SI Transitions in BSCCO Mixed Crystal Thin Films

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Temperature (T) dependence of the sheet resistance ($R_{\square}$) has been investigated on the c-axis oriented thin films of the (Bi2212/Bi2201) mixed crystal with different molar fractions. The $R_{\square}$-T superconducting characteristic deteriorated with reduction of the Bi2212 fraction, and almost disappears at 48 mol% where a superconductor-to-insulator transition took place, with the resistance on the normal state, R_N, reaching 4.1 kΩ at 80 K. This R_N value is close to the universal quantum number, $h/(2e)^2 \cong 6.5$ kΩ predicted by the Kosterlitz-Thouless (KT) transition theory. The $R_{\square}$-T characteristics of the 48 mol% thin film can be elucidated as a competitive process of KT transition brought about by charge or vortex in the two-dimensional layer structure.

Keywords : SI transition , BSCCO, Mixed crystal, Thin film, KT transition

1. INTRODUCTION

It is known that the superconductor-insulator (SI) ansition takes place in the two-dimensional array of e granular junctions which are in order of submicron ze, for instance, Al granular thin film[1]. In such ·anular films, a key factor for the discrimination ›tween the superconductor and insulator is the critical ıeet resistance defined by $h/(2e)^2 \cong 6.5$ kΩ, the so-ılled quantum resistance R_q which is independent of e materials. Here, h and e are the Planck constant and ıarge, respectively. In the case of the granular nction exhibiting lower resistivity than R_q in the ›rmal state, the superconductivity comes out with duction of temperature, while in the one higher than ı the resistivity enhances up with reduction of mperature, which results in an insulator.

In the $Bi_2Sr_2Ca_nCu_{n+1}O_y$ (n = 0, 1, and 2) compound, hich is hereafter abbreviated as the BSCCO or Bi22n :+1), there are three types of the energetically stable ructures, that is, the Bi2201 (insulator to super-›nductor with $T_c \leq$ 20 K), the Bi2212 ($T_c \cong$ 80 K) and e Bi2223 ($T_c \cong$ 110 K), with all of them having a rong two-dimensionality in the structural and ectronic states. The difference among these phases structurally originates in only the introduction [$CaCuO_2$]-stacking fault, so that it is hardly possibl obtain each, pure BSCCO[2]. The mixed crystal t films prepared in this study are consisted of the Bi2: (the lattice parameter of c-axis: about 30Å) and Bi2201 (about 24Å) phases with various ratios. ' scanning electron microscope observation displa: that granular domain size in these thin films does exceed ~μm in a similar condition to the granular films reported by Kobayashi *et al.*[1]. This sugg that the SI transition model in the two-dimensio mixed crystal thin films will be applicable tc the t films with the mixture of the two Bi2201 and Bi2: phases. Since the resistivity produced depends larg on the arrangement of each phase, even if the grains the Bi2212 superconducting phase and the Bi2: insulating one are distributed randomly in the mi: crystal specimen, the electronic current would fl through only the Bi2212 phase channels. The BSC thin film must be considered the size effect in atomic scale as well as in the mesoscopic one, differ from a granular Al thin film because the supercurr flows in only the [CuO_2]-layer in the BSCCO and coherence length, ξ, is much shorter than that of Accordingly, in cases that the Bi2212 phases

›arated by the intermediate Bi2201 phase completely, : resistance would happen. Namely, it will be possible to discuss these resistivities without exact owledge concerning the inside of the domain size in : BSCCO thin films.

In this article, we tried to discuss about the pearance of the SI transition in the BSCCO mixed 'stal thin films from the comparison between the ɜet resistance, $R_{\square}$, in the normal state and R_q. ›reover, temperature dependence of $R_{\square}$, will be ıcidated by a competitive process of vortex and/or arge Kosterlitz-Thouless (KT) transitions proposed Fazio and Schön[3].

