Hall Coefficient in the Superconducting and Non-superconducting $Pr_2Ba_4Cu_7O_{15-\delta}$ with Metallic Double-chain

Junki TADA[1], Michiaki MATSUKAWA[1,*], Takahisa KONNO[1], Satoru KOBAYASHI[1], Makoto HAGIWARA[2], Tsuyoshi MIYAZAKI[2], Kazuhiro SANO[3], Yoshiaki ŌNO[4], Akiyuki MATSUSHITA[5]

[1]*Department of Materials Science and Engineering, Iwate University, Morioka 020-8551*
[2]*Department of Comprehensive Sciences, Kyoto Institute of Technology, Kyoto 606-8585*
[3]*Department of Physics Engineering, Mie University, Tsu 514-8507*
[4]*Department of Physics, Niigata University, Niigata 950-2181*
[5]*National Institute for Materials Science, Ibaraki 305-0047*

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Intermediate between $PrBa_2Cu_3O_{7-\delta}$ (Pr123) with the CuO single-chains and $PrBa_2Cu_4O_8$ (Pr124) with the CuO double-chains is the $Pr_2Ba_4Cu_7O_{15-\delta}$ (Pr247) compound with an alternative repetition of the CuO single-chain and double-chain blocks along the *c*-axis. For the Pr247 compound, it is possible to examine physical properties of the metallic CuO double-chain by controlling oxygen content δ along the semiconducting CuO single-chain. From the anisotropic resistivity measurement of single crystal Pr124, we note that its metallic transport is responsible for the conduction in the CuO double-chain.[1)] Matsukawa et al., discovered that the superconductivity in oxygen removed polycrystalline $Pr_2Ba_4Cu_7O_{15-\delta}$ appears around the onset $T_c^{on} =\sim 15$ K.[2)] The Hall coefficient measurement of the superconducting Pr247 with $T_c^{on} = 15$ K revealed that the main carrier is varied from hole to electron at intermediate temperatures below 120 K upon decreasing temperature, indicating an electron-doped superconductor.[3)] In our previous paper, the effect on magnetic field on the superconducting phase in the Pr247 was examined.[4)] In this work, we report the temperature dependence of Hall coefficient in the superconducting $Pr_2Ba_4Cu_7O_{15-\delta}$ with higher $T_c^{on} =\sim 27$ K, to clarify transport properties of the metallic CuO double-chain. Our finding indicates that an enhancement of the superconducting transition temperature originates from a further increase in doped electron carriers due to a reduction treatment.

Polycrystalline samples of $Pr_2Ba_4Cu_7O_{15-\delta}$(Pr247) were synthesized using a citrate pyrolysis method.[5)] After several annealing processes, resultant precursors were pressed into a pellet and it was then calcined at 890°C for 120 h under ambient oxygen pressure. The x-ray diffraction pattern of the present Pr247 shows neither peak of Pr123 or Pr124 phase was detected except for a small amount of $BaCuO_2$. A reduction treatment on its as-sintered sample in vacuum at 500 °C for 48 h yields oxygen removal, resulting in a realization of the superconductivity with $T_c^{on} = 27$ K as shown in Fig.1. A typical dimension of the pelletized rectangular sample is $9.9\times2.4\times1.7\,mm^3$. The Hall coefficient measurement was carried out with a five-probe technique using the Physical Property Measuring System (Quantum Design, PPMS) from 2 K up to 200 K in a zero-field cooling process. The applied magnetic field H is perpendicular to the excited electric current parallel to the longitudinal direction of the sample. Sweeping the applied field H from -7 T to 7 T, we measured the transverse voltage $V(H)$ across its sample at selected temperatures. The Hall voltage was then estimated by using $V_H = [V(H)-V(-H)]/2$, to eliminate its longitudinal magnetoresistance due to the misalignment of the voltage contacts. First of all, the temperature dependence of of the magnetic susceptibility M/H of the as-sintered and reduced samples of $Pr_2Ba_4Cu_7O_{15-\delta}$ is shown in Fig.1. A reduction treatment on the as-sintered sample causes the appearance of superconductivity with $T_c^{on} = 27$ K accompanied by a

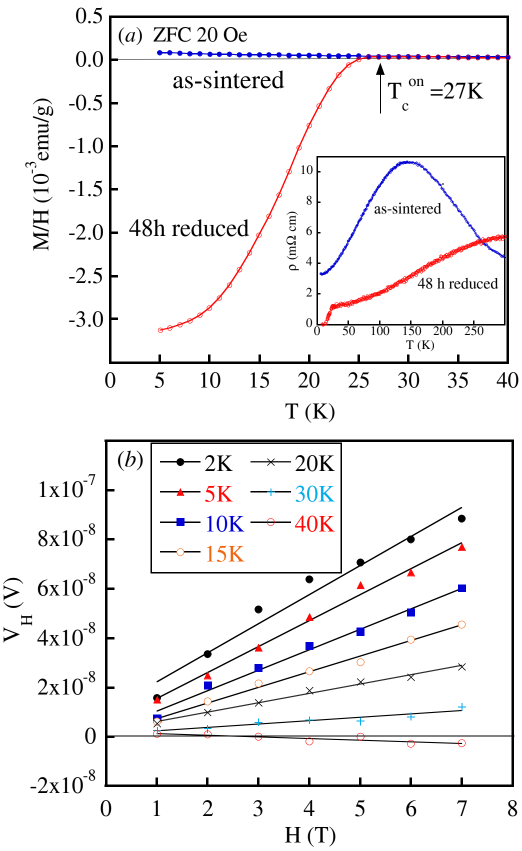

Fig. 1. (color online) (a)Temperature dependence of the magnetic susceptibility M/H of the as-sintered and reduced samples of $Pr_2Ba_4Cu_7O_{15-\delta}$ measured at a magnetic field of 20 Oe in zero-field cooling. The resistivity of both the as-sintered and reduced samples is displayed as a function of T in the inset. (b)Magnetic field dependence of the Hall voltage for the non-superconducting $Pr_2Ba_4Cu_7O_{15-\delta}$ up to 7 T at the selected temperatures below 40 K.

