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Relations between tensile stresses and critical current densities of coated conductors

Jaeun Yoo and Dojun Youm
Korea Advanced Institute of Science and Technology, Taejon, Korea

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Abstract

The relations between tensile stresses and critical current densities (J_c) of coated conductors were measured. Around 320 MPa of tensile stress, the critical current densities of coated conductor fabricated on pure Ni tape were reduced to zero at 77K, where J_c for zero stress was order of 10^5A/cm. The critical tensile stress was much enhanced for the coated conductors fabricated on NiCr alloy tapes. However fabrication conditions for the growth on such alloys are much different from those on the pure Ni and it was not easy to get good textures and large critical currents. The detailed fabrication methods on those alloys will be presented.

Keywords : coated conductor, YBCO, tensile stress, NiCr alloy

I. Introduction

The development of the high transition temperature superconductor tapes for applications to magnets, motors, transformers and transmission lines has been proceeding actively. For many applications, YBCO based coated conductors on biaxially textured substrates are attractive candidates because of their high critical current densities, order of MA/cm^2 at 77K in self field [1]. To texture f.c.c. metal substrates such as Ni [2], NiCr, NiV, PtPd [3] were cold rolled and annealed at high temperature. To avoid degrading superconductive qualities by metal diffusion, oxides buffer layers, CeO_2/ YSZ /CeO_2 were grown biaxially textured on metal substrates.

In addition to Jc, there is equally necessary condition such as mechanical force dependence of critical current density for applications of superconductor tapes to making high fields, because Electromagnetic forces are extremely high in high field magnets [4]. The mechanical characteristics of J_c are less well investigated. Several researches were accomplished by C.L.H. Thieme *et al* [5] and C Park *et al* [6]. C. L. H. Thieme *et al* investigated about axial strain dependence of J_c in YBCO films on IBAD YSZ using inconel 625 substrates. They observed gradual deceasing of J_c with strain increase. C. Park *et al* studied about the bend strain tolerance of critical current in YBCO coated conductors using Ni RABiTS. They obtained the result that the compressive dependence of I_c was better than the bend strain dependence

In this paper, we studied relations between tensile stresses and critical currents of YBCO based coated conductors using Ni, Ni-13 atomic % Cr (NiCr) RABiTS. Critical currents remained almost constant by certain tensile stress and above this stress, decreased abruptly. We defined critical stress, where critical currents begin decreasing, and compare that in YBCO films on NiCr with that on Ni. However fabrication conditions for the growth on such alloys are much different from those on the pure Ni and it was not easy to get good textures and large critical currents. Procedures of fabrication on those alloys were presented in detail.

II. Experimental

Biaxially textured Ni and NiCr substrates were obtained by cold rolling of Ni and NiCr rods followed by recrystallization. The thickness of rolled Ni or NiCr tapes was about 80 – 100 μm. The temperature range for recrystallization of NiCr alloy was 900-1000 °C, which is narrower than that for Ni.

An e-beam evaporation technique was used to deposit buffer layers directly on Ni and NiCr. After the pressure in the chamber had reached 6 × 10^{-6} Torr at room temperature, a gas mixture of H_2 and Ar with volume fraction 1:10.5 was introduced until the pressure inside the chamber reached 100 mTorr. Ni and NiCr substrates were annealed at 650 °C, for 1 hour at that pressure. CeO_2 (5nm)/ YSZ (300nm) / CeO_2 (40nm) multi layers were deposited on the Ni at 600C-700 °C, and Ce metal, sintered Y_2O_3 stabilized Zr_2O_3 (YSZ) were used as sources respectively, for the oxide growth. A residual gas analyzer mounted in the e-beam system was used to analyze the chemistry of the oxidation formation. The background H_2O, H_2, O_2 partial pressures were around 10^{-6} - 10^{-5}, 10^{-6}, 10^{-8} Torr, respectively. As soon as Ce was evaporated, H_2 partial pressure increased up to range of 10^{-4}-10^{-5} Torr, because H_2O vapor oxidize CeO_2 film. We deposited YSZ films on the CeO_2 buffered Ni tapes. Biaxially textured CeO_2 films guaranteed biaxially textured YSZ films. The deposition rate was 1Å/s, for CeO_2, and 2-3Å/s for YSZ.

However growth conditions of oxide films on alloys are much different from those on pure Ni substrates and it was not easy to get good textured films on direct NiCr. Most of CeO_2 films deposited on direct NiCr tapes under various conditions had (111) axes as surface normal. To avoid this unexpected growth, we deposited Ni layers before growing CeO_2 films on NiCr tapes. The deposition temperature and thickness of Ni on NiCr were most important parameters. We also deposited biaxially textured CeO_2 (5nm)/YSZ (300nm)/CeO_2 (40nm) multilayers on the Ni -buffered NiCr tapes at 600 °C under same conditions for Ni tapes.

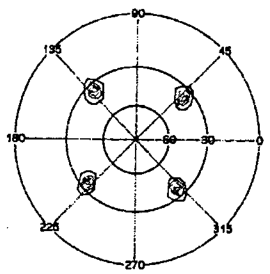

Fig. 1. (111) pole figure of cube textured Ni-13 at. % Cr substrate

YBCO films were then deposited on the CeO_2 /YSZ/CeO_2// (Ni and Ni / NiCr) by thermal co-evaporation of yttrium metal, barium metal and copper metal. The buffered tape mounted on cylindrical substrate holder continuously passed the vacuum area for metal deposition, and order of mTorr O_2 pocket heating area for oxidation of metals, in turn. The temperature range for YBCO deposition was 690-730 °C. O_2 pressure and temperature inside pocket were important for the formation of Cu-O planes of YBCO.