2. EXPERIMENTAl

The mixed crystal thin films with various molar ıction ratios between the Bi2212 (T_c(onset) = 82 K) d the Bi2201 (insulator) phases have been fabricated an ion beam sputtering method[4]. The measure- ɜnt of X-ray diffraction patterns on these mixed 'stal samples displayed that a series of the respective aks come from the (00*l*) reflections appeared as ıgle peaks at the intermediate positions between the ›pective peaks from the pure Bi2212 and Bi2201 bstances. This fact indicates that the grain sizes in the xed crystals are enough smaller than the X-ray netration length of micrometer. The Bi2212 molar ıction was estimated from the intermediate peak sition of the (002) line in reference of the Bi2212 d Bi2201 pure phase data as described in a previous per[5].

The electrical resistivity was measured by a conven- ›nal four probe method with the applied current of 1 .

3. RESULTS AND DISCUSSION

Figure 1 shows temperature dependence of the sheet ›istances in the *c*-axis oriented thin films with various mpositional ratios of the Bi2212 to Bi2201 phases. ıe Bi2201 thin film with the stacking of 120 half unit lls exhibits a semiconducting (or insulating) behavior th ΔE_{gap} = 37 meV as plotted in Fig. 1. T_c (onset) of ɜ superconducting samples remain almost constant at : K notwithstanding the Bi2212 molar fractional ange (> 48 %), while the resistance behavior below (onset) depends on the molar fraction or the normal ›istance. Namely, in 92 mol% thin film T_c (zero) hibits approximately 40 K, and in 60-80 mol% it duces to around 10 K. The normal sheet resistance r this sample attains to 4.1 kΩ, which is close to 6.5 kΩ, a quantum universal resistance, and suggests tł this 48 mol% mixed crystal would locate just on t border of SI transition.

It is well-known that vortex and anti-vortex pair c be generated by applying transport current to the tw dimensional compounds such as BSCCO in the tempe ature range between the vortex KT transition point, 1 and the superconducting transition temperature T_{c0} terms of the Ginzburg-Landau mean field theory. Sin they can move around independently over T_{c0}, t energy dissipative process is realized, then the resi: ance never reaches zero although it decreases wi reduction of temperature. On the other hand, below 1 the vortex is combined with the anti-vortex, and t Lorentz forces with the opposite vector bring attracti interaction with each other, therefore, the resistan vanishes out due to the vortex-anti-vortex pairir Namely, this exhibits that in the two-dimension mixed crystal thin films, the temperature where t zero resistance takes place is represented as T_{KT}^{V} bas on the KT transition theory. In our BSCCO thin filn the temperature was observed at 45 K for the 92 mol Bi2212 mixed crystal thin film, at 7 K for 82 mol% a at 15 K for 66 mol%. Here, we cannot give an appı priate explanation for the inversion of T_{KT}^{V} between and 66 mol%. A plausible explanation may be given the cause of the different distribution on the percolati paths among the specimens. T_{c0} means a phase tran tion point from the insulating or semiconducting stɛ to the superconducting one, and corresponds to (onset) in this letter. However, in the case of t granular two-dimensional system the Cooper pair staı to generate by the thermal fluctuations as described terms of the theories of Aslamazov and Larkin[6] aı

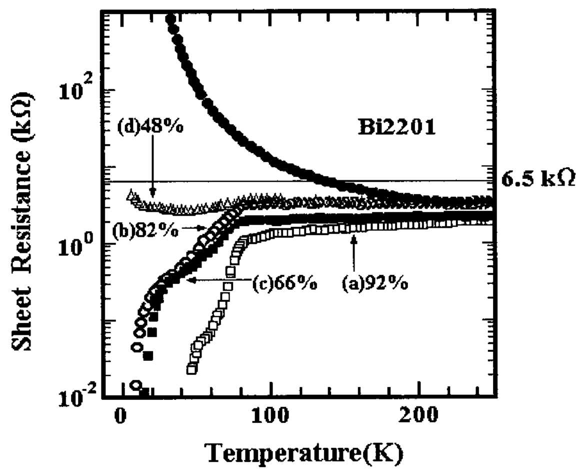


Fig. 1. Temperature dependence of sheet resistance in the (Bi2212/Bi2201) mixed crystal thin films w different Bi2212 fractions.

