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Fabrication of cube textured NiO seed layer for YBCO coated conductor

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Abstract

The cube textured NiO was formed on pure Ni tape using a simple approach of oxidizing the surface of the Ni tape for 3–20 min in air at 1130–1200 °C. The thickness of the NiO layer was about 1–5 μm. X-ray diffraction (XRD) θ–2θ scan, ω-scan, φ-scan, and pole figure were employed to characterize the in-plane alignment and cube texture of NiO film, and they showed that the NiO film was cube textured. The integrated intensity ratio of NiO I(2 0 0)/{I(2 0 0) + I(1 1 1)} was more than 99%, and the in-plane and out of plane full width at half maximum (FWHM) of the NiO buffer layer were 6.8° and 6.6°, respectively. Yttria-stabilized zirconia (YSZ) as a barrier layer and CeO_2 as a cap one were deposited by pulsed laser deposition (PLD), and $YBa_2Cu_3O_{7-x}$ (YBCO) layer was prepared on them by PLD as well. YBCO superconducting layer with critical temperature (T_c) > 88 K and critical current density (J_c) > 4×10^5 A/cm^2 (77 K, 0 T) has been obtained successfully on Ni tape with a textured NiO seed layer.

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Keywords: YBCO coated conductor; NiO surface oxidation epitaxy; Cube textured

1. Introduction

High temperature superconducting (HTS) wires/tapes which carry large amount of current in high magnetic field are required for practical applications, such as power electric devices and high field magnets. There have been great progresses in the development of long-length coated conductor, otherwise called the second generation HTS wire, and high current carrying coated conductors longer than several meters have been reported since 2002. The current issues in coated conductor include identifying more economical manufacturing process of the multi-layer films, improving the uniformity and reproducibility, and increasing the current carrying capability.

Cube textured (1 0 0) [0 0 1] metal tapes, manufactured by thermo-mechanical treatment, have been proven to be suitable substrates for coated conductor process [1,2] when intermediate buffer layers are inserted between metal and YBCO superconducting layer. Matsumoto et al. [3] reported

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the potential of the surface oxidation epitaxy (SOE) process for formation of a cube textured NiO buffer on the textured Ni. This NiO can be epitaxially grown by direct oxidation of the tape surface. Results of the SOE process for coated conductors have been reported by many research groups [4–8]. In our work, Ni tapes were treated under the different oxidation conditions to form cube textured NiO which can be used as the first layer of the buffer architecture. The aims were to prevent the interaction between the YBCO and the metal substrate, and to hinder unexpected formation of the NiO(1 1 1) during deposition of buffer and superconducting layers for YBCO coated conductor by the SOE process. SOE process was found to be a simple and low cost technique which is suitable for long-length tape. Biaxially textured NiO seed layer was formed by controlling the oxidation conditions, as well as the texture of Ni substrate. In order to smoothen or flatten the surface roughness and to reduce mismatch with YBCO, YSZ and CeO_2 films were deposited on Ni substrate with NiO seed layer before YBCO deposition. The J_c at liquid nitrogen temperature was more than 4×10^5 A/cm^2.

2. Experimental

Pure Ni was introduced into the (1 0 0) [0 0 1] cube texture by cold rolling with deformation in excess of 98% to the final thickness of 0.1–0.15 mm, followed by recrystallization thermal treatment for 1 h at 900–1000 °C. The Ni tapes have a typical (1 0 0) [0 0 1] cube texture with in-plane FWHM of 7–9°. Prior to oxidation, Ni tapes were cut into small pieces. Chemical polishing was performed to Ni samples before SOE process, and then the Ni samples were ultrasonically cleaned in acetone.

The surface oxidation process was conducted in a horizontal tube furnace. The NiO growth in air was carried out at temperature range of 1100–1250 °C. When the furnace was heated to the required temperature, the sample was put into the furnace directly. After pre-determined oxidation time at high temperature, the sample was rapidly taken out of the furnace and cooled down to the room temperature in air.

X-ray diffraction (XRD) θ–2θ scan, ω-scan, φ-scan, and pole figure were employed to characterize the in-plane and out of plane alignment. The surface morphologies were examined by optical and scanning electron microscope (SEM). Energy dispersive spectrum analysis (EDS) in the SEM was used to evaluate phase compositions.

Furthermore, YSZ as a barrier layer and CeO_2 as a cap one were deposited on Ni substrates with NiO seed layer by pulsed laser deposition (PLD), and YBCO layer was prepared by PLD as well. The thickness of YBCO was less than 380 nm. The electrical properties of the YBCO film were measured by standard four-probe method with a criterion of 1 μV/cm for full width of sample.