*E-mail address: matsukawa@iwate-u.ac.jp

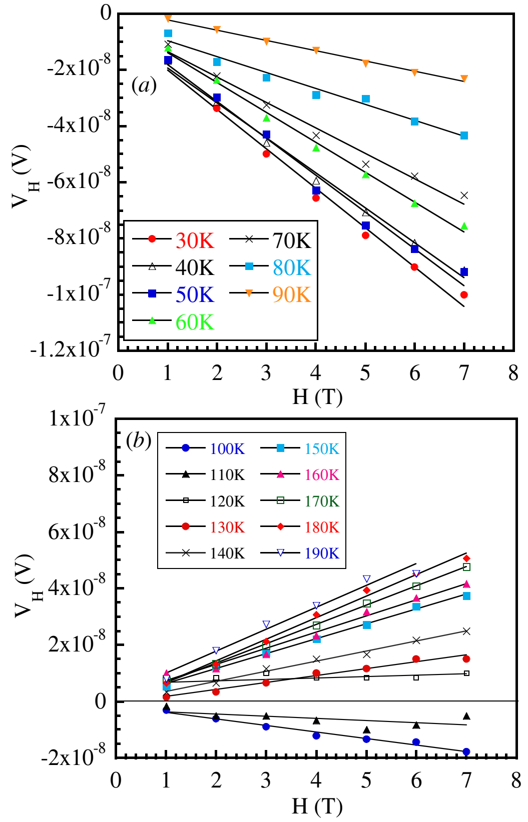

Fig. 2. (color online) Magnetic field dependence of the Hall voltage for the superconducting $Pr_2Ba_4Cu_7O_{15-\delta}$ with T_c^{on} = 27 K recorded at the selected temperatures, (a) T < 100 K and (b) $T \geq$ 100 K.

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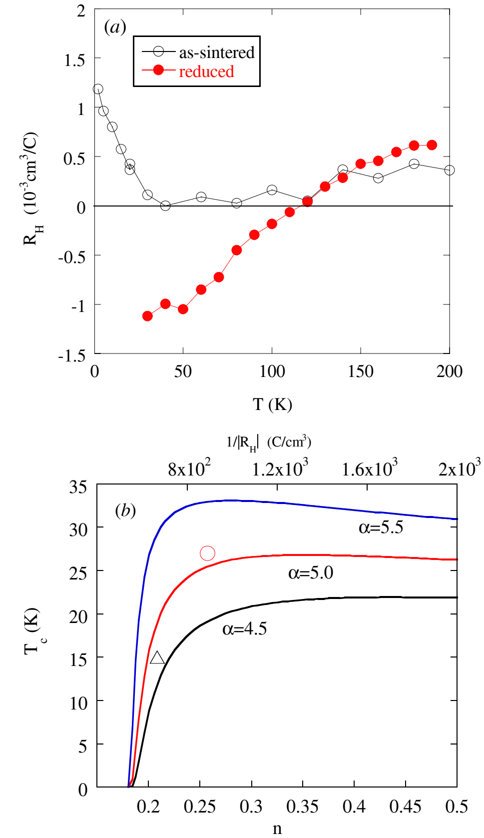

Fig. 3. (color online) (a) Temperature dependence of the Hall coefficient R_H in the superconducting and non-superconducting $Pr_2Ba_4Cu_7O_{15-\delta}$. (b)$T_c$ is calculated as a function of the electron number (lower axis) on the basis of quasi-1D zigzag chain Hubbard model. α is a short-wavelength cutoff parameter. For comparison, T_c is plotted as a function of $1/|R_H|$ at T =30 K(upper axis). (○: the present data, △:high pressure synthesis[3])

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metallic behavior over a wide range of temperatures (the inset of Fig.1(a)). Figures 1(b) and 2 represent the Hall voltage for both the as-sintered and reduced samples as a function of the applied field at several temperatures. For the as-sintered non-superconducting sample, V_H and its derivative with respect to H exhibit their positive values except for the data at 40 K. As collected in Fig.3(a), the temperature profile of R_H of the non-superconducting Pr247 is, both in its magnitude and temperature dependence, very similar to that of the polycrystalline Pr124 with metallic CuO double chains.[6] On the other hand, upon cooling temperature, the value of R_H for the reduced superconducting sample shows its negative sign at the lower temperatures below 120 K and then gradually decreases down to 30 K. Our data are in good agreement with the temperature variation of R_H of the lower T_c sample.[3] In Fig.3(b), we show T_c as a function of the electron number for several cutoff parameters calculated on the basis of the quasi-1D zigzag chain Hubbard model.[7] For comparison, the value of T_c^{on} is plotted as a function of $1/|R_H|$ collected at 30 K. A rapid rise in T_c^{on} is well described by this calculated curve in the case of $\alpha = 0.5$.

In summary, we investigated the Hall coefficient of the superconducting and non-superconducting Pr247 as a function of temperature up to 200 K. Our findings indicate that the enhanced T_c is ascribed to an increase of doped electron carrier, which is qualitatively explained by the calculated result on the basis of the the quasi-1D zigzag chain Hubbard model.

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