Characteristics of a Bulk High-Critical Temperature Superconductor Fabricated by the Shock Compaction Method: Possible Use as a Highly Sensitive Magnetic Sensor

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Abstract : A magnetic sensor, constructed of bulk Bi-Pb-Sr-Ca-Cu-O (BPSCCO), was fabricated by use of the shock compaction method, employing a propellant gun-system, and then sintered under through use of an electronic furnace. The specimen as a magnetic sensor was maintained in the superconducting state at 77.4 K, under a current density J of approximately 40 A/cm^2 in the absence of an excitation magnetic field B_{ex}. The superconducting state was then broken and the specimen exposed to a B_{ex} value of 40×10^{-4} T. That is, the resistance R_{meas} of the specimen occurred when exposed to 40×10^{-4} T under a constant J of 40 A/cm^2. The magnetic sensitivity S of the specimen was approximately 13 %/(10^{-4} T) over the range of measurement of the magnetic field B_{meas} from 0 to $\pm5\times10^{-4}$ T, under a constant 40×10^{-4} T for the value of B_{ex}, being approximately 13 times greater than that of a giant magnetoresistance (GMR) sensor. It was, consequently, determined that it was possible to apply the bulk BPSCCO specimen as a highly sensitive magnetic sensor.

１．はじめに

In constructing highly sensitive magnetic sensors, the present authors have been studying the use of bulk Bi-Pb-Sr-Ca-Cu-O (BPSCCO) as the magnetic sensor, which was fabricated by use of the shock compaction method, employing a propellant gun-system. The BPSCCO specimen as a magnetic sensor was maintained in a superconducting state at 77.4 K under a current density J of about 40 A/cm^2 in the absence of excitation magnetic field B_{ex}. The superconducting state was then broken and the specimen exposed to a B_{ex} value of 40×10^{-4} T. That is, the resistance R_{meas} of the specimen occurred when exposed to 40×10^{-4} T under a constant J of 40 A/cm^2. The magnetic sensitivity S of the specimen was estimated as 13%/(10^{-4} T) over the range of measurement of the magnetic field B_{meas} from 0 to $\pm5\times10^{-4}$ T, under a constant B_{ex} of 40×10^{-4} T, being about 13 times greater than that of a giant magnetoresistance (GMR) sensor. Consequently, it was determined that the bulk BPSCCO specimen could be possibility used as a highly sensitive magnetic sensor.

２．研究経過

In the fabrication of the bulk BPSCCO specimens to be used as magnetic sensors, commercial BPSCCO powder (Dowa Mining Co., Ltd., DSC-045001) was formed into pellets by using a compressor under pressures ranging from 200 to 300 MPa. The pellets were further subjected to shock compaction pressures of about 4 GPa for about 1 μsec. The specimens were sintered under a temperature of 845 °C for 48 hours, by heating in dry air to a temperature of 845 °C at the rate of 14 °C/min, cooled in dry air to a temperature of 300 °C at the rate of 5 °C/min, and then cooled to room temperature by a natural cooling. The pellets, measuring 0.5 mm in thickness and 10 mm in diameter, were cut into rectangular-shaped test specimens using a diamond saw at a low cutting rate to reduce the effects of heat.

The magnetic characteristics were evaluated with all sensors placed in an excitation magnetic flux density B_{ex}, that is, a homogeneous DC magnetic field. The B_{ex} was applied perpendicular to the surface of the sensors which measured 9.4 mm in length and 1.7 mm in width. The measuring system used in obtaining the magnetic characteristics was shielded by two Mu-metal cylinders around a metal dewar vessel. The four-terminal method was used during resistance measurements of the sensors.

３．研究成果

The change in resistance of the sensor with the shock compaction method due to the measuring flux density B_{meas} do not exhibit a normal state for values of B_{ex} under 40×10^{-4} T and values of J less than 35 A/cm^2. Therefore, a magnetic measuring system can be constructed in order to realize a normal state of the sensor, and is biased for a homogeneous DC magnetic flux density B_{bias} of 40×10^{-4} T. The B_{bias} is applied perpendicular to the surface of the magnetic sensor by use of a Helmholtz coil. These, in turn, are shielded by a metal dewar which holds liquid nitrogen at room temperature (300 K), and two layers of permalloy sheets.