3. Results and discussion

The highly cube textured Ni tapes were obtained by cold rolling process followed by recrystallization thermal treatment. On the textured Ni tapes, cube textured NiO was formed using SOE technique in air at the oxidation temperature of 1110–1250 °C for 3–30 min. The thickness of the NiO layer was about 1–5 μm. It has been found that the texture of NiO layer in SOE process was affected enormously by oxidation temperature and time, as well as the texture and morphology of the Ni substrate. When oxidation was carried out at the temperature in the ranging from 1130–1200 °C for 3–30 min, NiO film was formed on Ni tape with a cube texture. The integrated intensity ratio of NiO $I(2\,0\,0)/\{I(2\,0\,0)+I(1\,1\,1)\}$ was more than 99% under above mentioned oxidation condition. When the temperature was lower than 1100 °C, the (1 1 1) peak of NiO appeared. When the temperature was higher than 1250 °C and the oxidation time was longer, the surface of NiO would become rougher. That was because the grain size increased in higher temperature than 1250 °C. Furthermore, the rate of heating and cooling temperature was an important factor for cube texture of NiO. In our work, the samples were directly placed a hot air furnace, in order to prevent the formation of a pre-existing NiO(1 1 1) film during placing samples into the furnace through lower temperature.

The X-ray φ-scans of Ni(1 1 1) and NiO(1 1 1) peaks are shown in Fig. 1, which demonstrates that the (1 0 0) textured NiO was obtained on the Ni surface with cube-on-cube orientation. High in-plane alignment of the NiO buffer layer can be seen from φ-scan. The average FWHM from X-ray φ-scan values for Ni(1 1 1) and NiO(1 1 1) are 6.8° and 6.6°, respectively. Fig. 2 presents the X-ray rocking curve of NiO(2 0 0) peak. The FWHM of 6.3° is similar to that of the Ni substrate. Fig. 3 shows the pole figure of NiO(1 1 1), which implies an excellent cube texture.

The SEM was used to study the surface morphology of NiO films, and typical result is shown in Fig. 4. No crack was found, but defects such as droplets, pin holes were observed. Some outgrowths of NiO occurred around Ni grain boundaries which were not beneficial to the deposition of YBCO on it.

In order to improve the surface morphology of a buffer layer and enhance lattice match between buffer layer and YBCO layer, YSZ and CeO_2 films were inserted as barrier and cap layers. And then YBCO was grown by pulsed laser deposition on a YSZ/CeO_2/NiO buffered Ni substrate. The best YBCO film fabricated on such buffered Ni showed a T_c onset of 91.5 K and a zero resistance at 88.4 K. The resistance versus temperature data is shown in the insert of Fig. 5. Fig. 5 describes that the I_c value in self-field and at 77 K is 14 A for 7.5 mm width sample. For most samples, J_c values were in the range of 4–5$\times10^5$ A/cm^2 (0 T, 77 K). The rough surface of the NiO layer, which can lead to rough surface and lower degree of texture of the layers deposited on the NiO, is believed to limit the critical current.

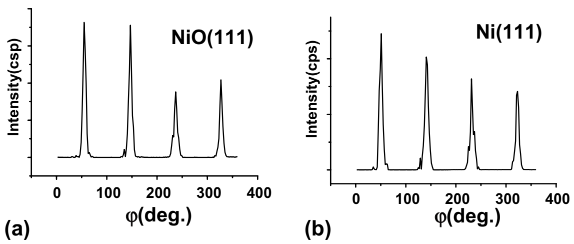

Fig. 1. X-ray φ-scan for (a) NiO(1 1 1) by SOE process and (b) Ni(1 1 1) substrate by rolling and annealing process.

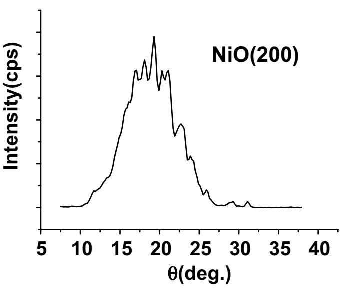

Fig. 2. X-ray ω-scan for (2 0 0) peak of NiO grown on Ni tape by SOE process.

