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Anisotropic Transport Properties Observed in $Bi_2Sr_2CaCu_2O_x$ Single Crystal Films

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We report here a large anisotropic transport phenomena observed in epitaxial $Bi_2Sr_2CaCu_2O_X$(2212) films. In particular, low temperature I-V curves containing inter-layer and intra-layer transports show a large anisotropy. Such anisotropy seems to be intrinsic in Bi-based superconductors.

Single crystal 2212 films were grown on tilted (001)$SrTiO_3$ substrates by using an ion-beam-sputtering technique[1]. The substrate surface normal was tilted about 4° toward [111]$SrTiO_3$, thus the step edges along [1$\bar{1}$0] and {001} terraces were regularly formed on the surface. The epitaxial growth of 2212 film is restricted by the step edges. The a-axis is parallel to [1$\bar{1}$0]$SrTiO_3$ and the b-axis with incommensurate modulation aligned to [110]$SrTiO_3$. Each Cu-O plane was continuous without any grain-boundaries and tilted according to the substrate surface inclination as shown in Fig.1. Therefore, the measured resistivity along [1$\bar{1}$0]$SrTiO_3$ (ρ_a) represents the a-axis transport of the film and that along [110]$SrTiO_3$ ($\rho_{b'}$)containing both b- and c-axis components.

Above the superconducting transition temperature(Tc), the resistivity along c-axis(ρ_c), calculated from the measured value($\rho_{b'}$) and angle of the tilt, was about four orders of magnitude higher than that along a-axis(ρ_a) as shown in Fig.2, where a geometrical translating formula $\rho_{b'}=\rho_c\sin^2\theta+\rho_a\cos^2\theta$ was used. Below Tc, the critical current density along c-axis(Jc(c)) was about one tenth of the critical current density along a-axis(Jc(a)) according to a geometrical translating formula $Jc(b')=Jc(c)\sin\theta+Jc(a)\cos\theta$.

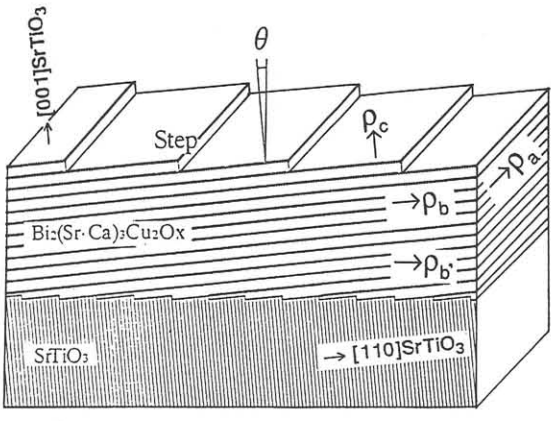

Fig.1 Schematic illustration of epitaxial 2212 film on tilted $SrTiO_3$ substrate.

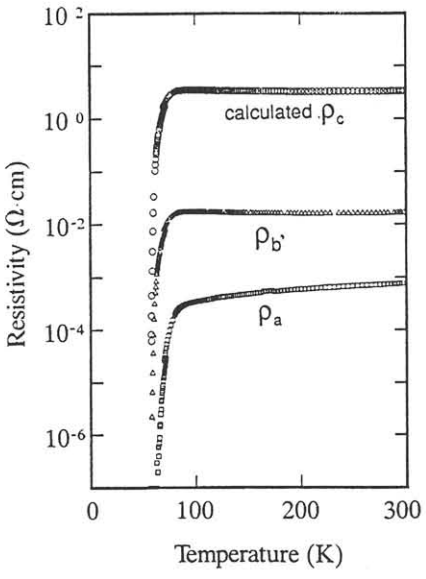

Fig.2 Resistivity versus Temperature.

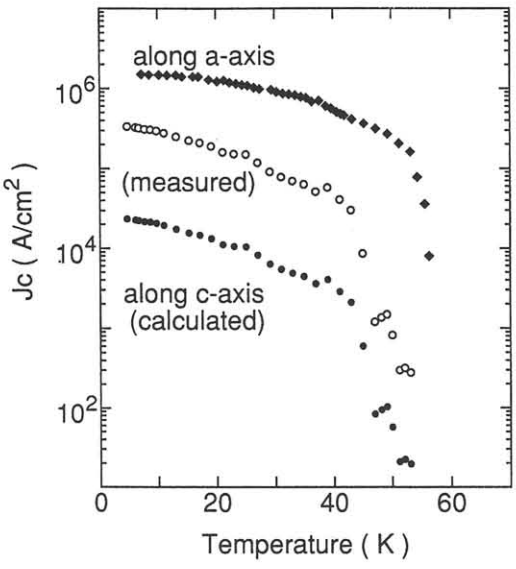

Fig.3. Current density versus Temperature.

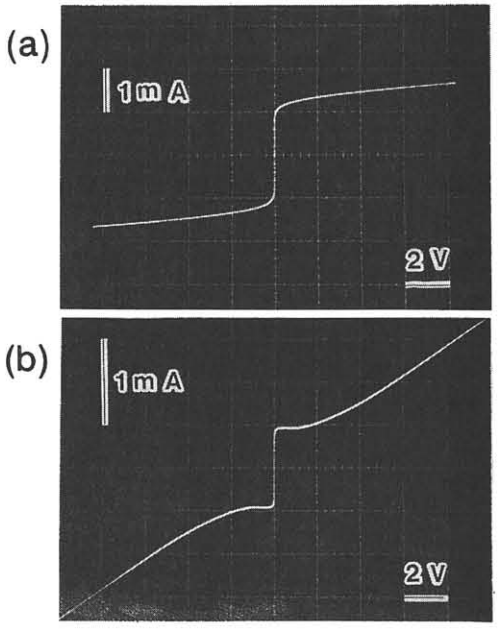

Fig.4 Typical I-V curve at 4.2K
(a) along a direction and
(b) along b' direction

The difference of low temperature I-V curves in two directions was quite remarkable. Compared with the usual flux-flow type I-V curve observed along a-axis(Fig.4(a)), the I-V characteristics containing c-axis component was distinctively different. For the latter case, the non-linear characteristics rather resembled that of a weak-link Josephson coupling, having an IcRn product of about 2.5V observed on a 5μ-wide and 5μ-long strip. It involves about 230 Cu-O/Bi-O/Cu-O coupling layers so each layer is supposed to have about 11mV of IcRn product. This value seems to be reasonable considering $2\Delta \approx 40$mV for this material.

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[1]J.Fujita et.al.
Appl.Phys.Lett.59,2445(1991).