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Pseudogap and superconductivity on a common scale of hole concentration for high-T_c superconductors

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Abstract

Room-temperature thermoelectric power S^{290} has been systematically studied in a chain-free double-layer $Y_{1-x}Ca_xBa_2Cu_3O_6$. As a function of hole concentration per planer Cu atom (P_{pl}), $S^{290}(P_{pl})$ of $Y_{1-x}Ca_xBa_2Cu_3O_6$ ($P_{pl}=x/2$) behaves identically to that of single-layer $La_{2-x}Sr_xCuO_4$ ($P_{pl} = x$). We demonstrate the phase diagram for the double CuO_2 layer $YBa_2Cu_3O_y$ and $Bi_2Sr_2CaCu_2O_y$ system as a function of the hole concentration determined by $S^{290}(P_{pl})$, and discuss the relation between the pseudogap property and the superconductivity on the common scale.

Key words: Room-temperature thermoelectric power ; hole concentration ; phase diagram ; pseudogap

1. INTRODUCTION

The relationship between pseudogap phase and superconducting phase has been systematically studied by the nuclear magnetic resonance (NMR) experiments, the resistivity ρ, and the angle-resolved photoemission spectroscopy (ARPES) in individual underdoped high-T_c superconductors (HTSC), such as $YBa_2Cu_3O_y$ (Y123*y*) and $Bi_2Sr_2CaCu_2O_y$ (Bi2212) [1-4]. However, the systematic and meaningful comparison among different systems is still impossible. The major difficulty stems from the fact that there was no simple consistent way to determine the hole concentration per planer Cu atom (P_{pl}) from system to system. In such a situation, the universal relation between the room temperature thermoelectric power (S^{290}) and P_{pl} has been proposed by Obertelli et al. [5] and widely used with the distinct advantage that it is material independent. However, S^{290} of $La_{2-x}Sr_xCuO_4$ (LS214) does not follow the universal relation [5], though the universal relation is based on the belief that $T_c(P_{pl})$ for HTSC is universally identical to that observed in LS214, except of the systems with a complex variation of T_c like Y123*y*. Originally, there is no reason why a maximum in T_c should appear at universally ~0.16. We wonder whether the scale for conversion of S^{290} into P_{pl} is valid.

In this Letter, we present an investigation of S^{290} in the double-layer $Y_{1-x}Ca_xBa_2Cu_3O_6$ (YC1236) with no CuO chain, where P_{pl} can be ambiguously determined by Ca-content x ($P_{pl}=x/2$). We find that $S^{290}(P_{pl})$ of YC1236 behaves identically as that of LS214. We argue that this new $S^{290}(P_{pl})$ can be used as an intrinsic scale to measure P_{pl} of different systems.

2. EXPERIMENTAL

The samples of YC1236 and $Y_{1-x}Ca_xBa_2Cu_3O_y$ (YC123*y*) were prepared by solid-state reaction. The prepared samples were single-phased as determined by the X-ray powder diffraction. The oxygen content y was determined by an iodometric titration. The ρ was measured by dc four-probe method. The thermoelectric power (TEP) was measured by conventional method.

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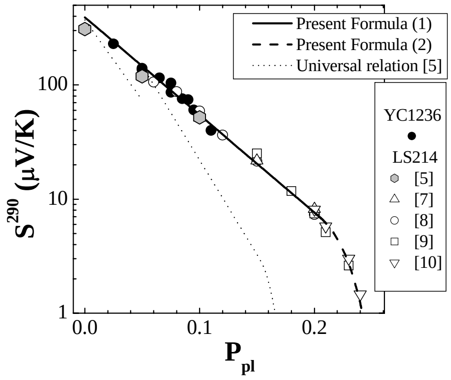

FIG. 1 S^{290} on the logarithmic scale vs P_{pl} for YC1236 with LS214. The data for LS214 are taken from Ref. [5, 7-10].

