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Fabrication of YBCO coated conductors using the nickel tapes textured in single crystalline qualities

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Abstract.

Ni tapes were textured by taking advantage of their secondary recrystallization. The obtained 18cm long tapes had textures of single crystalline qualities with their [001] axes tilted with respect to the surface and their [010] axes parallel to the rolling direction. $YBCO/CeO_2/YSZ/CeO_2$ films grown on the Ni tape had the same crystalline orientations. Magnetic field dependent I-V relations were measured on a 5cm section of the tape. Jc defined by 1mV criterion was 1.5 x $10^5 A/cm^2$ at 77K under zero field and was reduced by ~50% under the applied magnetic field of 5T.

Keywords: coated conductor, YBCO, recrystallization

I. Introduction

Superconducting coated conductors have gained much attentions for the expectations of realizing the potential of high Tc superconductors in large scale devices[1]. The merit of coated conductors is the critical current density of MA/cm^2 range under large magnetic fields at the liquid nitrogen temperature[2], which is much superior to that of the silver sheathed BSCCO tapes[2]. A coated conductor comprises a YBCO film and buffer layers on a biaxially textured Ni tape[1][2]. The Ni tape can be easily textured by rolling and recrystallization process known as RABiTS[1]. The deposition methods of textured buffer layers and YBCO films are well known[3].

The Ni tapes processed by RABiTS are recrystallized in cube textures, where grains of several tens of m size[4] are mostly aligned so as their [001] axes normal to the surface and their [010] axes parallel with the rolling direction[1]. For the best textured one, the alignment of in-plane orientations is as good as 6° measured by XRD - scan[1]. Since the crystalline orientations of grains are basically probabilistic in RABiTS, there is no guarantee for the absence of grains with large angle misorientations[4]. Hence for a hundreds meter long tape one might worry a present of a single small region populated by mis-oriented grains which causes a great reduction of critical current. These problem motivated us to seek for a new method of texturing Ni tape hopefully more perfect than RABiTS. We took the advantage of secondary recrystallization and obtained Ni tapes textured in single crystalline qualities with tilted [001] axes. In this paper we describe the new texturing method, rolling assisted tilted textured substrate(RATS).

II. Sample preparation

The basic procedure for RATS is same as that for RABiTS, i.e. the rolling and recrystallization[1]. However the starting material is very pure Ni and the rolling is intentionally and slightly imperfect. A 3mm thick 99.9% Ni plate was rolled to a 80m thick tape. When the tape thickness reached 200~150m, we rolled the tape by slightly unbalanced roller intentionally so as to make the shape of the tape not straight but slightly bent. Then in the final rolling process we balanced the roller and made the tapes straight. Hence the deformation texture was intentionally imperfect. The imperfection was so slight as not to be detectable by XRD pole figure. The tape was 0.5cm wide and 18cm long. One end of the tape was welded with a stainless steel wire and hanged it in a long quartz tube of vertical position carefully so that it didn't touch the wall of the tube. The vacuum in the tube was 10^{-5} Torr. The hot zone in the middle of the quartz tube was heated up to 1100℃. At first the Ni tape was placed below the heating zone and was slowly brought up. It took about 5 hours for the tape to pass the hot zone completely. Then the tape was cooled to the room temperature. Fig.1a shows the Ni[111]-XRD pole figure where the two peaks at the high valued -angle were partially observed by the limit of the goniometer rotation. The peaks were very sharp as indicated by the FWHM as small as 2°. The [010] axis was parallel with the rolling direction and the [001] axis was tilted by ~23°with respect to the surface normal axis, as shown by the schematic diagram in Fig.1b. We divided the 18cm long tape into nine pieces of ~2cm long tapes and found their crystalline orientations were exactly coincident. We couldn't see any grain boundaries on the tape surface polished that had been polished and etched by nitric

