Non-ohmic resistance due to nanostructural inhomogeneity in RPrBaCuO

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Abstract

Non-ohmic resistance observed for complex cuprates $R_{1-x}Pr_xBa_2Cu_3O_y$ (R =Gd, Nd, Ho, Y) with Pr-content x ranging from 0 to 0.8 has been investigated in reference to the nanostructural inhomogeneity. At Pr-content above the percolation threshold x_{pc}, where the overall superconductivity vanishes, the resistance has been found to considerably depend on the supplied current I. The dependence is classified into three types according to the range of x; firstly the resistance at around x_{pc} increases with increasing I, subsequently it becomes independent of I, and eventually the resistance at x much higher than x_{pc} changes into a decreasing function of I. A model has been given of this non-ohmic resistance in terms of a breaking process of the percolation network and a local rise in Joule heat.

Key words: cuprates; percolation; clusters; negative resistance; non-ohmic conduction

1. Introduction

Complex cuprates $R_{1-x}Pr_xBa_2Cu_3O_y$ (RPBCO) with rare earth element R such as Gd, Nd are yielded by doping the superconducting cuprate $RBa_2Cu_3O_y$ with Pr, which is substitutable with R at the same site. This RPBCO can also be regarded as a solid solution consisting of crystal unit cells of RBCO and PBCO, where a superconducting network of RBCO is constructed. Since the superconducting coherence length is extremely short as comparable to the lattice constant, the superconductivity in this solid solution can sense a nanostructural inhomogeneity. In this system, as Pr-content x increases, there appears a percolation threshold x_{pc} at which the overall superconductivity begins to vanish, that is, the superconducting network extending throughout the system is broken down [1, 2]. After this breaking, the superconducting (or highly conductive) phase RBCO appears as finite clusters dispersedly embedded in the high resistive matrix PBCO. It is interesting to see how the structural inhomogeneity as resulted from this percolation transition characterizes the transport properties of this complex cuprate RPBCO. Recently we have found that such nanostructural inhomogeneity causes the current dependence of the resistance [1, 3]. This non-ohmic behavior appears at high x, where the current path becomes fragile. The present study aims at elucidating the relationship between the non-ohmic resistance and the nanostructural inhomogeneity in RPBCO.

2. Experiments

The samples of RPBCO (R =Gd, Nd, Ho, Y, $0.8 \geq x \geq 0$) were synthesized by the solid reaction method from a stoichiometric mixture of R_2O_3, Pr_6O_{11}, $BaCO_3$ and CuO, through the repeated processes of pulverizing and subsequent calcining at 840 °C or 930 °C in air. This process was completed by sintering at

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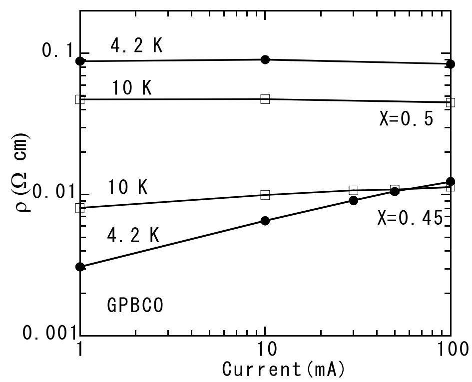

Fig. 1. Current dependence of the resistivity ρ for GPBCO with x =0.45 and 0.5 at 4.2 K and 10 K.

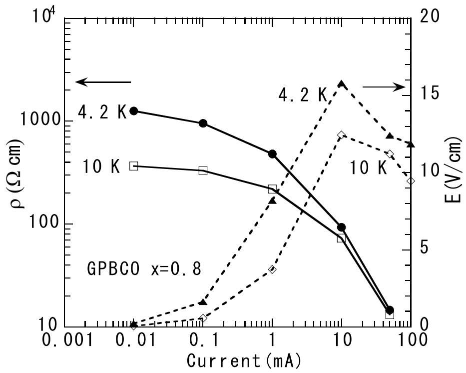

Fig. 2. Current dependence of the resistivity ρ for GPBCO with x =0.8 at 4.2 K and 10 K; the broken curves denote the electric filed E.

930 °C for 24 hours in an oxygen flow and annealing at 400 °C in the same atmosphere. The electrical resistivity was measured by the conventional four-probe method. The samples were rectangular parallelepiped having dimensions of 7 × 5 × 1 mm^3 typically. The temperature was measured by directly contacting a thermocouple (Au-0.07 at.% Fe vs. chromel) to a sample surface.

3. Experimental results and discussion

It is a common feature for all compounds RPBCO that a transition takes place at the percolation threshold x_{pc}, above which the overall superconductivity vanishes and instead a semiconducting behavior appears [4, 5]. The threshold takes a value x_{pc}=0.55 for YPBCO (R=Y) and HPBCO (R=Ho) [1], and x_{pc}=0.45 for GPBCO (R=Gd). For NPBCO (R=Nd), x_{pc} was found to vary in a range $0.35 \geq x_{pc} \geq 0.15$, depending on the sample fabrication conditions. As x increases, the resistivity ρ comes to depend on the supplied current I on a low temperature side, and near the percolation threshold, its dependence becomes considerable. Figure 1 shows this dependence for GPBCO with x=0.45 at T=4.2 K and 10 K. As the current I increases, ρ rises. This type of non-ohmic resistance is explained in terms of a breaking process of the superconducting percolation network, where the narrow superconducting-paths are broken stepwise by increasing I, giving gradual rise in the resistance. As x increases apart from x_{pc}, this dependence disappears, the resistance being ohmic, as seen for x=0.5.

At sufficiently high x, ρ comes to depend again on I, but changes into a decreasing function of I, as demonstrated in Fig. 2. This negative resistance was found to occur also for NPBCO, HPBCO and YPBCO. However the x where this resistance begins to emerge is, in general, higher for larger x_{pc}. At such x, the superconducting network is completely broken, and highly conducting clusters (RBCO) as the vestige of the broken network are dispersed in the highly resistive matrix of semiconducting PBCO. The current path preferably threads such clusters to take the resistance as low as possible across the sample. The resistance yielded comes from the highly resistive gaps separating conductive clusters. Therefore, the Joule heat is locally generated there, giving a local rise in temperature so that the resistance is lowered by increasing I. Figure 2 exhibits also the current dependence of the electric filed E, where E decreases with increasing I on the side above 10 mA. The negative resistance effect may lead to some functional applications as controlling the current in a system.

4. Summary

As the Pr-content increases, the resistance exhibits different dependence on the supplied current I. One is an increasing function of I, and another is a decreasing function of I. The former is described in terms of the stepwise breaking of the superconducting percolation network. The negative resistance is described in terms of a dispersed structure where the inhomogeneous current-distribution generates local Joule heat to lower the overall resistance.

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