Development of $REBa_2Cu_3O_x$ Coated Conductor on Textured Metal Substrate

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Sumitomo Electric had been using textured Ni-alloy substrates in its development of $REBa_2Cu_3O_x$ (RE123) coated superconducting tapes. Here, RE means Ho and Gd. The Company has successfully fabricated a Ho123 superconducting coated conductor on Ni-alloy tape that is 200m and has an Ic value of 205 A/cm-width. However, Ni-alloy substrates are unsuitable for AC applications because of high magnetic loss of Ni. Moreover, Ni-alloy substrate has low mechanical strength. Therefore, the authors have developed a new textured metal substrate called a clad-type substrate. The clad-type substrates have low magnetization and high mechanical strength. However, Ic of superconducting coated conductors prepared on clad-type substrates was lower than that of superconducting coated conductors prepared on Ni-alloy substrates.
The authors conducted focusing on causes of low Ic, and found that it is originated by defects on surface of clad-type substrates in most cases. Based on this finding, the authors smoothed surface of clad-type substrates. As a result, the Ic values of the coated conductors prepared on with smooth surfaces were close to those of the coated conductors prepared on Ni-alloy substrates.

1. Introduction

$REBa_2Cu_3O_x$ (RE: Y and rare-earth elements) coated conductors are a prospective material for use in various applications.(1) Examples of applications are power transmission cables, superconducting magnetic energy storage systems (SMESs) and electrical transformers. The authors are researching the application of RE123 conductors to AC cables.

In general, RE123 conductors are in the form of a multi-layer tape comprising a metal substrate, buffer layers, a superconducting layer, a stabilization layer, and a protective layer. It is important that the superconducting layer of a RE123 conductor is biaxially oriented and has a high crystallinity. There has been two methods for obtaining a biaxially oriented texture. One method is to prepare an oriented buffer layer on an amorphous layer, and the other method is to prepare a textured metal substrate.(2) The authors use the latter method for obtaining textured metal substrates.

Textured metal substrates can be made from face centered cubic(FCC) metals, such as Cu, Ni, Ag and their alloys.(2) The authors used textured Ni alloys as substrates.(3)-(5) However, Ni-alloy substrates are unsuitable for use in AC applications. This is because textured Ni alloys have high magnetization loss and low mechanical strength. High magnetization loss can cause high AC loss and low mechanical strength makes handling of RE123 conductors difficult. To solve these problems, several reports have been made on the development of textured Ni-alloys that exhibit low magnetization loss at 77.3K. The authors developed a new type of textured metal substrate and called it "clad-type" substrate. The clad-type substrate has low magnetization loss and high mechanical strength. However, the critical current (Ic) of a RE123 conductor grown on the clad-type substrate had been lower than that of a RE123 conductor grown on the Ni-alloy substrate. In this paper, the authors report on the development of a high-Ic RE123 conductor grown on the clad-type substrate.

2. Architecture and preparation method of RE123 conductor

The developed RE-123 conductor is composed of a textured metal substrate, a CeO_2/YSZ/CeO_2 buffer layer structure, a RE123 superconducting layer, an Ag stabilization layer and a Cu protective layer. **Figure 1** shows the architecture of the new RE123 conductor. **Table 1** shows the function of each layer.

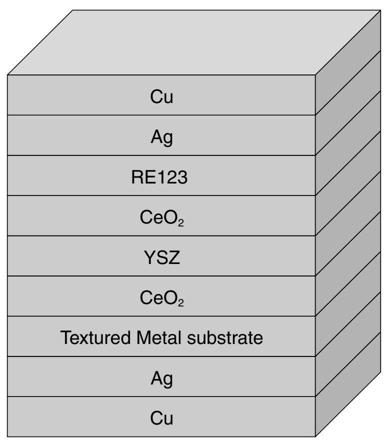

Fig. 1. Architecture of RE123 conductor

Table 1. Function of each layer

Material	Function	Method
Cu	Protection layer	Electroplating
Ag	Stabilization layer	DC sputtering
RE123	Superconducting layer	PLD
CeO_2	Lattice-matching layer	RF sputtering
YSZ	Inter-diffusion barrier layer	RF sputtering
CeO_2	Seed layer	RF sputtering
Textured Ni-alloy or clad-type substrate	Textured metal substrate	–

2-1 Textured metal substrate

In this paper, the textured Ni-alloy metal substrate and the clad-type substrate are used as the substrates for RE123 conductors. The thickness of the textured Ni-alloy substrate and the clad-type substrate are 90 μm and 100 μm, respectively.

