Proceedings of the Korean Superconductivity Society Meeting 2000
(KSS 2000), YongPyung, Kangwondo, Korea, Aug. 16-18, 2000

Magneto-resistances of the coated conductors fabricated on the tilted single crystalline Ni substrates and RABiTS

J. Yoo[a], H. Kim[a], K. Jung[a], S. Oh[b], and D. Youm[a]
[a] *Korea Advanced Institute of Science and Technology, Taejon, Korea*
[b] *Korea Basic Science Institute, Taejon, Korea*

Received 22 July 2000

Abstract

Magneto-resistances of the $YBa_2Cu_3O_{7-\delta}$ based coated conductors fabricated on the tilted single crystalline Ni substrates and RABiTS (rolling assisted bi-axially textured substrate) were measured under various magnetic fields. The activation energies of vortices were estimated from them by fitting equation of $\rho = \rho_0 \exp(-U(H,T)/k_BT)$. When currents flew in the rolling direction for the case of the tilted single crystalline YBCO on the RATS, the activation energies were similar to those of c-axis normal YBCO films on the $SrTiO_3$ single crystal substrates [5] and were slightly larger than those of the RABiTS coated conductors. On the contrary, for the currents flowing in the transverse direction, the magnetoresistances show double transitions in the temperature with much smaller activation energies.

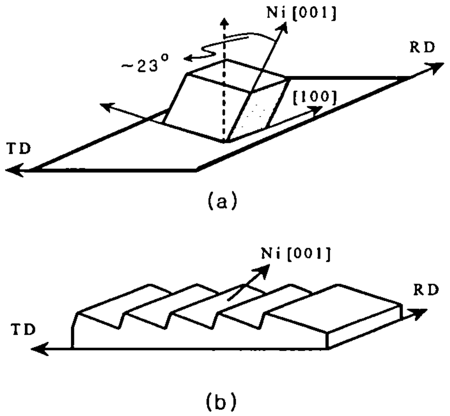
Keywords : Magneto-resistance, coated conductor, YBCO

I. Introduction

Superconductor coated conductors have gained much attention for the expectation of realizing the potential of High T_c superconductors in large scale devices. Recent progress of the fabrication of highly textured $YBa_2Cu_3O_{7-\delta}$ (YBCO) coated conductor, avoiding the weak links, is to texture the metal substrates by cold rolling and annealing process, what is said, rolling assisted biaxially textured substrates (RABiTS) where oxide buffer layers can be also grown cube textured [1]. However the crystalline orientations of grains are basically probabilistic so that there is no guarantee for the absence of grains with high angle misorientations which reduce severely critical current [2].

Recently we reported a different type of recrystallization. Cold rolled Ni tapes became a large single crystal [3] : [100] axis of Ni was tilted with respect to the surface and [010] axis was parallel to the rolling direction. $YBCO/CeO_2/YSZ/CeO_2$ films were grown on the Ni tapes and we found the same crystalline orientations as tilted one of the Ni substrate. We believe that the single crystalline texture guarantee the absence of misorientation grains. On this new type Ni, we call RATS (Rolling assisted tilted textured substrate), the superconducting properties were anisotropic in the surface plane. The critical current flowing in the rolling direction (//RD) is much larger than flowing in the transverse direction (//TD). This anisotropy is due to the fact that the current //TD tunnel numerous Cu-O planes of YBCO unlike the current //RD in the Cu-O planes. Since the tilted crystalline film grow with the surface morphology comprising numerous microsteps as shown in Figure 1, one might concern that such morphology include some defects or weak links degrading qualities of film and reducing the field dependent critical current density, but it is not true.

In this paper, we compared activation energies in RATS coated conductors with those on the RABiTS, and $SrTiO_3$. Activation energies of vortices were estimated from results of measurements of anisotropic magnetoresistances (MR) as functions of temperature under various magnetic fields.



ilted
ated
conductor (b) of surface morphology

II. Experimental

Sample preparations Procedures for the fabrications of the RATS coated conductors are described in detail in Ref.[3]. In brief, we rolled a 3 mm thick 99.9% Ni rods until the thickness of Ni tapes reached 80 μm, whose deformation textures were intentionally and slightly imperfect. These cold rolled Ni tapes moved through heating area at temperature 900~1100 °C in a long quartz tube. Tapes underwent the secondary recrystallization, which seemed to be triggered by the imperfections of rolling texture. In general, the size of grains formed by secondary recrystallization is very large. Moreover, by RATS process, the whole tape whose width is 1 cm and length is 50cm could be recrystallized into a single crystal with its crystalline axis tilted. [001] axis was tilted by ~23° with respect to the surface while the [010] axis parallel to the rolling direction as shown in Figure 1(a). Tapes textured by RATS were to flexible and bent spontaneously into a lot of inclined step- shape. Hence we diffused carbon impurities into tapes in order to prevent them from undergoing the spontaneous bending. We deposited buffer layers, CeO_2(5nm)/ YSZ(300nm)/ CeO_2(20nm) and ~100 nm thick YBCO film on the Ni tape. The YBCO (103), CeO_2 (111) and YSZ (111) pole figures showed their crystalline orientations were coincident with that of Ni. Hence the YBCO – a(b) axis was parallel to the rolling direction, and the YBCO – c axis was parallel to Ni [001] which was tilted. In this crystalline orientation, ab planes are aligned along the rolling direction so that large supercurrent can flow. Texture-qualities of the samples used in this experiment were similar to those in Ref. [3] as confirmed by XRD pole figures.

