Thermal transport of $Pr_2Ba_4Cu_7O_{15-y}$ compound with alternative repetition of a single-and double chain

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Abstract

We have studied thermoelectric power (S), thermal conductivity and magnetoresistance (MR) of $Pr_2Ba_4Cu_7O_{15-y}$ (Pr247) compound with the alternative repetition of a single-and double chain. The value of S in Pr247 showed a metallic behavior at lower temperatures, accompanying the appearance of MR effect as well as Pr124. This finding is discussed on the basis of the metallic conduction along the CuO double chain.

Key words: Pr247 compound; thermoelectric power; double chain;

It is well known that the Pr substitution for the Y-site in $YBa_2Cu_3O_{7-y}$ (Y123) and $YBa_2Cu_4O_8$ (Y124) compounds drastically suppresses T_c and superconductivity in Y123 and Y124 systems disappears beyond the critical value of Pr, $x_c = 0.5$ and 0.8, respectively [1,2]. Such a suppression effect on superconductivity due to the Pr substitution has been explained by the hybridization theory with respect to Pr-4f and O-2p orbitals [3]. The $PrBa_2Cu_4O_8$ (Pr124) compound with metallic CuO double chains along the *b*-axis is one of candidate materials to examine electronic states of low dimensional crystals[4]. On the other hand, the Pr $Ba_2Cu_3O_{7-y}$ (Pr123) compound with a single chain is very sensitive to oxygen contents and resulting deficiencies of oxygen easily destroy metallic connection along the CuO chain. In the $Pr_2Ba_4Cu_7O_{15-y}$ (Pr247) compound , a single and double chains are stacked alternatively between CuO planes and it is possible to examine physical properties of a double CuO chain varying oxygen contents along a single chain.

In this paper, we have studied thermoelectric power, thermal conductivity and magnetoresistance of the $Pr_2Ba_4Cu_7O_{15-y}$ with the alternative repetition of a single- and double-chain. This finding is discussed on the basis of metallic conduction along the double chain. Polycrystalline samples of Pr247 were synthesized using a powder sintering method under high-oxygen pressure. A reduced sample was annealed in argon atmosphere. The dimensions of rectangular samples are typically $2.6\times2.5\times4.2mm^3$. The X-ray diffraction powder pattern showed that the samples measured are composed almost of an entirely single phase Pr247. Resistivity measurements were performed by a conventional four-probe technique. Magnetoresistance was measured as a function of temperature in a magnetic field of 8T using the superconducting magnet, where an electric current was supplied to the samples perpendicular to the direction of applied field. The thermoelectric power and thermal conductivity were simultaneously measured in the temperature range from 10 to 300K using a steady-state heat-flow method. A temperature gradient across the samples with 1-2 K/cm was monitored with differential- type thermocouples of Chromel-AuFe alloy. Thermoelectric voltage was detected using Cu wires and thermoelectric power of Cu wires was subtracted from the measured values.

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The temperature variation of electrical resistivity of polycrystalline samples of Pr247 compounds is shown in Fig.1, where our previous data in Pr123 and Pr124 are cited [5,6]. The resistivity of both Pr247 and Pr124 samples increases with decreasing temperature from room temperature, then reaches a maximum value in the vicinity of 150K, and finally showed a positive temperature coefficient indicating metallic character. The value of the resistivity for Pr247 compound is about one-order grater than that of Pr124 with CuO double chain but much smaller that that of semiconducting Pr123 with single chain. This finding strongly indicates that metallic conduction along CuO double chain determines the total electrical transport. The resistivity data of a reduced sample were suppressed over the wide range of temperatures in comparison with those of the as-sintered sample. This finding seems to be an unusual behavior since oxygen atoms along single chain are removed due to Ar-annealed treatment. However, it is expected that oxygen deficiencies along the single chain shrink the b-axis lattice parameter so that the shorten CuO bond-length enhances the transfer integral along the metallic double chain. Accordingly, the enhanced transfer integral results in an increase of electrical conduction along the CuO double chain stable with oxygen vacancies although we have no experimental evidences for the crystal structure . Here, it should be noted that an oxidized procedure for the reduced sample reproduces nearly both in the magnitude and the temperature dependence the resistivity data of the as-sintered sample. In the inset of Fig.1, the transverse magnetoresistance ,$\Delta\,\rho\,/\rho$=(ρ(H)-ρ(0))/ρ(0), of Pr247 is plotted as a function of temperature in a magnetic field of 8T. A rapid increase of magnetoresistance was observed at lower temperatures as well as Pr124. Such an observed enhancement by applied field indicates a dimensional cross-over of CuO double chains from 1D to quasi-2D electronic states at low temperatures. The value of $\Delta\,\rho\,/\rho$ of the reduced sample reached an increase of 8.5 percent at 8T and was about 20 percent greater than that of the as-sintered sample. This finding seems to be consistent with the higher electroic conduction observed in the reduced sample.

In Fig.2 we shows the temperature dependence of the thermoelectric power S(T) of Pr247. For comparison, the data of Pr123 and Pr124 are presented. The S (T) value of as-sintered sample remains almost a constant near the room temperature, then rapidly decreases from 200K and finally reached a very small value of 1μV/K below around 50K. The S at high temperatures may be expressed in term of Heikes formula describing the thermoelectric power for a narrow band materials. The low temperature S exhibited a metallic behavior accompanying the appearance of the MR effect as well as Pr124. This finding indicates not only the metallic conduction along CuO double chains but also with a bandlike conduction between double chains as proposed by the authors in [4]. There was no clear difference in S between the as-sintered and reduced cases. The thermal conductivity of Pr247 exhibited a similar behavior with the Pr124 data but was in contrast with the low-T variation of Pr123 [7] (not shown here).

In summary, we have studied thermoelectric power, thermal conductivity and magnetoresistance of Pr247 compounds. This finding was discussed on the basis of metallic conduction along the double chain.

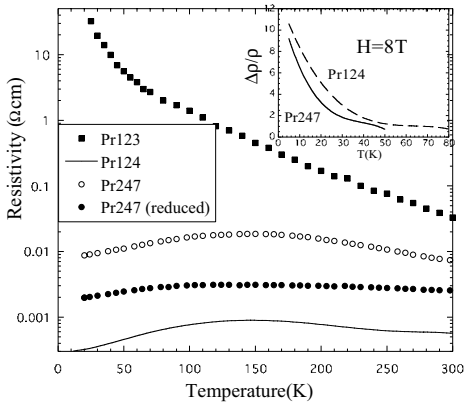

Fig. 1. Temperature variation of electrical resistivity of polycrystalline samples of Pr247 compounds. The inset shows the transverse magnetoresistance of both Pr247 and Pr124.

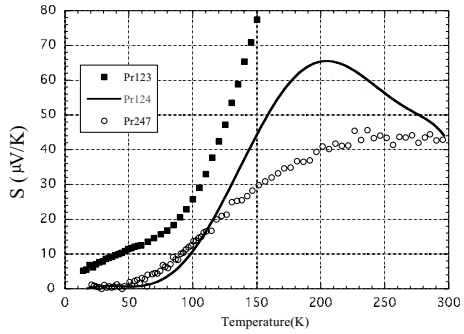

Fig. 2. Temperature dependence of the thermoelectric power of Pr247. For comparison, the data of Pr123 and Pr124 are presented.

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