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Fabrications of YBCO Coated Conductors Using Tilted Single Crystalline Nickel Tapes

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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. The reproducibility of this texturing was checked by taking statistics on the crystal orientations of 24 Ni tapes. 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. J_c defined by 20μV/mm criterion was 1.5 x 10^5A/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 attention for the expectations of realizing the potential of high T_c 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]-[6].

The Ni tapes processed by RABiTS are recrystallized in cube textures, where grains of several tens of μm size [7] are mostly aligned with their [001] axes normal to the surface and their [010] axes parallel to the rolling direction [1]. For the best textured one, the alignment of in-plane orientations is as good as 6° measured by XRD(X-ray diffraction) ϕ-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 [7]. Hence for a hundred meter-long tape one might worry the presence of a single small region populated by mis-oriented grains which causes a great reduction of critical current. These problems 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. Experimental

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

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rolling is intentionally and slightly imperfect. A 3mm thick 99.9% Ni plate was rolled to a 80μm thick tape. When the tape thickness reached 200~150μm, we rolled the tape using a slightly unbalanced roller to make the shape of the tape slightly bent on purpose. 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 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. Figure 1(a) shows the Ni[111]-XRD pole figure where the two peaks at the high valued χ-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. 1(b). We divided the 18cm long tape into nine pieces of ~2 cm long tapes and found that their crystalline orientations were exactly the same. We couldn't see any grain boundaries on the tape surface that had been polished and etched by nitric acid. This means that the entire 18cm long tape was an extremely large, single grain having single crystalline structure. We made many Ni tapes by the same method. Their [010] axes were always parallel with the rolling directions within 3° with their [001] axes were tilted by +(20°~28°) or -(20°~28°). The orientations for the ± signs are described in Fig. 1(b). Hence the crystalline orientations of all the tapes, which had undergone RATS process independently, were not the same. However, for each tape, once the tilt angle was determined initially, then the crystalline orientation was fixed throughout the whole length of the sample, revealing that the tape was totally single crystalline. In order to find out the detailed recrystallization process, we stopped heat treatment when the middle part of the tape was passing the hot zone and cooled it to the room temperature. After this process, 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. This means the deformed rolling texture was converted to RABiTS texture by the primary recrystallization, and later converted to RATS texture by the secondary recrystallization [8]. 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 secondary recrystallization. Here it is noted that control of the amount of inten-

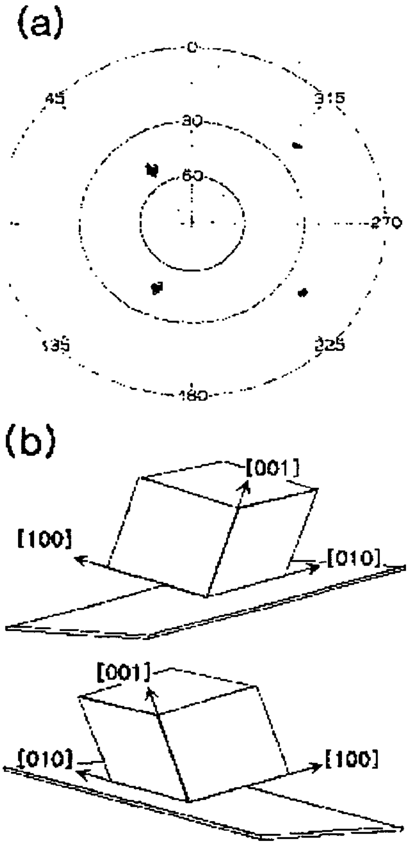

Fig. 1. (a) Ni [111] pole figure for the Ni tape. The two peaks for higher χ angles on the right hand side are partially shown. (b) Schematic figures for the crystalline orientations tilted by a + angle (upper figure) and by a - angle (lower figure) of the Ni tape. The [010] axes for both are parallel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

tional imperfection in the rolling texture was important. It is because too much imperfection resulted in destroy of textures due to spontaneous and random granular secondary recrystallization. On the other hand, too slight imperfection results in incomplete conversion of the 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 of the tape, should be uniform along the tape. Although the successful single crystalline recrystallization of the whole tape was obtained under strict conditions, our experimental results demonstrated that 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 [8]. However our experimental results indicated the recrystallization of the tilted orientation is completely prevailing under the RATS conditions. Hence the grains with large angle misorientations could be eliminated in a very long Ni tape, if the RATS method is successfully applied.

