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Metal Oxide Bicrystal Josephson Junctions of a New Type with High Critical Parameters

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Abstract—The film bicrystal Josephson junctions of a new type based on a metal oxide high-T_c superconductor of the $YBa_2Cu_3O_{7-x}$ (YBCO) system are suggested and studied. In junctions of the new type, in contrast to the known ones, the working surfaces situated on the opposite sides of the bicrystal interface have different crystal orientations: one is (001)YBCO and the other is rotated (misoriented) relative to it by an asymmetric bicrystal angle around a certain axis lying in the substrate plane. The main electrical and dynamic (microwave) characteristics have been determined for junctions of the new type based on $NdGaO_3$ bicrystal substrates with the misorientation angle varying from 13 to 28°. These junctions exhibit high values of the critical parameters at T = 77 K, including the critical current density I_C = (2–5) × 10^5 A/cm^2 and the characteristic voltage $V_C = I_C R_N$ = 0.6–0.9 mV. Advantages of the bicrystal Josephson junctions of the new type over the known junctions are considered. © *2005 Pleiades Publishing, Inc.*

According to the existing models of the bicrystal Josephson junction [1–3], relatively large values of the superconducting order parameter in metal oxide superconductors create prerequisites for the formation of junctions with high values of the characteristic voltage (up to several millivolts at T = 77 K). As is known, this voltage determines the signal and noise parameters of the Josephson devices. However, metal oxide bicrystal junctions of the well-known (and the only practically used) type based on $YBa_2Cu_3O_{7-x}$ (YBCO) show the real values of V_C at T = 77 K not exceeding 300 μV [4]. In the junctions of this type, the working surfaces situated on the opposite sides of the bicrystal interface have the same orientation (001)YBCO and are misoriented by a symmetric bicrystal angle around the [001]YBCO axis (Fig. 1a). A characteristic feature of the junctions of this type is that the misoriented (001)YBCO surfaces occur in the same plane, so that we deal with a planar bicrystal junction (PBJ).

Recently, it was experimentally demonstrated [5, 6] that V_C in bicrystal Josephson junctions with (001)YBCO surfaces also misoriented by a symmetric bicrystal angle, but around the [100]YBCO axis lying in the substrate plane (Fig. 1b), may reach 1.2 mV at T = 77 K. Orientations of the working bicrystal surfaces in these junctions are also the same, albeit different from (001)YBCO. Since the (001)YBCO planes in the junctions of this type make a bicrystal angle with each other, the structure is called tilted bicrystal junction (TBJ) [5]. Unfortunately, the junctions of this type have a significant disadvantage related to the anisotropic electric properties of the working surf aces, which leads to difficulties in the creation of a preset topology of the electric chain involving superconducting electrodes and Josephson microbridges (e.g., the quantization circuits in SQUIDs).

This paper describes film bicrystal Josephson junctions of a new type based on a metal oxide high-T_c

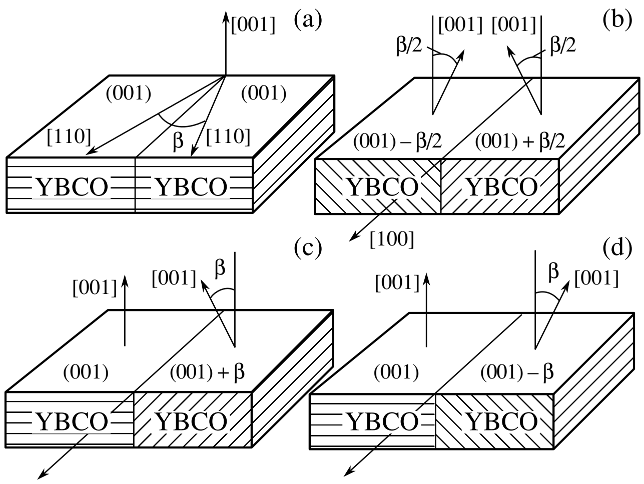

Fig. 1. Schematic diagram showing the bicrystal Josephson junctions of various types: (a) planar bicrystal junction (PBJ); (b) tilted bicrystal junction (TBJ) with symmetric misorientation angle; (c, d) tilted asymmetric bicrystal junction (TABJ) with asymmetric bicrystal angles +β and –β, respectively.

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Electric parameters of planar (PBJ) and tilted symmetric (TBJ) and asymmetric (TABJ) bicrystal Josephson junctions

