Electrical Properties of a High Tc Superconductor for Renewed Electric Power Energy

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Abstract - Effects of Ag_2O doping on the electromagnetic properties in the BiSrCaCuO superconductor. The electromagnetic properties of doped and undoped Ag_2O in the BiSrCaCuO superconductor were evaluated to investigate the contribution of the pinning centers. It was confirmed experimentally that a larger amount of magnetic flux was trapped in the Ag_2O doped sample than in the undoped one, indicating that the pinning centers of magnetic flux are related closely to the occurrence of the magnetic effect. We have fabricated superconductor ceramics by the chemical process. A high Tc superconductor with a nominal composition of $Bi_2Sr_2Ca_2Cu_3O_y$ was prepared by the organic metal salts method. Experimental results suggest that the intermediate phase formed before the formation of the superconductor phase may be the most important factor. The relation between electromagnetic properties of Bi HTS and the external applied magnetic field was studied. The electrical resistance of the superconductor was increased by the application of the external magnetic field. But the increase in the electrical resistance continues even after the removal of the magnetic field. The reason is as follows; the magnetic flux due to the external magnetic field penetrates through the superconductor and the penetrated magnetic flux is trapped after the removal of the magnetic flux. During the sintering, doped Ag_2O was converted to Ag particles that were finely dispersed in superconductor samples. It is considered that the area where normal conduction takes place increases by adding Ag_2O and the magnetic flux penetrating through the sample increases. The results suggested that Ag_2O acts to amplify pinning centers of magnetic flux, contributing to the occurrence of the electromagnetic properties.

Keywords: Bi HTS, Electric power, Electrical property, Magnetic force, Magnetic flux

1. Introduction

Since the discovery of high Tc oxide superconductors with transition above liquid nitrogen temperature, many efforts have been focused on improving the fabricability of ceramic superconductors and increasing the critical current density of the systems [1-4]. Recently several effective methods, which could fabricate ceramic superconductors into a wire or a tape shape with high Jc, have been successfully developed for the Bi HTS system.

With the discovery of superconductivity in the Bi HTS system with superconducting temperatures, significant effort has been directed towards developing high current superconducting wire technologies.

Considerable exertion has been directed towards developing high current superconducting wire technologies. Much of this work has focused on achieving the crystallographic texture needed in high temperature superconductor (HTS) wire or tape in order to realize the high critical current density (Jc) at 77 K.

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Compared with the earlier developed YBaCuO superconductor, this oxide system contains no rare earth element and has greater chemical resistance against moisture, but the critical current density, Jc, is lower and requires prolonged annealing to form the high Tc and other phases. So far, much effort has been devoted to the fabrication and application of this superconducting oxide system. Generally the preparation of superconducting oxides by conventional solid state reaction relies upon the repeated milling and sintering of an oxide and carbonate mixture. With such a process, the time required to obtain acceptable homogeneity is very expensive and serious contaminations may be introduced during the milling process. On the other hand, chemical solution methods are much more efficient in the production of mixtures of high homogeneity. When a sufficiently strong current exceeding the critical current passes through a type II superconductor in the mixed state, the Lorentz force exceeds the pinning force between the flux line and the moving charge and the core lattice is set in motion against viscous drag force inducing voltage drops in the sample [5, 6]. The early works of Kim et al. [7] showed that the voltage drop develops in the type II superconductor of the mixed state, and the flux flow resistivity remains zero up to the critical current. Above the

critical current the slope dv/di increases, and the voltage drop increases with current until the liner flux flow region is attained. This paper reported the fabrication of the BiSrCaCuO high Tc superconductor by the organic metal salts method, and the characteristic change of flux flow resistivity with external magnetic field and field polarity.