The magnetic sensitivity S can be defined as

$$S = \frac{100}{B_{\mathrm{meas}}} \cdot \frac{R_{\mathrm{meas}}(B_{\mathrm{meas}}) - R_{\mathrm{meas}}(B_{\mathrm{meas}} = 0\ \mathrm{T})}{R_{\mathrm{meas}}(B_{\mathrm{meas}} = 0\ \mathrm{T})} \quad \%/(10^{-4}\ \mathrm{T}). \tag{1}$$

Here, $R_{\mathrm{meas}}(B_{\mathrm{meas}})$ and $R_{\mathrm{meas}}(B_{\mathrm{meas}}=0\ \mathrm{T})$ are the resistance in a measure magnetic field B_{meas}, and that in the absence of a magnetic field, respectively. The values of magnetic sensitivity S increase as the values of ρ decrease, such as shown in Figs. 1 and 2. These results demonstrate that, the value of S can be readily controlled by the value of J. Figures 1 and 2 are the results for the sensors with and without the shock compaction method, respectively.

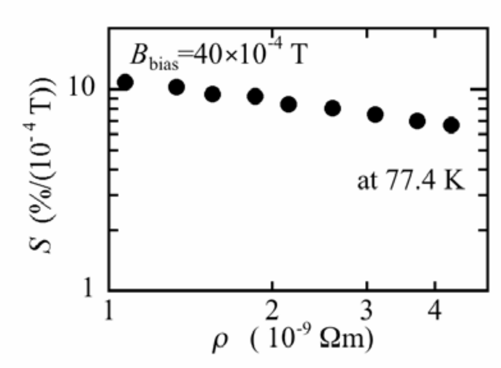

Figure 1. The sensitivity S for the sensor constructed with the shock compaction method as a function resistivity of ρ, under a constant condition of B_{bias} of 40×10^{-4} T.

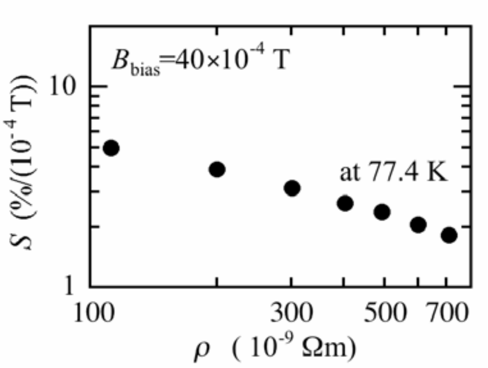

Figure 2. The sensitivity S for the sensor constructed without the shock compaction method as a function of ρ, under a constant condition of B_{bias} of 40×10^{-4} T.

The solid circles in Fig. 3 reveal the dependence of resistance $R_{\mathrm{meas}}(B_{\mathrm{meas}})$ of the sensor constructed with the shock compaction method on the measure magnetic field B_{meas} over the region of ±5×10^{-4} T, under temperature condition of 77.4 K. Here, the values of $R_{\mathrm{meas}}(B_{\mathrm{meas}})$ have been normalized by the value of $R_{\mathrm{meas}}(B_{\mathrm{meas}}=0\ \mathrm{T})$. It was found that no hysteresis characteristics occurred over the range of B_{meas} values of ±5×10^{-4} T. The S of the sensor constructed with the shock compaction method was about 13 %/(10^{-4} T) over the range of measurement of the magnetic field B_{meas}, being approximately 13 times greater than that of a giant magnetoresistance (GMR) sensor. In addition, the open circles in Fig. 3 are the results for the sensor without the shock compaction method. From the results of Figs. 1, 2, and 3, it was found that the sensitivity S of the magnetic sensor was improved by use of the shock compaction method.

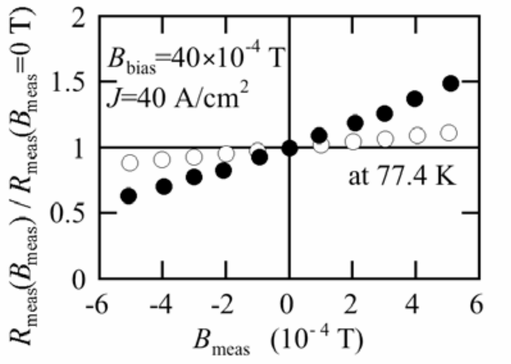

Figure 7. The dependence of $R_{\mathrm{meas}}(B_{\mathrm{meas}})$ for the sensors with (solid circles) and without (open circles) the shock compaction method on the measure magnetic field B_{meas}.

４．まとめ

As one of the basic areas of research for the fabrication of a highly sensitive magnetic sensor, the present paper has examined a superconducting magnetic sensor, namely, that constructed from bulk BPSCCO, by use of the shock compaction method. From the all characteristics of the sensor constructed with the shock compaction method, it was found that the sensitivity S of the magnetic sensor was improved by the shock compaction method. These results were found to be important criteria for designing a highly sensitive magnetic sensor.

５．発表（投稿）論文

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