EFFECT OF JOSEPHSON MEDIUM UNDER TUNNELING IN Bi–Sr–Ca–Cu–O

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Tunneling characteristics of high-T_c oxide superconductor Bi–Sr–Ca–Cu–O *have been measured in the wide bias voltage and temperature range. Near zero bias voltage tunneling conductivity $\sigma(U)$ is expressed by the $U^{1/2}$ at low temperature, which goes to the linear one at $U > 100$ mV. Background conductivity metaloxide is determinated by a Shottky barrier on the surface of high-T_c. It has been found that the peaks of $\sigma(U)$ curves for low-ohmic contacts are well described by theoretical model of destruction of superconductivity of the intergranular weak links. Parameters of these links are estimated. Zero bias anomalies (conductivity peak) are explained by breakdown of weak links with low critical current.*

The metaloxide high-temperature superconductors (HTSC) prepared by the solid state reaction technique are the Josephson media whose macroscopic properties are described in the approximation of a net of superconducting weak links [1,2]. It is namely the Josephson-medium specific character which results in initiation of multiple singularities in high-T_c tunneling spectra [1–5]. For the Josephson medium of high-T_c the averaging of quasi-particle effects is performed on the surface of individual granules adjacent to the tunnel barrier, so tunneling to each individual grain may take place irrespective of the others [6,7]. Thus, the peculiarities of the Josephson medium under tunneling HTSC may affect the current-voltage characteristics due to breakdown of percolating current channels. This gives rise to additional resistance and corresponds to the peaks of differential resistance in derivatives dU/dI vs U [6,7].

The aim of the present paper is to estimate the correlation between the experiment and the theoretical interpretation of the effect of the destruction of superconductivity of the weak links in tunnel characteristics of contacts HTSC–metal.

Point and film tunnel contacts based on metaloxide Bi–Sr–Ca–Cu–O have been studied. Polycrystalline samples $Bi_2Sr_2Ca_2Cu_3O_{8-\delta}$ were prepared by the solid state reaction technique, using high purity powder metal oxides and carbonates as described in refs. [3,4,7]. The metaloxide ceramics possessed the critical temperature of superconducting transition $T_c = 105$ K, the width of transition $\Delta T_c = 5$ K, critical current density $j_c = 400$ A/cm^2. The tunnel contacts were fabricated by thermal sputtering in vacuum of film electrode (Pb, Pb–Bi) onto as-cleansed surface of ceramic plates of $10 \times 1 \times 0.1$ mm^3. Current and potential contacts at ceramics were sintered by silver-based paste. Point tunnel contacts were created in an arrangement with the adjustable pressing of one or two Nb–Ti needles with 100 μm tip diameter in the surface of Bi–Sr–Ca–Cu–O. It should be noted that samples having the film injector were stable, particular in case of thermal cycling. Tunnel conductivity was measured using usual modulation four-probe technique. Temperature was measured with a Cu–CuFe thermocouple.

Fig. 1 shows the dependence of tunnel conductivity dI/dU vs U for the Nb–Ti/Bi–Sr–Ca–Cu–O point-contact at different temperatures. From these curves it is well obvious that for metaloxide Bi–Sr–Ca–Cu–O the typical $dI/dU = \sigma \sim U$ dependence is observed in the wide temperature range. The conductivity $\sigma(U)$

under low bias voltage and low temperatures is expressed by the root dependence $\sigma(U) \sim U^{1/2}$ (insert of Fig. 1), which goes to the linear one at $U > 100$ mV. Voltage of this crossover U_{cr} dependens on resistance of the tunnel contact $R_t(0)$ at zero bias voltage. With $R_t(0)$ decrease the U_{cr} value increases. The linear dependence

