Properties of YBa$_2$Cu$_3$O$_{7.5}$ Granular Josephson Junction

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Abstract YBa$_2$Cu$_3$O$_{7.5}$ weak link junctions with width from 0.1 mm to 0.3 mm and length from 0.2 mm to 0.5 mm was made by hand with a razor blade. The current voltage characteristics of the microbridges show, under microwave irradiation, pronounced Shapiro steps up to transition temperature. A careful measurement of the dependence of the critical supercurrent on the external magnetic field and laser light is presented.

Key words high temperature superconductivity, YBa$_2$Cu$_3$O$_{7.5}$, Josephson junction, weak link

1 Introduction

Superconducting weak links are very intriguing, due to the fact that these relative simple structures show Josephson effect[1]. In theory, only the structures that have dimensions comparable with the coherence length $\xi$ are expected to show true Josephson behavior$^{2,3}$. In practice, it is found that the weak links with dimensions comparable with effective magnetic field penetration depth $\lambda_{eff}$ exhibit Josephson-like effects, like Shapiro steps under microwave irradiation$^{4}$.

Different applications have different criteria for the junction qualities. For most of the applications, the junction should first have reproducible parameters such as the critical current ($I_c$) and the normal resistance ($R_n$). Secondly, the junction should have a high $I_cR_n$ product. The $I_cR_n$ value is important to the speed, the high frequency limit, the noise, and the output voltage of the Josephson devices. Thirdly, the noise level of the junction should be low for high quality applications. Finally, the junction should allow itself to be positioned freely on the chip as required for electronic circuit designs, and the cost of the fabrication should be low. Further development of high temperature superconducting devices requires an understanding of the reason behind the poor quantitative reproducibility of junction characteristics that will ultimately lead to an improvement in fabrication.

In this article we present the characteristic of the granular weak link junctions. Besides $I$-$V$ characteristics, the response of the granular bridge junctions to the microwave irradiation, magnetic field, and laser radiation has been investigated.

2 Experiment Details

The following data refer to the measurement performed on 2 $\mu$m thick granular weak link junction of YBCO. The films are deposited by spray gun onto YAZ (10 mm × 3 mm × 0.3 mm) substrates. The film is annealed in flowing oxygen at 950 °C for one hour and then annealed for another one hour at 580 °C. The electrical contact is made of evaporation silver pads which is attached by small indium dot to the silver wires. The sample is cut into weak link by using a razor blade, its size is 0.1 mm in length, 0.3 mm in width, 0.3 mm in thickness and its resistivity between 50--80 $\Omega$ at room temperature. The electrical and microwave response measurements are carried out in close cycle He cryostat. The sample is in good thermal contact with a copper holder whose temperature is measured with four-probe wiring. In order to heat the junction to the transition and beyond, an electrical heating coil of small diameter wire is attached to the copper cooling stage. This coil dissipates a modest amount of power (2 W), and heats the film to the desired temperature. The operation temperatures of the sample are controlled by temperature control to within 0.1 K. The resistivity is detected by conventional four probe techniques. A special dc tee allows biasing the sample and monitoring dc resistance. The microwave radiation is supplied by K-band (26.5--40 GHz) millimeter wave source with maximum power 10 mW. We use a cw He-Ne laser as the light source.
with chopping frequency from 100 ~ 2500 Hz. The current-voltage (I-V) characteristic of each junction is measured using four-probe method. In our set up, the magnetic field produced by a Helmholtz coil is perpendicular to the a-b plane of the film and parallel to the junction, a maximum of approximately 33 mT and a minimum of 0.01 mT can be applied.

3 Results and Discussions

The typical zero resistance critical temperatures of YBCO films are about 88 K. Fig. 1 shows the $R$-$T$ curve of our sample. The $I_cR_n$ product is about 1 mV ($I_c\approx500 \mu$A and $R_n\approx2$ $\Omega$) for present junction. This value is typical of such kind of junction but smaller than BCS prediction (up to 40 mV) for high-$T_c$ materials without surface or interface depressed order parameter\(^4,5\).

First we investigate the high frequency response of the junctions to the applied millimeter wave radiation with a frequency 36 GHz and the induced step is observed. Fig. 2 shows two $I$-$V$ characteristics with radiation and without radiation at 78 K. These characteristics can be described by the resistively shunted junction model. Shapiro steps occur at voltage $V_n = 1 \, n \Phi_0$, where $n$ is the number of harmonic of microwave radiation. It is found that the current-voltage characteristic may exhibit hysteresis, so that the path taken for increasing $I$ is not the same as that for decreasing $I$.

One of the most striking features of the behavior of Josephson junction is the occurrence of diffraction and interference phenomena of supercurrents when magnetic fields are applied. The extremely high sensitivity of the Josephson current to the magnetic fields is the key to the most important applications of the Josephson effect. Furthermore, a careful study of the dependence of the maximum dc Josephson current on the applied magnetic field represents a very powerful method to investigate the current density distribution inside the junction. Fig. 3 shows the $I$-$V$ curves of the junction under magnetic field. The magnetic field dependence of the $I$-$V$ curves for the junction is measured at 70 K. The resulting behavior is illustrated in Fig. 3 (a). The junction critical current decreases rapidly and monotonically for magnetic fields as small as 1.5 mT. The general behavior of our sample can best be described by the rapid decrease of the critical current in the small field followed by oscillation around a persistent critical current value.

![Fig. 1](image1.png)

Fig. 1 $R$-$T$ curve of the granular films with bias current 1.0 mA.

![Fig. 2](image2.png)

(a) Granular Josephson junction, $X = 5$ mV/div, $Y = 500$ $\mu$A/div
(b) Shapiro steps, the microwave frequency 36 GHz, $X = 5$ mV, $Y = 200$ $\mu$A/div

![Fig. 3](image3.png)

(a) Without magnetic field (b) With magnetic field

Fig. 3 $I$-$V$ curves of the junction under magnetic field ($X = 5$ mV, $Y = 200$ $\mu$A/div)

Fig. 4 shows the $I$-$V$ characteristics of the Josephson junction in voltage stage dominated by thermal fluctuations with He-Ne laser illumination at different temperatures. This junction shows a temperature dependent $I$-$V$ curve. When illuminated with radiant energy, breaking of the Cooper pairs occurs creating a photoexcitation current and the junction voltage is increased. It will be shown that the pair breaking Josephson junction can generate photoexcitation current and cause an increase in