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Electromagnetic Properties of Bi System Superconductor for Magnetic Levitation Car Maglev

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Abstract - Effects of Ag_2O doping on the electromagnetic properties in the BiSrCaCuO superconductors. The electromagnetic properties of the Ag_2O doped and undoped BiSrCaCuO superconductor were evaluated to investigate the contribution of the pinning centers to the magnetic effect. It was confirmed experimentally that a large 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. 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 acts to increase the pinning centers of the magnetic flux, contributing to the occurrence of the electromagnetic properties.

Keywords: Ag, Electromagnetic effect, Flux, Magnetic property, Pinning.

1. Introduction

The recent worldwide success in applying high temperature superconductors to electric power components, such as motors, cables, and current limiters, has renewed the interest in this technology. These achievements were only possible due to the rapid worldwide progress in developing high Tc superconductor wire and tape with acceptable performance for these prototype demonstrations [1-3].

This talk will briefly highlight the performance of high Tc superconductor wire and tape related to the current and long-range objectives of these power system related applications. The major problems facing this technology will be discussed, as well as the prospects for commercialization and integration into the utility sector. The eventual widespread utility acceptance for superconducting power equipment will ultimately be based on several key factors; the system performance must be improved over conventional technology; the efficiency, reliability and maintenance must be comparable to conventional power equipment; the life cycle costs must be lower; and the installed costs must be highly competitive and justifiable to the utilities. The later is impacted by the current high cost of high Tc superconductors.

The response of the superconductor to the magnetic field is one of the fundamental characteristics in which magnetic flux is repelled (Meissner effect) and it produces a levitating force. Superconductor levitation over a permanent magnet and vice verse has attracted significant engineering attention because it offers non-contact lubrication and virtually friction free bearing systems, such as the hybrid superconducting magnetic levitation (HSMB) system by McMichael et al. [4], ISTEC by Fukuyama et al. [5], and superconductive magnetic levitation car (Maglev) [6].

Flywheel energy storage is the most prospective of the applications. In the present work, the effects of Ag_2O doping on the magnetism and superconductor levitation/ suspension of the BiPbSrCaCuO superconductor were investigated in view of flux pinning.

2. Experimental

Samples were made by the conventional solid state method using Bi_2O_3, PbO, $SrCO_3$, $CaCO_3$, and CuO powders of 99.9% purity. The molar ratio of the starting materials was 1.84: 0.34: 1.91: 2.03: and 3.06, respectively for Bi: Pb: Sr: Ca: Cu and the powder mixture was calcined in an alumina crucible at 810℃ for 24h in air. After grinding the calcined cake, the precursor powder was mixed with Ag_2O powder of 99.9% purity.

The powder mixtures were pressed into pellets under $300 kg/cm^2$, followed by sintering at 830-850℃ for various time periods up to 120 h. The disk sample with a

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diameter of 8mm and thickness of 1mm weighed 0.3g. The magnetization characteristics of the Ag_2O doped and undoped BiPbSrCaCuO samples were examined by $\triangle M=M^+-M^-$ obtained from the hysteresis curves with a 3×3×5mm specimen using a vibrating sample magnetometer (VSM) between 0 to 0.2T at 77K.

The temperature dependence of DC susceptibility was measured using a magnetic balance at a static magnetic field of about 7×10^{-3} T. The toroidal magnet used in this study was a samarium cobalt rare earth NEOMAX, B=0.15 T. The distribution of magnetic flux density along the axial direction was measured by using a gaussmeter, LakeShore INC.

3. Experimental Results and Discussion

Fig.1 shows an example of a stable superconductor levitation and suspension of 2% Ag_2O doped sample above and beneath a toroidal magnet. The floating height between the bottom surface of the sample and the top surface of the toroidal magnet, and the suspension distance between the top surface of the sample and the bottom surface of the toroidal magnet were 2mm and 3mm, respectively. The 2% Ag_2O doped sample in suspension was in field cooled condition, cooled to 77K, in the presence of the magnetic field of the toroidal magnet having magnetic flux of about 0.1T. The flux density is almost zero in the region located about 3mm from the lower surface of the toroidal magnet.

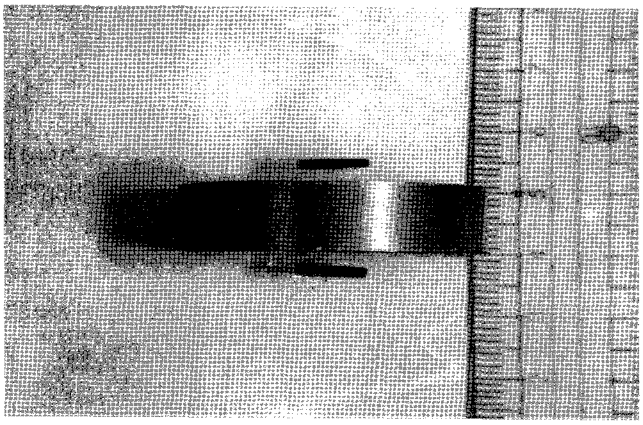


Fig. 1. 2% Ag_2O doped sample stable superconductor levitation and suspension above and beneath a toroidal magnet.

