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Evaluation of the lattice matching effect on critical current density for surface coated $YbBa_2Cu_3O_7$

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Abstract

Yb-123 superconducting layer was coated on $(Gd_{0.92}Er_{0.08})_2O_3$-buffered Ni substrate with a 100% lattice match. Ni was annealed to get a biaxially textured substrate. Both buffer layer and superconducting layer were coated with a non-vacuum sol–gel method. Coated film was characterized by means of XRD, ESEM. T_c and I_c of films are measured by the direct current 4-probe method. Critical transition temperature and critical current density of the superconductor were measured as 81 K and 1×10^4 A/cm^2, respectively.

Keywords: Lattice match; $YbBa_2Cu_3O_7$; Superconductor; Sol–gel

1. Introduction

Mismatch is one of the limitations of high quality coated conductor. Mismatch between buffer layer and superconducting layer lowers the current density of the superconducting film. Since high current density superconducting film requires a highly oriented substrate/buffer layer, matching is highly effective to install oriented layers [1]. Other issues of the coated conductors are stability of the substrate and buffer layer, diffusion barrier capability of the buffer layer and a smoothness and shine surface of substrate and buffer layer [2].

There are several ceramics to be established as buffer layers such as $SrTiO_3$ [3], CeO_2, $BaTiO_3$ [4], Nd_2O_3, MgO [5], $La_2Zr_2O_7$, Gd_2O_3, Er_2O_3 [6], Eu_2O_3 [7], etc. Each buffer layer has some amount of mismatch with superconducting RE-123 (RE: Y, Yb, La, Ho, Gd, Er, Sm, Tb, rare earth). The parameter "*a*" of unit cell in the orthorhombic superconducting RE-123 phase varies between 3.81 and 3.82 μm. But the parameter "*a*" of unit cell in the buffer layers, written above, varies between 3.674 μm (Lu_2O_3) and 4.005 μm (La_2O_3). Any of the buffer layers was not match 100% with the superconducting RE-123. The best matching one with Y-123 is the Gd_2O_3 and has a mismatch of 0.07% [8].

Okuyucu et al. [9,10] introduced mixed oxide buffer layer. By using mixed rare earth oxide, unit cell of the buffer layer can be adjusted to match 100% with any superconducting RE-123. The unit cell of the mixed oxide buffer layer can be changed between two unit cells of the components. When any two of the rare earth oxides are mixed together, they form a single phase oxide. No secondary phase forms. Since the value of their atom's radiuses is close to each other, they can replace easily [11].

Sol–gel method has some advantages such as cost saving and be suitable for long length coating. Since sol–gel method does not need vacuum, coating requires less equipment and consequently low cost. Sol–gel method is also suitable for the reel-to-reel continues system [12]. Molecular beam epitaxy, ion beam spray, laser deposition, electron beam evaporation, electro-decomposition and plasma spraying are among the other coating methods for the coated conductors [2].

2. Experimental

Buffer layer solution was prepared using Gd-2,4-pentanedionate and Er-2,4-pentanedionate precursors. Acetyl acetone, glacial acetic acid and methanol were used as solvents. After having pink transparent solution, Gd/Er ratio was adjusted to have a lattice parameter of 3.819 Å which is equal to the lattice parameter, *a*, of Yb-123. Ultrasonically cleaned

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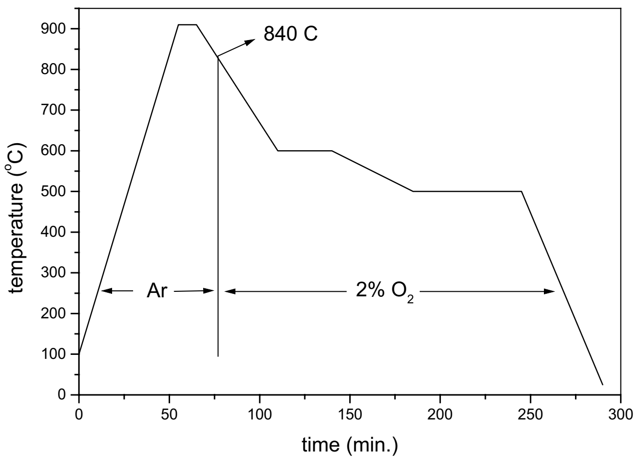

Fig. 1. Annealing profile of eight-dipped Yb-123 superconductor.