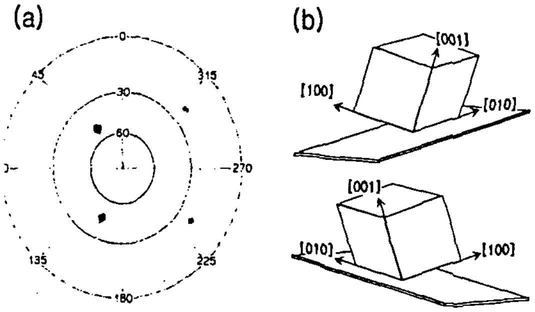

Fig. 1. (a) Ni [111] pole figure of the Ni tape. The two peaks for higher χ angles on the right-hand side are partially shown (b) schematic figures for the crystalline orientations tilted by a +angle(upper figure) and by a -angle(lower figure) of the Ni tape. The [010] axes for both are parallel to the rolling direction

acid, which means that the entire 18cm long tape was a single grain, extremely large in size, and so it was single crystalline. We made many Ni tapes by the same way. The [010] axes of them were always parallel with the rolling directions within 3° and the [001] axes were tilted by +(20°~27°) or -(20°~27°), where the orientations for ±signs are indicated in Fig.1b. Hence the crystalline orientations of all the tapes which had undergone RATS process independently were not same. However, for each tape, once the tilt angle was determined initially, then the crystalline orientation was fixed in the whole length of the sample so that the tape was totally single crystalline. In order to find out the detailed recrystallization process we stopped the heat treatment when the middle part of the tape was passing the hot zone and cooled it to the room temperature. We could see three regions of different textures in the middle of the tape, i.e. the rolling texture, the RABiTS texture, and the RATS texture, which means the deformed rolling texture was converted to RABiTS texture by the primary recrystallization and then it was converted to RATS texture by the secondary recrystallization[5]. The welded point for connection with the hanging wire provided the initial nucleation seed for the secondary recrystallization with tilted orientation. And the imperfections of rolling texture seemed to trigger the second recrystallizations. Controling the amount of intentional imperfection of the rolling texture was important. Too much imperfection resulted in destroy of textures which is spontaneous and random granular secondary recrystallizations. Too slight imperfection results in incomplete conversion of texture from the primary recrystallization (RATBiTS) to the secondary one (RATS). Hence the imperfection, which is achieved by the unbalanced rolling process resulting in bending the tape, should be even along the tape. Although the successful single crystalline recrystallization of the whole tape was obtained under strict conditions, our experimental results demonstrated it was clearly possible to texture a 18cm long tape in perfectly single crystalline quality by RATS. It is well known that the crystalline orientations obtained by secondary recrystallizations are various under other conditions[5]. However our experimental results indicated the recrystallization of tilted orientation is completely prevailing under the RATS conditions. Hence the absence of grains with large angle misorientations might be guaranteed in a very long Ni tape, if the RATS method is applied.

The tapes textured by RATS were too flexible and mechanically too soft. Moreover, as triggered by an applied weak force, sharp bends occurred spontaneously in many places of the tape and the tape was deformed in a meander shape. The spontaneous sharp bend might be caused by concentration of numerous mobile dislocations created by the external force. This problem was solved by addition of impurities. After recrystallization, ~300mTorr ethanol vapor was introduced into the hot quartz tube so that some impurities (probably carbon atoms from the decomposed ethanol) were allowed to diffuse into the Ni tape. The recrystallization and the impurity doping were carried out in-situ at the same temperature. The tape became a little stiffer and showed no spontaneous deformation. We believe the impurities might hinder the mobile dislocations. XRD measurements showed no change of the crystalline structure.

We grew two types of YBCO films on the RATS-textured Ni tapes; one was c-axis normal and the other was c-axis tilted as the Ni substrates. We already reported that a c-axis normal YBCO film can be grown on a tilted crystalline YSZ substrate using CeO_2 buffer layers[6]. Actually we could grow a c-axis normal YBCO film on the tilted crystalline Ni tape, i.e RATS textured one, using the same buffer layers as in the ref [6] and the hollow cathode dc-sputtering. However the hollow cathode dc-sputtering is not appropriate for long tape substrate. We believe the coevaporation method is

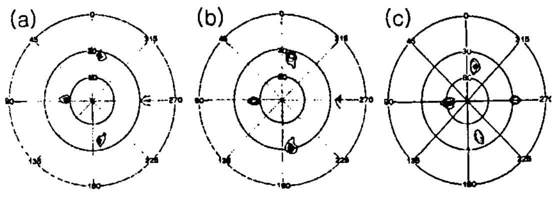

Fig. 2. (a)CeO2[111] pole figure; (b) YSZ[111] pole figure; (c) YBCO[103] pole figure

appropriate for deposition of YBCO films on the long Ni tapes. However by the coevaporation method we could not get successful c-axis normal YBCO films on the tilted crystalline Ni tapes even using the same buffer layer as in the ref [6], which might be due to the different conditions in growth for the two different methods, sputtering and evaporation. Instead, we could get well textured tilted crystalline YBCO film on the 18 cm long RATS-Ni tape using evaporation method with a cylindrical rotating sample holder in a double chamber system. Since, as shown in Fig.1b, the a(b) axes of the tilted crystalline YBCO films were parallel with the tape direction even though the c-axes were tilted, the critical current was not much deteriorated. Hence, in this paper we'll describe only the properties of the tilted crystalline YBCO films deposited on the RATS-Ni tapes by the coevaporation method.

