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Quasiparticle-injection effect in $YBa_2Cu_3O_x$-based planar structures

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The supercurrent I_S of a YBCO bridge can be modulated by the quasiparticle-injection current I_G from YBCO/Au or YBCO/PBCO/Au junctions. The behavior of these structures is determined by two effects: 1) summation of the currents I_S and I_G in the YBCO bridge; 2) nonequilibrium suppression of the supercurrent I_S by the quasiparticle-injection. The current gain coefficient $\Delta I_S/\Delta I_G$ increases linearly with decreasing temperature, reaching a value of 1.5 for YBCO/Au structures at 65 K. The nature of the nonequilibrium state and the effectiveness of the PBCO barrier layer for the formation of the quasiparticles are analyzed.

1. INTRODUCTION

Injection-controlled three-terminal devices are an interesting object for the study of nonequilibrium superconductivity and for practical application as transistor-like superconducting elements at liquid-nitrogen temperatures. A first study of the quasiparticle injection in YBCO/Al structures shows a current gain of 5-7 at 4.2 K [1]. The number of thermal quasiparticles N_T increases with operating temperature. It complicates the creation of the nonequilibrium state ($\Delta N_{inj}*N_T$) at the same injection levels and decreases the gain coefficient. Injection-controlled structures have not been studied yet at high temperatures.

In this report we investigate the modulation of the supercurrent of YBCO microbridges under quasiparticle injection from YBCO/Au and YBCO/PBCO/Au planar contacts at temperatures of 60 K to 85 K.

2. DEVICE STRUCTURE

Schematic views of the YBCO/PBCO/Au structure are shown in Fig.1. A planar geometry of the structure was chosen to provide uniformity of the injected quasiparticle flow into the YBCO films. The thickness of the YBCO, PBCO and Au layers is 40-80nm, 0-20nm and 30-40nm, respectively. PMMA photoresist covers the edges of the YBCO strip. The junction area varies between 8x20 μm^2 and 20x30 μm^2. The critical current density J_C of the YBCO bridges is $5{\cdot}10^5$-$3{\cdot}10^6$ A/cm^2 at 77 K.

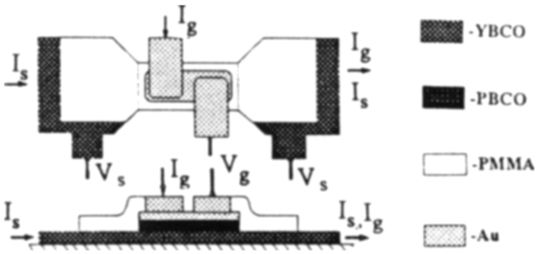

Fig.1. Schematic view of YBCO/PBCO/Au structure with indication of the terminals.

3. RESULTS AND DISCUSSION

The critical value I_C of the controlled current I_S of a YBCO bridge is shown in Fig.2 as a function of the injection current I_G from the YBCO/Au contact at different temperatures. The same dependencies are measured if both I_S and I_G are reversed. $I_C(I_G)$ dependencies of the YBCO/PBCO/Au structures show similar behavior to that presented in Fig. 2.

First we discuss the effect of current summation in the YBCO bridge. Asymmetrical input of the injected current I_G into the structure (Fig.1) creates different distribution of the total current density J_S+J_G in the YBCO strip. If J_S and J_G are in the same direction, their sum J_S+J_G cannot exceed the J_C value of the YBCO bridge near the entrance of these currents into the junction area. Pure summation results in the dependence $I_C(I_G)=I_C(0)-I_G$. For the opposite direction of J_S and I_G the weakest place is on the other side of the junction and $I_C(I_G)=I_C(0)$ due to summation effect. Thus, even at a uniform current flow of I_G through the contact area, non-uniformity of the current flow through the bridge

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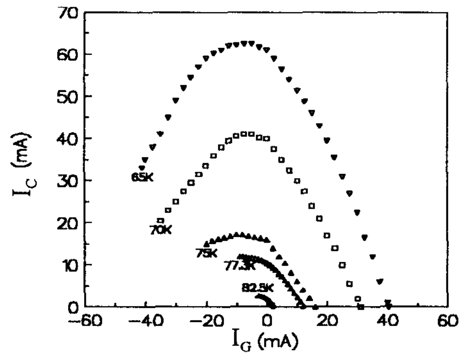

Fig.2. Dependence of the critical current I_C of the YBCO bridge on the injection current from YBCO/Au contact at different temperatures.

causes different $I_C(I_G)$ dependencies for the parallel and opposite directions of the current flows.

