# Surface States Transport in Nanowires of Topological Insulator $Bi_{0.83}Sb_{0.17}$

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***Abstract* — We have investigated the transport properties of topological insulator based on single-crystal $Bi_{0.83}Sb_{0.17}$ nanowires. The single-crystal nanowire samples in the diameter range 75 nm – 1.1 μm were prepared by the high frequency liquid phase casting in a glass capillary using an improved Ulitovsky technique; they were cylindrical single-crystals with (10$\underline{1}$1) orientation along the wire axis. The samples resistance increases with decreasing temperature, but at low temperatures decrease in the resistance is observed. This effect is a clear manifestation of the presence on the surface of topological insulators highly conductive zone. The Arrhenius plot of resistance *R* in samples with diameter *d*=1.1 μm and *d*=75 nm indicates a thermal activation behavior with an activation gap *ΔE*= 21 and 45 meV, respectively, which proves the presence of the quantum size effect in these samples. We found that in the range of diameter 1100 nm - 75 nm when the diameter decreases the energy gap is growing as 1/*d*. We have investigated magnetoresistance of $Bi_{0.83}Sb_{0.17}$ nanowires at various magnetic field orientations. From the temperature dependences of Shubnikov de Haas oscillation amplitude for different orientation of magnetic field we have calculated the cyclotron mass $m_c$ and Dingle temperature $T_D$. For the first time the Aharonov-Bohm oscillations in $Bi_{0.83}Sb_{0.17}$ 100 nm nanowire were observed.**

***Index Terms* — Topological insulator, Bi-Sb nanowires, Shubnikov –de Haas oscillations, Aharonov-Bohm oscillations**

## I. INTRODUCTION

A topological insulator is a material with a bulk electronic excitation gap generated by the spin-orbit interaction, which is topologically distinct from an ordinary insulator. This distinction, characterized by a $Z_2$ topological invariant, necessitates the existence of gapless electronic states on the sample boundary. The strong topological insulator is predicted to have surface states whose Fermi surface encloses an odd number of Dirac points and is associated with a Berry's phase of *π*. This defines a topological metal surface phase, which is predicted to have novel electronic properties. The semiconducting alloy $Bi_{1-x}Sb_x$ is a strong topological insulator due to the inversion symmetry of bulk crystalline Bi and Sb [1]. At $0.09<x<0.18$, the system evolves into a direct-gap insulator whose low-energy physics is dominated by the spin–orbit coupled Dirac particles at L-point in the Brillouin zone. In the present paper we report measurements of temperature dependences of resistance as well as magnetic field dependences of magnetoresistance of topological insulator $Bi_{0.83}Sb_{0.17}$ nanowires in glass coating

## II. EXPERIMENT AND DISCUSSION

Individual $Bi_{0.83}Sb_{0.17}$ nanowires were fabricated using the Ulitovsky technique (see schematic diagram at inset on Fig. 1(a)), by which a high-frequency induction coil melts a $Bi_{0.83}Sb_{0.17}$ boule within a borosilicate glass (Pyrex) capsule, simultaneously softening the glass. Glass capillaries containing $Bi_{0.83}Sb_{0.17}$ filament [2] were produced by drawing material from the glass. The nanowire samples in the diameter range 75 nm – 1.1 μm were cylindrical single-crystals with (10$\underline{1}$1) orientation along the wire axis. In this orientation, the wire axis makes an angle of 19.5° with the bisector axis $C_1$ in the bisector-trigonal plane. Bulk Bi–Sb crystals are difficult to grow successfully and require special techniques to avoid constitutional supercooling and the resulting segregation. However, by the Ulitovsky technique due to the high frequency stirring and high speed crystallization (> $10^5$ K/s) it is possible to obtain homogeneous monocrystalline $Bi_{0.83}Sb_{0.17}$ nanowires.

The samples for the measurements were cut from long wires and were from 3 mm down to 1 mm in length, were mounted on special foil-clad fiber-glass plastic holders. Electrical contact to the copper foil was made with In-Ga eutectic.

Magnetic field-dependent resistance *R(B)* measurements in the 0 to 14 T range were carried out at the International High Magnetic Field and Low Temperatures Laboratory (Wroclaw, Poland), and we employed a device that tilts the sample axis with respect to the magnetic field and also rotates the sample around its axis. Shubnikov-de Haas oscillations measured by using the technique of magnetic field modulation with amplitude of 75 Oe that allowed us to register amplitude of the oscillations directly at the lock-in amplifier output.