2. Experimental

The high Tc superconductor of the Bi system with the nominal composition of $Bi_2Sr_2Ca_2Cu_3O_y$ precursor was prepared from mixed powders of Bi_2O_3, $SrCO_3$, $CaCO_3$, and CuO by the organic metal salts method. A mixture of nitrate salts in a suitable molar ratio with total weight of 50 gm was dissolved in 150 ml distilled water. The nitrate solution was then vigorously stirred with a few drops of 60 wt% HNO_3 solution added to assist the dissolution. After a clear solution was obtained, powered citric acid and ethylene glycol were added. The resulting light blue solution was magnetically stirred and heated at 80℃. A vigorous reaction occurred and an enormous amount of N_2 gas evolved during this procedure. When a vigorous liquid began to set into gel form, the gel was dehydrated at 120℃ for 12 hours, while the color of the gel changed from blue to green, and finally a solid precursor material of a brownish yellow color was obtained. The solid precursor was ground with mortar and pestle. The powered precursor was then transferred into an alumina crucible and placed in an air furnace. It was slowly heated to 400℃ for 10 hours. The furnace temperature was then slowly raised to 850℃, and calcination was performed at this temperature for 5 hours followed by furnace cooling to room temperature. The calcined powder was then ground with mortar and pestle. After grinding the calcined cake, the powder mixtures were pressed into pellets under 300 kg/cm^2, followed by sintering at 850℃ for 50 hours. The electrical transport properties of the BiSrCaCuO superconductors were measured by the conventional four probe method. The present author used a conductive silver paste to attach copper leads to the sample. The magnetic characteristics were evaluated with a magnetometer placed dc magnetic field, applied perpendicular to the surface of the magnetometer. The phases formed after calcinations and sintering were analyzed by X-ray powder diffraction (XRD) using $CuK\alpha_1$ radiation. The compositions of the sample were evaluated by electron probe micro analysis (EPMA). The U shaped superconductors were polarized by field cooling at 77 K with a samarium cobalt rear earth permanent magnet of B = 0.15 T, 46 mm in length and 10 mm in thickness. The disk sample with a diameter of 8 mm and thickness of 1mm weighed 0.3 g.

3. Experimental Results and Discussion

Fig. 1 (a) shows an XRD pattern of a 5 wt% Ag_2O doped BiSrCaCuO superconductor, while Fig.1 (b) is an XRD pattern of an undoped sample, where (●) and (○) denote the peaks of 110 K phase and 80 K phase, respectively. Figure 1 reveals the structure of super-conductor crystalline state. From XRD patterns, the presence of the superconducting low Tc phase (80 K phase) was confirmed in the undoped sample because of the presence of the (115) diffraction peak. In order to investigate the reaction between Ag_2O and the superconducting phases, powder X-ray diffraction analysis was carried out on the calcined powder. The high T_C superconducting phase ($Bi_2Sr_2Ca_2Cu_3O_{10}$, 2223 phase) is the main phase but a small amount of the low T_C phase ($Bi_2Sr_2Ca_1Cu_2O_8$, 2212 phase) remained.

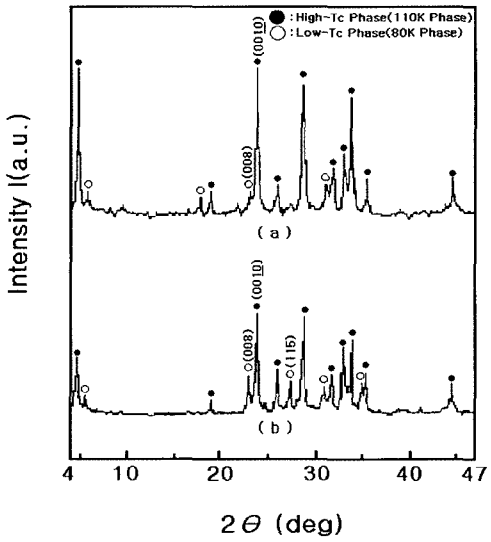

Fig. 1. The X-ray diffraction patterns of powdered superconducting BiSrCaCuO, (a) is the case of Ag_2O doped superconductor, (b) is undoped superconductor; • and ○ denote high Tc phase (110 K phase) and low Tc phase (80 K phase), respectively.

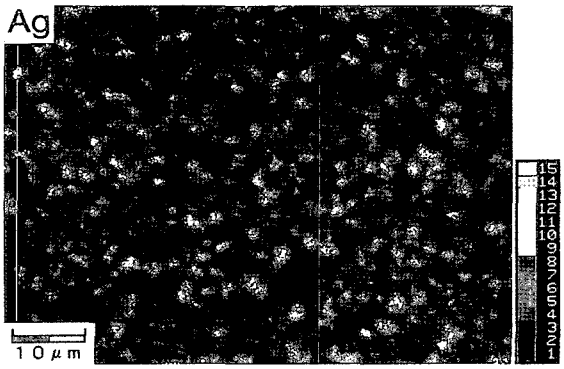

Fig. 2. PMA image of the BiSrCaCuO superconductor with Ag_2O addition.