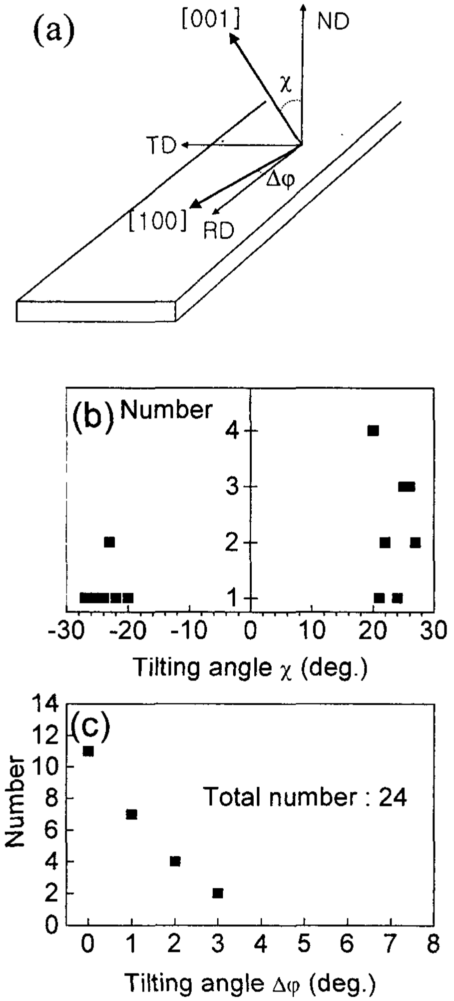

Fig. 2. (a) A schematic figure for the crystalline orientation of RATS. Rolling Direction (RD), Transverse Direction (TD), and Normal Direction (ND) were defined in the tape frame. [001] and [100] are the axes of Ni grain. χ is an angle between [001] axis and ND and $\Delta\varphi$ is the angle of Ni[100] deviated from RD. (b) Statistical data for χ angles and (c) Statistical data for $\Delta\varphi$ angles for 24 RATS samples.

In order to check the reproducibility of RATS texturing, we made 24 RATS Ni tapes, which were all ~ 5cm long and single crystalline with tilted axes. Then we took statistical data for their crystalline orientations. Figure 2(a) shows a schematic diagram for the tilted crystalline orientation, where the Ni[001] axis of a RATS Ni tape is tilted by the angle χ and almost included in the plane defined by ND(normal direction) and TD(transverse direction). χ is the angle between ND and Ni[001]. Ni[100] axis is almost parallel to RD(rolling direction). Figure 2(a) also shows that $\Delta\varphi$ is defined by the surface projection value of the deviation angle of Ni[100] from RD. Figures 2(b) and 2(c) show the statistical data for χ and $\Delta\varphi$ for the 24 samples. These angles were estimated from XRD 2θ and ϕ–scan data, where the 24 χ's are in either + 20~+28° or –20~ –28° with the 24 $\Delta\varphi$'s being in ± 0~3°. Each sample appeared single crystalline, of course. This means that the crystalline orientation was fixed for the whole length of the tape during the process of recrystallization if the tilt angle was determined initially. The above-mentioned angles for the dispersion of orientations indicate the degree of reproducibility of RATS texturing. Here we note that the difference between the positive and the negative χ's, which is the largest misorientation at the boundary of possible two domains, is the most serious problem. For removing the undesirable boundary, a long tape should be totally single crystalline. However, for a practical several hundreds meters-long tape, it may not be easy to make the tape totally single crystalline by fixed orientations of recrystallized crystals. So, we are now seeking a different way to make tapes tend to recrystallize with their crystalline orientations tilted to only one side.

