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Application of Superconductor/Photosemiconductor Contact Structures in Electronics

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In recent years, two-dimensional (2D) nanostructured materials, such as nanoplates and nanosheets, have attracted much attention because of their unique electronic, magnetic, optical, and catalytic properties, which mainly arise from their large surface areas, nearly perfect crystallinity, structural anisotropy, and quantum confinement effects in the thickness. The 2D nanostructured materials can be used as building blocks for advanced materials and devices with designed functions in areas as diverse, as lasers, transistors, catalysis, solar cells, light emission diodes, chemical and biological sensors. We report physical properties of YBCO/BiOI contact structures and electrophysical properties of BiOI single crystal.

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1. Introduction

The integration of high temperature superconductors (HTSC's) with conventional semiconductor (SeC)-based technology would have important consequences for micro- and cryophotoelectronics, with the promise of high performance hybrid circuits, incorporating the best of what superconductors and semiconductors have to offer, as well as the possibility for novel devices [1].

The high temperature superconductors (HTSC's) are considered to be low carrier density materials. Therefore, the light can penetrate the superconductor and can effectively excite the quasiparticles in it. The study of light detection by a "HTSC-photosemiconductor" hybrid contact structures (HCS's) is very perspective for fabrication of multifunctional photonic circuits – high speed detectors with reasonable sensitivity, covering a broad electromagnetic spectrum [1 – 2]. Therefore, for deeper investigation of such type compounds we need fabrication of the HCS's based on oxygen-containing photosemiconductor [3].

The BiOX single crystals are layered 2D structured materials. The crystal structure of BiOX is very similar to the symmetry of space groups P4/mmm and/or I4/mmm, which are typical for the $YBa_2Cu_3O_{7-\delta}$ and $Bi(Tl,Hg)_2Sr(Ba)_2Ca_{n-1}Cu_nO_{2n+4}$ HTSC's. Besides, the BiOX crystals, as well as HTSC's contain oxygen. The thermal expansion coefficients and the lattice constants of BiOX crystals in the (001) base plane are in good agreement with the same parameters of the HTSC's. Therefore the BiOX crystals are good "sparring partners" for the fabrication of "HTSC – photosensitive semiconductor" hybrid contact structures.

2. Experimental details

The BiOX crystals were grown by the vapour gas transport reaction method in closed volume. The compound BiOX of 99,99% purity was loaded into a high quality polished quartz ampoule (150 – 165 mm in length and 15 mm in diameter; combination of a cylinder and a cone). The ampoule was evacuated to a vacuum of 10^{-4} Torr. After pumping the ampoule was filled with water vapour and HX transport agent (TA). The system of chemical gas-transport reactions is as follows:

$$2BiOX \to Bi_2O_3 + BiX_3; \quad (1)$$

$$BiX_3 \uparrow + H_2O \uparrow \to BiOX + 2HX \uparrow; \quad (2)$$

$$Bi_2O_3 + 2HX \uparrow \to 2BiOX + H_2O \uparrow . \quad (3)$$

During the transport three gaseous compounds are involved: H_2O, HX and BiX_3. The reactions cycle (1-3) is closed and is carried until the BiOX is finaly transport into a single crystal from polycrystalline bismuth oxyhalide.

In this paper we report on the formation process of "ceramics HTSC($YBa_2Cu_3O_{7-\delta}$)/single crystals(BiOI)" HCS. Preliminarily $YBa_2Cu_3O_{7-\delta}$ ceramic were treated in oxygen ions plasma atmosphere for reconstruction of the superconducting properties of disturbed surface layer. The HCS's were finally annealed at a temperature of $T = 230 - 250$ °C.

3. Results and discussion

The unique temperature behaviour of the HCS's resistance consists in an N-shape anomaly around the superconducting transition temperature (interval 82 – 107 K; $T_c = 92$K; Fig. 1(left)). The temperature dependence of the BiOI semiconductor resistance can be described by the exponential function $\rho(T) = \rho_0 \exp(-\frac{E_g}{kT})$, where $E_g = 1.89$ eV and $\rho_0 = 10^2 - 10^6$ Ω·cm, depending on the activation regimes (temperature intervall 170 – 300 K).