2-2 Buffer layers

All buffer layers are grown by RF-sputtering. The first layer on the textured metal substrate is a CeO_2 layer that acts as a seed layer. The second layer is a YSZ layer acting as an inter-diffusion prevention layer, and the third layer is a CeO_2 layer acting as a lattice-matching layer between the superconducting layer and the buffer layers. The buffer layers are evaluated after each layer is grown. In-plane orientation ($\delta\varphi$: full-width-at-half-maximum of CeO_2 (111) peak or YSZ (111) peak evaluated by φ-scan) and $\theta/2\theta$ diffraction pattern are evaluated using X-ray diffraction (XRD). Surface morphology and surface roughness (Ra) are observed by scanning electron microscopy (SEM) and atomic force microscopy (AFM)

2-3 Superconducting layer

Superconducting layers are grown by using a reel-to-reel pulsed laser deposition (PLD) system. Thick superconducting films can be obtained by the multilayer deposition technique. $HoBa_2Cu_3O_x$ (Ho123) is generally used as the superconducting material,[(6)–(8)] but $GdBa_2Cu_3O_x$ (Gd123) is used in this study. As shown in **Fig. 2**, the Ic value of Gd123 is higher than that of Ho123. The authors chose Gd123 as the superconducting material. After the superconducting film is grown, the crystalline orientation of the film is evaluated by XRD and the surface morphology is observed by SEM and AFM. The Ic properties of the grown films are measured by the four-probe method after O_2 annealing.

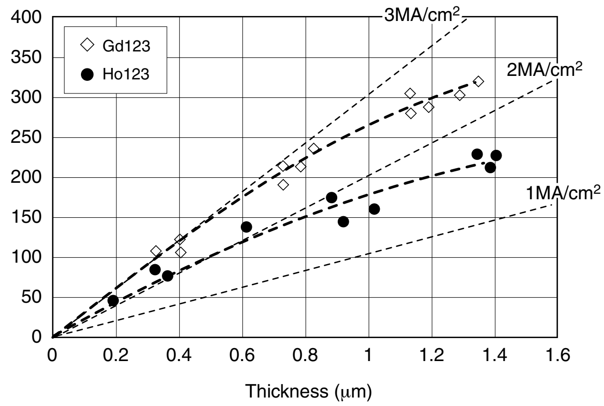

Fig. 2. Ic dependence on RE123 layer thickness

2-4 Stabilization layer and protective layer

An Ag stabilization layer up to 10μm thick is deposited by DC sputtering and a Cu protective layer up to 20μm thick is coated on the stabilization layer by electroplating.

3. Development of clad-type substrate

3-1 Magnetization properties and mechanical properties of metal substrate

Figure 3 shows the magnetization curves of the textured Ni-alloy substrate and the clad-type substrate (at ±0.1 T in 77.3 K). **Table 2** shows the comparison of the properties between three types of metal tapes commonly used as the substrates for RE123 conductors. Here, magnetization loss was calculated from **Fig. 3**. The magnetization loss of the clad-type substrate was about one twenty-fifth that of the textured Ni-alloy substrate. Furthermore, the clad-type substrate demonstrated higher mechanical strength compared with the textured Ni-alloy substrate.

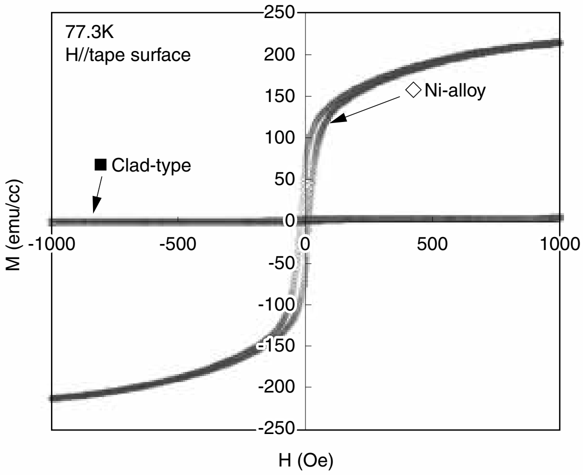

Fig. 3. Magnetization curves of Ni-alloy and clad-type substrates

Table 2. Magnetization loss and mechanical strength of substrate

Substrate	Magnetization loss (J/m^3)	Strength (MPa)
Textured Ni-alloy	1300	200 MPa
Clad-type	52	500 MPa
Hastelloy	Up to 0	500 to 1000 MPa

These results show that the clad-type substrate is suitable for use in AC applications.

