High T_c Superconductor Applications and Thick Film Preparation

Dea-Wha Soh, *Member, KIMICS,* **Zhanguo Fan,** *Nonmember*

Abstract**—**High T_c superconducting lines will be applied as key materials in the areas of power transmission line; magnetic levitation of vehicle; magnetic separation; magnetic energy storage and marine propulsion. A combination method of electrophoresis deposition and zone-melting for preparation of YBaCuO tape is proposed. The submicron particle powder of YBaCuO made by sol-gel method is used in the electrophoresis process. A 40~50 ㎛ thickness of YBaCuO film on Ag plate could be deposited in about three minutes. After deposition the film is rolled and heat treated in order to increase the density and the adhesion of the film to the Ag plate. Silver(Ag) and lead oxide(PbO) were added in the YBaCuO powder in order to reduce its melting point. The YBaCuO coating with controlled Ag and PbO contents was preliminarily zone-melted at about 945℃.

Index Terms**—**Electrophoresis, Zone-melting, YBaCuO, Thick film, Applications.

I. INTRODUCTION

The high T_c superconductors are the promise materials in the applications of the fault current limiting device, the current lead, and the power transmission etc[1,2]. Especially, for making high magnet in liquid nitrogen temperature the high T_c superconductors are even hopeful, because of the high magnetic field and small dimension of the magnet. The high magnetic field can be used in the areas of separation of mixed particles, the magnetic levitation vehicle of the transportation[3], as well as the marine propulsion[4]. The typical high T_c superconductors are $YBa_2Cu_3O_x$ (T_c=90 K) and $(BiPb)_2Sr_2Ca_2Cu_3O_y$ (T_c=110 K). Because the melting point of $(BiPb)_2Sr_2Ca_2Cu_3O_y$ is lower than that of silver, it can be fabricated to superconducting wire or tape by PIT method, which can be used for making magnetic coil. The drawback of superconducting BiPbSrCaCuO is that its critical current decreases very fast with the increasing magnetic field. Therefore the scientists make efforts to find effective flux pinning center in $(BiPb)_2Sr_2Ca_2Cu_3O_y$, meanwhile $YBa_2Cu_3O_x$ superconductor which has good superconductivities under high magnetic field, are being tried to fabricate wire or tape by many methods[5,6,7]. In the paper a combination of electrophoresis deposition and zone-melting process is proposed to make YBaCuO tape.

In order to prepare the YBaCuO tape by means of zone-melting method in air, Ag based alloys were planed to synthesize as the substrate of YBaCuO thick film. In the other way, some chemicals such as Ag, PbO, which could decrease the melting point of YBaCuO, are added in YBaCuO powder. If the melting point of YBaCuO can be reduced to below the melting point of silver, the silver tape could be used for the substrate of YBaCuO thick film. The superconductivities (T_c and J_c) of YBaCuO samples with different addition contents were measured. By means of the relation between superconductivities and the additive contents, the maximal additive content which do not reduce the superconductivities could be determined.

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II. APPLICATIONS OF HIGH T_c SUPERCONDUCTORS

1. Transmission Lines

One consideration of using superconductive line is the efficiency of energy transmission. The electric energy is transferred from a source to load over the transmission line, on which some parts of power dissipate into air by Joule heat of the line resistance. If the superconductive line which has not resistance and can carry large current were used, a lot of energy (Ohmic losses) would be saved and the transformers in both sides of sources and utilities would be deleted. The other consideration is the city aesthetics. The use of superconductive line is one of the methods for putting the power lines underground.

2. Magnetic Levitation

There are a variety of ways that magnetic levitation (Maglev) of trains can be achieved. The most designers use conventional magnets for magnetically levitated trains. The most possible application of superconductivity is that of maglev trains, proposed to run at 500 ㎞/hr. The superconducting electromagnet on vehicle could provide even high field to lift the vehicle 10~20 ㎝ above the guiderail. Two different kinds of maglev are competing in todays development. The difference is the way the vehicle attaches to the guideway : either attractive levitation forces (electromagnetic suspension) or repulsive forces (electrodynamic levitation).

3. Magnetic Separation

Magnetic separation of ores has been used with success for decades in the mining industry. Conventional electromagnets separate iron from aluminum or copper scrap; magnetic field are not generally strong enough to divert impurities from water or flue gas streams. However, a superconducting magnet of 20 T would be a very effective separation device. The superconducting magnet is designed for the separation due to its high magnetic field. Nowadays the idea of superconducting magnetic separation will be applied for water purification.