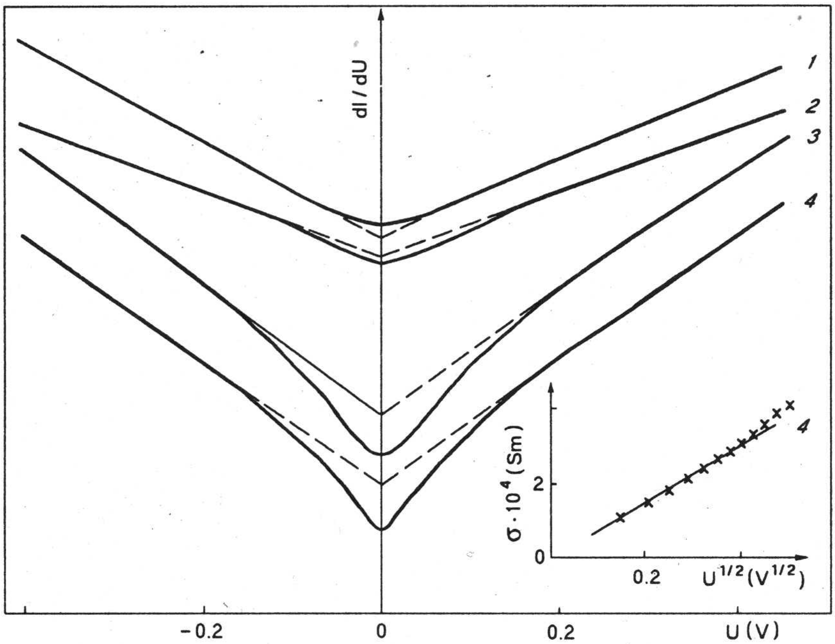

Fig. 1. Tunnel conductivity $dI/dU - U$ of Nb–Ti/Bi–Sr–Ca–Cu–O point contact at temperature: *1* — 180; *2* — 100; *3* — 55; *4* — 4.2 K. In the insert: the root dependence $\sigma \sim U^{1/2}$

of tunnel conductivity $dI/dU \sim U$, which was for the first time found in Y–Ba–Cu–O base tunnel junctions, is related to the formation of space charge on their interface and to the occurrence of Shottky barrier [7,8]. The like behaviour of the background $\sigma(U)$ characteristics in our case can be explained also by existing Shottky potential barrier on the surface of Bi–Sr–Ca–Cu–O metaloxide ceramics. This leads to essential asymmetry of the $\sigma(U)$ curves. With the temperature decrease the characteristics became symmetrical and enhancement of the electron-electron interaction in ceramic surface layer leads to the root dependence [9] $\sigma \sim U^{1/2}$ at low U. For the film tunnel structures $Pb_{80}Bi_{20}$/Bi–Sr–Ca–Cu–O with high resistance R_t the $\sigma(U)$ dependence for high T can be expressed as $\exp(U/E_{00})$. Fig. 2 shows experimental curves for tunnel junction with $R_t(U = 0) = 3.3$ kOhm at $T = 300$ K, $R_t(U = 0) = 25$ kOhm at 80 K. This expression conforms to the process of thermoelectronic emission through small-height Shottky barrier [10]. With temperature decrease background conductivity of the junction is basically defined by the electronic processes in the disordered layer on the surface of HTSC ceramic.

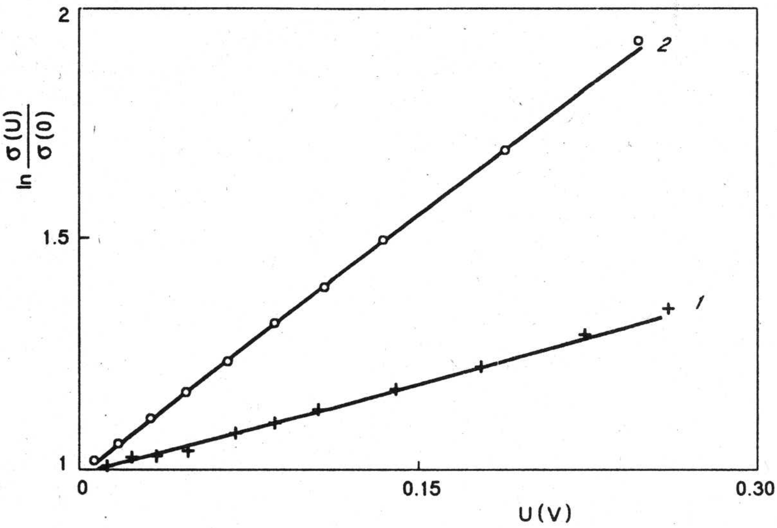

Fig. 2. Normalized characteristics of tunnel conductivity ln $|\sigma(U)/\sigma(0)|$ — U of $Pb_{80}Bi_{20}$/Bi–Sr–Ca–Cu–O film contact at temperature: *1* — 300; *2* — 80 K