The tapes textured by RATS were too flexible and mechanically too soft. Moreover, when triggered by an applied weak force, sharp bends occurred spontaneously at many places of the tape and the tape was deformed in a meander shape. However, the spontaneous sharp bend, possibly caused by concentration of numerous mobile dislocations created by the external force, could be solved by addition of impurities. After recrystallization, ethanol vapor of ~300 mTorr 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 to 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 [9]. 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 ref. [9] and the hollow cathode dc-sputtering. However, since the hollow cathode dc-sputtering is not appropriate for long tape substrate, the co-evaporation method is believed more appropriate for deposition of YBCO films on long Ni tapes. By the co-evaporation method, we could not get successful c-axis normal YBCO films on the tilted crystalline Ni tapes even if the same buffer layer was used as in ref. [9]. This may be due to the different growth conditions between the two different methods, i.e., the sputtering method and the evaporation method. Instead, we could get well textured tilted crystalline YBCO film on the 18 cm long RATS-Ni tape using the evaporation method with a cylindrical rotating sample holder in a double chamber system. Since, as shown in Fig. 1(b), the a (or b) axes of the tilted crystalline YBCO films were parallel to the tape direction even though the c-axes were tilted, the critical current was not much deteriorated. Here we described only the properties of the tilted crystalline YBCO films deposited on the RATS-Ni tapes by the co-evaporation method.

Buffer layers of CeO_2 (200Å) / YSZ(3000Å) / CeO_2(50Å) were deposited on the 18cm long Ni tape by e-beam evaporation [3]-[6], where the tape was wound around a cylindrical sample holder heated up to 650℃ by four halogen lamps and rotated by 0.5 RPM. The evaporation sources were metallic Ce and ceramic YSZ [1]. The base pressure was $\sim 10^{-6}$ Torr. Initially the Ni surface was deoxidized by 20 mTorr hydrogen gas [3]-[6]. 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 Figs. 3(a) and 3(b), CeO_2[111]

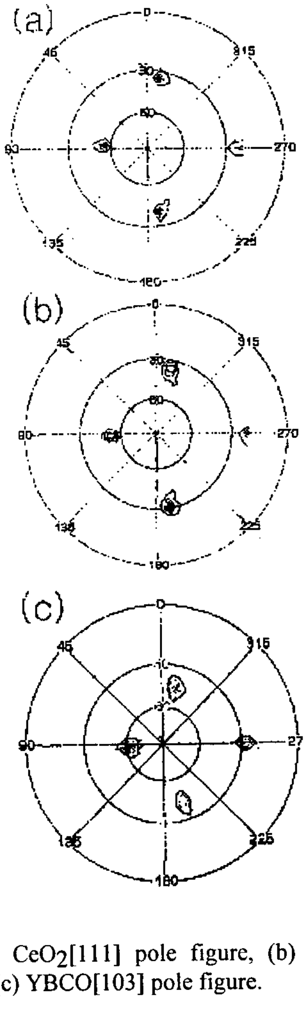

Fig. 3. (a) CeO_2[111] pole figure, (b) YSZ[111] pole figure and (c) YBCO[103] pole figure.

and YSZ[111] pole figures showed that the crystalline orientations of the buffer layers were the same 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 the tilted Ni[001].

A ~700 Å 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 5x10^{-3} Torr oxygen gas [10]. The reaction chamber is connected to a evaporation chamber through an opening. The vapors of co-evaporated Y, Ba and Cu were supplied through the opening and deposited on the tape with the oxygen pressure in the evaporation chamber maintained at less than 10^{-6} Torr, which was due to the very small oxygen gas leak through the gap between the cylinder and the opening frame. The temperature of the tape was 690 ℃ during deposition. The YBCO[103] pole figure in Fig. 3(c) shows the crystalline orientations of the YBCO film was coincident with that of Ni tape. Hence, the a (or b) axis was parallel with the rolling direction and the c axis was parallel with the tilted Ni[001] (YSZ[001] or CeO$_2$[001]). SEM pictures indicated that the YBCO film surface was somewhat rough, which is the general feature of tilted crystalline films [11].

