Heavy-ion Irradiation dependence of the Superconducting properties of $(Cu,C)Ba_2Ca_3Cu_4O_{10.5-\delta}$

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Abstract

To enhance or improve critical currents density (J_c) and irreversibility field (H_{irr}) of $(Cu,C)Ba_2Ca_3Cu_4O_{10.5-\delta}$ ((Cu,C)-1234), pinning centers were introduced by heavy-ion in these compounds and we have investigated their heavy-ion irradiation dependence. The polycrystalline samples were irradiated with Au^{15+} ions (240 MeV energy) at various fluence of 1×10^{11}, 2.5×10^{11} and 5×10^{11} ions/cm^2. J_c and H_{irr} were determined for the irradiated samples as well as unirradiated samples. J_c (77K, 1T) increase from 3.9×10^4 A/cm^2 to 4.1×10^6 A/cm^2 for at fluence of 1×10^{11} ions/cm ^{2} of heavy-ion irradiated sample and decreases with further increase of fluence. These results indicate the possibility of further enhancement of J_c and of achieving a very high H_{irr} of (Cu,C)-1234 below a fluence of 1×10^{11} ions/cm^2.

Key words: Heavy-ion irradiation; (Cu,C)-1234; Magnetic measurement; Critical Current density (J_c); Irreversibility field (H_{irr})

1. Introduction

It is known that the distance between the group of CuO_2 layers is one of the key factors which determine the two-dimensionality of the oxide superconductors. The crystal structure of (Cu,C)-12(n-1)n series is analogous to that of materials described as $MBa_2Ca_{n-1}Cu_nO_{2n+2-\delta}$ (M=Hg [1], Tl[2], Cu [3] etc.). For the practical applications of superconductors such as superconducting magnets, J_c must be high enough in applied magnetic fields, which requires the introduction of effective pinning centers. Especially, in Cu- based superconducting cuprates, (Cu,C)-1234 could be promising candidates for the application of the next generation because of high critical temperature (T_c), J_c and H_{irr}. In previous papers[4, 5], we reported the effect of the introducing pinning centers into (Cu,C)-1234 by heavy-ion or neutron irradiation. From these results, introducing pinning centers by heavy-ion is effective to increase J_c and H_{irr} for (Cu,C)-1234. Here, we report on the dependence of the heavy-ion irradiation of the polycrystalline (Cu,C)-1234.

2. Experimental and results

The polycrystalline (Cu,C)-1234 was prepared by the solid state reaction method using the high-pressure apparatus (RIKEN CAP-07, ∼3.5 GPa, 1173∼1373 K

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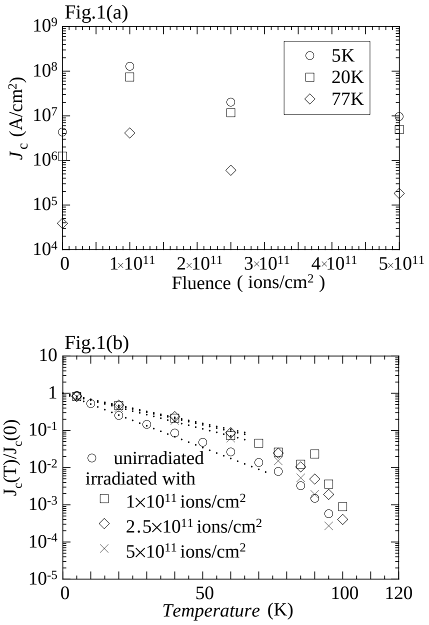

Fig. 1. (a) Irradiation dependence of J_c values for (Cu,C)-1234 and (b) Temperature dependence of $J_c(T)/J_c(0)$ values for (Cu,C)-1234.

for 2 hours). Nominal composition was ($Cu_{0.5}$ $C_{0.5}$)-1234. X-ray diffraction patterns of powdered sample were obtained by using Rigaku RINT 1000 diffractometer equipped with a graphite monochrometer on the counter side. Lattice parameters are determined to be a= 3.860 $\AA$, c= 17.96 $\AA$. Polycrystalline samples were cut and polished into thin discs less than 100 μm in thickness. Samples were irradiated with Au^{15+} ions, which were accelerated to 240 MeV with the fluence of 1×10^{11} ions/cm^2, 2.5×10^{11} and 5×10^{11} ions/cm^2 at room temperature using a Tandem accelerator at JAERI. The ion energies were estimated from the range-energy relations proposed by Ziegler[6]. For the heavy-iron irradiated (Cu,C)-1234 samples, the length of the ion tracks was determined by the stopping powers calculated using TRIM 2000 codes. The tracks of the Au^{15+} ion of 240 MeV were 12.2 μm and this value being smaller than the thickness of the (Cu,C)-1234 samples, so that all of the irradiated ions stop inside of the samples. Superconducting transition temperature T_c determined from ac susceptibility is 118K. T_c of these compounds slightly decreased ($\sim$1 K) after irradiation.

J_c is determined from M-H curves using the Bean's model [7], J_c (A/cm^2)=h_p/d, here the effective particle size d was used 2 μm. Detail of the determination of d was described as in previous paper[5]. J_c shows a remarkable increase from 3.9×10^4 to 4.1×10^6 A/cm^2 at 77 K and 1T for heavy-ion irradiated with the fluence of 1×10^{11} ions/cm^2 (Fig.1(a)). For the fluence higher than 1×10^{11} ions/cm^2, J_0 slightly decreases. It is reported that J_c values of oxide superconductors decrease exponentially with temperature, $J_c \propto$ exp(-T/T_0)[8, 9]. This demonstrates that heavy-ion defects significantly improve the current-carrying properties of (Cu,C)-1234, as shown in Fig.1(b). Similar behavior reported for $HgBa_2Ca_2Cu_3O_{8+\delta}$(Hg-1223)[10]. The parameter T_0 of (Cu,C)-1234 slightly decreases for the fluence higher than 1×10^{11} ions/cm^2 because of the damaging sample surface. The values of H_{irr} at 77K for heavy-ion irradiated (Cu,C)-1234 extrapolating the $J_c(H)$ curves to a J_c criterion of 10^3 A/cm^2, increased 12.5T. This value is higher than for neutron irradiated (Cu,C)-1234[4, 11] and is also comparable with that of $NdBa_2Cu_3O_{7-\delta}$ with best pinning center engineering [12]. H_{irr} is described by the power law dependence of $H_{irr}(T)$=$H_{irr}(0)(1$-$T/T_c)^\alpha$. The exponent α values are 2.0 for the unirradiated (Cu,C)-1234, 1.8 for the irradiated with the fluence of 1×10^{11} ions/cm^2, 2.3 for the irradiated with the fluence of 2.5×10^{11} ions/cm^2 and 3.3 for the irradiated with the fluence of 5×10^{11} ions/cm^2, respectively. The α value increases more than the fluence of 1×10^{11} ions/cm^2. The α value for the irradiated (Cu,C)-1234 with the fluence of 1×10^{11} ions/cm^2 is smaller than that of Hg-1223[13], but slightly larger than those of $YBa_2Cu_3O_{7-\delta}$ and $YbBa_2Cu_3O_{7-\delta}$ [14, 15]. Heavy-ion irradiation was much effective to introduce strong pinning centers in (Cu,C)-1234. These results indicate the possibility of the further enhancement of J_c and H_{irr} of (Cu,C)-1234 below the fluence of 1×10^{11} ions/cm^2.

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