SEM micrograph indicated the surface of the YBCO film consisted of numerous microsteps, which is the general feature of the tilted crystalline films [4]. Stripe-like steps were made of the outgrowths in the direction of a(b) axis and were well aligned as shown in Figure 1(b). The distance between the two adjacent steps was about 200 ±50 nm. Since the tilt angle of ab planes which make inclined surfaces of the steps was ~23°, one can easily find out that the thickness of the YBCO film modulates between ~60 nm and ~140 nm with period ~200 nm, the average thickness is about 100 nm.

Experimental results and discussions Using four probe method, we measured MR vs. temperature under various magnetic fields applied normal to the tape surface. We took two types of geometries for the directions of applied currents of 100 μA, i.e. the current //RD and current//TD. Figure 2(a) and 2(b) showed MR for the two geometries, respectively. Curves for the current //RD show the very common feature while curves for the current //TD show an interesting double transitions which indicate a kind of crossover phenomena of vortices. Field - dependent activation energies U(H) were estimated by the equation (1) [5] and (2) [6] as shown in Fig 4.

$$\rho = \rho_o \exp(-U(T,H) / k_B T) \quad (1)$$

$$U(T,H) = U_o(1-T/T_c)H^{-q} \quad (2)$$

Fitting parameters U_o, ρ_o, q were given in Table 1. Here fitting parameters for the current //TD were obtained only from the data above the crossover temperature. Parameters for the YBCO film on a single crystal $SrTiO_3$ substrate and a RABiTS Ni substrate are also shown for comparison, where those of RABiTS conductors were estimated from the measured MR curves as shown in Figure 3. Among three parameters, we'll consider the activation energy of a vortex in a pinning center.

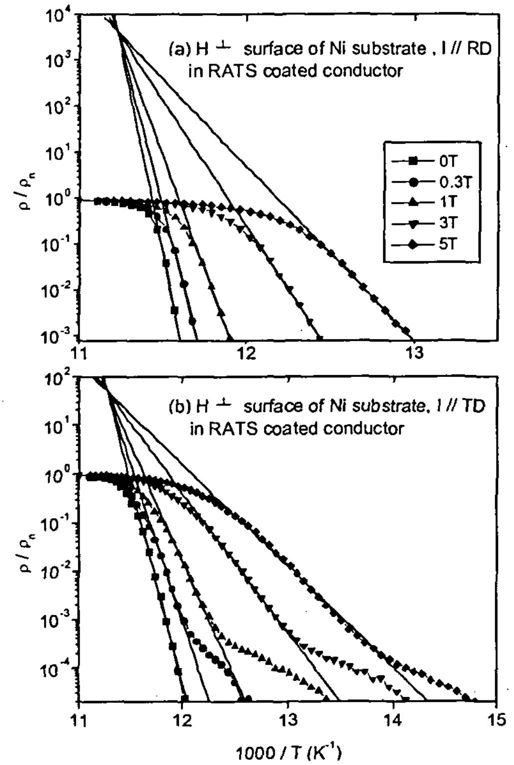


Fig. 2. Normalized magneto-resistances as function of 1000/T under various magnetic fields (0, 0.3, 1, 3, 5 Tesla). (a) for the current //RD (b) for the current //TD in the RATS coated conductors.

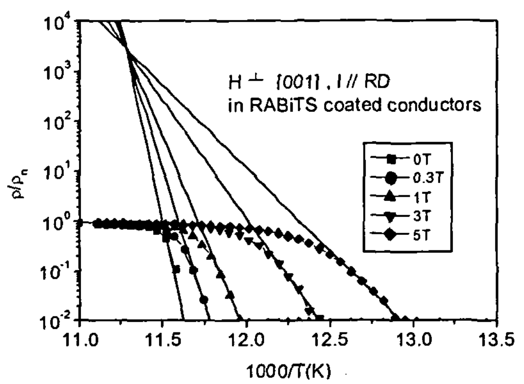


Fig. 3. Normalized magneto-resistances as function of 1000/T under various fields (0, 0.3, 1, 3, 5 Tesla) in the RABiTS coated conductors.

These results can be summarized as follows :

1. Activation energies (U_{RD}) for the current //RD were similar to U_{STO} of c-axis normal YBCO films on STO single crystals, and slightly larger than those of RABiTS coated conductors.