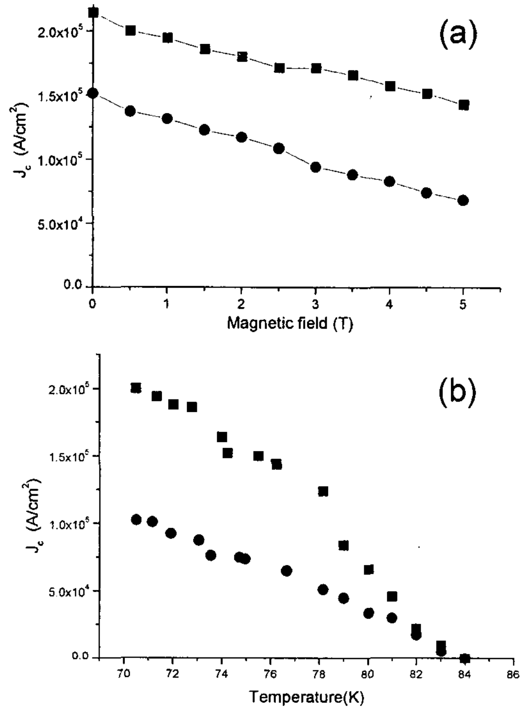

Fig. 4. (a) Applied magnetic field vs J_C along the tape direction at 77K (squares) and 70K (triangles). (b) Jc vs temperature for the currents flowing in two directions; one along the tape (squares) and the other across the tape (circles).

III. Results

The critical current densities (Jc's) were determined from the current vs voltage (I-V) curve under various magnetic fields, where the sample was a short tape of 5cm in length. It was cut from the 18cm long tape to be placed in the measurement system under applied magnetic field. The field direction was normal to the tape surface. The I-V curves look like those of the RSJ-like Josephson junctions. Moreover, the voltage dropped to finite values as the current decreased below a certain value and somewhat slowly decreased to zero. At the moment, we don't know whether this feature is an intrinsic property of the RATS-YBCO films or due to the too small thickness of ~700 Å for the YBCO film with rough surfaces. 1 mV criterion was used in determining the J_c with the two voltage probes separated by almost 5cm, giving about 20μV/mm criterion. Figure 4(a) shows the applied magnetic field vs Jc along the tape direction at 77K and 70K, respectively. The reduction rate of J_c by applied field is about 50% for 5 Teslar, which is similar to that for the c-axis normal film [2].

In order to check the directional properties of the critical current, we measured the critical current densities for the currents flowing in two different directions; one along the tape and the other across the tape. Figure 4(b) shows J_c vs temperature data for the two different cases. It appeared that J_c along the tape was about 1.5 x 10^{5}A/cm^2 at 77 K, which is about twice of that across the tape. This kind of anisotropy seems natural because the current flowing across the tape must tunnel through numerous a-b planes of YBCO crystal, while the current along the tape flows along the a-b planes.

The superconducting properties of our RATS coated conductors appeared somewhat inferior to those of the RABiTS coated conductor. Considering much larger J_c's reported in tilted crystalline YBCO films [11], the inferiority is not believed intrinsic to the RATS-coated conductors and improved J_c can be observed from the YBCO films of better qualities. Studies to produce YBCO films with high J_c are currently under progress by using the long substrate tapes with single crystalline textures and no misoriented grains.

IV. Summary

We textured pure Ni tapes by rolling and heat treatment under somewhat strict conditions. To improve the mechanical properties of the tape, impurities were diffused into the tape 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 that the tapes were crystallized by secondary recrystallizations. Also, the XRD pole figures revealed that the textures of the YBCO/CeO_2/YSZ/CeO_2 films grown on the Ni tape were the same as that of the substrate. J_c, which was defined by 20μV/mm criterion in the 5cm long sample, was 1.5 x 10^5 A/cm^2 at 77K with zero field and decreased by ~50% in the applied magnetic field of 5 T.