The amplification effect of these structures ($K_G \equiv I_C(I_G=0)/I_G(I_C=0)>1$) is caused by quasiparticle injection. The injection-affected change of the supercurrent ΔI_C as a function of I_G is shown in Fig.3. Experimental data are plotted as $\Delta I_C = I_C(0) - I_C(I_G)$ at $I_G<0$ (i.e if I_G is opposite to I_S) and $\Delta I_C = I_C(0) - I_C(I_G) - I_G$ at $I_G>0$ due to asymmetrical current flow, as was discussed above. The reasonable symmetry of the $\Delta I_C(I_G)$ curves supports the idea that this has a common nature.

The spectrum of the injected quasiparticles is almost linear with energy. Thus, the injection can simply raise the effective temperature $T^*>T_{bath}$ for both quasiparticles and phonons. At high operating temperatures and small thickness of the films the response to the injected power $P_G = I_G \cdot V_G$ is determined by heat flow through the film-substrate interface, rather than by the heat diffusion time via the layers ($\tau_{diff} \sim d / D \ll \tau$) [2]. Thus, a simple heating T*-model can be applied for these structures [3]:

$$P_G = I_G \cdot V_G = c(T^{*4} - T_{bath}^4) \qquad (1)$$

The simulated curve is the dependence:

$$\Delta I_C = I_C(T_{bath}) - I_C(T^*) = f(P_G) \qquad (2)$$

plotted by using eq.1) for the effective temperature T* and I_C (T) dependence for the values $I_C(T^*)$. A linear increase of the gain coefficient with decreasing temperature agrees with the T*- model.

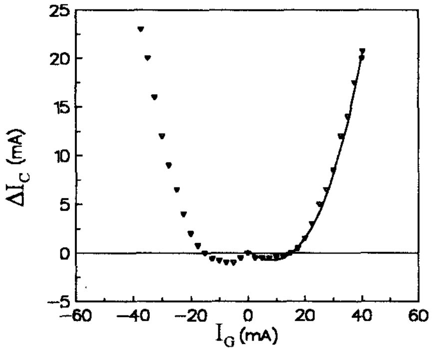

Fig.3. Injection-suppressed part of I_C as a function of injection current at several temperatures. Simulated curve is a solid line.

The operating speed of the YBCO/Au structures can be estimated as a bolometric response time $\tau \sim 1$-2 ns [2]. Our measurement shows no difference in the gain coefficient K_g up to the frequencies of 50 KHz.

A PBCO barrier layer of 0-20 nm thickness has been used to increase the power P_G and to vary the spectrum of the injected quasiparticles. In the YBCO/PBCO/Au structures the absolute value of K_G decreases with PBCO barrier thickness. The PBCO barrier seems to be effective only at small thicknesesses due to the short hopping distance of the carriers in the c-axis direction and an extra energy loss in the barrier. The largest values of the gate power P_G have been applied to the junctions with a thick PBCO barrier, but the K_G coefficient is the smallest in these structures. This disagrees with a simple T*-heating by injected power and needs further analysis.

4. CONCLUSIONS

The behavior of the injection-controlled YBCO/Au and YBCO/PBCO/Au structures is determined by the summation of the transport I_S and injection I_G currents in the YBCO bridge as well as by nonequilibrium suppression of the supercurrent I_S due to quasiparticle injection. The injection effect agrees qualitatively with a simple T*-heating model. A current gain of 1.5 in absolute values of the currents and $dI_S/dI_G \sim 2$-3 at 65K can be achieved in YBCO/Au structures.

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