The difference in the magnetization, $\triangle M=M^+-M^-$, showed that the magnetization decreases with applied field due to the increase in the intrinsic pinning by normal conducting volume. $\triangle M$ increases with dopent, maximizing at 2% doping, and decreases with further doping of 10% and 20% as indicated in Fig. 2. The magnetic flux is generated by a vortex current that circulates around the vortex with a sense of rotation opposite to that of the diamagnetic screening surface current. 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.

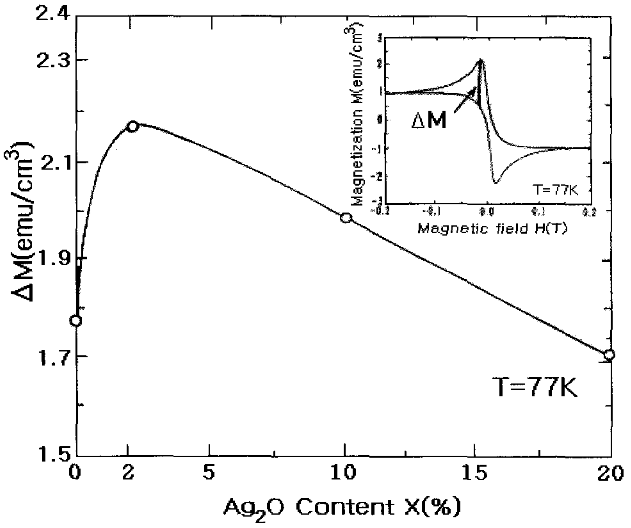


Fig. 2. $\triangle M$ dependence on Ag_2O addition from the characteristics of magnetization hysteresis.

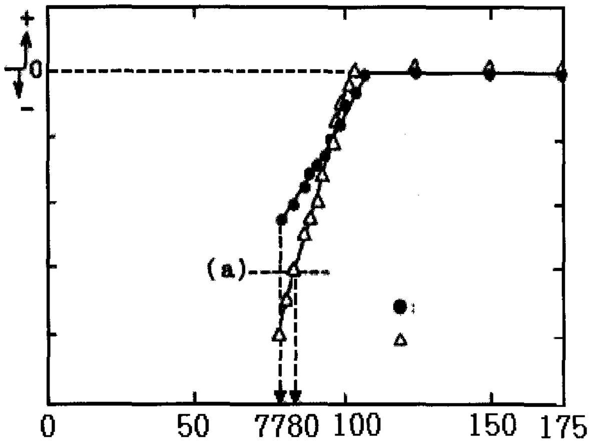


Fig. 3. Temperature dependence of dc susceptibility in the BiPbSrCaCuO superconductor.

The temperature dependence of DC susceptibility measured between 77K and 175K is shown in Fig. 3. The diamagnetic transition occurs nearly at the same temperature for both doped and undoped samples.

However, the greater temperature dependence for the undoped sample, $(dx/dT)_{undoped} > (dx/dT)_{doped}$, indicates the greater diamagnetism for the undoped sample than the doped sample in which 2% of normal conducting Ag_2O was doped. 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 acts to increase the pinning centers of the magnetic flux, contributing to the occurrence of the electromagnetic properties. The larger diamagnetism in the undoped superconductor repels externally applied magnetic field and creates a mirror image of the external magnet producing levitation force.

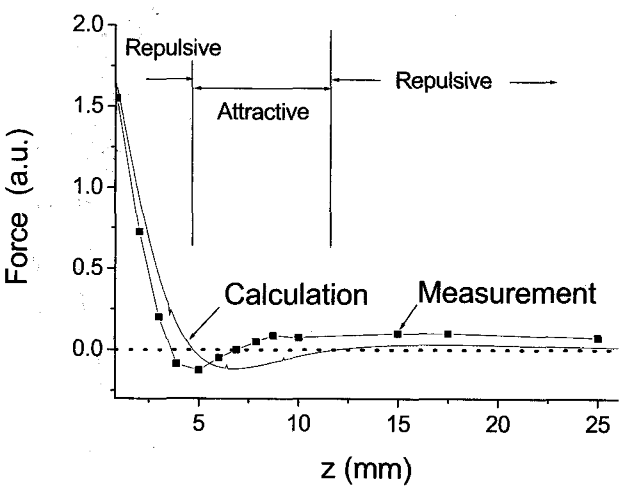
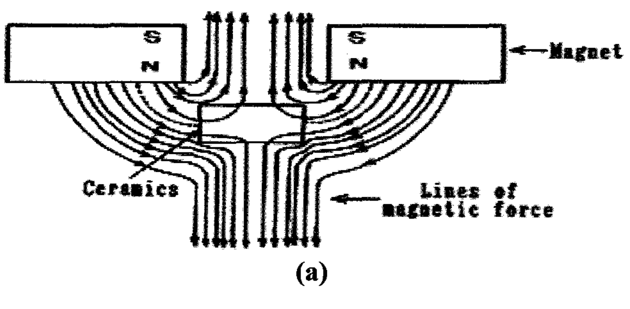


