Critical temperature oscillation in the thermal cycle below 16 K in $Y_{0.83}Ca_{0.17}Ba_2Cu_3O_6$

Tatsuya HONMA [a,1], Pei Herng HOR [b], Mitsuho TANIMOTO [a]

[a] *Dept. of Physics, Asahikawa Medical College, Midorigaoka-Higashi 2-1-1-1, Asahikawa 078-8502, Japan.*

[b] *Dept. of Physics, and Texas Center for Superconductivity, Univ. of Houston, Houston, TX77004, U.S.A.*

Abstract

In an $Y_{0.83}Ca_{0.17}Ba_2Cu_3O_6$ polycrystalline sample, under thermal cycling below 16 K, an unusual relaxation effect of the superconducting resistive transition has been observed after the pressure is changed at RT. The normal-state resistivity does not change. Since there is no mobile oxygen in the present sample, the effect of oxygen rearrangement can be ignored. The observed results can be understood by the charge redistribution within the CuO_2 planes.

Key words: granular superconductivity; pressure effect; Josephson coupling; charge redistribution

1. Introduction

For some high-T_c cuprates, such as $YBa_2Cu_3O_{6+y}$ (Y123) with CuO_y chain and $Tl_2Ba_2CuO_{6+\delta}$ (Tl2201) with $Tl_2O_{2+\delta}$ layer, pressure can induce oxygen rearrangement (OR) within these charge reservoir layers, which significantly enhances the pressure effect on the critical temperature T_c and Hall coefficient R_H [1,2]. Since the oxygen configuration is frozen at the low temperature (LT), typically below ~100 K, the pressure effect is substantially reduced by changing pressure at LT. This procedure has led to the observation of relaxation effect that the pressure effect on T_c or R_H due to pressure change at LT eventually evolves into that at RT due to thermally activated OR [1,3]. $Y_{1-x}Ca_xBa_2Cu_3O_6$ is a system without CuO_y chain and therefore free from the OR effects under pressure [2]. Ca doping destroys the antiferromagnetic phase and incipient superconductivity signaled by a resistive kink at T_{c1} is observed at x=0.17-0.18 and a zero-resistivity state at ~0.20 [4]. This is consistent with microscopic electronic phase separation into hole rich region and hole poor one observed by the muon spin relaxation experiment [5]. In the "local" superconductor $Y_{0.83}Ca_{0.17}Ba_2Cu_3O_6$, we have observed an unexpected pressure-induced two-step transition at T_{c2} and T_{c3} [6]. Further, a relaxation effect at RT has been observed for the pressure range between 0.1 and 0.3 GPa. The two-step transition exhibits strong current effect [6]. Therefore, the superconductivity at T_{c1} is attributed to the superconducting islands, and those at T_{c2} and T_{c3} are attributed to the Josephson coupling between the islands. Since no pressure effect on R_H is observed [2], both results could come from the pressure-induced charge redistribution within the CuO_2 planes. In this paper, we have studied the LT thermal cycling effect on $\rho(T)$ or T_c of a sample quenched to below 85 K right after releasing the pressure from 0.35 GPa to 0.15 GPa at RT.

2. Experimental

$Y_{0.83}Ca_{0.17}Ba_2Cu_3O_6$ was prepared by a solid state reaction [2]. Pressure was changed at RT by a piston cylinder method, and determined by the Pb manometer. The pressure medium was a mixture of flourinert (FC77:FC70=1:1). The resistivity ρ was measured by ac four-probe method. Temperature T was determined

[1] E-mail: homma@asahikawa-med.ac.jp

by the k-type thermocouple or Ge temperature sensor.