The formation characteristics of the 2223 phase and the related superconducting property of Ag doped BiSrCaCuO were investigated. From the results, we infer that the formation of the 2223 phase depends on sintering condition.

The presence of Ag in the doped sample is attributed to the reduction of Ag_2O in oxide ceramics during reaction sintering, similar to those observed in the Ag_2O doped YBaCuO superconductor [4]. Dou et al. [9] reported that the formation of the 2223 phase was suppressed when the Ad doped superconductor was treated in air. They proposed that the major obstacle for the formation of the 2223 phase is the introduction of the Ag_2O-PbO-CuO solid solution by the Ag doping. The doped Ag was converted to Ag_2O in sintering, resulting in the preferential formation of the Ag_2O-PbO-CuO solid solution. As a result, the Cu deficient composition led to the degradation of Tc by the suppression of the formation of the 2223 phase. The degradation of Tc depended on the Ag content. In our experiment, however, the Ag doped superconductor showed high Tc as well as sufficient formation of the 2223 phase. Furthermore, our XRD and microstructural investigation for the Ag_2O doped superconductor revealed that the doped Ag_2O was converted to Ag metal phase in the superconducting matrix. Thus the possibility of the introduction of the Ag_2O-PbO-CuO solid solution by the oxidation of Ag into Ag_2O is excluded in the Ag doped HTS system. The variation of the lattice parameter of the 2212 phase was proposed as other evidence of the reaction among the doping elements and the superconduction phases. In the sample with 5wt% Ag, the c and parameters were reduced from 3.095 and 0.545 nm to 3.0175 and 0.530 nm, respectively. The reduction of the lattice parameters was a function of the Ag content. The lattice parameters of the 2212 phase and the 2223 phase for the superconductors were calculated from the XRD patterns

Fig. 3 shows the R-T curves of the sintered pellets with their XRD patterns shown in Fig. 1. Their zero -resistance temperature, Tc(0), was found to be 105K. The transition temperature T_C of all specimens tested was shown to be 105 K.

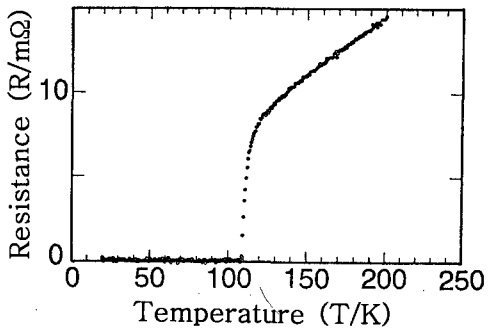

Fig. 3. Temperature dependence of the electrical resistance of BiPbSrCaCuO.

The voltage–current characteristics of a doped Ag_2O BiSrCaCuO superconductor are indicated in Fig. 4.

The curves (a) and (c) were obtained at the external magnetic field at 77 K.

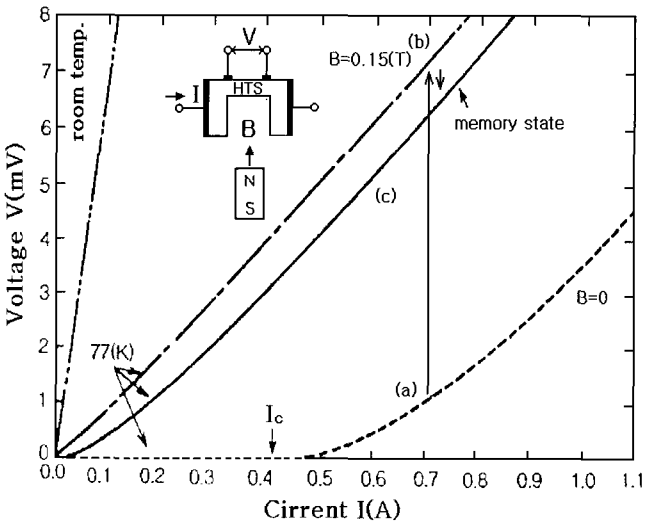

Fig. 4. Voltage–current characteristics of the HTS superconductor.

