The effect of Pr and Ca doping on the flux pinning and superconducting properties in $YBa_2Cu_3O_{7-\delta}$

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Abstract

The effects of Pr- and Ca- doping on the critical current density J_c and the critical temperature T_c in $(Y_{1-x-y}Pr_xCa_y)Ba_2Cu_3O_{7-\delta}$ have been investigated. The Pr-doping has been found to enhance the pinning force and the J_c at 70K on applying magnetic field; J_c takes a maximum at x=0.05 for $\mu_0 H$=2.0T (optimum concentration). This result indicates that the Pr ions in YBCO induce the nanometric inhomogeneities that act as effective pinning centers in the presence of magnetic field. The Ca-doping is expected to supply the mobile holes to the CuO_2 planes. However, this doping does not contribute to further enhancement of J_c at the optimum x.

Key words: $YBa_2Cu_3O_{7-\delta}$; chemical doping; critical current density; flux pinning

1. Introduction

Recently, there has been renewal of interest in practical applications of the Y-123 type superconductors (i.e. $RBa_2Cu_3O_{7-\delta}$, R: rare-earth elements), because of their potential for providing high critical current density J_c in magnetic field at liquid nitrogen temperature. For the practical applications, it is quite important to improve further the J_c. Among the various attempts to enhance the pinning force by introducing pinning centers, such as the normal state impurity phases like R_2BaCuO_5(R211) and the columnar defects generated by heavy ion irradiation, we are especially concerned with the points defects generated by chemical doping [1]. In high-T_c superconductors, such as $YBa_2Cu_3O_{7-\delta}$, the core of flux line or vortex is comparable in size to the coherence length ξ, which is estimated to be of the order of nano-meter [2]. Therefore, the point defects are expected to act as effective pinning centers to increase the J_c. The aim of the present work is to elucidate the effect of Pr- and Ca- doping on the Y site in $YBa_2Cu_3O_{7-\delta}$. These doping is expected to introduce the effective pinning centers without remarkable suppression of the matrix superconductivity.

This paper reports the behaviors of T_c and J_c for $(Y_{1-x-y}Pr_xCa_y)Ba_2Cu_3O_{7-\delta}$ ($0 \leq x \leq 0.15$, $0 \leq y \leq 0.15$) samples prepared by standard solid-state reaction method. The doping effects for enhancing the pinning force will also be discussed.

2. Experimental

The samples were prepared by solid-state reaction from stoichiometric mixtures of Y_2O_3, Pr_6O_{11}, $CaCO_3$, $BaCO_3$, CuO. The size and morphology of grains were observed by scanning electron microscope (SEM). The critical temperature T_c was determined from the temperature dependence of the ac diamagnetic susceptibility χ. The J_c was determined from the magnetization curve on the basis of Bean's critical state model [3]. The magnetization was measured by use of SQUID magnetometer. The details of sample preparation and these measurements were reported

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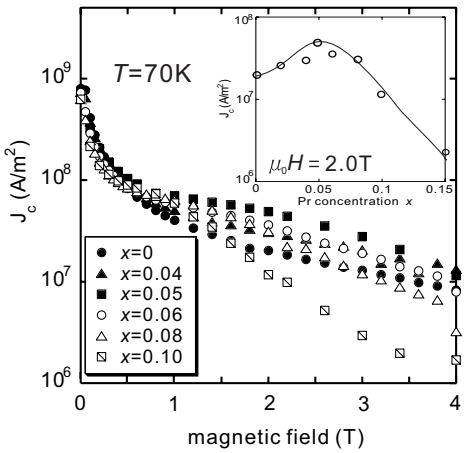

Fig. 1. Field dependence of the critical current density J_c for various values of x in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$. The inset shows the J_c at 70K as a function of x for $\mu_0 H$=2.0T.

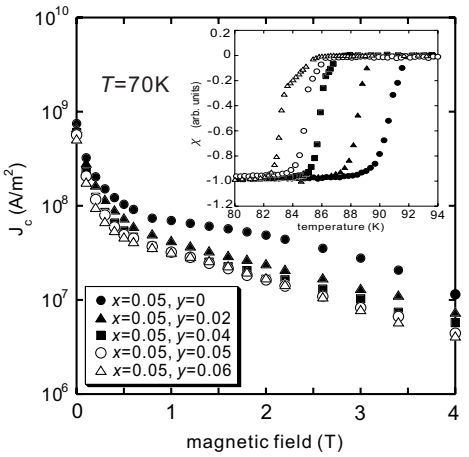

Fig. 2. Field dependence of the critical current density J_c for various values of y in $(Y_{0.95-y}Pr_{0.05}Ca_y)Ba_2Cu_3O_{7-\delta}$. The inset shows temperature dependence of the ac diamagnetic susceptibility χ for these samples.

elsewhere [1].

3. Result and Discussion

Figure 1 shows the magnetic field dependence of the J_c at 70K for $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ (YPBCO) samples with various x. For all samples, J_c monotonically decreases as the field increases. The important point to note is that a shoulder-like feature appears in each curve. Furthermore, the bend at the beginning of the "shoulder" becomes remarkable as x increases, which leads to the enhancement of J_c in the field. This feature may indicate that many pinning centers are induced in the presence of magnetic field, and the density of these centers increases with Pr-doping. The enhancement of J_c is manifest from the Pr-concentration dependence of J_c for $\mu_0 H$=2T, as shown in the inset of Fig.1. This inset clearly exhibits the occurrence of a maximum of J_c at x=0.05. From this result, we may say that a little amount of Pr-doping in YBCO introduces the effective pinning centers that act in the presence of the field.

Figure 2 shows the magnetic field dependence of the J_c at 70K and the temperature dependence of the χ (inset) for $(Y_{0.95-y}Pr_{0.05}Ca_y)Ba_2Cu_3O_{7-\delta}$ samples with various y. The figures indicate that the additional Ca-doping, which is expected to supply the mobile holes to the CuO_2 planes [4], does not cause the further increase in both T_c and J_c. Moreover, it should be noted that there is no significant variation in the shape of the "shoulder" with Ca-doping. The decrease in T_c with Ca-doping may indicate that the hole doping due to the Ca substitution makes the superconducting matrix of YBCO turn into the overdoping region. In addition, from the invariability of the "shoulder" shape, we may say that the Ca-doping does not induce the inhomogeneities that will act as the pinning centers in the system.

4. Conclusion

The effects of Pr- and Ca- doping on J_c and T_c in YBCO have been investigated. We found that a little amounts of Pr-doping introduces the effective pinning centers, which especially act in the presence of magnetic field, and enhance the J_c remarkably in the field. However, the additional Ca-doping to optimally Pr-doped samples (x=0.05) does not lead to the further increase in J_c and T_c.

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