Quasiparticle-injection effect in YBa$_2$Cu$_3$O$_x$-based planar structures

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The supercurrent $I_0$ of a YBCO bridge can be modulated by the quasiparticle-injection current $I_a$ 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 $I_o$ in the YBCO bridge; 2) nonequilibrium suppression of the supercurrent $I_s$ by the quasiparticle-injection. The current gain coefficient $\Delta I_s/I_o$ 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/AI structures shows a current gain of 5-7 at 4.2 K [1]. The number of thermal quasiparticles $N_v$ increases with operating temperature. It complicates the creation of the nonequilibrium state $(\Delta N = N_v)$ 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 $\mu$m$^2$ and 20x30 $\mu$m$^2$. The critical current density $J_c$ of the YBCO bridges is $5 \times 10^3$-3-$10^4$ A/cm$^2$ at 77 K.

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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 $I_o$ from the YBCO/Au contact at different temperatures. The same dependencies are measured if both $I_s$ and $I_o$ are reversed. $I_c(I_o)$ 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 $I_o$ into the structure (Fig.1) creates different distribution of the total current density $J_s+J_o$ in the YBCO strip. If $J_s$ and $J_o$ are in the same direction, their sum $J_s+J_o$ 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 $I_c(I_o)=I_c(0)-I_o$. For the opposite direction of $J_s$ and $I_o$ the weakest place is on the other side of the junction and $I_c(I_o)=I_c(0)$ due to summation effect. Thus, even at a uniform current flow of $I_o$ through the contact area, non-uniformity of the current flow through the bridge

Fig. 1. Schematic view of YBCO/PBCO/Au structure with indication of the terminals.
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 $I_c(I_o)$ dependencies for the parallel and opposite directions of the current flows.

The amplification effect of these structures ($K_o=I_c(I_o=0)/I_o(I_c=0)>1$) is caused by quasiparticle injection. The injection-affected change of the supercurrent $\Delta I_c$ as a function of $I_o$ is shown in Fig. 3. Experimental data are plotted as $\Delta I_c=I_c(0)-I_c(I_o)$ at $I_o<0$ (i.e. if $I_o$ is opposite to $I_c$) and $\Delta I_c=|I_c(0)-I_c(I_o)|-I_o$ at $I_o>0$ due to asymmetrical current flow, as was discussed above. The reasonable symmetry of the $\Delta I_c(I_o)$ 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 $T^*>T_{th}$ for both quasiparticles and phonons. At high operating temperatures and small thickness of the films the response to the injected power $P_o=I_oV_o$ is determined by heat flow through the film-substrate interface, rather than by the heat diffusion time via the layers ($\tau_{diff}=d/\rho c D$) [2]. Thus, a simple heating $T^*$-model can be applied for these structures [3]:

$$P_o=I_oV_o=c(T^*-T_{th})^4$$

The simulated curve is the dependence:

$$\Delta I_c=I_c(T_{th})-I_c(T^*)=f(P_o)$$

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.

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

A PBCO barrier layer of 0-20 nm thickness has been used to increase the power $P_o$ and to vary the spectrum of the injected quasiparticles. In the YBCO/PBCO/Au structures the absolute value of $K_o$ decreases with PBCO barrier thickness. The PBCO barrier seems to be effective only at small thicknesses 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 $P_o$ have been applied to the junctions with a thick PBCO barrier, but the $K_o$ 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 $I_o$ currents in the YBCO bridge as well as by nonequilibrium suppression of the supercurrent $I_c$ 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 $dI_s/dI_o \approx 2-3$ at 65K can be achieved in YBCO/Au structures.

REFERENCES