Buffer layers, CeO_2(200Å) / YSZ(3000Å) / CeO_2(50Å), were deposited on the 18cn long Ni tape by e-beam evaporation[3] where the tape was wound around a cylindrical sample holder which was heated up to 650℃ by four halogen lamps and rotated by 0.5 RPM. The evaporant materials were metallic Ce and ceramic YSZ[1]. The base pressure was $\sim 10^{-6}$Torr. Initially the Ni surface was deoxidized by 20mTorr hydrogen gas[3]. During the deposition of the first CeO_2 layer, the partial pressures of oxygen, water, and hydrogen were $\sim 10^{-8}$, $\sim 10^{-6}$, and $\sim 10^{-6}$ Torr respectively. In Fig.2a and 2b, CeO_2[111] and YSZ[111] pole figures showed the crystalline orientations of the buffer layers were coincident with that of Ni. Hence CeO_2[101] and YSZ[101] are parallel with the rolling direction, and CeO_2[001] and YSZ[001] are parallel with Ni[001] which is tilted.

A ~700Å thick YBCO film was deposited on the buffer layers by a coevaporation method. The tape was wound on a cylinder of 2.7cm diameter, which was rotated in a small reaction chamber filled with 5×10^{-3}Torr oxygen gas[7]. The reaction chamber is connected to a evaporation chamber through an opening. The vapours of coevaporated Y, Ba and Cu were supplied through the opening and deposited on the tape. The oxygen pressure in the evaporation chamber was less than 10^{-6}Torr, which was due to

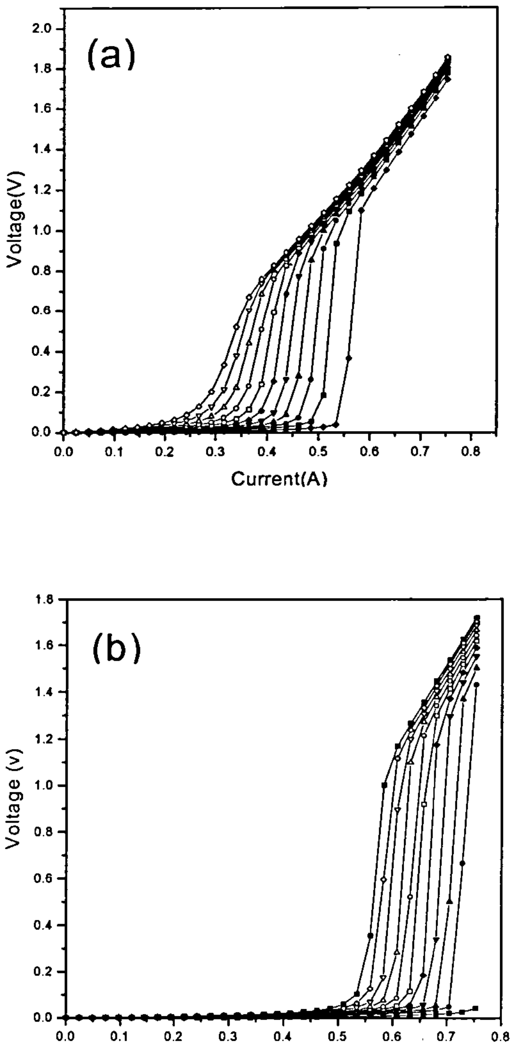

Fig.3a;I-V curves at 77K for various applied magnetic fields 3b;I-V curves at 70K for various applied magnetic fields.The applied fields were 0T, 0.5T, 1T, 1.5T, 2T, 2.5T, 3T, 3.5T, 4T, 4.5T, and 5T for the curves from right at each temperature.

the very small oxygen gas leak through the gap between the cylinder and the opening frame. The temperature of the tape during deposition was 690℃. The YBCO[103] pole figure in Fig.2c shows