4. Magnetic Energy Storage

If a hydroelectric plant is not run around the clock, energy is simply wasted. One of the storage ways for the power produced in the night is pumped hydropower. Water is pumped to an elevated location at night, and drained through turbines to generate power the next day. Limitations on the pumped hydropower include finding an appropriate site, relatively low (75%) efficiency, and environmental impacts. The superconductivity technology will be used in 21st century for the Magnetic Energy Storage (MES). The energy is stored in the magnetic field of a rather large, underground superconducting solenoid. For a persistent current level I in the MES inductor L, stored energy is $LI^2/2$. The solenoid is reversibly connected to the external power system via a rectifier inverter power conversion system. When demand is low the ac line is rectified to supply dc current to the solenoid. During peak demand periods, the dc current in the solenoid is inverted to 60 Hz and fed back into the power grid, 95% efficiency for superconducting MES is expected.

5. Motor in Marine Propulsion

A very large scale example of the use of high magnetic fields is that of magnetohydrodynamic (MHD) ship propulsion. The Lorentz force on a charge moving in a magnetic field is

$$\mathbf{F} = q\mathbf{V}\times\mathbf{B}$$

Therefore, if a current flows in a circle around a magnetic field line, a force will be created that is perpendicular to both. The ions in seawater will experience a force while orthogonal **E** and **H** fields are applied to seawater. To accelerate a ship the force must be directed along the axis of the ship, through a thruster tube, rather like a jet engine.

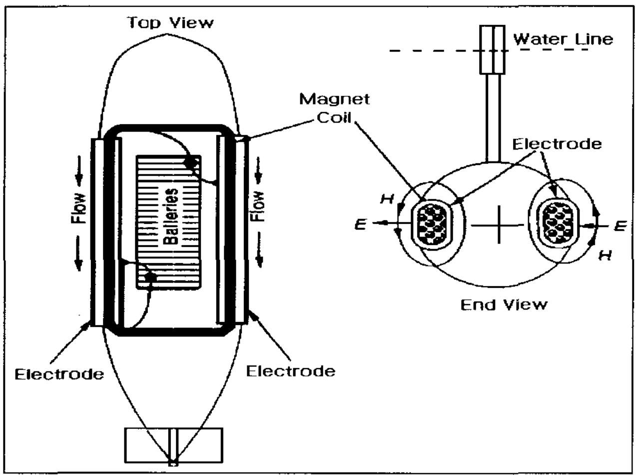

Fig. 1 Illustration of construction of MHD propelled submarine.

This requires that the flowing current and the magnetic field lie in the cross-section of the ship. Obviously, as **B** increases, so does the acceleration. In the first design (see figure 1), the orthogonal **E-H** fields are applied at the outside surface of the vessel. This has the advantage of efficiency; large volumes of fluid can be pumped. A drawback, particularly for military submarines, is that the enormous **H** fields could be easily detected. In the second design, the electrodes are housed in a longitudinal tube that is contained within the vessel. While somewhat less efficient, this approach has the advantage that it is possible to confine the **E** and **H** fields within the vessel.

III. EXPERIMENT DESIGN AND DISCUSSIONS

The superconducting wires or tapes are the key and important materials for the construction of high magnetic fields used in above applications. In the study of superconducting wires or tapes with high critical current density at high magnetic field, a combination method of electrophoresis deposition and zone-melting technique is proposed, which can be operated in air.

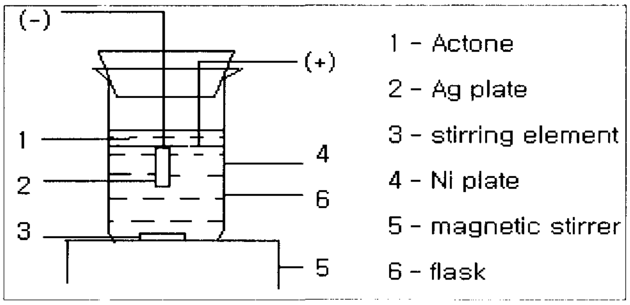

Fig. 2 Device of electrophoresis deposition for YBaCuO thick film

1. Deposition of YBaCuO Thick Films by Electrophoresis

During the electrophoresis process the original powder is required to be rather tiny particles. If the superconductor particles in the solvent are too large, on the one hand they will sediment quickly, and on the other the deposited films after sintering tend to crack which will lead to the decreasing their critical transport currents. Since well-distributed and compact films show better properties, the fine powder of YBaCuO made by sol-gel method [8] is suspended in the electrophoresis solution.

The YBaCuO thick film was deposited by the electrophoresis, of which the experimental details was described in the previous paper [9]. The device for electrophoresis is shown in figure 2. 20 mg of iodine and 2 mg of fine YBaCuO powder per 100ml acetone were used in the Pyrex beaker under which a magnetic stirrer stirred 5 minutes before each deposition in order to make homogenous suspension of the YBaCuO powder in the electrophoresis solution. A 40~50 μm thickness of YBaCuO film on Ag plate could be deposited in about three minutes. After deposition the film is rolled and heat treated in order to increase the density and the adhesion of the film to the Ag plate.