Acknowledgments

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References

[1] A. Goyal, D. P. Norton, J. D. Budai, M. Paranthaman, E. D. Specht, D. M. Kroeger, D. K. Christen, Q. He, B. Saffian, F. A. List, D. F. Lee, P. M. Martin, C. E. Klaubunde, E. Harfield and V. K. Sikka, "High critical current density superconducting tapes by epitaxial deposition of $YBa_2Cu_3O_X$ thick films on biaxially textured metals ," Appl. Phys. Lett. 69, 1795-1797 (1996)

[2] D. P. Norton, A. Goyal, J. D. Budai, D. K. Christen, D. M. Kroeger, E. D. Specht, Q. He, B. Saffian, M. Paranthaman, C. E. Klaubunde, D. F. Lee, B. C. Sales and F. A. List, "Epitaxial $YBa_2Cu_3O_7$ on Biaxially Textured Nickel(001) : An Approach to Superconducting Tapes with High Critical Current Density," Science 274, 755-757 (1996)

[3] Q. He, D. K. Christen, J. D. Budai, E. D. Specht, D. F. Lee, A. Goyal, D. P. Norton, M. Paranthaman, F. A. List, D. M. Kroeger, "Deposition of biaxially-oriented metal and oxide buffer-layer films on textured Ni tapes: New substrates for high-current, high –temperature Superconductors," Physica C 275, 155-161 (1997)

[4] M. Paranthaman, A. Goyal, F. A. List, E. D. Specht, D. F. Lee, P. M. Martin, Q. He, D. K. Christen, D. P. Norton, J. D. Budai, D. M. Kroeger, "Growth of biaxially textured buffer layers on rolled-Ni substrates by electron beam evaporation," Physica C 275, 266-272 (1997)

[5] C. Y. Yang, S. E. Babcock, A. Goyal, M. Paranthaman, F. A. List, D. P. Norton, D. M. Kroeger, A. Ichinose, "Microstructure of electron-beam-evaporated epitaxial yttria-stabilized zirconia/CeO_2 bilayers on biaxially textured Ni tape," Physica C 307, 87-98 (1998)

[6] Sanghyun Oh, Jaeun Yoo, Kyuhan Lee, JunHo Kim, and Dojun Youm, "Comparative study on the crack formations in the CeO_2 buffer layers for YBCO films on textured Ni tapes and Pt tapes," Physica C 308, 91-98 (1998)

[7] E. D. Specht, A. Goyal, D. F. Lee, F. A. List, D. M. Kroeger, M. Paranthaman, R. K. Williams, and D. K. Christen, "Cube-textured Nickel substrates for high-temperature superconductors," Superconductor Science and Technology 11 (10), 945-949 (1998)

[8] A. Berger, P. J. Wilbrandt, F. Ernst, U. Klement, and P. Haasen, Progress in Materials Science 32, 1 (1988)

[9] JunHo Kim and Dojun Youm, "Growth of textured c-axis normal $Y_1Ba_2Cu_3O_{7-\delta}$ thin films on yttria-stabilized zirconia substrates with crystalline axes tilted with respect to the surfaces," Physica C 275, 273-278 (1997)

[10] W. Prusseit, S. Corsepius, F. Baudenbacher, K. Hirata, P. Berberich, and H. Kinder, "Epitaxial growth of $Y_1Ba_2Cu_3O_7$ films on GaAs with MgO buffer layers," Appl. Phys. Lett. 61, 1841-1843 (1992)

[11] M. Bauer, R. Semerad and H. Kinder, "YBCO films on Metal Substrates with Biaxially Aligned MgO Buffer layers," IEEE Trans. Appl. Supercond. 9, 1502 -1505(1999)