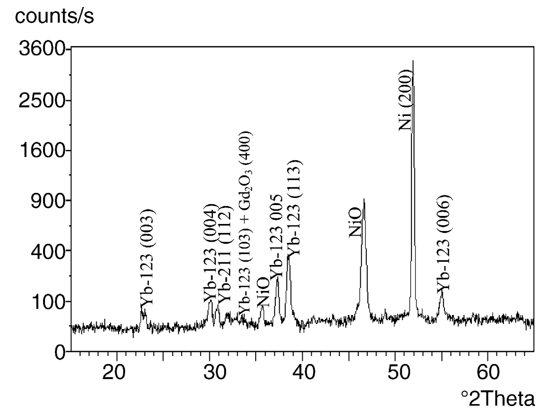

Fig. 2. XRD pattern of eight-dipped Yb-123 superconductor.

Ni substrate was dipped into the solution and sent through the three-zone vertical furnace. Details of the buffer layer coating were published in somewhere else [9,10].

Superconducting layer was coated with the same manner on buffered Ni substrate and annealed at temperatures between 800 and 880 °C for different time periods. Desired thickness for each layer was obtained by repeating the coating process.

X-ray diffraction profiles of Ni tape, buffer layer and superconducting layer were recorded using a Scintag diffractometer with a Cu K_α radiation. Data were collected over the range $10^\circ < 2\theta < 65^\circ$ by using 0.2° steps with an integration time of 0.5 s. Microstructure investigation of the surface of the buffer layer and superconductor layer was carried out with an Electroscan type Environmental Scanning Electron Microscope. Critical superconducting transition temperature was measured with four-point-measurement method.

3. Results and discussions

In this study, Ni substrate and buffer layer are perfectly textured. Annealing details of Ni and coating and characterization details of buffer layer are published in somewhere else.

The effect of 100% match of buffer layer and superconducting layer on quality of superconductivity is one of the important factors. Using all acetates precursor, superconducting layer was coated on a buffered Ni substrate. To have a 100% match with the unit cell of $YbBa_2Cu_3O_{7-\delta}$ (0.3819 nm), the composition of buffer layer, $(Gd_{0.92}Er_{0.08})_2O_3$ (GEO), was formed to get such a unit cell.

Superconducting Yb-123 was coated on $(Gd_{0.92}Er_{0.08})_2O_3$-buffered Ni substrate. Dipping of substrate into superconducting solution was repeated eight times to get the desired thickness. Less than eight dippings gave uncoated regions on the substrate and thicker coating destruct the texture of superconducting phase.

The superconducting layer was annealed using the annealing pattern given in Fig. 1. The superconducting layer was partly textured after annealing (Fig. 2). Ar gas was used during the heating to prevent the Ni substrate then 2% of O_2 in Ar was used to form the $YbBa_2Cu_3O_7$ phase. As it is known, $YbBa_2Cu_3O_7$ is an oxygen deficient phase and when heated in inert or reducing atmosphere, stoichometry of oxygen in the Yb-123 phase will reduce and the semiconductor $YbBa_2Cu_3O_{6.4}$ phase will form [2].

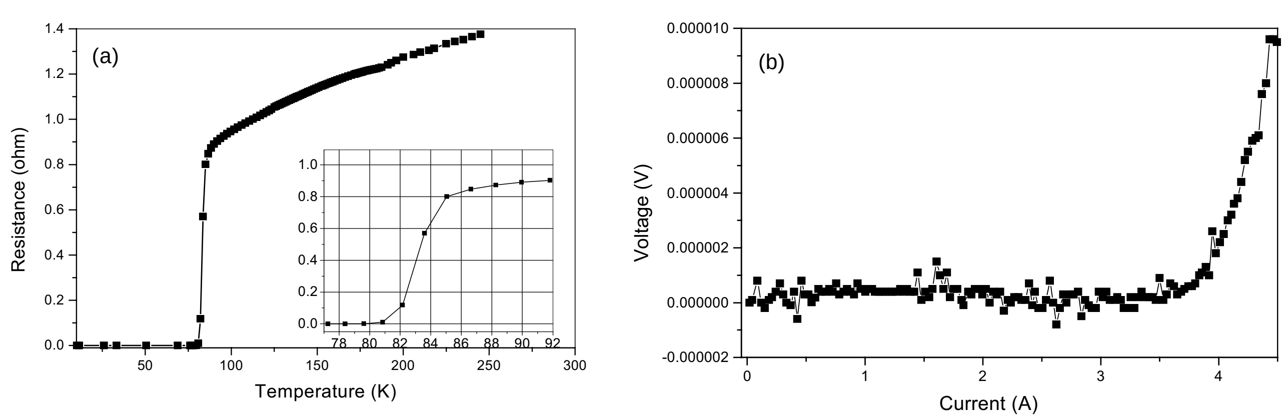

Fig. 3. (a) Temperature vs. resistance and (b) current vs. voltage (at 4.2 K) graphs of eight-dipped Yb-123.