The authors then fabricated superconducting cables using the textured Ni-alloy substrate and the clad-type substrate, and compared the AC loss in these cables. The AC loss of the cable using the textured Ni-alloy substrate was 2 W/m/phase while that of the cable using the clad-type substrate was 0.17 W/m/phase (1kA at 60Hz in 77.3K). This result also confirms that the clad-type substrate is suitable for AC applications.

3-2 Comparison of Ic properties

Figure 4 shows the comparison of the Ic property dependence on superconducting layer thickness between the Gd123 layers grown on the textured Ni-alloy and clad-type substrates. The Ic value increased with the Gd123 layer thickness for both substrate types and started to saturate at above 2 μm thickness. However, the Gd123 layers on the clad-type substrates have lower Ic values than those of Gd123 layers on the textured Ni-alloy substrates when in the same thickness. This means that the critical current density (Jc) of Gd123 films grown on the clad-type substrates are lower compared to those on textured Ni-alloy substrates.

This result shows that it is necessary to improve Ic of Gd123 conductors on the clad-type substrates. Therefore, the authors researched the cause of low Ic of Gd123 conductors on the clad-type substrates.

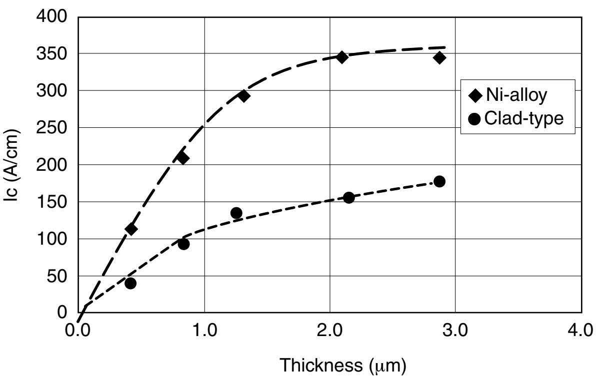

Fig. 4. Ic dependence on thickness of Gd123 layer on Ni-alloy and clad-type substrates

3-3 Cause of low Ic of Gd123 conductors on clad-type substrates

The authors focused on substrate surface morphologies. **Figure 5** shows the surface morphology of the textured Ni-alloy substrate and **Fig. 6** shows that of the clad-type substrate. The textured Ni-alloy substrate surface in **Fig. 5** is smooth. On the other hand, the clad-type substrate surface in **Fig. 6** has some defects on it. There are two types of defect: one is line-like defect indicated by a white allow in **Fig. 6**, and the other is hole-like defect indicated by a black allow in **Fig. 6**. Moreover, it is confirmed from **Fig. 7** that the clad-type substrate has larger surface roughness (Ra) at layers every than the textured Ni-alloy substrate. As shown in **Fig. 8**, hole-like-defects are observed on the Gd123 layer grown on the clad-type substrate. The hole-like-defects are about 3 μm in diameter, about the same size as the defects observed on the surface of the clad-type substrate.

It is assumed that these defects are the cause of low Ic of the Gd123 conductor on the clad-type substrate. In order to achieve higher Ic, the clad-type substrate must have smooth surface without defects.

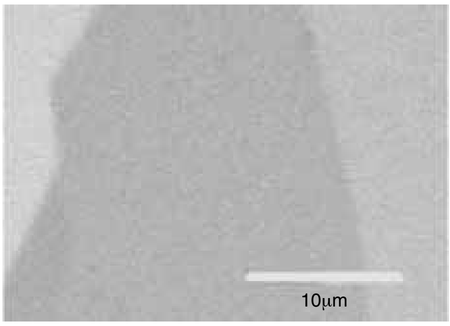

Fig. 5. SEM image of Ni-alloy substrate surface

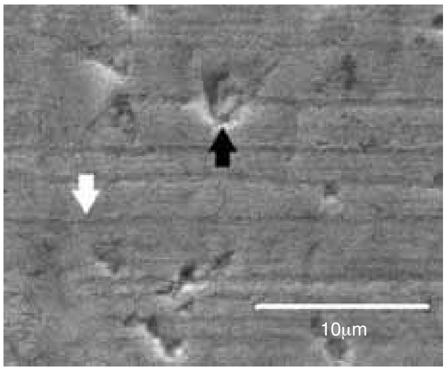

Fig. 6. SEM image of Ni-alloy substrate surface
(Black arrow: hole-like defect, White arrow: line-like defect)

