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Upper Critical Field of New Oxide Superconductor Bi–Sr–Ca–Cu–O

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The upper critical field H_{c2} of Bi-Sr-Ca-Cu-O superconducting material, with a resistive transition above 100 K, was investigated by observing variations in resistivity with temperature down to 50 K and with magnetic fields up to 12 T. The slope of the critical field, the change in H_{c2} with temperature, was -1.5 T/K for the midpoint of the transition. The values of H_{c2} at 77 K and 0 K were estimated by extrapolation to be 41 T and 108 T, respectively.

KEYWORDS: oxide superconductor, Bi–Sr–Ca–Cu–O, upper critical field, coherence length, Ginzburg-Landau parameter

Since the first discovery of high-T_c oxide superconductors by Bednorz and Müller,[1] many researchers have attempted to discover new oxides having even higher superconducting transition temperatures. Among them, the discovery of Ba–Y–Cu–O compound was epoch-making because its transition temperature T_c exceeded 77 K, the boiling point of liquid nitrogen.[2] Recently, a new breakthrough has been achieved. One of the authors and his co-workers discovered superconductivity above 100 K in the Bi–Sr–Ca–Cu–O system.[3] This paper reports the upper critical field H_{c2} of this Bi–Sr–Ca–Cu–O material near T_c in magnetic fields up to 12 T. From these results, the H_{c2} values at 77 K and 0 K are estimated by extrapolation.

The sample investigated was prepared by a powder method, using Bi_2O_3, $SrCO_3$, $CaCO_3$ and CuO powders as starting materials. The nominal composition was $BiSrCaCu_2O_x$. The mixed powder was calcined at 800°C and 820°C, and then was sintered at 870°C. A more detailed presentation of sample preparation will be published elsewhere.[4] Resistivity vs temperature curves were measured by a standard four-probe resistivity method in constant magnetic fields up to 12 T. A rectangular slab, $0.6\times3\times20$ mm^3 in dimension, was mounted on a sample holder such that the magnetic field was applied transversely to the current flow. Electrical contact to the sample was made by a conducting silver paste. The sample was in contact with helium gas in a temperature-controlled cryostat, and temperature was monitored with a calibrated carbon glass resistor. Measuring current density of the sample was 55 mA/cm^2.

Resistivity vs temperature curves obtained at various magnetic fields are shown in Fig. 1. At zero field, the majority of transition occurred above 103 K, with the onset transition temperature being 115 K. Since the measuring current density is much greater than the critical current density (0.6 mA/cm^2 at 100 K) of the sample, zero resistivity is not attained until the temperature is decreased below 80 K even in a zero magnetic field. As the applied magnetic field is increased, the low-temperature portion of the transiton curve shifts to low temperature, resulting in a broad transition. The high-temperature portion, on the other hand, is only slightly influenced by the magnetic field. A similar resistivity vs temperature behavior was observed in Ba–Y–Cu–O[5,6] and La–Sr–Cu–O[7] compounds.

H_{c2} values were derived from the resistivity vs temperature curves shown in Fig. 1. Two H_{c2} values are plotted in Fig. 2 as a function of temperature. The circles show H_{c2} values defined at the midpoint of the transition, while squares are defined at the point of 90% of the normal state resistivity at T_c onset. At low magnetic fields, a small positive curvature is observed in H_{c2} vs temperature curves. A similar positive curvature was also observed in the Ba–Y–Cu–O system.[5,6] The slope of the H_{c2} vs temperature curve, dH_{c2}/dT, is about -1.5 T/K for the midpoint transition and -7 T/K for 90% resistivity transition. H_{c2} at 77 K, estimated from a linear extrapolation, is 41 T and 245 T for the midpoint and 90% resistivity transition, respectively. These H_{c2} values are about twice as large as those for the Ba–Y–Cu–O system.[8,9] This is due to a larger temperature difference between T_c and liquid nitrogen temperature (T_c-77 K) in the Bi–Sr–Ca–Cu–O system. This high H_{c2} value at 77 K suggests that the Bi–Sr–Ca–Cu–O compound is more promising for the application to high-field devices operating at 77 K.

H_{c2} at 0 K can be estimated from the relation $H_{c2}(0\text{ K})=-0.69\times T_c\times(dH_{c2}/dT)_{T_c}$ according to the Werthamer-Helfand-Hohenberg (WHH) theory of type II superconductors in the dirty limit. $H_{c2}(0\text{ K})$ values of 108 T and 540 T were obtained for the midpoint and 90% resistivity transition, respectively. This $H_{c2}(0\text{ K})$ value for the midpoint is lower than the Pauli paramagnetic limiting field, H_p, of 190 T derived from the equation $H_p=1.84\times T_c$.