2. Activation energies U_{TD} for the current //TD were much smaller than others.

3. MR curves for the transverse current in RATS coated conductors show double transitions in temperature.

The strong anisotropy of activation energies must be due to our samples own particular properties (1) tilted ab planes and (2) thickness modulations, which are the most salient anisotropic characteristics of thin RATS coated conductors. Tilted ab planes result in the strong anisotropy of critical current, as described in Ref.[3], because the current //TD flow through tunnels of ab planes, instead in ab planes. And critical current under high fields depends mostly on the activation energies of vortex - pinning. However the anisotropy of U might not be due to the geometry of tilted crystal, because unless the temperature is not much below the liquid nitrogen temperature, the coherence length is longer than the space between Cu-O planes and so the anisotropic intrinsic pinning is negligible [7]. The similarity of U_{RD} and U_{STO} seems due to the single crystalline properties of both films, while the small value of U_{TD} might result from more complex reasons. One may consider the softening of vortex matter elasticity [8]

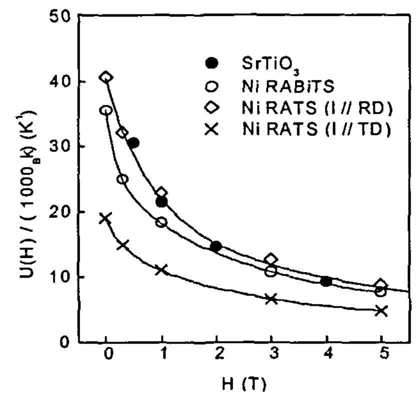


Fig. 4. $U(H)/1000k_B$ as functions of magnetic field for the YBCO films on various substrates, where k_B is the Boltzman constant. The lines are guides for eyes.

Table 1. The activation energies U_o and other parameters ρ_0/ρ_n , q estimated from figure 2. The parameters of films on STO crystals are borrowed from Ref.[5] for comparison. The unit of $U_0/(1000k_B)$ is K^{-1} T^{-q}

	ρ_0/ρ_n	$U_0/(1000k_B)$	q
Ni(RATS) I//RD	4279.1	20.11	0.46
Ni(RATS) I//TD	49.9	9.91	0.40
Ni(RABITS)	2924.8	16.31	0.42
$SrTiO_3$	401 ± 5	18.84	2/3

When the thickness of YBCO film modulates between 60nm and 140 nm with a period 200 ±50 nm, one can suppose that vortices experience the modulating potential of free energy and the density of their distribution must also modulate with the same period so that the distribution of vortices looks like numerous stripes aligned parallel to the tape. In this case, it is well known that softening of vortex matter elasticity occurs upon the width of the stripe like distribution of the vortex approaching the submicron size [8]. When the vortices move along stripes by Lorentz force of the current //TD their pinning effectively soften and make small activation energy. Moreover the crossover feature seems to be due to occurrence of inter - stripes correlation at somewhat low temperature. This is just one of possible explanations for our experimental results although it does not explain yet why softening did not occur for the current in the rolling direction. For better explanation, more accurate reasoning and calculation are necessary. The important point we would emphasize is that the vortices-pinning forces for the current //RD in the RATS coated conductors are as strong as those of the films on STO single crystals and superconductive qualities of films are good at least for the current //RD, which is practical one.

III. Summary

In summary, magnetoresistances as functions of temperatures in coated conductors fabricated on RATS and RABiTS were measured under various magnetic fields. Activation energies of vortices were estimated from data. For the current //RD, activation energies were similar to those of c-axis normal YBCO films on $SrTiO_3$ single crystals, and were slightly larger than those of the RABiTS coated conductors. For the current //TD, magnetoresistance curves had double transitions in temperature with much smaller activation energies. These results imply superconductive qualities of films on RATS Ni substrates are good at least for the current flowing in the rolling direction.

Acknowledgments

This work is supported by the Korean Ministry of Science & Technology and Korean Basic Science Institute.

References

[1] A. Goyal, D. P .Norton, J. D. Budai, M. Paranthaman, E. D. Specht, D. M. Kroeger, D. K. Christen, Q. He, S. Saffian, F. A. List, D. F. Lee, P. M. Martin, C. E. Klabunde, E. Hartfield, and V. K. Sikka, Appl. Physi. Lett. 69, 1795 (1996)

[2] E. D. Specht, A. Goyal, D. F. Lee, F. A. List, D. M. Kroeger, M. Paranthaman, R. K. Williams and D. K. Christen, Supercond. Sci. and Technol. 11, 945 (1998)

[3] Hosup Kim, Jaeun Yoo, Koochae Jung, Jaeseoung Lee, Sangjun Oh and Dojun Youm, Supercond. Sci. and Technol. 13, 995 (2000)

[4] M. Bauer, R. Semerad and H. Kinder, IEEE Trans. Appl. Supercond. 9, 1502 (1999)

[5] Xu Xiaojun, Fu Lan, Wang Liangbin, Zhang Yuheng, Fang Jun, Cao Xiaowen, Li Kebin and Sekine Hisashi, Phys. Rev. B 59, 608 (1999)

[6] B.W.Kang, W. N. Kang, S. H. Yun and J.Z. Wu, Phys. Rev. B 56, 7862 (1997)

[7] P. Berghuis, E. Di Bartolomeo, G. A. Wagner and J. E. Evetts, Phys. Rev. Lett. 79, 2332 (1997)

[8] Yoichi Ando, Hioshi Kubota and Shoji Tanaka, Phys. Rev. Lett. 69, 2581 (1992)