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Physical Properties of "HTSC/Photosemiconductor" Micro- and Nanoplates Based Junctions

V. Bunda[a,*], S. Bunda[a], F. Vashchuk[a], A. Feher[b] and J. Kováč[c]

[a]Faculty of Information Sciences, Transcarpathian State University, Zankovetska St. 89-A, Uzhgorod 88 015, Ukraine

[b]Centre of Low Temperature Physics, Faculty of Science, P.J. Šafarik University
Park Angelinum 9, Kosice 04154, Slovakia

[c]Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 47, Kosice, Slovakia

In this paper we report the formation process and electrophysical properties of "high temperature superconductor ($YBa_2Cu_3O_{7-x}$)/photosemiconductor (BiOCl:Ti)" micro- and nanoplates based junction. The energy band model of «HTSC–semiconductor» junction is proposed.

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1. Introduction

The integration of high temperature superconductors (HTSC's) with conventional semiconductor-based technology would have important consequences for micro- and cryophotoelectronics. The rapid progress in the fabrication of high quality HTSC thin films on oxygen containing substratum such as $SrTiO_3$, MgO, and $LaAlO_3$ has been observed, but results on semiconductors like Si, Ge and GaAs have been less impressive [1].

HTSC's are considered to be low carrier density materials. Therefore, light can penetrate the superconductor and can effectively excite the quasiparticles in it. The study of light detection by a "HTSC/photosemiconductor (PSC)" micro- and nanoplates based junctions (NPBJs) is very perspective for fabrication of multifunctional photonic circuits — high speed detectors with reasonable sensitivity covering a broad electromagnetic spectrum [2].

2. Experimental details

The titanium doped BiOCl:Ti bismuth oxychloride layers were prepared by the laser ablation method (LTYPTSH-500 type laser, $\lambda = 0.53$ μm, frequency = 50 Hz) on surface of $Y_1Ba_2Cu_3O_{7-x}$ HTSC. The morphology and composition of the synthesized products were characterized by field emission scanning electron microscope (FESEM) and energy-dispersive X-ray spectroscopy (EDS), respectively. The junctions were finally annealed at $T = 230$–$250\,^{\circ}$C for the recrystallization procedure and fine contact formation. The contacts were prepared with indium and In–Ga–eutectic composition for the superconducting ceramics and with silver (or C + H_2O conducting glue) for the semiconducting layers. The pairwise contact resistances were measured at room temperature before and after cooling and also at low temperature. The current–voltage dependences of junctions were linear and did not exceed 1–2 Ω for HTSC ceramic and 35–70 kΩ for BiOCl:Ti thin films, respectively. Electrophysics measuring were performed using the standard four-probe configuration mode. The error in the temperature monitoring in each case does not exceed 0.01 K.

3. Results and discussion

In the "HTSC–semiconductor" system three principal types of junctions can be formed: tunnelling (1), proximity (2) and combinated (3) [2, 3]. In $d \gg \xi_p$ approaching (ξ_p — value of coherence length in the HTSC; d — the thickness of insulator (I) layer between super- and semiconductor) the electrical properties of junction are mainly determined by the parameters d of the transition layer. At $d \sim \xi_p$ both the HTSC–I–SC junction (junction of type 1) with high differential resistance ρ_d values ($\rho_d > 10^3$–10^5 Ω cm, at the bias voltage $V_{tr} \Rightarrow 0$) and proximity contact (junction of type 2) with the $\rho_d \Rightarrow 0$ take place. In the case $d \sim \xi_p$ and $0 < \rho_d < 10^3$–10^5 Ω cm junctions of type 3 (combinated "proximity–tunnelling" junction) take place.

Figure 1 shows the dependence of resistance versus temperature for the $YBa_2Cu_3O_{7-\delta}$–BiOCl:Ti junction along the semiconductor layer (curve 1) and through the junction (curve 2). The curve 3 characterizes the temperature dependence of $YBa_2Cu_3O_{7-\delta}$ HTSC ceramics resistance. The temperature behaviour peculiarities of "HTSC–SC" junction resistance consists in an N-shape anomaly (curves 1 and 2 in Fig. 1) around the superconducting transition temperature $T_c = 92$ K (curve 3; temperature area $85 \div 105$ K). The temperature dependence of the BiOCl:Ti photosemiconductor resistance can be described by the $\rho(T) = \rho_0 \exp(-E_g/kT)$ exponential function, where $E_g = 2.8 \div 3.2$ eV and $\rho_0 = 107$ Ω cm (depending on the activating modes).

The energy band model of "HTSC–semiconductor" junction is shown in Fig. 2. At temperatures $T < T_c$ we observed the changes of elementary excitations spectra of HTSC-formation of the $2\Delta_0$ energetic gap near the

* corresponding author; e-mail: viktor.bunda@upjs.sk

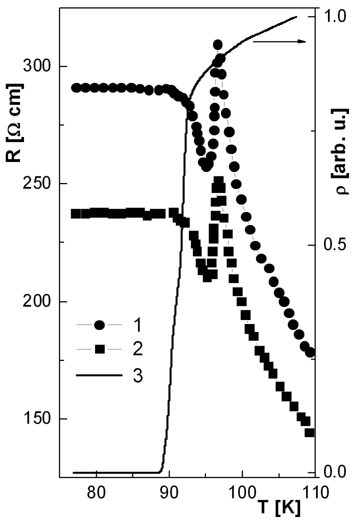

Fig. 1. Temperature dependence of resistance for the $YBa_2Cu_3O_{7-x}$–BiOCl:Ti junction through (curve 1) and along (curve 2) the structure. Curve 3 — temperature dependence of $YBa_2Cu_3O_{7-\delta}$ resistance.

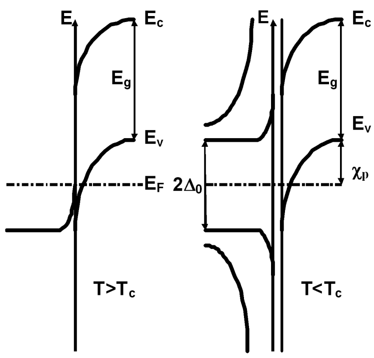

Fig. 2. The energy-band diagram for the "$YBa_2Cu_3O_{7-x}$–BiOCl:Ti" junction.

Fermi level. This provides the possibility for the mutual control of their properties. The unique of the temperature dependence "$YBa_2Cu_3O_{7-\delta}$–BiOCl:Ti" junction resistance and negative differential resistance values in the current–voltage characteristics around superconducting transition can be related to quantum tunnelling of quasiparticles through the junction. The Fermi surface divides basic and excited states of quasiparticles (Cooper's pairs). This provides the possibility for the mutual control of their properties.

In conclusion, "$YBa_2Cu_3O_{7-x}$/BiOCl:Ti" junctions are high effective heterophotoresistors (spectral sensitivity 0.31–0.80 μm) by possibility of photoelectric analysis of polarisation plane. It was found that the micro- and nanoplates in the arrays were polycrystalline, with dimension of 130×130 nm^2 in (001) plane and 600 nm length.

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