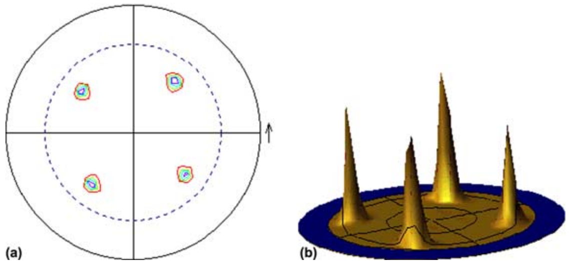

Fig. 3. X-ray pole figure of NiO(1 1 1): (a) NiO(1 1 1) 2D pole figure. (b) NiO(1 1 1) 2.5D pole figure.

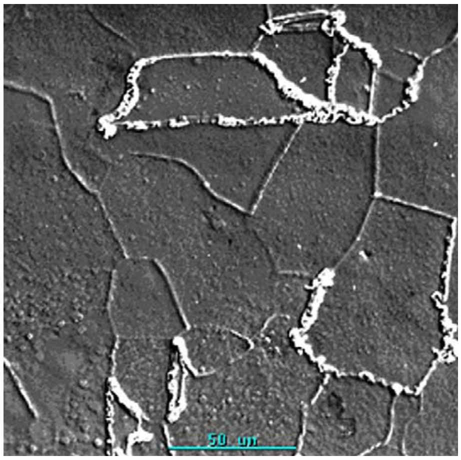

Fig. 4. SEM surface morphology of NiO grown on Ni tape by SOE process.

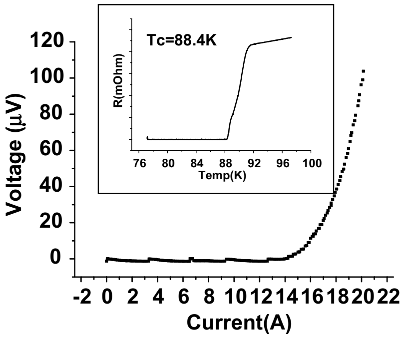

Fig. 5. Critical current of the YBCO film deposited on the CeO_2/YSZ/NiO buffered Ni. Inset shows resistance versus temperature data for YBCO.

4. Summary

The highly cube textured NiO seed layer on textured pure Ni tape was successfully obtained by SOE technique. The integrated intensity ratio of NiO I(2 0 0)/{I(2 0 0) + I(1 1 1)} was more than 99%, and the in-plane and out of plane FWHM of the NiO seed layer were 6.8° and 6.6°, respectively. The SEM observation implied that the surface morphology of NiO film was crack-free, even though it was not very smooth. YSZ as a barrier layer and CeO_2 as a cap one were deposited by PLD, and YBCO layer was prepared by PLD as well. As a consequence of investigation, YBCO superconducting coatings with a high *c*-axis orientation, high T_c exceeding 88 K and J_c higher than 4×10^5 A/cm^2 at 77 K, 0 T have been obtained successfully on Ni tapes with a textured NiO seed layer.

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References

[1] A. Goyal, D.P. Norton, J. Budai, M. Parantharam, E.D. Specht, D.M. Kroeger, D.K. Christen, Q. He, B. Sa.an, F.A. List, D.F. Lee, P.M. Martin, C.E. Klubunde, E. Hat.eld, V.K Sikka, Appl. Phys. Lett. 69 (1996) 1795.

[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. Klabunde, D.F. Lee, B.C. Sales, F.A. List, Science 274 (1996) 755.

[3] K. Matsumoto, S.B. Kim, J.G. Wen, I. Hirabayashi, T. Watanabe, N. Uno, M. Ikeda, IEEE Trans. Appl. Supercon. 9 (1999) 1539.

[4] K. Matsumoto, A. Takechi, T. Ono, I. Hirabayashi, K. Osamura, IEEE Trans. Appl. Supercon. 13 (2003) 2535.

[5] D.Q. Shi, M. Ionescu, J. McKinnon, W.M. Chen, S.X. Dou, Cryog. Eng. 48 (2002) 525.

[6] M. Kai, T. Izumi, K. Hasegawa, Y. Tokunaga, S. Asada, Y. Nakamura, T. Izumi, T. Watanabe, Y. Shiohara, Physica C 378–381 (2002) 998.

[7] Z. Lockman, X. Qi, A. Berenov, W. Goldacker, R. Nast, B. deBoer, B. Holzapfel, J.L. MacManus-Driscoll, Physica C 383 (2002) 127.

[8] T. Watanabe, Y. Ohashi, T. Maeda, M. Mimura, I. Hirabayashi, IEEE Trans. Appl. Supercon. 13 (2003) 2484.