In tunnel characteristics of superconducting Bi–Sr–Ca–Cu–O ceramic the peculiarities are observed caused by current breakage of weak links. These peculiarities are registered not only for contacts with $R_t(0) << 10^3$ Ohm, which is typical of metal oxide ceramics of the Y–Ba–Cu–O and La–Sr–Cu–O type, but for the higher-ohmic

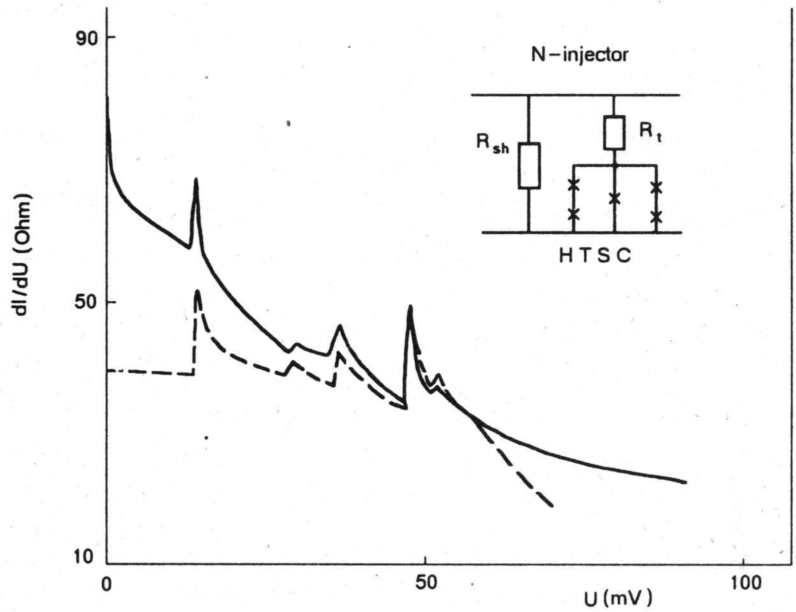

Fig. 3. The experimental and calculated dependencies $dU/dI - U$ showing the effects of current destruction of intergrain junctions. In the insert: the equivalent scheme of circuit used under simulation

ones with $R_t(0) \leq 10^5$ Ohm (see Fig. 3). Breakage in this case may be explained by nongomogeneous tunnel barrier thickness. It led to localization of tunnel current at small part of current paths including the superconducting weakly linked sections of percolating cluster of the metaloxide ceramic. This fact is also confirmed by our

