Josephson junction based on topological insulator / superconductor heterostructure for topological quantum computation.

D. S.Yakovlev[1,2*], S.V. Egorov[1], O.V. Skryabina,[2] S.N.Kozlov[2], V.S. Stolyarov2

[1]*Russian Quantum Center, 100 Novaya Street, Skolkovo, Moscow region 143025, Russia*
[2]*Moscow PlaceTypeInstitute of PlaceTypePhysics and Technology, 141700 PlaceTypePlaceTypeDolgoprudny, PlaceTypeRussia*
*E-mail: dmitry.yakovlev@phystech.edu

The recent burst of the quantum information processing stimulated an intensive search for new physical implementations of quantum bits. Superconducting proximity devices using low-dimensional semiconducting elements enable both the ballistic regime in the proximity transport and reliable control of individual qubits. We report the observation of a superconducting proximity effect induced by Nb contacts on a single nano-crystalline flakes of Bi2Te2Se topological insulator. The several geometries of topological insulators under the investigation include single Josephson junction with wide normal region and a pair of connected in parallel forming a nano-SQUID. The Josephson effect is observed in voltage-current characteristics which show strong hysteresis in the critical current behavior. Also, in a regime of dc voltage bias the effect of Andreev reflections point towards the predominance a ballistic transport of Cooper pairs and multi-component nature of the proximity induced superconductivity in Bi2Te2Se. Also, the data on the critical current is presented as magnetic field dependencies with Fraunhofer-like patterns and as the decay with the temperature.

The unique property of topologically protected surface modes, characterized by a spin-momentum locking, are revealed in hybrid systems, where such materials are brought into a contact with superconductors [1, 2]. This combination is known to provide a topological superconducting order, which might have a degenerate ground state with the exotic edge modes – Majorana fermions. The latter is believed to be a basis of topological quantum computation with the quantum bits are encoded by Majorana bound states in a non-local way [3]. The transport in topological Josephson junctions (JJ) attracts a great attention of researchers due to well-known 4π-periodic effect, which is believed to be a Majorana states signature [4]. In this context, the three-dimensional topological insulators (3DTI) covered with a conventional superconductors are actively studied [5]. Beside of that, 3DTI are promising for a new spin transport effects and gate tunable Josephson transport, again, due to the essential spin-orbital coupling of the surface electrons. The questions studied in this paper are (i) how does the 3DTInano-crystalline based JJ, deposited on Si/SiO2substrate, behave in magnetic field and at different temperatures and(ii) whether the orientation and the crystal shape does affects the Josephson transport. In a conventional technologies, the 3DTI part of JJ is fabricated by means of a flake exfoliation from a bulk crystal or by means of a molecular-beam epitaxy (MBE) . The main disadvantage of the exfoliation method is that the sizes of crystals obtained are large and reach several laterally. To localize the transport current across this type of TI it is necessary to applying additional e-beam lithography and plasma etching procedures. This results in a complete lost of the information about crystallographic orientations. The use of MBE for the deposition and growth of nano-sized single crystals of 3DTI is also difficult. Here we demonstrate the electronic transport properties of Bi2Te2Se based JJ on single nano-crystal made by means of physical vapor deposition (PVD). This technique does not have such disadvantages as exfoliation and, at the same time, is much simpler than the MBE method. It is expected that our investigations and the method of sample preparation will provoke an interest of the studies of superconductivity in ballistic nano-sized topological insulators. In this paper, we demonstrate the Josephson effect characteristics for Bi2Te2Se 3DTI nano-crystals which link Nb superconducting contacts. From a normal resistance measurements it follows that the interface with Nb is highly transparent. The critical current as a function of temperature and magnetic field and voltage-current characteristics are measured. There are three types of the geometry of normal regions involved in the devices: (i) very wide 3DTI flake,(ii) one that restricted to the contact widths and (iii) that of a nano-SQUID with two flakes. The multiple Andreev reflections (MAR) effect is observed for a sub-gap voltages, $eV < \Delta$. This clearly demonstrates that the transport through the flake is ballistic.

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