Joint of REBa$_2$Cu$_3$O$_{7-\delta}$ Coated Conductors using Metal Organic Deposition

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Abstract

Joint techniques connecting REBa$_2$Cu$_3$O$_{7-\delta}$(REBCO) coated conductors (CCs) are required to fabricate long length CCs and to repair locally damaged one. Two pieces of REBCO CC were attempted to be jointed using a metal organic deposition (MOD) method. The starting solution for YBCO layer was coated on GdBCO layer of CCs and calcined to fabricate precursor films, two of which were stuck together in a face to face manner, and then these films were pressurized and crystallized to joint them. Two CCs were successfully jointed together with c-axis oriented YBCO without pores and reacted phases at the joint interface.

Keywords: Joint; Coated conductor; MOD

1. Introduction

There have been several techniques to joint REBCO CCs together to fabricate long length superconducting wires for magnet for applications, such as a diffusion joint using stabilizing layer [1,2], a solder joint [3,4], and a superconducting joint [5]. Among these joint techniques, the diffusion joint and the solder joint are very simple techniques with low resistances from stabilizing layer and solder layer between two REBCO layers, respectively. Even the resistance at the jointed interfaces is low enough, it still causes the current loss and the transition to the normal conducting state due to the resistive heating, unquestionably.

Recently, Park et al. reported that the success of zero joint resistance using the direct superconducting joint
techniques with complicated processes, including high temperature heat treatment (1123 K) for jointing in high vacuum [5]. Nevertheless, lower temperatures and ambient pressures are desired to achieve zero joint resistance for industrial applications.

In this paper, we propose a possible fabricating technique of a superconducting joint by the MOD method at lower heating temperatures than previous report [5] in ambient pressure.

2. Experimental

Fluorine-free starting solution for YBCO films was spin-coated onto 5×10 mm² GdBCO CCs as substrate. The coated samples were calcined at 823 K for 2 hours, and the two pieces of precursor film were held together in a face to face manner with 5×6 mm² overlapped in an Inconel holder, as schematically shown in fig. 1. The overlapped sample was pressurized by two bolts and tightened by torque of 5 N·m, followed by annealing at 1043 K to crystallize two calcined layers and to joint them, then oxygenating at 773 K for 2 hours.

The crystal orientation of the sample was examined by an X-ray diffractometer (XRD, Rigaku-RINT2100) mounted on a horizontal θ/2θ goniometer, surface morphology of the sample was investigated by a scanning electron microscope (SEM, Zeiss-ULTRA55), and microstructure of the jointed sample was examined by a transmission electron microscope (TEM; JEM-3200FSK).

Fig. 1. Schematic illustration of sample jointing.

3. Results and discussion

3.1. Evaluation of crystal orientation

The jointed sample was peeled off and the crystal orientation of the REBCO layers was investigated from a whole region of the overlapped area by XRD θ/2θ profiles. Figs. 2a and 2b show XRD patterns of GdBCO CC and overlapped area of the jointed sample, normalized by the peak intensity of CeO₂ 200, respectively. Fig. 2a has GdBCO 001 peaks and Gd₂BaCuO₅ 131 and 321 peaks. In addition to fig. 2a, new peaks locating at 2θ =16° and 27° appeared in fig. 2b, which were assigned to Y₂Cu₂O₅ 200 and 111, respectively. The integrated intensities of the REBCO 005 peak were compared between GdBCO CC (fig. 2a) and jointed sample (fig. 2b) by using the relative value to the CeO₂ 200 substrate peak. As a result, ratio of integrated intensities of REBCO to the CeO₂ increased from 0.54 (fig.2a) to 1.02 (fig.2b). This result suggests the formation of c-axis oriented YBCO layer on c-axis oriented GdBCO layer. It can be seen in fig. 2b that there were other peaks at lower angular side of each main 001 peak, indexed as “lower 001 peak”, probably caused by the phase with oxygen under doping. Table 1 shows c-axis lattice parameters calculated from lower 001 peaks and main 001 peaks, and oxygen contents were estimated from these lattice parameters [6]. From the results of table 1, oxygen under doped YBCO estimated from lower 001 peaks was present in overlapped area. It suggested the presences of two YBCO phases, one with oxygen under doping, and another one with adequate oxygen doping. XRD patterns of jointed region (including non-jointed region) and non-jointed region are shown in figs. 3a and 3b, respectively. It can be seen in fig. 3a that there were both main 001 peaks and lower 001 peaks, as shown in fig. 2b, but lower 001 peaks were not present in fig. 3b. It was clear from these results that jointed region was the phase which oxygen content was under doped. It was thought that jointed region has no oxygen paths while annealing because of adhesion between YBCO layers.
3.2. Microstructure observation