2. Zone-melting of the thick film deposited by electrophoresis

The orientation of YBaCuO should be formed in the process from the partial melted state slowly cooling down to condensed state. The melting temperature of YBaCuO is about 1010℃ in air, therefore Ag (961℃ of melting point) can not be used as substrate. In the experiment fragments of Ag-Pd alloy was used as substrate of YBaCuO. When Pd content is 20 wt%, the melting point of Ag-Pd alloy is 1060℃. In the experiment zone melting temperature was selected to 1040℃, and moving speed of the sample was 2 ㎜/hour. The critical current density is smaller than 100 A/㎠. The reason of the small J_c may be due to the low temperature (1040℃) for zone-melting in air. If the melting point of Ag-Pd alloy is increased, the content of Pd in the alloy needs to increase. It is impossible to use the noble metal Pd for either research experiment or applications. Therefore the reduction of melting point of YBaCuO is carried out. Silver(Ag) and lead oxide(PbO) were added in the YBaCuO powder in order to reduce its melting point in the experiment. When Ag content is less than 15 wt%, it does not have effect on the superconductivity, but it can diminish the micro cracks in the textured YBaCuO. PbO is added in the Bi-system superconductor to make Pb substitution for some Bi positions to increase the stability of Bi-2223 phase, which was thought that PbO may not have effect on the superconductivity of YBaCuO, but reduce the melting point. The experimental results are desirable, which can be seen in figure 3. Both of Ag and PbO can reduce the melting point of YBaCuO respectively. When Ag (10%) and PbO (10%) were added at the same time the melting point of YBaCuO can be reduced to 943℃.

The process of electrophoresis deposition of YBaCuO film with controlled contents of impurities is complicated, which may be studied hereafter. Instead the YBaCuO coating with controlled Ag and PbO contents was preliminarily zone-melted at about 945℃. The critical current densities (J_c) of the zone-melted samples are 54, 75, 160, 80 A/㎠. For comparison the J_c value of electrophoresis deposited YBaCuO thick films are 1215, 1458, 1921 A/㎠. Increasing J_c of the samples after zone-melting would be expected results, but after zone-melting J_c was decreased, which may be because of the microcracks created in the thick films in the cooling down process of the melted samples. It will be improved in the hereafter experience.

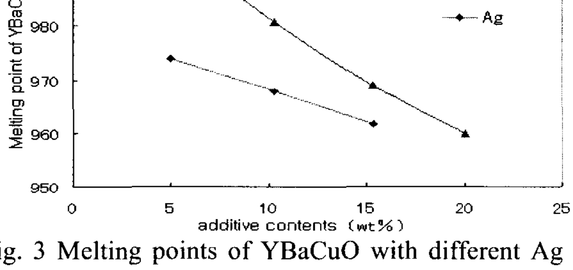

Fig. 3 Melting points of YBaCuO with different Ag or PbO content.

IV. CONCLUSIONS

High T_c superconductors, especially the high magnet made of superconducting wires will be useful in scientific research, industry, aerospace, maritime etc. The superconductivity of high T_c $(BiPb)_2Sr_2Ca_2Cu_3O_y$ need to be improved. YBaCuO wire may be promise material due to its high critical current density in high magnetic field. It is difficult for making YBaCuO wire or tape by Oxide Powder In Tube (OPIT) because its melting point is about 50℃ higher than that of Ag, which is used as tube in OPIT method. The combination of electrophoresis deposition and zone-melting technique was designed, instead of the other YBaCuO deposition in vacuum on textured metals with textured buffers. That method is simple process worked in air, but that either increasing the melting point of Ag-alloys for substrate, or reducing the melting point of YBaCuO by additives, is needed. The zone-melting of YBaCuO thick film with additives is being tested.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. Wesche, High-temperature Superconductors, Kluwer Academic Publishers, Boston, 1998.

[2] A. R. JHA, Superconductor Technology, John Wiley & Sons, New York, 1998.

[3] Thomas P. Sheahen, Introduction to High-Temperature Superconductivity, Plenum Press, New York, 1994.

[4] James D. Doss, Engineers Guide to High-temperature Superconductivity, John Wiley & Sons, New York, 1989.

[5] Y. Iijima, M.Hosaka, N. Tanabe, et al, J. Mat. Res., Vol. 12, p. 2913, 1997.

[6] M. Fukutomi, S. Aoki, et al, Physica C, Vol. 219, p. 333, 1994.

[7] K. Onabe, H. Akata, in: T. Yamashita (Eds.), Adv. Superconductivity VII, Springer, Tokyo, p. 598, 2000.

[8] F. H. Lee, J. Wang, D. W. Soh, Z. G. Fan, J. Chinese Rare Earth Society, Vol. 20, p. 501, 2000.

[9] D. W. Soh, Y. Q. Shan, J. C. Park, et al, Physica C, Vol. 337, p.44, 2000.

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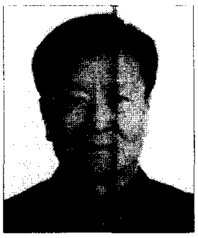

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