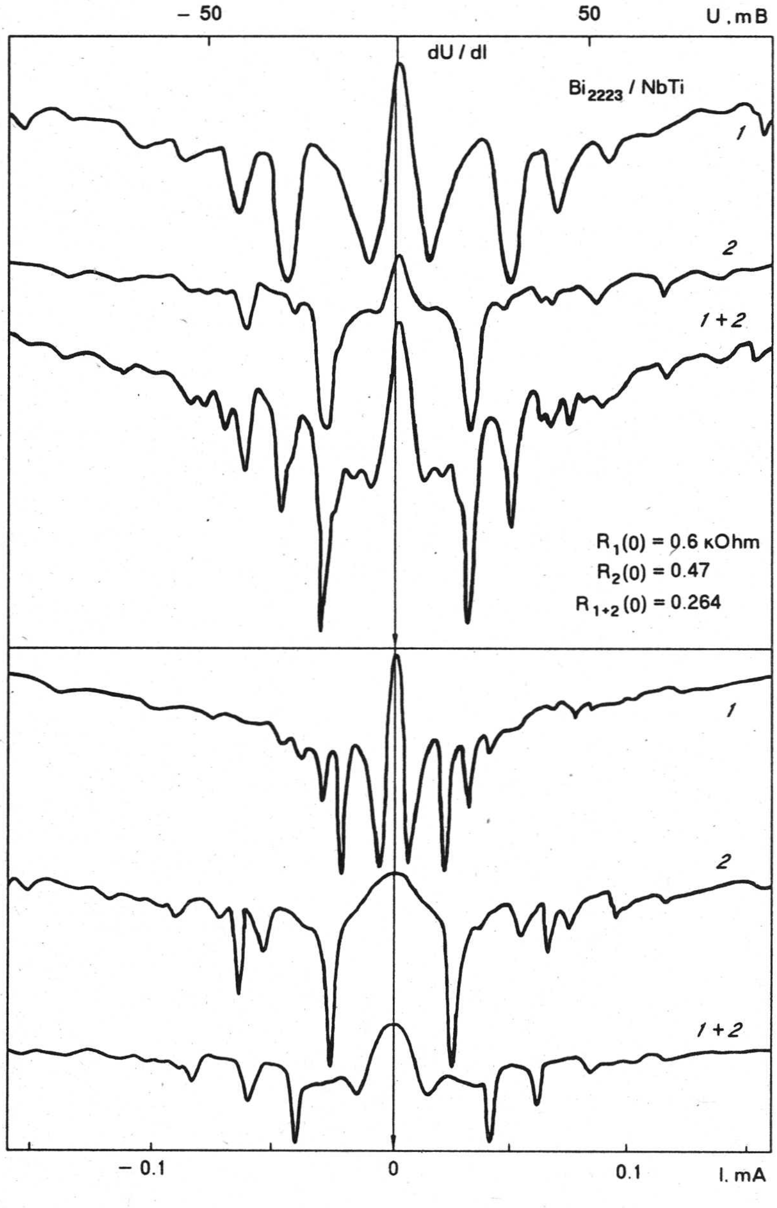

Fig. 4. Tunnel characteristics *dI/dU – U* of Nb–Ti/Bi–Sr–Ca–Cu–O contact with double-needle injector recordered in potential and current coordinates: *1* — the first injector, *2* — the second injector, *1+2* — first and second injectors at the same time

measurements made with Y–Ba–Cu–O films with incomplete superconducting transition with respect to R and remainder resistance at temperature 4.2 K. The peak structure of the $dU/dI - U$ curves is also typical of them (curve 1, Fig. 5).

As it has been noted [6,7] the effects of current breakage result in the increase of measuring circuit resistance and are registered as dU/dI vs U peaks. Fig. 3 shows an example of calculating the like breakage for some Josephson links near the tunnel contact and its comparison with the real experimental curve for contact $Pb_{80}Bi_{20}$/Bi–Sr–Ca–Cu–O. One can see the good coincidence both with respect to position and amplitude of singularities. Difference between the curves seen at low bias voltages is due to energy gap of the Pb–Bi injector. The theoretical curve has been calculated for a sandwich of the *N–I*-Josephson medium type. The corresponding equivalent scheme used for calculation is shown in the insert. The crosses show the weak links whose superconductivity is destructed by current. The essential amplitude of the peaks is determined by high differential experimental dU/dI of the weak link under the stepwise transition to the resistive state, which shunted resistance R_{sh} of the rest area of the tunnel junction. In calculation we have obtained the following values of the Josephson junctions parameters: the critical current of a single superconducting weak link $I_c \sim (5\div20)\cdot10^{-7}$ A, resistance $R_j \sim 500\div3000$ Ohm. Value of I_cR_j is 0.2÷2.0 mV which is of the order of magnitude of values obtained directly from the measurements of the Josephson effect for bismuth-based ceramics [11]. The peaks in $dU/dI - U$ curves for lower-ohmic contacts ($< 10^3$ Ohm) are due to contacts having different parameters : $I_c \sim 10^{-4}$ A and $R_j \sim 1\div10$ Ohm.

The current character of the singularities observed in conductivity of tunnel contacts is also confirmed by the experiments in point-contact with double-tip injector. The design made it possible to use them singly or in combination. It turned out that location of dU/dI spectrum singularities obeys the law of current distribution in such electrical circuits. Peculiarities observed for single-tip injectors are also displayed for the "double" injector and are respectively displaced along the axis of currents when writing the $dU/dI - I$ characteristics (Fig. 4).