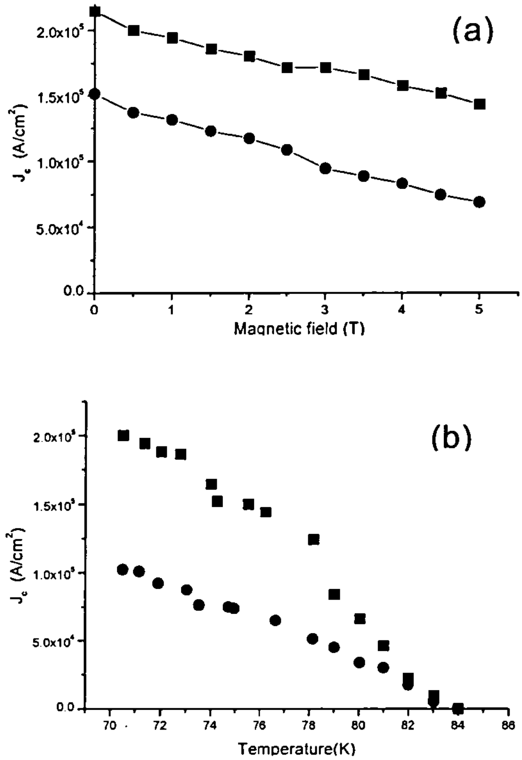

Fig.4a;Applied magnetic field vs Jc along the tape direction at 77K(squares) and 70K(triangles) 4b;Jc vs temperature for the currents flowing in two directions, along the tape (squares) and across the tape (circles).

the crystalline orientations of the YBCO film was coincident with that of Ni tape. Hence, the a(b) axis was parallel with the rolling direction and the c axis was parallel with the Ni[001] (YSZ[001] or CeO_2[001]) which is tilted. SEM micrograph indicated the YBCO film surface was somewhat rough, which is the general feature of tilted crystalline films[8].

III. Experimental results

The critical current densities, Jc's, are determined from the current vs voltage(I-V) curve for each field as shown in Fig.3a for 77K and 3b for 70K, where the sample was a short tape of 5cm length. It was cut from the 18cm long tape to be put into the measuring system with applied magnetic field. The filed direction was normal to the tape surface. As one can see in these figures, the I-V curves look like those of the RSJ-Josephson junctions. Moreover the voltages drop to finite values as the currents decrease below certain values and somewhat slowly decrease to zero. We don't know this feature is intrinsic for RATS-YBCO films or caused by the too small thickness, ~700Å, of the YBCO film with rough surfaces. The Jc was estimated at the point where the voltage was 1mV, across the two voltage probes of almost 5cm distance, which is about 20V/mm. Fig.4a shows the applied magnetic field vs Jc along the tape direction at 77K and 70K. The reduction rate of Jc by applied field is about 50% for 5Teslar, which is similar to that for the c-axis normal film [2].

In order to check the directional properties of critical currents, we measured the critical current densities for the currents flowing in two directions, along the tape and across the tape. Fig.4b shows Jc vs temperature for the two types of geometry. Jc along the tape at 77K was about 1.5 x 10^5A/cm^2 which is about twice of that across the tape. This anisotropy is a matter of course because the current flowing across the tape must tunnel numerous ab planes of YBCO crystal while the current along the tape flows along the ab planes.

The superconducting qualities of our RATS coated conductors were somewhat inferior to those of the RABiTS coated conductor. Much larger Jc's in tilted crystalline YBCO films were reported[8]. Hence we believe the inferiority is not intrinsic of RATS coated conductors and Jc must be improved by better quality YBCO films. Moreover we believe the merit of the single crystalline textures of long substrate tapes, which guarantees the absence of mis-oriented grains might compensate those inferiority.

IV. Summary

We textured pure Ni tapes by rolling and heat treatment under some what strict conditions. To improve the mechanical properties of the tape, impurities were diffused into it after texturing. The obtained 18cm long tapes were single crystalline with [001] axes tilted with respect to the surface and [010] axes parallel to the rolling direction. Our experimental observations indicated the tapes were crystallized by secondary recrystallizations. The XRD pole figures revealed the textures of the YBCO/CeO_2/YSZ/CeO_2 films grown on the Ni tape were same as that of the substrate. The I-V curves look like those of the RSJ-Josephson junctions. Jc, which was defined by 1mV signal in the 5cm long sample, was 1.5 x 105A/cm2 at 77K with zero field and was ~50% reduced by the applied magnetic field of 5T.

Acknowledgements

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