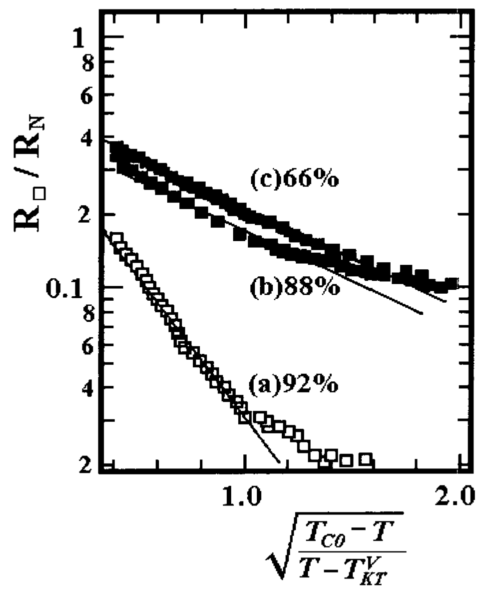
'hompson[7], therefore, T_{c0} should be somehow differ-nt from T_c(onset). T_c(mid) where the resistance shows half value at T_c(onset) is more likely as T_{c0} according) a proposal of Ota *et al.*[8]. Then, T_{c0} is given as 74 K ›r 92 mol%, 62 K for 82 mol% and 63 K for 66 mol%.

In the case where the resistance behavior in the issipative state is dominated by the vortex KT ansition, the temperature dependence of resistance an be expressed as:

$$R = a\exp\left(-2\sqrt{b\frac{T_{co}-T}{T-T_{KT}^{V}}}\right) \qquad (1)$$

ere, a and b are constants. Thereby, the logarithms of ieet resistance $R_\square$ are depicted as a function of $\{(T_{c0}-$ $)/(T-T_{KT}^{V})\}^{1/2}$ in Fig. 2.

A linear relationship is approximately realized nong them for the mixed crystal thin films over 66 ıol%. This suggests that the resistance character in ıese specimens is dominated by the vortex KT ansition. Whereas, in the thin film with 48 mol% the ıperconductive behavior was observed in the mperature range from 50 to 80 K, but below 50 K the ›miconducting behavior was replaced, that is, the ›sistance never reaches zero. This behavior supports ı idea that the mixed crystal thin film of 48 mol% i2212 locates really on the border of superconducting-sulating(SI) transition as described already from a ›mparison between the resistance in the normal state



.g. 2. A linear dependence of the normalized resist-ıce $R_\square/R_N$ on $\{(T_{c0}-T)/(T-T_{KT}^{V})\}^{1/2}$ in the thin films ith the different molar ratios. R_N value corresponds to ı one at T_c(onset).

and the quantum universal.

The resistance upturn below 50 K cannot be ruled the vortex KT transition of Eq. (1) in the 48 mol% ı film, but the charge KT transition is considered to predominantly realized in the lower temperature reg Namely, in this thin film the competitive charge vortex KT transitions take place corresponding to e temperature region. The concave type $R_\square$-T curve Fig. 1 is considered due to temperature dependence the free carrier density, $n(T)$, which is represented the following expression based on the charge transition theory[8].

$$n(T) = n_0\exp\left(\frac{-2b^c}{\sqrt{T/T_{KT}^{c}-1}}\right)$$

Here, n_0, b^c are constants, respectively. As the sl conductance, $G_\square$, is in proportion to this carrier den $n(T)$, it is given by

$$G_\square = G_0\exp\left(\frac{-2b^c}{\sqrt{T/T_{KT}^{c}-1}}\right)$$

The semiconducting behavior of the sheet resista $R_\square(T < 50\ \mathrm{K}) = G_\square^{-1}$ for the 48 mol% thin film v fitted by Eq. (3) using the least mean squares meth and shown in Fig. 3. The charge KT transition po T_{KT}^{c}, and a constant, b^c, were calculated as fitting pa meters and obtained to be 0.05 K and 1.9, respectiv However, the obtained value of the b^c seems to be large since it is generally close to 1. Thus, T_{KT}^{c}, v