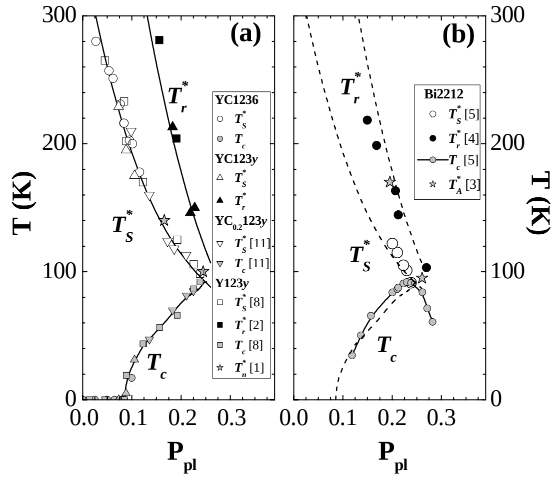

FIG. 2 Phase diagram for (a) Y123 and (b) Bi2212 system. The broken lines are obtained from Y123 system.

3. RESULTS AND DISCUSSION

Figure 1 shows S^{290} on the logarithmic scale vs P_{pl} for YC1236 with LS214. The P_{pl} for YC1236 and LS214 are determined as $x/2$ and x, respectively. The observed $\log(S^{290})$ of YC1236 varies linearly with P_{pl} ($0.025 \leq P_{pl} \leq 0.11$). This relation can be represented by Formula (1). Further, this Formula (1) reproduces the values of S^{290} reported in LS214 [7-10] very well over a much wider range until P_{pl}=0.207. For P_{pl}>0.207, $S^{290}(P_{pl})$ is linear in P_{pl}. It can be represented by Formula (2).

$$S^{290} = \begin{cases} 392\exp(-19.7P_{pl}) & (0.00 \leq P_{pl} \leq 0.207) \quad (1) \\ 40.47 - 163.4P_{pl} & (0.207 < P_{pl}) \quad (2) \end{cases}$$

The observed $S(T)$ was well scaled by the temperature (T_S^*) showing a broad peak and the peak value ($S(T_S^*)$). The details are reported in [6]. The various characteristic temperatures including T_S^* are shown in Fig. 2. T_S^* for YC1236, YC123y and $Y_{0.8}Ca_{0.2}Ba_2Cu_3O_y$ (YC$_{0.2}$123y) [8] are found to lie on a common curve which decreases from ~300 K at P_{pl}~0.025 to ~100 K at P_{pl}~0.22. The T_c for YC1236, YC123y, YC$_{0.2}$123y [11], and Y123y [8] also lie on a common bell shaped curve which appears at P_{pl}~0.09 and reaches a maximum at ~0.25. T_S^* seems to be connected with T_c at slightly overdoped level. This is a typical feature for the pseudogap or spingap temperature. The T_r^*, the temperature where the T-linear behaviour at high temperature is disappeared, for Y123y [3] and YC123y form another curve above the T_S^* curve. The P_{pl} was estimated from the $T_c(P_{pl})$ curve. We note that T_n^*, the temperature where the maximum of the ^{63}Cu nuclear relaxation rate $(T_1T)^{-1}$ vs T curve appears, falls on not the T_r^* curve but the T_S^* curve [1]. Similar phase diagram is obtained also in Bi2212 [4, 5]. Thus, we find that $T_S^*(P_{pl})$ and $T_r^*(P_{pl})$ behaves similarly, irrespective of the crystal structure, in the double CuO_2 layer Y123 and Bi2212 systems. We also note that T_A^*, the temperature at which the leading-edge gap observed by ARPES falls to zero, falls on the T_r^* curve.

In summary, we have shown that S^{290} of YC1236 follows that of LS214. On the common scale by using of the present $S^{290}(P_{pl})$, we showed that the characteristic temperatures T_S^*, T_r^* and T_c behave similarity for the double-layer Y123 and Bi2212 systems, at least. Our results provide a unified way to systematically study and compare differ HTSC material systems and place further insights of and constrains on the origins of pseudogaps.

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