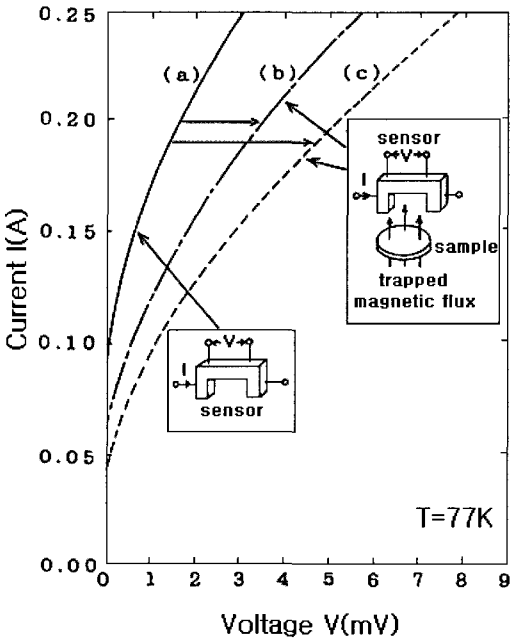

Fig. 5. Detection of the trapped magnetic flux in HTS superconductor by using a magnetic sensor of YBaCuO superconductor.
(a) Current-Voltage characteristics of the YBaCuO superconductor used as a magnetic sensor.
(b) Current-Voltage characteristics of the magnetic sensor when the Ag_2O doped HTS superconductor is set closely to the sensor.
(c) Current-Voltage characteristics of the magnetic sensor when undoped HTS superconductor is set closely to the sensor.

The curve (b) at 77 K gradually approaches the curve (c) after the removal of the external magnetic field. If the voltage is applied again after returning to zero voltage, related V–I characteristics are shown in curve (c). This means that the sample is in the memorized state. The voltage V_{MAG} that appeared across the field cooled HTS sample increased with the external magnetic field, showing a linear region in the range between 10^{-4} and 3×10^{-3} T.

The change of the I-V curve of the magnetic sensor indicates that magnetic flux from the external magnetic field was trapped in the BiPbSrCaCuO superconductor and the trapped flux was detected by the YBaCuO superconductor magnetic sensor. When the external magnetic field is applied to the YBaCuO superconductor magnetic sensor, some regions of the magnetic sensor will be destroyed, especially the weak link regions and the defective areas. The destroyed regions will be increased with the rise of the magnetic flux.

This causes the increase in the voltage drop. In other words, some superconduction parts are cut-off and the voltage drop across the magnetic sensor appears. The curve (a) in Fig. 5 is the I-V curve of the YBaCuO superconductor magnetic sensor, the curve (b) is that for the undoped sample in which trapped magnetic flux is placed close to the sensor, and the curve (c) is that for the case of the Ag_2O doped sample with trapped magnetic flux. As shown in Fig. 5, the change of the I-V curve due to the trapped flux in the Ag_2O doped sample is larger than that due to the trapped flux in the undoped sample, indicating that more flux was trapped in the Ag_2O doped sample. Therefore, Ag_2O in the BiPbSrCaCuO superconductor acts as the pinning center, strengthening the magnetic properties [10-11].

4. Conclusion

The electromagnetic properties of both the Ag_2O doped and undoped BiSrCaCuO superconductor were evaluated to investigate the contribution of the pinning centers. It was confirmed experimentally that a larger amount of magnetic flux was trapped in the Ag_2O doped sample than that in the undoped one, indicating that the pinning centers of magnetic flux are related closely to the occurrence of the magnetic effect. We have fabricated superconductor ceramics by the chemical process. The relation between electromagnetic properties of the Bi HTS and external applied magnetic field were studied. The electrical resistance of the superconductor was increased by the application of the external magnetic field. However, the increase in the electrical resistance continued even after the removal of the magnetic field. The reason is as follows; the magnetic flux due to the external magnetic field penetrates through the superconductor and the penetrated magnetic flux is trapped after the removal of the magnetic flux. During the sintering, doped Ag_2O was converted to Ag particles that were finely dispersed in superconductor samples. It is considered that the area where normal conduction takes place increases by adding Ag_2O and the magnetic flux penetrating through the sample increases. The results suggested that Ag_2O acts to increase pinning centers of magnetic flux, contributing to the occurrence of the electromagnetic properties.

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