) were grown by melting bismuth and antimony together using the facile self flux method. The XRD measurements displayed highly indexed 00l lines and confirmed the crystalline nature as well as the rhombohedral structure of the $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15) crystals. Raman spectroscopy measurements for $Bi_{1-x}Sb_x$ system revealed four peaks within the spectral range of 10 to 250 cm^{-1} namely A_{1g} and E_g modes corresponding to Bi-Bi and Sb-Sb vibrations. Scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDAX) measurements showed the layered surface morphology and near stoichiometric chemical composition of $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15) crystals. Furthermore, EDAX mapping confirmed the homogeneous distribution of Bi and Sb elements. Temperature dependent electrical resistivity curves with and without applied magnetic field exhibited a metallic behaviour and linear non-saturating magneto-resistance (MR) respectively for all the antimony (Sb) concentrations of x = 0.05, 0.1 and 0.15. The lowest Sb concentration sample with x = 0.05 ($Bi_{0.95}Sb_{0.05}$) exhibited the highest MR value of about 1400%, followed by x = 0.1 and 0.15 samples ($Bi_{0.9}Sb_{0.1}$ and $Bi_{0.85}Sb_{0.05}$) with MR values reaching up to 500% and 110% respectively at 2 K and 6Tesla applied field. Also, a coexistence of negative MR and WAL/WL behaviour is observed at lower magnetic fields (below ±0.2Tesla) in $Bi_{0.9}Sb_{0.1}$ and $Bi_{0.85}Sb_{0.05}$ system. To further elaborate the transport properties of $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15), the magneto-conductivity (MC) is fitted to the HLN (Hikami Larkin Nagaoka) equation and it is found that the charge conduction mechanism is mainly dominated by WAL (weak anti-localization) along with a small contribution from WL (weak localization) effect. Summarily, the short letter discusses the synthesis, interesting transport and magneto-transport properties of $Bi_{1-x}Sb_x$ (x = 0.05, 0.1 and 0.15), which could be useful in understanding the fascinating properties of topological insulators and their technological applications.

Introduction

The advancement in the field of condensed matter physics is a result of the discovery of novel materials with exotic properties. Recently, the discovery of various Dirac materials viz., Graphene, three dimensional (3D) Topological Insulators (TIs) and Topological (Dirac/Weyl) semi-metals has attracted immense interest concerning both fundamental research and device applications [1–3]. In particular, 3D TIs, one of the newest wonders in condensed matter physics community has attracted significant attention due to their relatively large bulk band gaps and topologically protected surface states along with a single Dirac cone at the Γ point of the Brillouin zone [1, 4–13]. Further, strong spin–orbit coupling (SOC) along with time reversal symmetry (TRS)

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PAPER

Structural, surface morphology and magneto-transport properties of self flux grown Eu doped Bi_2Se_3 single crystal

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Keywords: topological insulator, crystal growth, magneto resistance, magneto conductivity, surface morphology

Abstract

Here, we report the effect of europium (Eu) doping in Bi_2Se_3 topological insulator (TI) by using different characterization techniques viz. X-ray diffraction (XRD), scanning electron microscopy (SEM) coupled with energy dispersive x-ray analysis (EDXA) and magneto-transport measurements. Good quality Eu doped Bi_2Se_3 ($Eu_{0.1}Bi_{1.9}Se_3$) single crystal is grown by the self flux method through the solid state reaction route. Single crystal XRD pattern displayed the high crystalline quality of the $Eu_{0.1}Bi_{1.9}Se_3$ sample along (00l) alignment whereas; the powder XRD confirmed the rhombohedral crystal structure without any impurity phases. SEM images exhibited a layered slab like structure stacked one over the other whereas; EDXA measurements confirmed the chemical composition of $Eu_{0.1}Bi_{1.9}Se_3$ sample. Further, the EDXA mapping showed the homogeneous distribution of Bi, Se and Eu elements. Temperature dependent electrical resistivity curves revealed a metallic behaviour both in the presence and absence of applied magnetic field. Magneto-transport measurements showed a decrease in the magneto-resistance (MR) value of the $Eu_{0.1}Bi_{1.9}Se_3$ sample (~32% at 5 K) in comparison to the pure Bi_2Se_3 sample (~80% at 5 K). For, $Eu_{0.1}Bi_{1.9}Se_3$ sample, a complex crossover between WL and WAL phenomenon was observed at lower applied magnetic fields, whereas the same was absent in case of the pristine one. Further, HLN (Hikami Larkin Nagaoka) fitted magneto-conductivity (MC) analysis revealed a competing weak anti localization (WAL) and weak localization (WL) behaviour. Summarily, in the present work we study the structural, surface morphology and magneto-transport properties of as grown $Eu_{0.1}Bi_{1.9}Se_3$ single crystals.

Introduction

The discovery of topological insulators (TIs), a new phase of quantum matter have surprised and fascinated physicists for about a decade [1–5]. In fact, it's extraordinary electronic properties along with a wide range of potential applications including the development of futuristic quantum computers is now among the hottest topics in physics research. In particular, TIs are characterized by a gapped bulk state and gapless surface/edge states which are further protected by time reversal symmetry (TRS) and have spin momentum locking property i.e., the conducting surface states of TIs are robust against time reversal invariant perturbations [1–11]. The existence of a topologically protected gapless surface state along with a single Dirac cone at the Γ point of the Brillouin zone is the most prominent property of a TI. Recent theoretical as well as experimental studies suggest that the breaking of TRS in TIs by magnetic doping opens up a gap in the spectrum of the surface states and hence generate massive surface carriers [12–14]. As reported, the bulk of a magnetically doped TI exhibits a long-range magnetic order both in the metallic and insulating phases through Van Vleck mechanism. Conversely, on the surface, such a long-range magnetic order can also be formed independent of the bulk magnetic ordering via the Ruderman-Kittel-Kasuya-Yosida (RKKY) exchange mechanism [12–16, 17, 18]. Consequently, doping three dimensional (3D) TIs (Bi_2Te_3, Bi_2Se_3, Sb_2Te_3) with transition metal elements (Cr, Fe, Mn, V, etc) leads to