Planar intrinsic Josephson junctions fabricated on Bi-2212 LPE films

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Abstract

We study the planar design of the intrinsic Josephson junctions (IJJs) using the $Bi_2Sr_2CaCu_2O_x$ (Bi-2212) films prepared by liquid phase epitaxy (LPE). Step-type IJJ stacks (step stacks) are fabricated from the LPE films grown on the step-patterned MgO substrates. The step stacks exhibit multibranched current-voltage characteristics inherent in the Bi-2212 single crystals. It is found that such behavior is limited to the films on small-angle steps, suggesting the incorporation of defects near the steep steps of substrates.

Key words: Bi-based superconductor; intrinsic Josephson junction; film; liquid phase epitaxy

1. Introduction

Many types of devices of the intrinsic Josephson junctions (IJJs) have been investigated for a novel high-frequency application of the $Bi_2Sr_2CaCu_2O_x$ (Bi-2212) superconductor. These are mesas [1], [2] and three dimensional (3D) devices based on whiskers [3] or single crystals [4], [5].

As an alternative base material, we have recently prepared single-crystalline Bi-2212 films by liquid phase epitaxy (LPE)[6], and presented the intrinsic Josephson effect on the as-grown films [7]. Although in Ref. [7] we adopted the 3D design similar to the whisker junctions, a planar device is more favorable for application, because of better processing and stability.

In this paper, we investigate the fabrication technique and the *I-V* characteristics of the planar IJJ stack, using the LPE films grown on step-patterned MgO substrates.

2. Experimental

The Bi-2212 films were grown by liquid phase epitaxy (LPE) [6]. A characteristic of our LPE technique is that the liquid phase is sandwiched into a thin layer between two MgO substrates. In this study, steps of 500-700 nm in height were preliminarily formed on the MgO surfaces by Ar-ion milling. The Bi-2212 film was grown epitaxially from the liquid phase, by moving the heating zone at a speed of 0.4 mm/h. We found after cleaving that the films on the bottom and lid sub-
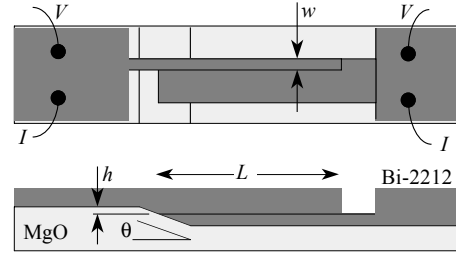

Fig. 1. Schematic diagrams of the junction stack fabricated on a step-patterned MgO substrate.

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strates showed no significant difference in growth morphology. The film thickness was 1-2 μm. Post-annealing at 400°C in 0.1 Torr of oxygen was performed for 15 hours to attain the optimal doping state.

A junction stack was patterned on a Bi-2212 single grain grown over the step, as illustrated in Fig. 1. We processed the film mainly by photolithography and Ar-ion milling, and also used focused-ion-beam etching to narrow the bridge. The difference in height between the upper terrace of MgO and the lower film surface defines the stack height h.

This planar-type IJJ stack (step stack) was first applied to the melt-processed Tl-Ba-Ca-Cu-O films [8]. Since the grain size $D \sim 1$ mm in our LPE films is much larger than $D \sim 10$ μm in the melt-processed ones, fabrication of a large junction is possible in the present technique. This advantage depends on the directional growth in the LPE process [6].

3. Results and discussion

First we discuss the influence of the slope angle θ (see Fig. 1) on the film quality. The step stacks of $\theta=15°$ exhibited superconductivity below T_c=80-83 K, while the resistance was finite even at 4.2 K in most of the stacks of $\theta=45°$. This degradation is probably related to disorder near the step, as observed in sputtering of $YBa_2Cu_3O_{7-\delta}$ on the step-patterned substrate [9]. The size of the defects was, however, undetectably small under SEM observation of the 50 nm resolution.

In the step stack of small θ, the junction length L has some ranges. For instance, the conditions $\theta=15°$ and h=100 nm lead to the variation of length ΔL=0.4 μm. Thus the step stack seems suitable for long junctions, in which $\Delta L/L$ is negligible.
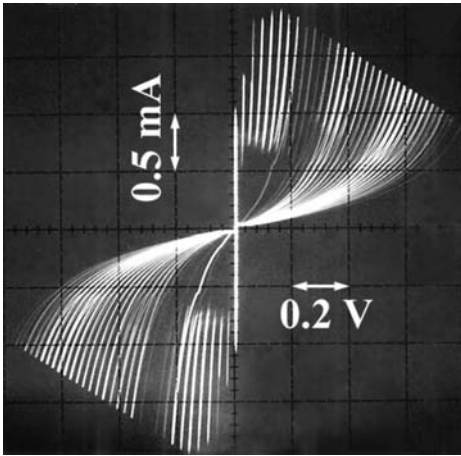

Fig. 2. I-V characteristics of the step stack at 4.2 K. The junction size is L=50 μm, w=3 μm and h=100 nm with $\theta=15°$.

Figure 2 displays the multiple branches in the I-V characteristics of the step stack. The critical current I_c is 1.1-1.9 mA (or 0.7-1.3 $\times 10^3$ A/cm^2 in density), and the voltage spacing V_c is about 30 mV at I_c. These data are reasonable for IJJs [1]-[5]. As the voltage increases, the I_c value on each branch gradually decreases, indicating the self-heating effect [10].

For several low-voltage branches in Fig. 2 the maximum currents are lower than others. This might be related to the prediction from the Koyama-Tachiki model [11], or simply to the inhomogeneity in the film.

Although we have not measured the higher voltage ranges at 4.2 K from the restriction of our measuring system, the I-V characteristics at 64 K (not shown) displayed the top branch at 0.8 V and V_c=10-13 mV. The ratio of these values gives a junction number N=61-80, which is consistent with N=67 calculated from the stack height 100 nm and the single junction spacing 1.5 nm.

In conclusion, a planar IJJ stack has been realized as the step stack on the LPE film. Since planar devices are mechanically stable and allow us high-density integration, the step stack is promising for a new application of the intrinsic Josephson effect.

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