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Microstructural characterization of TFA-MOD processed $Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ with $BaZrO_3$

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$Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ with $BaZrO_3$ film was fabricated on CeO_2 buffered $LaMnO_3$/ion beam assisted deposition-MgO/$Gd_2Zr_2O_7$/Hastelloy C276TM substrates by the metal organic deposition process using trifluoroacetates. Both microstructural and analytical characterizations were performed by transmission electron microscopy with selected area electron diffraction method and energy dispersive X-ray spectroscopy. The thickness of $Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ with $BaZrO_3$ film was found approximately 700 nm and the film was composed of *c*-axis oriented $Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ grains. Several types of particles, $(Y,Gd)_2Cu_2O_5$, CuO and $BaZrO_3$, were formed within the $Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ film, whose sizes were about 100–200 nm for $(Y,Gd)_2Cu_2O_5$ and CuO particles, and about 10–20 nm for $BaZrO_3$ particles, respectively. In the $Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ film, $(Y,Gd)_2Cu_2O_5$ and CuO particles were dispersed heterogeneously, whereas $BaZrO_3$ nanoparticles were found dispersed homogeneously with random orientation. In addition, electron tomographic observation was carried out to attain the three-dimensional information of polyhedral $BaZrO_3$ nanoparticles.

1. Introduction

The discovery of layered cuprate superconductors by Bednorz and Müller (1986) and then superconductivities of $YBa_2Cu_3O_{7-y}$ (YBCO) with high critical temperatures, T_C, by Wu et al. (1987), $REBa_2Cu_3O_{7-y}$ (REBCO; RE: rare earth element) has received a large attention due to its T_C higher than the boiling point of the liquid nitrogen temperature, ~77 K (Wu et al., 1987). Among those REBCOs, $Y_{1-x}Gd_xBa_2Cu_3O_{7-y}$ (YGdBCO) is one of the best candidates for industrial applications, since it has high critical current density under high magnetic field than YBCO (Miura et al., 2009). In fact, large numbers of industrial applications composed of REBCOs coated conductors has been expected such as motors (Oswald et al., 1999), generators (Nitta, 2002), power transmission cables (Mukoyama et al., 2007), transformers (Tomioka et al., 2011), fault-current limiters for the electric utility grid (Yumura et al., 2009) and superconducting magnetic energy storage (SMES) (Shikimachi et al., 2009).

There are still several matters to be overcome to commercialize REBCOs CC, such as the anisotropic angular dependence of J_C (Jia et al., 2005) and the degradation of J_C under the magnetic fields, especially at high temperatures (Awaji et al., 1999). It is therefore that further improvement in J_C under the applied magnetic field is inevitable for industrial applications in high magnetic fields, such as electric transformers and SMES devices, not only for fields applied parallel to the *c*-axis, $B \parallel c$, but also for magnetic fields applied at any angle. One of the most effective ways to improve the "flux pinning" and to reduce the anisotropic dependence is to introduce pinning centers, such as non-superconducting nanoparticles with sizes similar to the superconducting coherence length into the REBCO superconducting matrix (Lei et al., 2011; Hänisch et al., 2005; Varanasi et al., 2006; Macmanus-Driscoll et al., 2004; van der Beek et al., 2002; Guitiérrez et al., 2007; Solovyov et al., 2007; Ijaduola et al., 2006; Holesinger et al., 2008a; Matsumoto et al., 2004).

Currently, there are several types of fabrication process available of REBCO coated conductors for pulsed laser deposition (PLD), chemical vapor deposition (CVD) and metal organic deposition (MOD), as listed in Table 1 (Shiohara et al., 2012). For the practical points of view, the following conditions have to be satisfied at the same time: (1) high performances of I_C, (2) long tape, (3) high production rate and (4) low cost (Izumi et al., 2005). The MOD process using trifluoroacetate (TFA) salts has several advantages, such as its inexpensiveness for fabricating REBCO CCs since it does not

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Table 1
Comparisons between the different fabrication methods of REBCO coated conductors (Shiohara et al., 2009, 2012).

	I_C (A/cm-w)	Length (m)	Growth rate	Yield	Cost
PLD	572	816	High	Middle	High
CVD	282	1065	Middle	Low	Middle
MOD	466	540	Low	High	Low

require any expensive apparatus and its high yield, with comparison to PLD and CVD processes (Shiohara et al., 2009; Yamada et al., 2005).

The microstructures of REBCO CCs were very much influenced by deposition process, and there are always inherent defects and second phases acting as pinning centers. PLD REBCO CCs have columnar structure and dislocations parallel to the *c*-axis (Dam et al., 1999; Holesinger et al., 2007). On the other hand, MOD REBCO CCs have lateral structure and include high density of planar defects parallel to ab plane act as pinning center (Holesinger et al., 2008b; Obradors et al., 2012). In addition, microstructures of pinning centers were influenced by those of matrix for the case of PLD (Kaneko et al., 2010) or MOCVD (Chen et al., 2009) process where nanorods with the REBCO structure were formed. Furthermore, nanoparticles can easily be introduced by MOD, which would act as the three-dimensional (3D) artificial pinning centers (APCs), to improve anisotropy of the magnetic field angle dependence of JC property under high magnetic field (Miura et al., 2009; Kiuchi et al., 2011). Llordés et al. reported that nanoparticles have incoherent and highly mismatched interface, which generate nanostrain region acting as the effective pinning center (Llordés et al., 2012).