The detailed consideration of the temperature dependence of the $YBa_2Cu_3O_{7-\delta}$/BiOI HCS resistance along the (100) plane at different values of the bias voltage V_{tr} shows the anomalies of resistance in the narrow temperature interval above T_c ($\Delta T = 5-7$ K). The resistance first decreases down to ρ_{min} at $T = T_c + (2 \div 4)$ K and then rapidly increases to the maximum at $T = T_c + 7$ K. Thus

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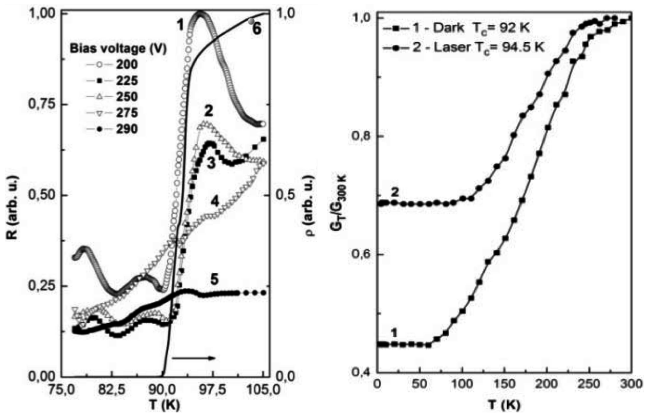

Fig. 1. (left) Temperature dependencies of resistivity of $YBa_2Cu_3O_{7-\delta}$/BiOI hybrid contact structure at different values of bias voltage along the (100) plane. The curve 6 characterizes the temperature dependence of the resistance of $YBa_2Cu_3O_{7-\delta}$ ceramics.
(right) Variation in normalized conductance of $YBa_2Cu_3O_{7-\delta}$/BiOI heterostructure in (1) dark; and (2) under laser irradiation.

the temperature dependence of $YBa_2Cu_3O_{7-\delta}$/BiOI heterojunction resistance is characterized by strongly pronounced N-shaped character in the narrow temperature interval above the superconducting transition.

The amplitude of the jumps of the resistance $R(T)$ (and the width of derivate negative value $dR(T)/dT$) was strongly dependent on the applied bias voltage. The bias voltages at which the resistance jumps have maximum amplitude are 90 –100 V and 220 – 255 V for planar and "through" geometry respectively. Subsequently, the resistance of heterojunction exponentially decreases with increase of temperature up to the room temperature.

The surface of $YBa_2Cu_3O_{7-\delta}$/BiOI heterostructure was irradiated by red He-Ne laser (with $\lambda = 632.8$ nm, $E = 1.95$ eV and power $P = 1.5$ mW) for 1 hour. The variation in the G_T/G_{300K} normalized conductance during laser irradiation was measured as a function of temperature and is shown in Fig. 1(right). It was observed that the T_c is further increased from 92 K to 94.5 K and critical current value J_c measured at 80 K is 1.85×10^3 A/cm^2. Here, the increase of superconducting parameters can only be attributed to the increase in carrier concentration when the sample was irradiated by laser light with the energy greater than the band gap of semiconductor [3].

We report the wide maximum in the resistance of BiOI single crystals (Fig. 2) in temperature region 75 – 200 K. Similar pequliarities for these crystals are observed in the temperature dependences of dielectric constant, specific heat and breaks in the X-ray diffraction in temperature region 150 – 230 K [2]. They testify that "antiferroelastic(AFE)-paraelectric(PE)" phase transitions are present, possibly by order-disorder mechanism [2].

Strongly pronounced N-shaped peaks in the temperature dependence of Y123/BiOI resistance are not associated with AFE-PE phase transitions in the BiOI crystal. They are also observed in the contact structures with Ge and Si elementary semiconductors (Y123/Ge(Si)) [3].

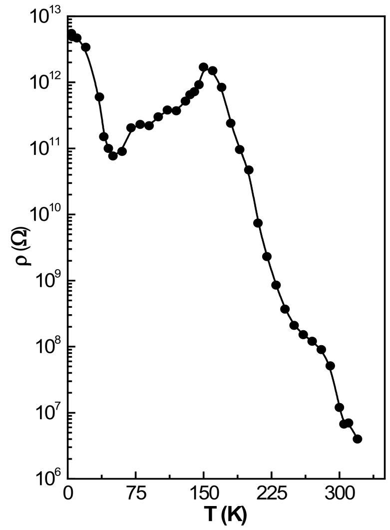

Fig. 2. Temperature dependence of resistivity of BiOI single crystal.

4. Conclusions

The transition of a HTSC to the superconducting state leads to a significant increase in the photosensitivity of the semiconductor layer of the heterostructure. This is due to single spin quantum tunneling processes of the Cooper pairs inside the semiconductor layer. Thus, we believe that hybrid structures based on "high-temperature superconductor-photosensitive semiconductor" can be used to create entirely new devices for cryophotoelectronics [1, 3].

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