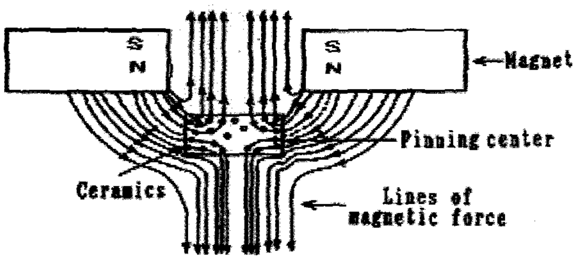
Fig. 4. Magnetic force exerted from the HTS sample in the non-linear magnetic field of the toroidal magnet.

The interaction force between a 2% Ag_2O doped HTS sample and a toroidal magnet is calculated and compared with the measured force by using an electronic balance along the symmetrical axis of the toroidal magnet as a function of axial distance (see Fig. 4). The presence of a HTS sample perpendicular to the non-linear magnetic field of a toroidal magnet distorts the distribution of the original field lines. As a result, the interaction force between the magnet and the sample exhibits a sort of concave shape consisting of the regions of repulsive force ($Z < 4.8$ mm), attractive force (4.8 mm $< Z < 11.8$ mm), null force ($Z = 4.8$ mm and 11.8 mm) and repulsive force ($Z > 11.8$ mm). The results in Fig. 4 indicate that the force exerted on the HTS sample changes the direction with respect to the null force points along the Z-axis. The repulsive force in the repulsive force region along the +Z direction balances the weight acting in the -Z direction, resulting in the stable levitation above a toroidal magnet. Similarly, by the symmetry with respect to the Z=0 plane, the suspension of the HTS sample occurs in the attractive region by balancing the weight. The asymmetric concave shaped magnetic force forms a vertical conical shaped magnetic wall around a levitated/suspended HTS sample, as demonstrated with a bowl shaped Type I superconductor lead providing a gravitational minimum value of the leading lateral stability. Thus, the lateral stability of the levitated/suspended HTS sample above/beneath a toroidal magnet is achieved by the characteristics of the asymmetric nature of the magnetic force with respect to the axis of the magnet.

The flux density is almost zero in the region located about 3mm from the lower surface of the toroidal magnet. The dotted line in Fig. 5 indicates the zero flux location where the suspension occurs when the superconductor is confined in this region. Fig. 5 (a) is the case for the Ag_2O undoped sample under the magnetic field in which the diamagnetism is weak at 77K, magnetic flux is trapped at numerous pinning centers, and the magnetic attractive force appears between the toroidal magnet and the sample. The number of pinning centers is small in the undoped sample and also in the magnetic attractive force. Thus, the magnetic suspension hardly occurs. However, when the temperature rises, the low Tc phase (80K phase) in the superconductor becomes a pinning center and the magnetic attractive force which lifts the undoped sample is added to the force due to the diamagnetism. Fig. 5 (b) is the case for the Ag_2O doped sample under the magnetic field in which the diamagnetism is weak at 77K as described in the A, magnetic flux is trapped at numerous pinning centers, and the magnetic attractive force appears between the toroidal magnet and the sample. Therefore, the magnetic attractive force due to the pinning centers and diamagnetic effect of the superconductor in the magnetic field from the toroidal magnet are superimposed, thereby causing the suspension.



(a)



(b)

Fig. 5. The distribution of magnetic flux of toroidal permanent magnet. (a) undoped BiSrCaCuO superconductor. (b) Ag_2O doped and undoped BiSrCaCuO superconductor.

4. Conclusion

Electromagnetic properties of Ag_2O doped and undoped BiPbSrCaCuO superconductors were evaluated to account for the magnetic suspension of a BiPbSrCaCuO superconductor under a toroidal permanent magnet. Since the diamagnetism effect at 77K is larger in the undoped sample than the Ag_2O doped sample, the invasion of the magnetic flux to the undoped sample is harder. That is, since the magnetic flux penetrating the undoped sample is smaller, the influence of the pinning center is weak and the suspension hardly takes place. On the other hand, in the Ag_2O doped sample, the diamagnetism is relatively weak at 77K and the magnetic flux easily penetrates the sample. Therefore, the influence of the pinning center is strong and the suspension is noticeable at 77K. The pinning center of the magnetic flux is related to suspension and the Ag_2O acts as the pinning center to the magnetic flux, thereby causing magnetic suspension to occur. In addition, the occurrence mechanism of the suspension was explained by using the qualitative model based on the relationship between the pinning center and the distribution of the magnetic flux from a toroidal permanent magnet.

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