So far, large numbers of microstructural and analytical characterization of pinning centers have been carried out to seek the relationship between the pinning centers and the physical properties in two dimensions, but they were not successful due to the lack of information in third dimension. It is therefore necessary to characterize in three dimensions, which would provide additional information of pinning centers to understand the role of them more precisely, such as the morphology, the orientation relationship, and the dispersion of them.

In this paper, microstructural and analytical characterizations of particles were carried out in detail. In addition, three-dimensional information at nanoscale was acquired to correlate physical properties and the dispersion and orientation of pinning centers.

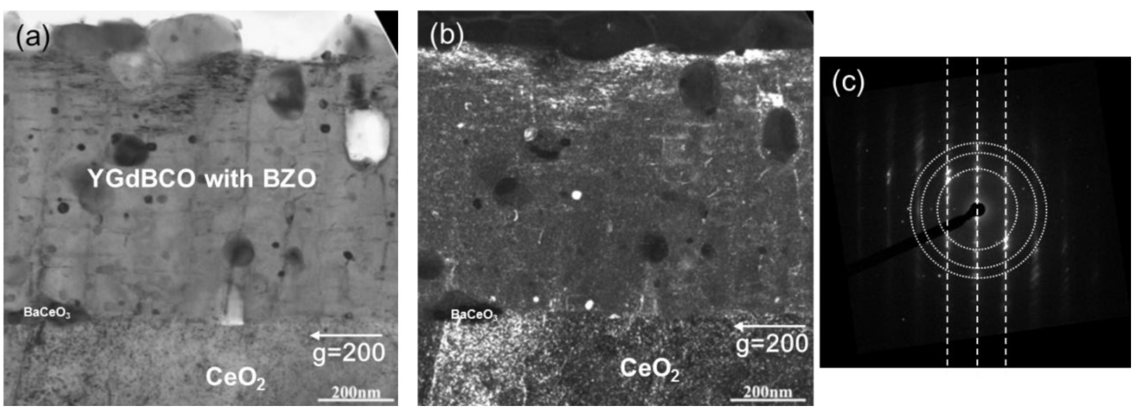

Fig. 1. Cross-sectional electron micrograph of the YGdBCO coated conductor: (a) bright-field TEM image, (b) dark-field TEM image and (c) corresponding SAED pattern.

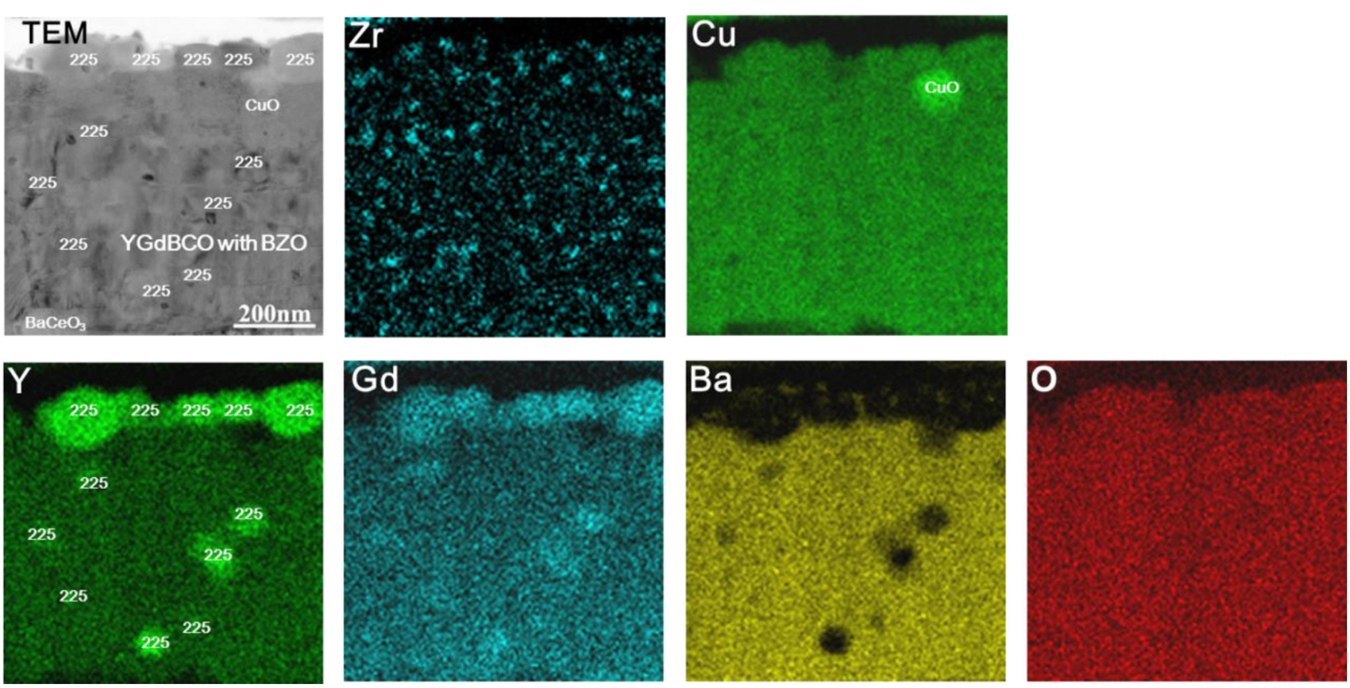

Fig. 2. Cross-sectional TEM image and elemental distribution maps of YGdBCO coated conductor.