The lower critical field, H_{c1}, has been estimated from magnetization data using the concept of the 'critical state'. The H_{c1} of Bi–Sr–Ca–Cu–O is about 4.5 mT at 77 K, as described elsewhere.[10] This H_{c1} value is much smaller than that of the Ba–Y–Cu–O compound.[8] Several parameters of Bi–Sr–Ca–Cu–O superconductor derived from H_{c1} and H_{c2} (midpoint) values are listed in

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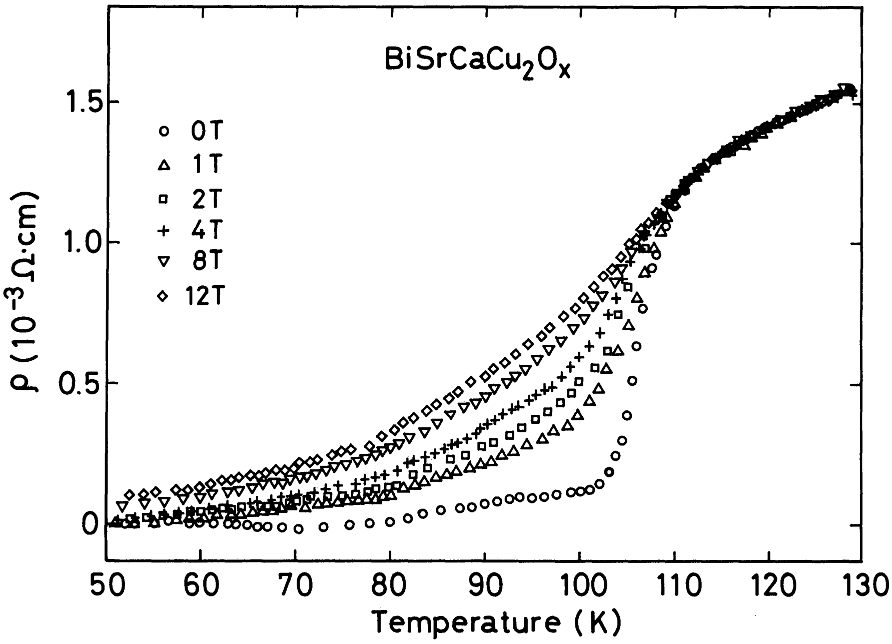

Fig. 1. Temperature dependence of resistivity for $BiSrCaCu_2O_x$ compound in various magnetic fields.

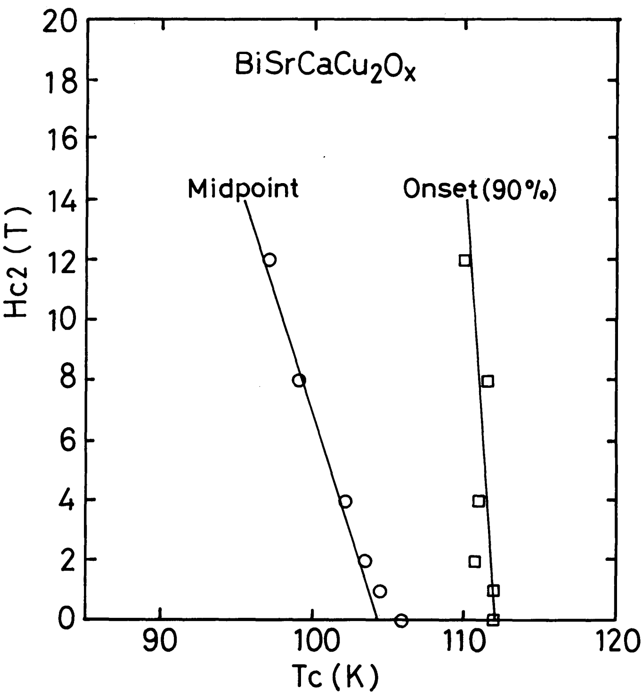

Fig. 2. Upper critical field H_{c2} as a function of temperature. Circles and squares show the H_{c2} values defined at the midpoint and the point of 90% normal state resistivity at T_c, respectively.

Table I. As shown in this table, the coherence length, ξ, is very small, as in the case of Ba-Y-Cu-O. It is remarkable that the Ginzburg-Landau parameter κ of this compound is much larger than that of Ba-Y-Cu-O compound.[8]

In summary, it is shown that the Bi-Sr-Ca-Cu-O compound has high upper critical fields of $H_{c2}(77\ \mathrm{K})=41$ T and $H_{c2}(0\ \mathrm{K})=108$ T. This result suggests that the material has the potential for generating a high magnetic field at liquid nitrogen temperature.

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Table I. Several parameters of $BiSrCaCu_2O_x$ superconductor.

	$BiSrCaCu_2O_x$ 77 K	0 K
H_{c1} (T)	4.5×10^{-3}	—
H_{c2} (T)	41	108
H_c (T)	0.19	—
H_p (T)	—	190
ξ (A)	28	17
λ (A)	4200	—
κ	150	—

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