Superconducting phase diagram of $La_{2-x}Sr_xCuO_4$ studied using single crystals with Sr-concentration gradient

Kazuhiko Ikeuchi [1], Tetsushi Uefuji, Masaki Fujita, Kazuyoshi Yamada

Institute for Chemical Reserch, Kyoto University, Gokashou Uji, Kyoto 611-0011, Japan

Abstract

We grew single crystals of $La_{2-x}Sr_xCuO_4$ with Sr-concentration gradient along the crystal growth. Doping dependence of the superconducting transition temperature T_c was determined by magnetic susceptibility measurement at different positions of the crystal. The results revealed a dramatic degradation of superconductivity at around $x \sim 0.12$ more clearly compared to the previously determined phase diagram using powder samples or single crystals with uniform Sr-concentration.

Key words: high-$T_c La_{2-x}Sr_xCuO_4$ single crystal; carrier concentration slope

1. Introduction

Doping holes into La_2CuO_4 creates many phases extending from the antiferromagnetic to normal metallic phases and in between the spin-glass and superconducting phases are locating [1] [2]. In order to study the phase diagram including such many phases we need to prepare many single crystals at different doping rate with high homogeneity for carrier-concentration.

In this report, we propose an alternative and more efficient method for the study of doping dependence of T_c using single crystals with carrier-concentration gradient. We present results of characterization of single crystal grown by using a traveling-solvent-floating-zone (TSFZ) method. From X-ray diffraction and magnetization measurements we confirmed that Sr-concentration in a crystal monotonically varies from that of the underdoped superconducting phase to the normal metallic phase along the direction of crystal growth.

2. Experiment

For the TSFZ crystal growth a large number of pellets with different Sr-concentration were stacked to prepare a charge rod with a step-like concentration gradient. Since the Sr-concentration in the melting zone changes continuously during the crystal-growth, the step-like concentration gradient transforms into the continuous one after the growth. We finally succeeded in growing single crystals with a 100mm in length and 6mm in diameter. The post-growth heat treatment was performed at 950 °C for 3 days under oxygen-gas flow. The spatial concentration gradient was confirmed by X-ray diffraction measurements. For the measurement with powder samples the crystal was cut into small pieces with ∼2mm width, which roughly corresponds to the distribution of Sr-concentration $dx \sim 0.005$. Each specimen was pulverized and the lattice parameter of the c-axis was determined by X-ray diffraction at room temperature. Moreover, in the optimally and overdoped regions diffraction measurement with single crystalline sample was performed. In this case the size of X-ray beam spot on the sample is about 0.8mm. In order to determine the lattice parameter at the different positions of the crystalline surface under the same

[1] Corresponding author. E-mail: ikeuchi@msk.kuicr.kyoto-u.ac.jp

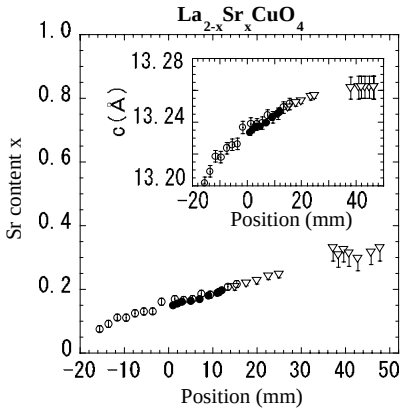

Fig. 1. Sr-content x as a function of relative position in the sample evaluated by X-ray diffraction measurement of (0,0,10) reflection with $\lambda = 1.5406$ Å at room temperature. Open circles denote results from pulverized powder samples, and solid circles and diamonds from two independent single crystalline samples. The c-axis lattice constants at each sample position is shown in the inset.

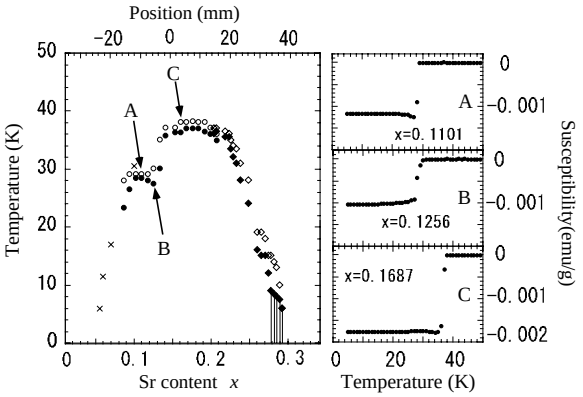

Fig. 2. (Left panel) Superconducting phase diagram obtained using single crystals with Sr-concentration gradient. Solid and open symbols denote midpoint and onset of T_c, respectively. Cross symbols denote onset Tc from single crystals with uniform Sr-concentration [4]. Data from different crystals are distinguished by the symbols of diamonds and circles. (Right panel) Temperature dependence of Meissner signals at each posito shown in the left panel of the figure.

experimental set-up the sample was mounted on a z-stage. Measurement was performed for two independent crystals. In order to calibrate the absolute value of lattice parameters between the powder and two single crystalline samples we measured standard samples with uniform concentration, x=0.00 and 0.15 under the same experimental set-up.

The T_c at each position of the crystal was determined using a SQUID magnetometer. The temperature dependence of Meissner signal from samples sliced into 1.5mm length was measured under a magnetic field of 10 Oe.

3. Result and Conclusion

The results of X-ray diffraction measurement are shown in Fig.1. A monotonic change in the lattice constant of c along the growth direction is observed for both powdered and single crystalline samples (see inset of Fig.1). From a comparison of the obtained values of lattice parameter with the reference values taken by powder and single crystalline samples with uniform Sr-concentration [3] we evaluated the averaged value of Sr-concentration at each position of the crystal as shown in Fig.1.

The left panel of Fig. 2 shows the Tc dependence on thus obtained Sr-concentration, the superconducting phase diagram determined by using single crystals with concentration gradient. The overall feature of the phase diagram is quite similar to that previously obtained one. However, near the Sr-concentration $x \sim 0.12$ a clear dip of T_c is seen not only in the onset of T_c but also in the middle point of T_c. The right panel of Fig.2 shows the magnetic susceptibility data near $x = 0.12$. The sharp superconducting transition as shown in the figure is one of main reasons for the discovery of the clear dip in T_c. To conclude, the application of single crystals with carrier-concentration gradient is one of effective methods for the precise study of phase diagram. We emphasize that this technique can be applicable to other metal oxide systems.

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References

[1] H. Takagi et al., Phys. Rev. B**40** (1989) 2254.

[2] H. Takagi et al., Phys. Rev. Lett.**68** (1992) 3777.

[3] P. G. Radaelli et al., Phys. Rev. B**49** (1994) 4163.

[4] M. Fujita et al., Phys. Rev. B**65** (2002) 064505-1.