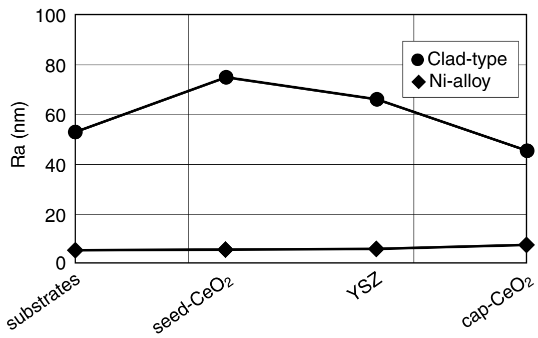

Fig. 7. Ra of each layer

3-4 Surface roughness improvement of clad-type substrates

In order to obtain smooth surface, surface treatment was applied to the clad-type substrate. **Figure 9** shows a SEM image of the clad-type substrate surface after surface treatment. The clad-type substrate surface in **Fig. 9** has no defects and is smoother than that in **Fig. 6**. Furthermore, Ra of the clad-type substrate is reduced by half after surface treatment.

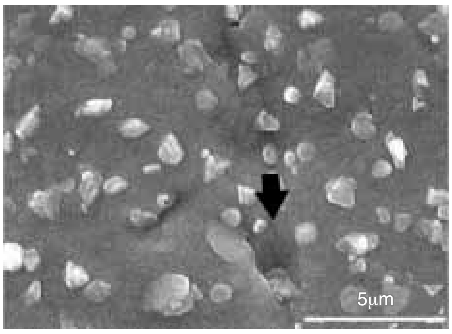

Fig. 8. SEM image of Gd123layer on clad-type substrate

3-5 Ic properties of Gd123 conductors on clad-type substrates after surface treatment

Gd123 conductors were grown on the clad-type substrates after surface treatment. The dependence of Ic on Gd123 layer thickness is shown in **Fig. 10**. It can be confirmed from **Fig. 10** that the Ic values of the clad-type substrates increase after surface treatment and the values reach to similar levels as those of textured Ni-alloy substrates. Moreover, at a thickness of 2 μm, the Ic value of the surface-treated clad-type substrate was 379 A/cm. This value is higher than that of the textured Ni-alloy substrate with the same thickness.

These results indicate that the clad-type substrate is a promising substitute for the textured Ni-alloy substrate.

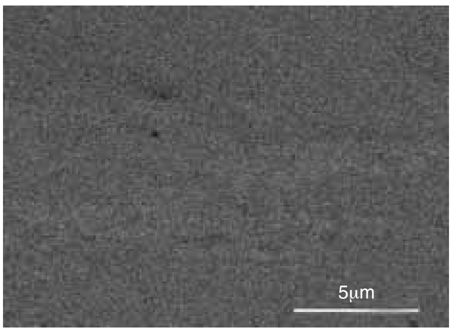

Fig. 9. SEM image of clad-type substrate surface after surface treatment

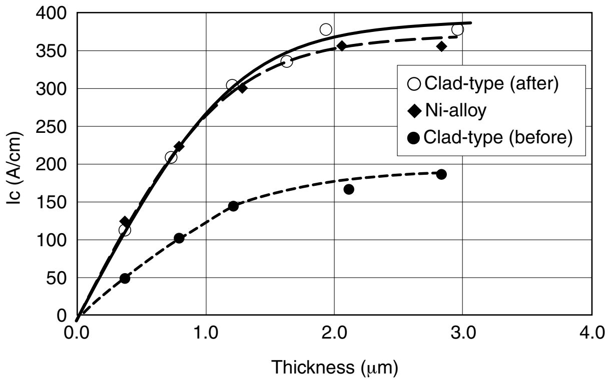

Fig. 10. Ic dependence on thickness of Gd123 layer on clad-type substrate after surface treatment

4. Conclusions

The authors have successfully developed a new type of textured metal substrate for RE123 conductors.

Conventionally used substrates for RE123 conductors were textured Ni-alloy substrates having two major problems. The authors developed a new type of textured metal substrate that does not have these problems. This new type of substrate is called the clad-type substrate. The Ic values of Gd123 conductors on the clad-type substrates are lower than those of Gd123 conductors on the textured Ni-alloy substrates. The study showed that low Ic of Gd123 conductors on the clad-type substrates is caused by the defects on the clad-type substrate surfaces. After surface treatment was applied on the clad-type substrates, their surfaces became smooth and Ic of Gd123 conductors on surface-treated clad-type substrates were close to that of Gd123 conductors on the textured Ni-alloy substrates. Moreover, at a superconducting layer thickness of 2 μm, Ic of the improved clad-type substrate was 379 A/cm. This value is higher than that of Gd123 conductor on the textured Ni-alloy substrate.

5. Acknowledgments

A part of this work was supported by the New Energy and Industrial Technology Development Organization (NEDO).

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