The Study of c-axis I-V Characteristics of Tl:2212 Thin Film

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Abstract

Tl:2212 thin films were made on $SrTiO_3$ substrate, which is at small slanting angle to the (001) direction. I-V characteristics were studied systematically and strong Josephson junction behavior was observed, owing to the c-axis contribution. A modified Ambegaokar-Halperin thermal-fluctuation model can well describe the c-axis I-V characteristics, indicating the interlayer capacitance plays an important role.

Key words: Tl:2212 thin film; I-V characteristics;Modified A-H model

1. Introduction

With the coherence length along c-axis being much less than the distance between Cu-O plans, the highly anisotropic high temperature superconductor such as Bi:2212 and Tl:2212 can be considered as an array of Josephson junctions in the c direction[1]. A number of experiments have been conduted on the c-axis I-V characteristics of Bi:2212 crystals[2]. In this paper, we will report our preliminary results of the c-axis I-V characteristics of Tl:2212 thin films.

2. Experimental

The Tl:2212 thin films were made by epitaxial growth on $SrTiO_3$ substrate, of which the (001) direction has a 12° tilted angle with the substrate surface[3]. Micro-bridges were fabricated on the film using photolithography and ion beam etching techniques. Typical size of the bridge is about $10\mu m \times 20\mu m \times 0.2\mu m$. Sputtered gold film was used in the contact area to reduce the contact resistance of the electrodes. Standard four-point method was used to measure the I-V and R-T characteristics at different temperatures and fields.

3. Results and Discussions

Typical I-V characteristics at different temperatures are shown in Fig. 1. Hysteresis in the I-V characteristics can be observed at low temperatures, showing typical Josephson effect behavior from c-axis compo-

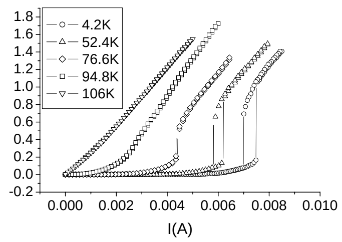

Fig. 1. The I-V characteristics of Tl:2212 thin film at different temperature.

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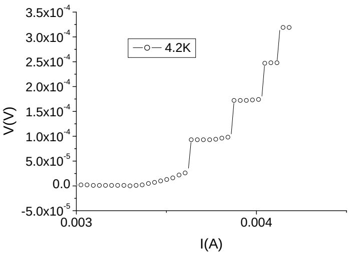

Fig. 2. The *I*-*V* characteristics at small currents at 4.2K.

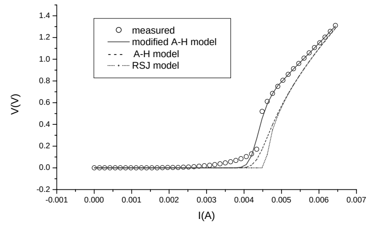

Fig. 3. The *I*-*V* characteristics at 76.6K, with fitted curves by RSJ model $(\cdots)$, A-H model (—), modefied A-H model (solid line)

nent. The hysteresis decreases in width with increasing temperature and disappears at a temperature above 76 K. Electrical transport along the c-axis takes place via Josephson tunneling between adjacent sets of CuO_2 planes. The *I*-*V* characteristics between the individual planes are strongly influenced by the inter-plane capacitance. This can be estimated from the onset of hysteresis in the *I*-*V* characteristics, when the McCumber parameter, β=$2\pi i_{\rm c}(T)r_{\rm n}^2(T)c/\Phi_0$, exceeds unity, where $i_{\rm c}$, $r_{\rm n}$ and c are the critical current, normal state resistance and capacitance across the superconducting planes, $\Phi_0 = h/2e$ is the flux quantum. Since $i_{\rm c}$, $r_{\rm n}$ can be extracted from the measured *I*-*V* curve, the value of the capacitance on the order of $2.4\mu{\rm m}10^{-13}$F can be then derived.

It is important to point out that there are early transitions in the low currents region of the *I*-*V* curves before the sudden jump in voltage being developed. It is not caused mainly by thermal fluctuations but by real transitions of individual junctions with smaller critical currents (Fig. 2), which may be attributed to the nonuniformity in width of the micro-bridge or of Tl/O_2 contents in the Cu-O layers along the C-axis. By ignoring those early transitions, a critical current density about $3.9\mu{\rm m}10^{-5}{\rm A/cm}^2$ at 4.2 K along the bridge can be derived, corresponding to a c-axis critical current density of $8\times104{\rm A/cm}^2$ which is consistent with reports in the literature[3].

We studied the bias-current uprising branch of the c-axis *I*-*V* characteristics, but failed to interpret our data by the simple Ambegaokar and Halperin (A-H) thermally-assisted phase slippage model[4]. It is then found that interlayer capacitance in this material can never be ignored, which results in increased phase-slippage and therefore voltage across the junction. And indeed the modified A-H thermal-fluctuation model[5], which includes the first-order correction for a finite capacitance, can well describe the measured c-axis *I*-*V* characteristics, as shown in Fig. 3. The fitted critical currents were derived from the sudden change in *I*-*V* curves and the fitted normal state resistance are fallen on a line which is just the low temperature extrapolation of the normal state resistance in the measured

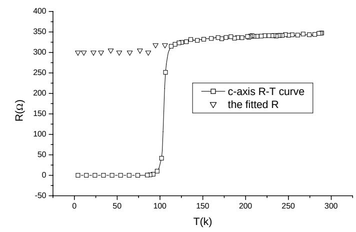

Fig. 4. *R*-*T* of Tl:2212 thin film and the fitted normal state resistance $(\bigtriangledown)$.

R-*T* curve (Fig. 4).

4. Conclusion

I-*V* characteristics of Tl:2212 thin film were measured. The hysteretic behavior and Josephson type line shape of the curves indicate strong c-axis contribution. The bias-current uprising branch of the *I*-*V* characteristics can be well described by the modified A-H model, which includes interlayer capacitance. The early transitions by individual junctions with small critical currents are attributed to the geometrical and/or chemical inhomogeneity.

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