Annealing effect of the irreversibility fields in $(Cu,C)Ba_2Ca_{n-1}Cu_nO_y$ (n = 3 and 4)

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Abstract

Annealing effect of the irreversibility fields (H_{irr}) in $(Cu,C)Ba_2Ca_2Cu_3O_y$ ((Cu,C)-1223) and $(Cu,C)Ba_2Ca_3Cu_4O_y$ ((Cu,C)-1234) have been investigated. The samples prepared under high pressure were post-annealed in nitrogen gas in the temperature range of 400 - 500 °C. H_{irr} of (Cu,C)-1234 was improved after annealing at 450 °C while T_c remained almost constant. This suggests that carrier density of 5-coordinated CuO_2 planes or conductivity of charge reservoir layers is changed by annealing while keeping that of 4-coordinated CuO_2 planes almost constant. Both samples show $H_{irr} \simeq 4$ T at 90 K by the post-annealing, which is quite attractive for practical application.

Key words: (Cu,C)-1223; (Cu,C)-1234; annealing effect; irreversibility field; high-pressure synthesis;

1. Introduction

$MBa_2Cu_3O_y$ (M = Y and Rare earth), which is regarded as a member (n = 2) of Cu-12(n-1)n system [1], is known to have high H_{irr} due to low anisotropy. Its research for application such as tape and bulk is developed well. $(Cu,C)Ba_2Ca_{n-1}Cu_nO_y$ (n = 3 and 4) [2], which is also a member of Cu-12(n-1)n system, can be considered to be a material which combines high T_c ($\simeq$ 120 K) and low anisotropy. Therefore, the possibility of application at the higher temperature ($\geq$ 77 K) is expected.

Previously, we studied annealing effect of (Cu,C)-1223 and demonstrated that (Cu,C)-1223 has a H_{irr} of 9.4 T at 77 K [3]. In this paper, we will show annealing effect of (Cu,C)-1234 as well as of (Cu,C)-1223. (Cu,C)-1223 and 1234 have crystallography inequivalent CuO_2 planes. The NMR study showed that charge distribution among the CuO_2 planes is quite inhomogeneous so that in the case of (Cu,C)-1234 nearly optimal doped four-coordinated CuO_2 planes sustain an overall T_c ($\geq$ 117 K) while heavily overdoped five-coordinated ones seem to have a lower T_c ($\geq$ 60 K) [4].

We expected that H_{irr} would be increased if the carrier distribution and concentration could be controlled by annealing.

2. Experimental

Precursors for (Cu,C)-1223 and 1234 having the nominal compositions of $Ba_2Ca_{1.6}Cu_{3.5}O_yC_x$ and $Ba_2Ca_{2.7}Cu_{4.6}O_yC_x$ were prepared from a mixture of $BaCO_3$, $CaCO_3$ and CuO powders at 880 °C for 24 hours in flowing oxygen gas with one in-

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termediate grinding. The residual carbon concentration x in both the precursors was estimated to be about 0.1 by infrared absorption method. One mol of the precursors were mixed with 0.4 and 0.3 mol of $CaCO_3$ and 0.52 and 0.4 mol of AgO (as an oxidizing agent) for sample preparation of n = 3 and 4, respectively. The mixtures with nominal compositions of $(Cu_{0.5}C_{0.5})Ba_2Ca_2Cu_3O_y$ and $(Cu_{0.6}C_{0.4})Ba_2Ca_3Cu_4O_y$ were sealed in gold capsules and heated at 960 °C for 4 hours and at 980 °C for 2 hours under 3.5 GPa, respectively, by means of a cubic-anvil-type apparatus (RIKEN CAP-07).

The samples were ground into powders and post-annealed in a nitrogen gas flow in the temperature range of 400 - 500 °C for 12 hours. Magnetic hysteresis loops were measured with a SQUID magnetometer (MPMS-XL Quantum Design) up to 7 T. Critical current density (J_c) was calculated by using Bean's critical state model (grain size of 7.5 μm was used). H_{irr} was estimated from the field dependence of J_c (J_c= 1000 A/cm^2 was used as a criterion).

3. Results and discussion

The X-ray diffraction patterns for (Cu,C)-1223 and 1234 showed nearly single phase. EDX analysis revealed that there is no Ag in the grain.

Figure 1(a) shows the temperature dependence of H_{irr} for (Cu,C)-1223. The T_c and irreversibility line are increased with the annealing temperature. In the previous report [3], we demonstrated that there exists an optimal annealing temperature (carrier concentration) to enhance H_{irr} lines. The sample annealed at 500 °C (T_c= 118 K) that is slightly overdoped state shows the H_{irr} of about 3.9 at 90 K and 6.2 T at 85 K. The H_{irr} at 77 K estimated by extrapolation is 9.8 T. These values are higher than the previously reported ones [3] because the carrier concentration would be much more optimized.

Figure 1(b) shows the temperature dependence of H_{irr} for (Cu,C)-1234. Unlike (Cu,C)-1223, the T_c is almost independent of annealing temperature (only 1 K decreased). The H_{irr} line, however, once decreased by annealing at 400 °C and increased by annealing at 450 °C suggesting that there exists an optimal annealing temperature to enhance H_{irr} lines like (Cu,C)-1223. The carrier concentration of the four-coordinated CuO_2 planes must be almost constant because T_c is not affected by annealing. The H_{irr} is known to depend on conductivity of charge reservoir layers as well as carrier concentration. The change of H_{irr} in (Cu,C)-1234 would result from that of carrier concentration of the five-coordinated CuO_2 planes and/or the charge reservoir layers (BaO-(Cu,C)O_y-BaO). Both samples

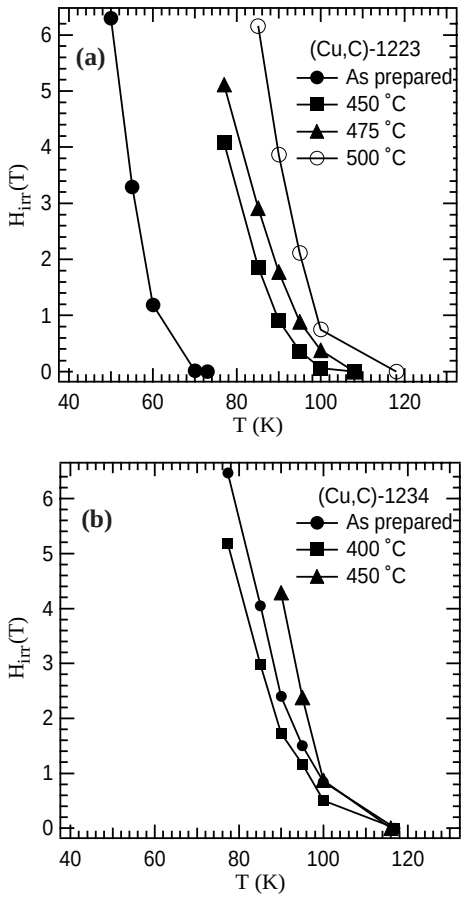

Fig. 1. Temperature dependence of irreversibility fields for (Cu,C)-1223 (a) and 1234 (b) as a function of annealing temperature.

of (Cu,C)-1223 and 1234 show a H_{irr} of about 4 T at 90 K which $YBa_2Cu_3O_y$ ($T_c \sim 92$ K) never achieved.

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