Junction type	Bicrystal angle β	Sample No.	T = 77 K			T = 4.2 K		
			I_C, mA	R_N, Ω	V_C, mV	I_C, mA	R_N, Ω	V_C, mV
PBJ	24°	J1	0.035	0.9	0.032	1.6	0.9	1.4
		J2	0.047	2.1	0.1	1.7	1.9	3.2
		J3	0.065	0.5	0.032	3.7	0.6	2.2
PBJ	28°	J1	0.017	4.4	0.075	–	–	–
		J2	0.012	2.0	0.050	–	–	–
		J3	0.012	2.8	0.033	–	–	–
TBJ	22°	J1	1.25	0.54	0.67	–	–	–
		J2	1.5	0.60	0.90	11	0.6	6.6
		J3	1.5	0.46	0.69	10	0.6	6.0
TBJ	28°	J1	0.11	2.5	0.28	–	–	–
		J2	0.24	1.3	0.31	–	–	–
		J3	0.075	4.5	0.34	–	–	–
TABJ	21°	J1	2.6	0.33	0.87	–	–	–
		J2	1.71	0.4	0.68	–	–	–
		J3	1.5	0.41	0.69	–	–	–
TABJ	28°	J1	0.49	1.64	0.80	4.0	0.7	2.8
		J2	0.26	1.04	0.27	4.1	0.5	2.1
		J3	0.1	1.92	0.19	2.2	1.8	4.0

superconductor of the YBCO system and characterizes the main parameters of this junction.

In contrast to the known junctions of the types described above, the working surfaces situated on the opposite sides of the bicrystal interface of the proposed junction have different crystal orientations: one is (001)YBCO and the other is rotated (misoriented) relative to it by an asymmetric bicrystal angle around a certain axis lying in the substrate plane (Figs. 1c and 1d). By analogy with the junction described in [5], the new type will be referred to as the tilted asymmetric bicrystal junction (TABJ).

In order to assess the prospects of using the tilted asymmetric bicrystal Josephson junctions, we have studied their main electrical and dynamic (microwave) characteristics for various values of the bicrystal angle. In order to provide for an objective judgment, we have also prepared and characterized the samples of junctions of the known types with symmetric (planar and tilted) misorientations. The junctions of all the three types were prepared using the same technology, based on the (001)YBCO films grown on the corresponding $NdGaOP_2$ bicrystal substrates with the misorientation angles β varying from 13 to 28°. The substrates for all junctions were also grown using the same technology [7] and had the bicrystal interfaces of almost identical quality. The tilted junctions of both type were misoriented relative to the [100]YBCO axis.

The metal oxide high-T_c superconductor YBCO films with a thickness of 150 nm were deposited by means of the dc cathode sputtering of a stoichiometric YBCO target in oxygen at a pressure of 300–400 Pa. The films were deposited onto substrates heated to 780–800°C and then cooled to room temperature for 1.5 h in the oxygen atmosphere. The obtained heteroepitaxial YBCO films had critical temperature within T_C = 87–89 K. The Josephson bridges across the bicrystal interface had a width of 4 μm and a length of 10 μm and were formed by high-frequency plasma etching in argon, followed by chemical etching in a 0.5% bromine solution in ethanol [8].

The current–voltage (I–V) curves were measured at various temperatures in the range from 4.2 to 77 K. The measurements were performed in the absence of a magnetic field and in a field of up to 100 Oe, or on the samples exposed to a monochromatic electromagnetic radiation with a frequency from 30 to 100 GHz. In order to decrease the influence of uncontrolled external fields, the investigation was performed in a screened room, with filtration of all signals in the leads connected to a sample.

The results of determination of the electric parameters of the Josephson junctions of the three types are summarized in the table. As can be seen from these data, the tilted junctions with both symmetric and asymmetric bicrystal angles possess (for the same cross section areas) significantly (tenfold) higher critical parameters at $T = 77$ K as compared to those for the planar junctions. The critical current densities of the tilted junctions are $I_C = (2–5) \times 10^5$ A/cm^2, and their characteristic voltages are $V_C = I_C R_N = 0.6–0.9$ mV.

Figure 2 shows the *I–V* curves of the tilted asymmetric junctions with the bicrystal angles $\beta = 21$ and $28°$. Both curves correspond to a hyperbolic dependence and are analogous to the *I–V* curves of the tilted junctions with symmetric bicrystal angles. As is known [8, 9], this dependence is characteristic of a resistive model of the Josephson junction, with two channels of the charge transfer: via the current of quasiparticles (V/R_N) and the superconducting current $I_S(\varphi) = I_C \sin\varphi$. It should be noted that the tilted junctions with asymmetric misorientation (as well as the known junctions of two types with symmetric misorientation) for $\beta < 19°$ exhibit nonhyperbolic *I–V* curves typical of a viscous vortex flow [9]. When the misorientation angle increases above 21°, the tilted junctions with asymmetric misorientation show a decrease in I_C. The inset in Fig. 2 shows the *I–V* curves plotted on a greater scale with respect to the voltage. As can be seen, the junction with $\beta = 21°$ exhibits an increase in the resistance upon an eight-fold growth in the current density, which is most probably related to the breakage of the superconducting state in the current leads. Thus, the working range of this junction is determined by the relations $I_C < I < 8I_C$.

In the tilted asymmetric junction, the critical current I_C was maximum at a zero applied magnetic field strength and exhibited a nonmonotonic decrease with increasing field, which is analogous to the behavior known for the distributed Josephson junctions [9]. The *I–V* curves of such junctions exposed to a monochromatic electromagnetic radiation in the millimeter wavelength range, $A\sin(2\pi f_c t)$ with $f_c = 56$ GHz, showed a good agreement between the characteristics measured in the dynamic regime and in the dc mode at $T = 77$ K. A decrease in the temperature gives rise to the excess current and leads to deviation from the resistive model.