3. Results and discussion

After the pressure was released from 0.35 GPa to 0.15 GPa at RT, the sample was quenched below 85 K. In such low-pressure range, the solidification effect of pressure medium can be ruled out. The $\rho(T)$ measurement was carried out under the thermal cycling between 1 K and 85 K to exclude the influence of the unwanted OR. The Pb manometer always indicated 0.15 GPa. When the sample was finally heated up to RT, the $\rho(T)$ (open circles) was identical to that in the first heating process (closed circles), except for the behavior below T_{c2} as shown in the inset of Fig. 1. Accordingly, the $\rho(T>T_{c2})$ is found not to be influenced by the LT thermal cycle. A significant change in $\rho(T<T_{c2})$ was induced by the thermal cycling below 16 K. The typical $\rho(T)$ is shown in Fig. 1. Below T_{c2}, the $\rho(T)$ decreases in two steps with reducing T (curve1). Subsequent thermal cycling brings a significant change in $\rho(T)$ around the tail part of the transition at T_{c2}. As the LT thermal cycling proceeds, the transition at T_{c2} has a shorter tailing part and becomes sharper. The $\rho(T)$ below ~3 K eventually increases with decreasing T and the transition at T_{c3} disappears. The insulating like $\rho(T)$ below ~3 K appears instead of the transition at T_{c3}. As the transition at T_{c2} is enhanced, that at T_{c3} is suppressed. This suggests a charge redistribution among the superconducting regions responsible for the transition at T_{c2} and that at T_{c3}.

We summarize the evolution of the oscillation of $\rho(T<T_{c2})$ due to LT thermal cycling as a function of time in Fig. 2. The time zero is defined as the time right after the release of pressure at RT and each pair (closed and open circles) of data points represents one thermal cycling between 1.3 and 65-85K until 285 hr and between 1.3 and 16 K over 285 hr. The ρ_{7K} and ρ_{2K}, resistivity at 7 K and 2 K respectively, for the curve 1-4 in Fig.1 are in the time domain of 320 - 416

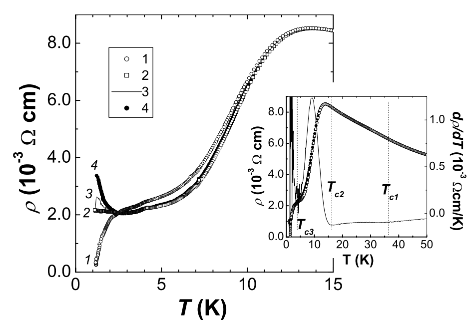

Fig. 1. $\rho(T)$ under the thermal cycling below 16 K. The inset shows the $\rho(T)$ until 70 K. The excitation current was 30 μA.

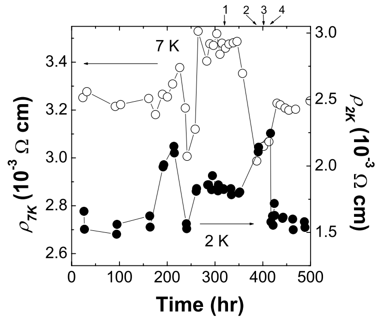

Fig. 2. ρ_{7K} (open cycles) and ρ_{2K} (closed cycles) as a function of the time. The number corresponds to curves shown in Fig.1.

hr. As the LT thermal cycling proceeded, ρ_{7K} and ρ_{2K} were found to oscillate. Until ~260 hr, both changed with the same trend. But, over ~260 hr, the trend in ρ_{7K} was opposite to that in ρ_{2K}. The result over ~260 hr suggested a charge redistribution through quantum tunneling between two electronic states. Beyond ~260 hr, the electronic states of the sample were tuned by the LT thermal cycling.

The oscillation in $\rho(T<T_{c2})$ is observed in the cooling process after the change in pressure at RT, in strong contrast to the usual relaxation effect observed in Y123 or Tl2201 [1]. This suggests no possibility of the OR and this oscillation is purely electronic in nature. Since the charge distribution varies with time in spite of a frozen local structure, the superconductivity may be responsible to the variation of the electronic states. Indeed, this seems to consistent with our observation of an intrinsic electronic phase separation of doped holes in the CuO_2 planes into distinct superconducting phases [7].

In summary, we have observed the unexpected oscillation of $\rho(T)$ below T_{c2}. This is characteristic different from the normal relaxation effect on T_c through the OR. The present result can be explained by the charge redistribution within the CuO_2 planes

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References

[1] S. Sadewasser et al., Phys. Rev. **B56** (1997) 14168.

[2] T. Honma et al., Phys. Rev. **B63** (2001) 212506.

[3] H. Takahashi et al., Physica **C217** (1993) 163.

[4] T. Honma, P.H. Hor, Physica **C341-348** (2000) 521.

[5] Ch. Niedermayer et al., Phys. Rev. Lett. **80** (1998) 3843.

[6] T.Honma, P.H. Hor, M. Tanimoto, in preparation.

[7] B. Lorenz et al., Phys. Rev. **B65** (2002) 144522.