Quantum Interference of Surface States in Nanowires of Topological Insulator $Bi_{0.83}Sb_{0.17}$

Konopko L.A., Nikolaeva A.A.
Ghitu Institute of Electronic Engineering and Nanotechnologies
Chisinau MD-2028, Moldova

Huber T.E.
Howard University, 500 College St. N.W.
Washington, DC 20059, U.S.A.

Rogacki K.
Institute of Low Temperatures and Structural Research, PAS
Wroclaw 50950, Poland

***Abstract* — We have investigated the galvanomagnetic 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. We have investigated magnetoresistance of $Bi_{0.83}Sb_{0.17}$ nanowires at various magnetic field orientations. The oscillations of longitudinal magnetoresistance (MR) of 75 and 100-nm $Bi_{0.83}Sb_{0.17}$ nanowires with two periods ΔB_1 and ΔB_2 proportional to Φ_0 and $\Phi_0/2$ were observed, where $\Phi_0 = h/e$ is the flux quantum. In the range 0 – 60 degrees of inclined angle of magnetic field, the observed angle variation of the periods is in agreement with the theoretical dependence□$\Delta B(\theta) = \Delta B(0)/\cos\theta$ of the flux quantization oscillations. However, the equidistant oscillations of MR exist in transverse magnetic fields under certain rotation angles. The observed effects are discussed.**

***Index Terms* — Topological insulator, Bi-Sb nanowires, magnetoresistance, Aharonov-Bohm oscillations**

I. INTRODUCTION

A topological insulator (TI) 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 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 were produced by drawing material from the glass. The nanowire samples in the diameter

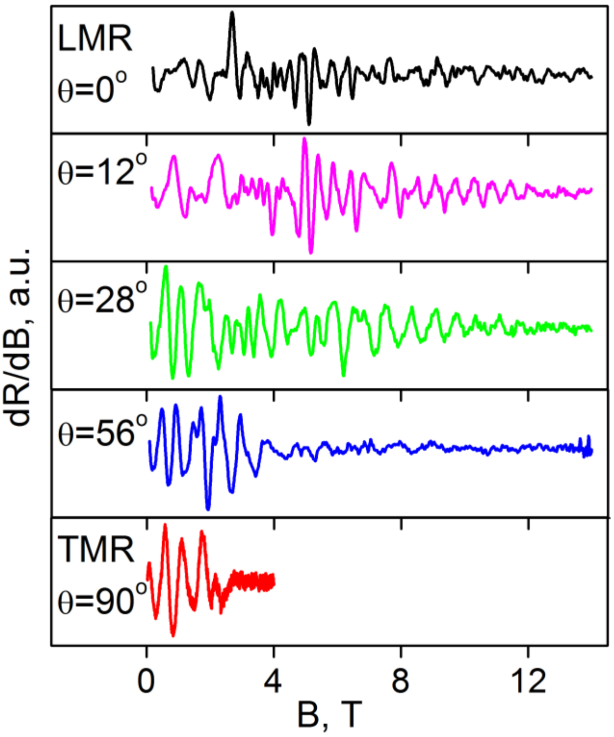

Fig. 1. Magnetic field dependence of the derivative of MR for 100-nm $Bi_{0.83}Sb_{0.17}$ nanowires, T=1.5 K (the monotonic part is subtracted) at different angles θ between the direction of applied magnetic field and the nanowire axis; θ = 0 and θ = 90° corresponds to the longitudinal MR and the transverse MR, respectively.

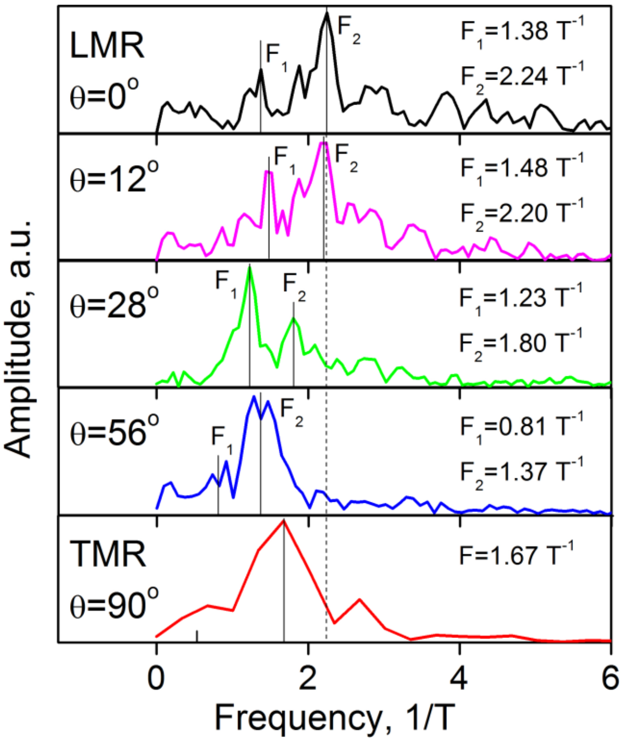

Fig. 2. Dependence of the FFT spectra of MR oscillations for a 100-nm $Bi_{0.83}Sb_{0.17}$ nanowire at T=1.5 K on the angle θ between the direction of applied magnetic field B and the nanowire axis; θ = 0 and θ = 90° corresponds to the longitudinal MR and the transverse MR, respectively.