The results of our investigations of the main parameters of the bicrystal junctions of the new type indicate that it is possible to obtain Josephson junctions with high critical parameters, $I_C = (2–5) \times 10^5$ A/cm^2 and $V_C = I_C R_N = 0.6–0.9$ mV, which is evidence of good prospects for their use in both microwave and low-frequency superconducting electronics.

It should be noted that bicrystal junctions of the tilted asymmetric type are free of the main disadvantages inherent in the known types. As was demonstrated above, the new junctions provide much better critical parameters at $T = 77$ K as compared to those of the planar junctions. In contrast to the tilted symmetric junctions, one of the working surfaces in the asymmetric junction is a practically isotropic (100)YBCO plane, on which additional elements of the Josephson devices

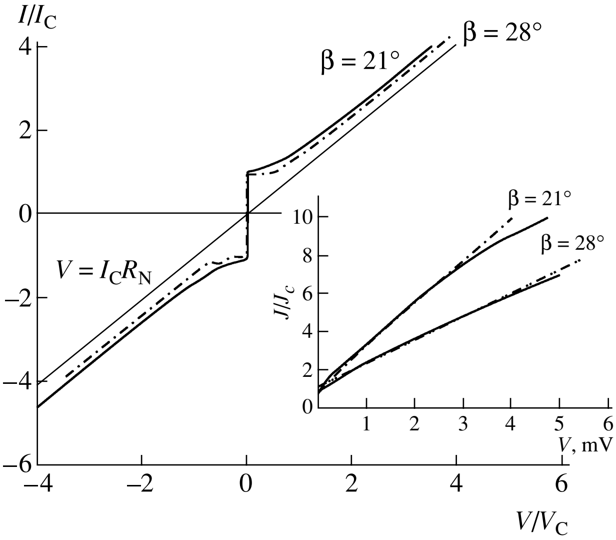

Fig. 2. Typical *I–V* curves of the tilted asymmetric bicrystal junctions with the misorientation angles $\beta = 21$ and $28°$ at $T = 77$ K. Thin solid line corresponds to the ohmic behavior. The inset plots the *J–V* curves on a greater scale with respect to the voltage; dashed lines show the asymptotic behavior of the linear components.

(filters, antennas, voltage control schemes, etc.) can be readily fabricated.

In addition, the Josephson junctions of the proposed type can be obtained not only on the bicrystal substrates, but on the usual substrates of the so-called biepitaxial configuration as well. This can be achieved by selecting appropriate materials of the dielectric sublayer(s) and substrate and finding the optimum substrate orientation by using the known criteria of mutual orientations for heteroepitaxy (see, e.g., [10]). Despite numerous investigations, only biepitaxial Josephson junctions with one fixed value of the bicrystal angle (45°, which far from the optimum [11]) have been obtained and characterized so far. According to our estimates, bicrystal junctions of the tilted asymmetric type in biepitaxial configuration can be obtained with a misorientation angle different from 45° and approaching the optimum value. The latter circumstance is extremely important, for opening way to the creation of biepitaxial bicrystal Josephson junctions with high critical parameters based on metal oxide high-T_c superconductors.

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REFERENCES

1. R. A. Riedel and P. F. Bagwell, Phys. Rev. B **57**, 6084 (1998).
2. Yu. S. Barash, Phys. Rev. B **61**, 678 (2000).
3. Y. Tanaka and S. Kashiwaya, Phys. Rev. B **53**, R11957 (1996).
4. L. R. Vale, R. H. Ono, and D. A. Rudman, IEEE Trans. Appl. Supercond. **7**, 3193 (1997).
5. U. Poppe, Y. Y. Divin, M. I. Faley, *et al.*, IEEE Trans. Appl. Supercond. **11**, 3768 (2001).
6. Y. Y. Divin, I. M. Kotelyanski, P. M. Shadrin, *et al.*, in *Proceedings of the 6th European Conference on Applied Superconductivity, Sorrento, 2003*, p. 166.
7. Yu. Ya. Divin, I. M. Kotelyanskiĭ, and V. N. Gubankov, Radiotekh. Élektron. (Moscow) **48**, 1238 (2003).
8. G. A. Ovsyannikov, I. V. Borisenko, K. I. Konstantinyan, *et al.*, Pis'ma Zh. Tekh. Fiz. **25**, (11), 65 (1999) [Tech. Phys. Lett. **25**, 913 (1999)].
9. K. K. Likharev, Rev. Mod. Phys. **51**, 101 (1979).
10. L. S. Palatnik and I. I. Papirov, *Epitaxial Films* (Nauka, Moscow, 1971) [in Russian].
11. F. Tafuri, F. Carillo, F. Lombardi, *et al.*, Supercond. Sci. Technol. **12**, 1007 (1999).

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