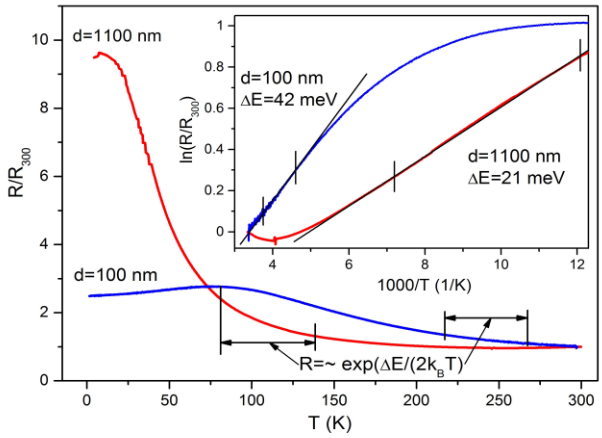

Fig. 1. Temperature dependencies of the relative resistance for 1100 nm and 100 nm $Bi_{0.83}Sb_{0.17}$ nanowires. The temperature ranges, within which the law of resistance exponential growth is valid, are also shown. Inset: The Arrhenius plot of $R/R_{300}$ in 1100 nm and 100 nm $Bi_{0.83}Sb_{0.17}$ nanowires indicates a thermal activation behavior with an activation gap $\Delta E$= 21 and 42 meV, respectively.

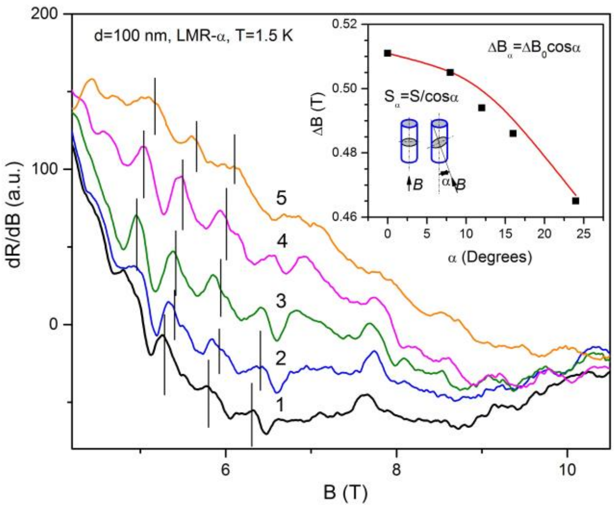

Fig. 2. Magneic field dependencies of derivative of magnetoresistance for 100 nm $Bi_{0.83}Sb_{0.17}$ nanowire, $T$=1.5 K. 1- longitudinal magnetoresistance (LMR), α=0; 2 - α=8°; 3 - α=12°; 4 - α=16°; 5 - α=24°. Inset: Dependence of oscillation period $\Delta B$ on inclined angle α of magnetic field relative to the nanowires axis.

Quantum confinement effect in semiconducting $Bi_{0.83}Sb_{0.17}$ nanowires increases the energy gap $\Delta E$ and thus increases the resistance. However, at low temperature conductivity of the topological surface states reduces the resistance. The greater is the relative amount of surface states volume with decreasing nanowires diameter, the stronger is the effect of reducing resistance. Temperature dependencies of the relative resistance $R/R_{300}$ for 1100 nm and 100 nm $Bi_{0.83}Sb_{0.17}$ nanowires are shown in fig. 1. The temperature ranges, within which the law of resistance exponential growth ($R\sim exp(\Delta E/(2k_BT)$) is valid, are also shown. The Arrhenius plot (see the inset) of $R/R_{300}$ in 1100 nm and 100 nm $Bi_{0.83}Sb_{0.17}$ nanowires indicates a thermal activation behavior with an activation gap $\Delta E$= 21 and 42 meV, respectively. With decreasing diameter of the nanowires shift of the temperature range of exponential growth of resistance into a higher temperature region (see Fig. 1) can be explained as follows: firstly, a rise in the energy gap increases the effective temperature of the energy spectrum smearing; secondly, relative volume of high-conductive surface region increases with decreasing nanowires diameter, and reduced resistance of the nanowire will be noticeable at higher temperature. In the region of diameter 1100 - 100 nm the dependence of energy gap $\Delta E$ on $Bi_{0.83}Sb_{0.17}$ nanowires diameter is well approximated by the equation of the energy gap growth with decreasing nanowires diameter $\Delta E\sim 1/d$.

From the temperature dependence of Shubnikov de Haas (ShdH) oscillation amplitude of longitudinal magnetoresistance for 200 nm $Bi_{0.83}Sb_{0.17}$ nanowire we have calculated the cyclotron mass $m_c$ = 1.96*10$^{-2}$ $m_0$, which was 3.5 times higher than in the Tashkin and Ando work [3]. The Dingle temperature $T_D$=9.8 K was determined. In 200 nm nanowire we have measured transverse magnetoresistance when $B\perp I$. For $B||C_3$ and $B||C_2$ directions of magnetic fields, the cyclotron masses and Dingle temperatures equal 8.5*10$^{-3}$ $m_0$, 9.4 K, and 1.5*10$^{-1}$ $m_0$, 2.8 K respectively.

For the first time the Aharonov-Bohm oscillations in $Bi_{0.83}Sb_{0.17}$ 100 nm nanowire were observed (see fig. 2). The oscillation period, as predicted by the theory of magnetic flux quantization oscillations, governed by the law $\Delta B=\Delta B_{parallel}$ cosα, where α - angle of magnetic field inclination relative to the nanowires axis.

## ACKNOWLEDGMENT

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