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 (> 10^3 K/s) it is possible to obtain homogeneous monocrystalline $Bi_{0.83}Sb_{0.17}$ nanowires.

The transport properties of TI $Bi_{0.83}Sb_{0.17}$ nanowires were investigated earlier [2]. The resistance of the samples was increased with decreasing temperature, but a decrease in resistance was observed at low temperatures. This effect is a clear manifestation of TI properties (i.e., the presence of a highly conducting zone on the TI surface).

We investigate the magnetoresistance (MR) of $Bi_{0.83}Sb_{0.17}$ nanowires at various magnetic field orientations. The non-monotonic changes of derivative of longitudinal MR that are equidistant in the magnetic field have been observed. According to the Fast Fourier Transform (FFT) spectra of this oscillation, they have two periods ΔB_1 and ΔB_2 proportional to Φ_0 and $\Phi_0/2$, where $\Phi_0 = h/e$ is the flux quantum. A derivative of MR was measured at various inclined angles of magnetic field. The oscillation parts of the MR derivative for 100-nm $Bi_{0.83}Sb_{0.17}$ nanowire at different angles θ between the direction of the applied magnetic field and the nanowire axis are shown in Fig. 1, T=1.5 K. The FFT spectra of MR oscillations are shown in Fig. 2. θ = 0 and θ = 90° corresponds to the longitudinal MR and the transverse MR, respectively. Observation of Aharonov-Bohm (AB) [3, 4] oscillations confirms the existence of a highly conducting layer on the surface of the $Bi_{0.83}Sb_{0.17}$ nanowire. In the range 0 – 60 degrees of inclined angle of magnetic field, the observed angle variation of the periods is in agreement with the theoretical dependence□$\Delta B(\theta) = \Delta B(0)/\cos\theta$ of the magnetic flux quantization oscillations. Dependence of frequencies of AB oscillations on the angle θ between the direction of applied magnetic field and the nanowire axis are shown in Fig. 3. However, the equidistant oscillations of MR exist in transverse magnetic fields under conditions where the magnetic flux through the cylinder nanowire $\Phi = 0$. Bi-Sb has a layered crystal structure along the C_3 axis. When there are few layers in the cross section of the nanowire, they can exhibit specific properties of edge states, which, possibly, will lead to the self-organization of these states and, similarly to Bi nanowires [5, 6], to the appearance of AB oscillations in a transverse magnetic field.

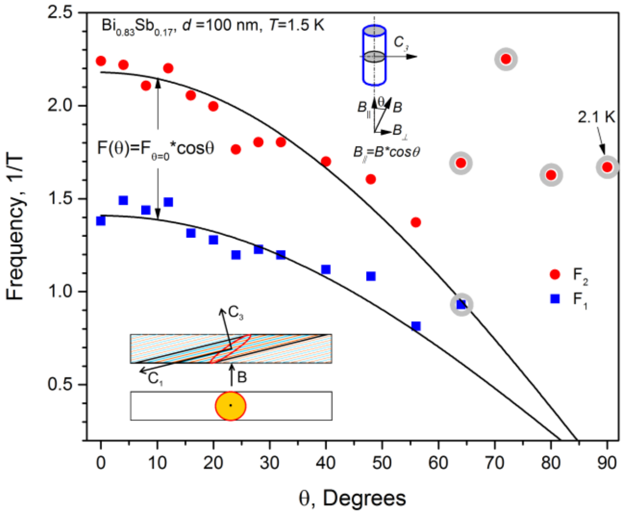

Fig. 3. Dependence of frequencies of AB oscillations for a 100-nm $Bi_{0.83}Sb_{0.17}$ nanowire at T=1.5 K on the angle θ between the direction of applied magnetic field and the nanowire axis; θ = 0 corresponds to the longitudinal MR. Frequencies F_1 and F_2 correspond to the MR oscillation with periods Φ_0 and $\Phi_0/2$, respectively. Top Insert: sketch of location of the nanowire in a magnetic field. Bottom Insert: sketch of stacks of $Bi_{0.83}Sb_{0.17}$ bilayers with closed conducting loop.

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