Figs. 4a and 4b show SEM images of peeled-off sample surface after joint and film surface of YBCO fabricated by MOD method, respectively. Two regions with different appearances are available in fig. 4a, a smooth surface and rough surface. The surface morphology of YBCO film in fig. 4b is very similar to the rough surface in the right hand side of fig. 4a, so it is suggested that smooth surface and rough surface as seen in fig. 4a are jointed region and non-jointed region, respectively. The areal ratio of the jointed region, the smooth surface region, was measured as about 4 to 5 % of the overlapped area.

![Fig. 2. XRD patterns of (a)GdBCO CC; (b) overlapped area of joint sample.](image)

![Fig. 3. XRD patterns of (a) jointed region; (b) non-jointed region.](image)

![Fig. 4. SEM images of surface morphology for (a) overlapped area; (b) YBCO film fabricated by MOD method](image)

**Table 1.** The c-axis lattice parameter and oxygen contents for REBa$_2$Cu$_3$O$_{7-\delta}$ calculated from lower 00$l$ and main 00$l$ peaks.

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<th></th>
<th>The c-axis lattice parameter (nm)</th>
<th>Oxygen content $\delta$</th>
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<tr>
<td>lower 00$l$ peaks</td>
<td>1.180</td>
<td>0.76</td>
</tr>
<tr>
<td>main 00$l$ peaks</td>
<td>1.173</td>
<td>0.44</td>
</tr>
</tbody>
</table>
The microstructure of the smooth surface was further examined in detail by cross-sectional TEM, obtained at low magnification and at high magnification, as shown in figs. 5a and 5b, respectively. Two layers of YBCO were found sandwiched between those of GdBCO, and joint interface of YBCO could be judged from the apparent contrast changes without pores or reacted layers at the middle of them. Selected area electron diffraction patterns (SAEDPs) from four circular regions (region 1-4) in fig. 5b are shown in fig. 5c. Epitaxial growth of c-axis oriented YBCO layers, as seen in fig. 5c (2) and (3), were observed on c-axis GdBCO layers, as seen in fig. 5c (1) and (4). Cross sectional TEM images, as well as SAEDPs confirm the successful joint between GdBCO layers by MOD method. Nevertheless, one of the YBCO layers on GdBCO CCs were found slightly inclined as measured from SAEDPs, probably due to the rough surface of GdBCO layer as shown in fig. 6. These results suggest that YBCO layers are grown epitaxially on GdBCO layers but with a small inclination due to the presences of particles on the surface. Therefore, it is necessary to minimize the number of particles on the surface of GdBCO layer for perfect jointing.

Fig. 5. TEM images of (a) low magnification; (b) high magnification; (c) SAEDPs for jointed sample.

Fig. 6. SEM image of GdBCO surface.

4. Conclusions

Joint of REBCO CCs were achieved in ambient pressures and lower temperatures using the MOD method. The c-axis oriented YBCO layers were observed between two GdBCO layers without pores and reacted phases at the joint interface. On the other hand, there are some problems to be solved for perfect jointing such as oxygen under doping and inclination of YBCO layers at the jointed region.

References