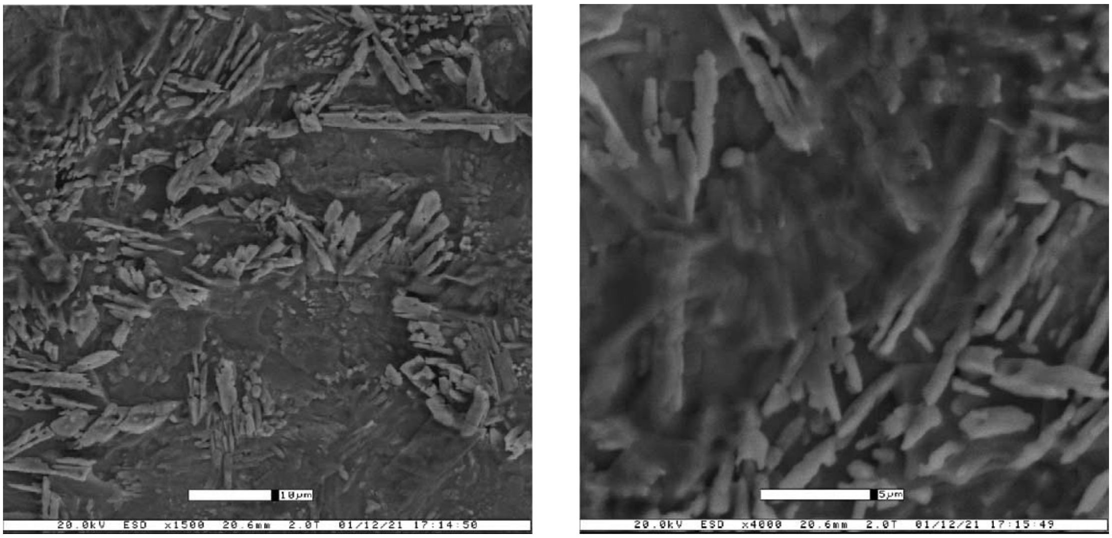

Fig. 4. ESEM micrographs of Yb-123 film onto GEO buffered Ni substrate.

XRD analysis showed that there are (0 0 3), (0 0 4), (0 0 5) and (0 0 6) peaks in the pattern and additionally there are also (1 0 3) and (1 1 3) peaks, which are not desired for high J_c superconductors. There is also Yb-211 (Yb_2BaCuO_x) phase which is not superconducting. Since annealing of coated superconducting Yb-123 was annealed in an atmosphere that contains oxygen, Ni substrate was oxidized. Ni was oxidized with the oxygen because of annealed together with oxygen containing $(Gd_{0.92}Er_{0.08})_2O_3$ at high temperature.

The T_c of the superconductor was measured to be 81 K (Fig. 3). Such a T_c is highly above the liquid nitrogen temperature. Critical current of the film was measured to be 3.7 A (Fig. 3) at 4.2 K. It seems here that 100% matching enhances the quality of texture of superconductor consequently I_c. Previous sol–gel coatings of superconductor with some amount of mismatching showed lower I_c's [12–14]. It can be claimed that this is the highest critical current value for a coated conductor with a non-vacuum process.

The thickness of the superconducting film could not be measured using metallographic methods because of brittleness of the film however from the experience of sol–gel processing the thickness of the film was estimated about 3–4 μm. For 4 μm thickness and 1 cm width of film, critical current density of the film is calculated to be about 1×10^4 A/cm^2. Such a current density is a favorably result for the coated conductors. This result should also be considered with low cost and long length coating possibility of sol–gel method.

ESEM micrographs show that the microstructure consists of needle/plate shaped grains with a little preferred orientation (Fig. 4). The needle growth could be due to the presence of a liquid phase, which is rich in Cu and Ba. This liquid would promote the tight stacking and orientation of the grains through capillary action [15]. But in this system, the first liquid is expected to appear at 930 °C under oxygen flow, corresponding to the ternary eutectic between (1 2 3), (0 1 1) and (0 0 1) [16]. For our sintering conditions (900 °C, 10 m), no liquid would be expected unless there was an interaction with GEO.

4. Conclusion

This study showed that lattice mismatch is not an issue for coated conductor any more. For anyone of the RE-123 mixed rare earth oxides can be used as buffer layer and lattice parameter of the buffer layer can be adjusted for the chosen RE-123. Hundred percent matching clearly enhance the texture quality and critical current density of the conductor. Sol–gel method is also favorably for the long length coated conductors. Mixing of rare earth oxides is also possible with other coating method.

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