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Heating Effect of Mesa-Type Intrinsic Josephson Junction Stacks using Pulse Current Measurement

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Abstract

We experimentally investigated the self-heating effect of large-scale mesa-type intrinsic Josephson junction stacks in the single-crystal Bi-2212 using pulse current measurement techniques. In addition, the effects of contact resistance between the electrodes and top of the mesa were studied. The current-voltage (*I-V*) characteristics obtained by using the pulse measurement technique showed significantly improved voltage suppression compared to the dc measurement. Furthermore, we proposed a new pulse waveform. Using the proposed waveform, *I-V* characteristics could be obtained with heat generation at the contact resistance only. It is revealed that the heating at the contact resistance had a significant effect on the *I-V* characteristics.

Keywords: Bi-2212; intrinsic Josephson junction; self-heating

1. Introduction

Intrinsic Josephson junctions (IJJs) in layered high critical temperature (T_c) superconductors such as the single-crystal $Bi_2Sr_2CaCu_2O_y$ (Bi-2212), which consist of many atomically stacked Josephson junctions, have been intensively studied [1,2]. Because IJJs are able to operate at a higher speed and are more sensitive than semi conductors, IJJs have been expected to be used in device applications. By the way, current-voltage (*I-V*) characteristics of IJJs are affected by self-heating because of various process (e.g. Joule heating, non-equilibrium heating and others [3]). It is important to rigorously evaluate the self-heating effect. Fenton et.al. reported the use of

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a pulse current measurement technique to decrease the self-heating effect [4-6]. However in mesa-type IJJs samples, the self-heating is generated not only in voltage state IJJs but also at the contact resistance between the electrode and top of the mesa. Krasnov and co-workers have argued that for a small sample, the electrode on top of the mesa can help to cool the mesa [7,8]. Although we agree with this argument in the case of a small sample and good electrode contact, the heating at contact resistance in large-scale samples has not been well studied. In this paper, *I*-*V* characteristics of mesa-type IJJ stacks were experimentally investigated for the case of self-heating suppressed using pulse current measurement techniques. Furthermore, to evaluate the contact resistance effect on the *I*-*V* characteristics, we have proposed a new pulse waveform. Using the proposed pulse waveform, *I*-*V* characteristics were observed with heat generation only at the contact resistance between the electrode and top of the mesa. In following experiments, note that heating at IJJs include heating by various heating process such as Joule heating, non-equilibrium heating and others.

2. Experiment

2.1. Sample

Bi-2212 single crystals were grown using the self-flux melting method [9], and 30 nm thick gold films were deposited on the cleaved surface platelet. Then, mesa-type IJJs with length, width and height of 300 μm, 70 μm and 300 nm respectively, corresponding to 200 junctions (N = 200) were fabricated on the platelet using photolithography and dry etching processing. Figure 1(a) shows the *I*-*V* characteristic of the fabricated sample measured by dc measurement at 3.7 K with three terminal methods. The voltage data were obtained by subtracting the voltage drop at the contact resistance with the inset of Fig.1(a) showing the raw *I*-*V* curve data with approximately 10 Ω contact resistance. The critical current, I_c, were obtained from the data in Fig.1 (a) is approximately 21 mA and the *I*-*V* curve is characterized by large hysteresis with negative resistance in the quasi-particle branch because of the self-heating effect.

2.2. Experimental setup

Experimental circuit and schematic of pulse waveforms are represented in Fig.1(b)-(e). The waves were supplied by a function generator. Current values were estimated using the voltage drop across the 10 Ω resistor and the output voltages across the IJJs were obtained as V_1-V_2 as illustrated in Fig.1(b). The width and rising edge of the

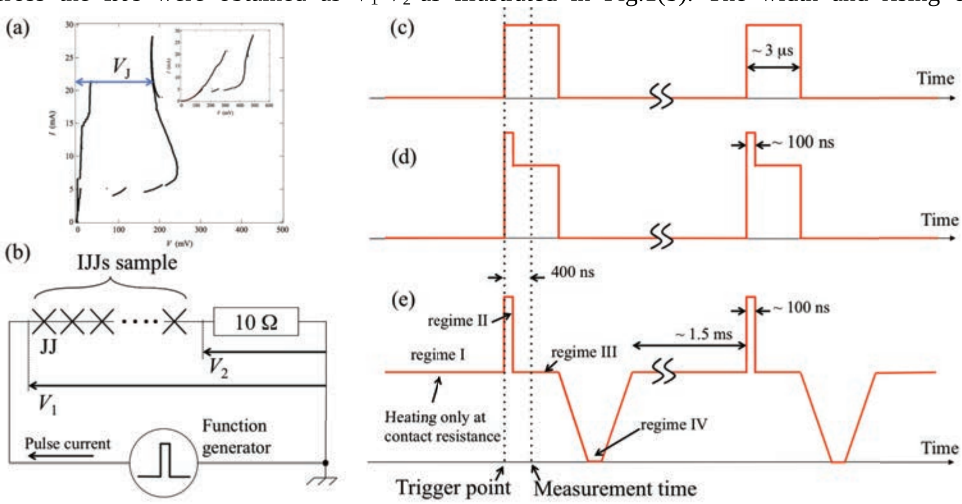

Fig. 1 (a) Typical *I-V* characteristics using dc bias with 300×70 μm² and 200 IJJs at 3.7 K. Insert shows raw *I-V* data. (b) Experimental setup. (c) Conventional pulse waveform. (d) Two-step pulse waveform. (e) Proposed pulse waveform.

conventional pulse waveform shown in Fig.1(c) were 3 μs and 20 ns respectively. A duty factor was less than or