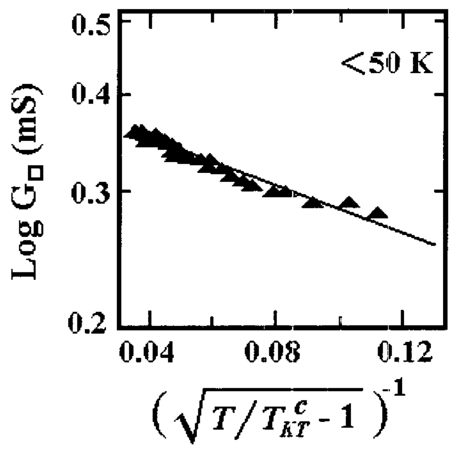
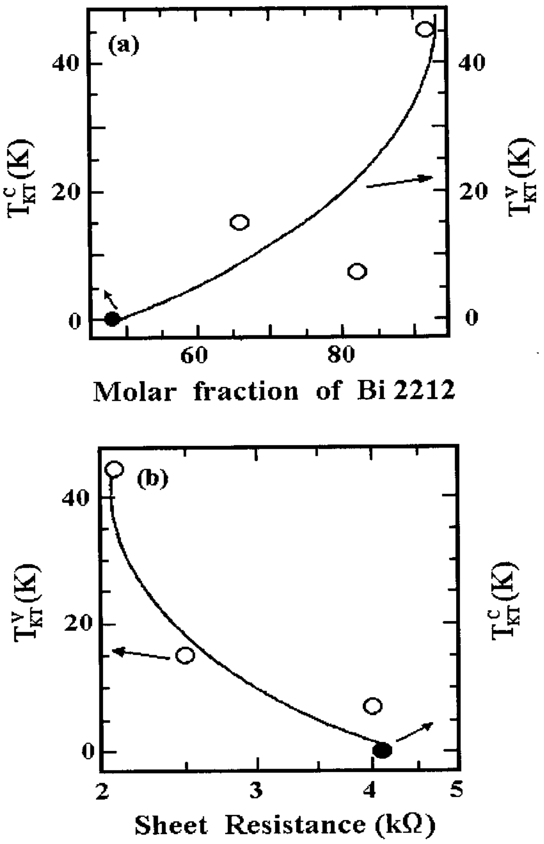


Fig. 3. Temperature changes of the sheet conductar $G_\square$, in the 48 mol% mixed crystal thin film below 5(and its least-squares-fitting line by Eq. (2). T_{KT}^{c} = 0.1(assuming that b^c = 1.



ʒ. 4. The correlation between KT transition temper- ıre and (a) molar fraction of Bi2212 phases or (b) eet resistance. 0 : T^{V}_{KT}, ● : T^{c}_{KT}.

timated at 0.16 K, assuming that b^c = 1, and there is tle difference of the standard deviation between both lculations. Accordingly, T^c_{KT} will be about 0.16 K. ıis fitting means that in the 48 mol% mixed crystal in film $R_□$ below 50 K is dominated by the vortex e. Both KT transition temperatures, T^c_{KT} and T^V_{KT}, are otted against molar fraction of the Bi2212 in Fig. 4(a) d against the sheet resistance in the normal state in g. 4(b). Fig. 4(a) exhibits that the charge KT transi- ın becomes predominant with the increase of the 2201 insulating phase and that the discrimination of transition takes place at 48 mol%.

4. CONCLUSION

It was found that the boundary of SI transition cates at the 48 mol% in the BSCCO mixed crystal in films. Moreover, it was clarified from the sheet sistances that the vortex and charge KT transitions uld take place competitively on the process of mperature variation even in a specimen with 48 ol%. The latter is depressed as temperature increases, while the former predominantly emerges. The critic point T^c_{KT} was realized at very low temperature becau of this competition. It turns out that in Fig. 4(b), t vortex KT transition temperature reduces as the she resistance $R_□$ enhances and around 4.1 kΩ, the vort KT transition has exhausted.

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