Thus, it has been ascertained that when changing tunnel contact resistance there appears a possibility to record and study the intergranular contacts with different parameters selectively. In this case the intergrain Josephson links having small critical current will display in the vicinity of zero bias voltage. We have simulated this situation by decreasing the value of the critical current of one (!) contact by the order of magnitude. In the dynamic contact resistance dU/dI vs U there occurs a conductivity peak (insert of Fig. 5). We have observed singularities of this type in tunnel experiments with the controllable barrier (Nb–Ti tip) for low-ohmic contacts (Fig. 4). The analogous possibility of zero anomalies initiation in microcontact spectra of bismuth and yttrium-base ceramics was reported by L. F. Ribal'chenko [12] and R. Escudero [13] with co-workers.

It should be noted that conductivity peak near zero bias voltage may occur if current of thermal fluctuations $I_f \left\{ I_f(\mu\text{ A}) = 0.084\ \text{T(K)} \right\}$ [14] is close to the critical current of weak links. At $T = 4.2$ K value $I_f = 0.3\,\mu$A and this situation is also possible for "bad" metaloxides. Another consequence of the fluctuation thermal current I_f is the essential smearing of the tunnel spectra singularities already at $T = 10\div15$ K. At $T = 40\div80$ K value I_f reaches $(3\div8)\cdot10^{-6}$ A and the curves have practically no peculiarities.

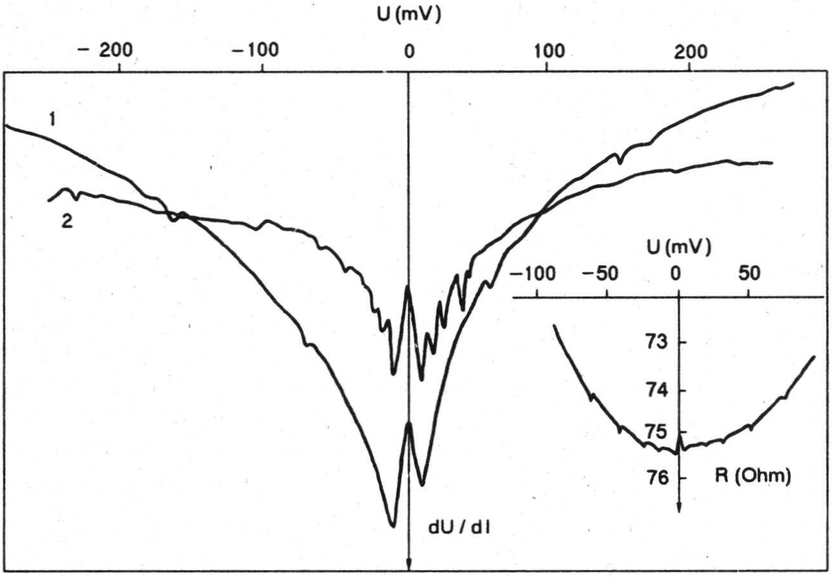

Fig. 5. Manifestation of zero conductivity maximum in $dU/dI - U$ of point–contacts to metaloxides: *1* — nonsuperconducting (with respect to the $R - T$ dependence) Y–Ba–Cu–O film, $R_t \sim 20$ Ohm; *2* — Bi–Sr–Ca–Cu–O ceramics, $R_t \sim 250$ Ohm. In the insert: the calculated dependence (critical current of the weak link $I_c \sim 10\,\mu A$)

In summary, it has been found that the peaks of the dynamic contact resistance observed under tunneling into metaloxides are well described by the suggested theoretical scheme and can be related to destruction of superconductivity of the intergranular weak links. The "resistive spectroscopy" gives the possibility to record and study the state of intergranular boundaries in metaloxides selectively by changing the resistance of tunnel contact formed on the surface of high-T_c superconductors. This information is rather valuable for solving the problems of composition nonstoichiometry, structure state of the grains and intergranular boundaries.

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