We measured the relation between tensile stresses and critical currents of coated conductors at 77K. We used 200 Hz sine waves for input and observed the signal of YBCO by standard four-probe method. Widths of samples were 1.5-2.5 mm, lengths were 10-15 mm, and the thickness of YBCO was 60 – 100 nm. The distance between voltage taps was 3-5 mm. The critical current measured with 1 μV criteria

Table 1. The growth conditions of the textured CeO_2 / Ni films on NiCr substrates

	(a)	(b)	(c)	(d)
Deposition temperature of Ni	650 °C	300 °C	500 °C	500 – 600 °C
Thickness of Ni	4 nm	4 nm	10 nm	≥ 20 nm
Deposition temperature of CeO_2	650 °C	650 °C	600 °C	600 °C
Thickness of CeO_2	80 nm	80 nm	80 nm	80 nm

III. Results and discussions

Figure 1 shows (111) pole figure of NiCr substrate. Only four peaks corresponding to the cube orientation are present. The texture of this substrate is as good as that obtained from Ni. The full–width–half-maximum (FWHM) of the out-of-plane texture as measured using X-ray rocking curve is 6°, the FWHM of in-plane texture as measured X-ray ϕ-scan is 7.6°

CeO_2 films deposited on direct NiCr tapes had (111) planes on the surfaces. To obtain cube textured CeO_2 films, we deposited Ni films on NiCr tapes. Best quality of CeO_2 film was obtained in the case of Fig2 (d). Growth conditions of textured CeO_2 / Ni films on NiCr substrates were summarized in Table 1 and Fig.2 shows X - ray 2θ scans of their results. AES (Auger Electron Spectroscopy) confirmed no Cr impurities on the surface of 20 nm thick buffered Ni film deposited on NiCr. So we think that Cr impurities on surface of NiCr tape disturbed the growth of textured CeO_2 films, probably, due to pre-oxidation of Cr or certain mechanisms.

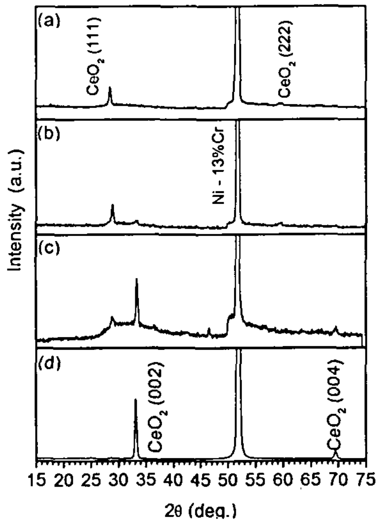

Fig. 2. X-ray 2θ scan of CeO_2 / Ni / NiCr under various deposition conditions summarized in Table 1

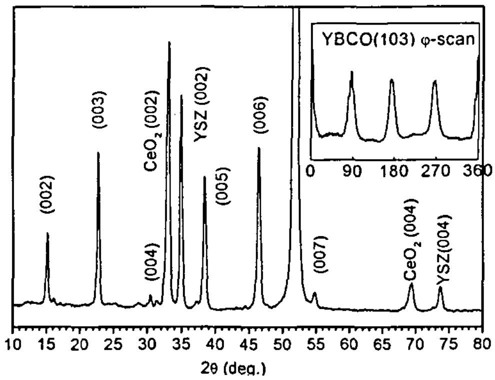

Fig. 3. 2θ scan and ϕ scan (inset) of YBCO film on CeO_2/YSZ/CeO_2/Ni/ NiCr. (00*l*) peaks are those from YBCO.

Figure 3 shows X-ray 2θ scan and ϕ scan (inset) of YBCO film on CeO_2 / YSZ / CeO_2 // (Ni and Ni / NiCr). YBCO also grow biaxially textured. The transition temperature T_c of this film was 87 K. The critical current was obtained as the function of temperature in Figure 4. Superconductive qualities of films on Ni and NiCr are comparable, where J_c for zero stress was order of $10^5 A/cm^2$.

Figure 5 shows the tensile stress dependence of the critical current. Critical currents remained almost constant by certain tensile stress and above this stress, begin to decrease. Around 100 MPa of tensile stress, the critical current of coated conductor fabricated on pure Ni tape began to reduce at 77K while critical stress of YBCO film on NiCr was about 270 MPa The critical tensile stress was much enhanced for the coated conductors fabricated on NiCr alloy tape. The YBCO films could experience actually different stress. Though needing to take into account the stress induced by thermal expansion mismatch, and adhesion strength of the metal/metal oxide interface [6], we think that these results are mainly due to mechanical properties of NiCr. With increasing Cr additions, the NiCr substrates were significantly strengthened [7]. Our result is very practical to choose appropriate substrates for applications of high T_c superconductor tapes.

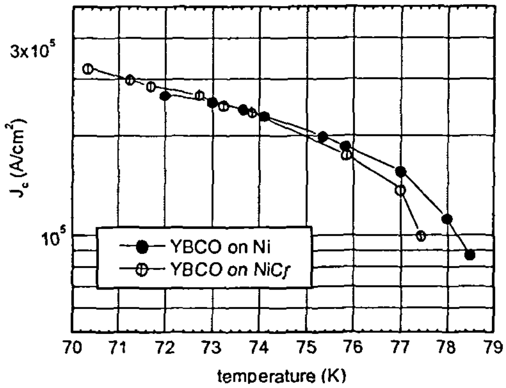

Fig. 4. Temperature dependences of critical current densities (J_c). J_c of YBCO (width 2.0 mm, thickness 80 nm) on Ni is $1.6 \times 10^5 A/cm^2$, J_c of YBCO (width 2mm, thickness 80nm) on NiCr is $1.4 \times 10^5 A/cm^2$ at 77K, self field.

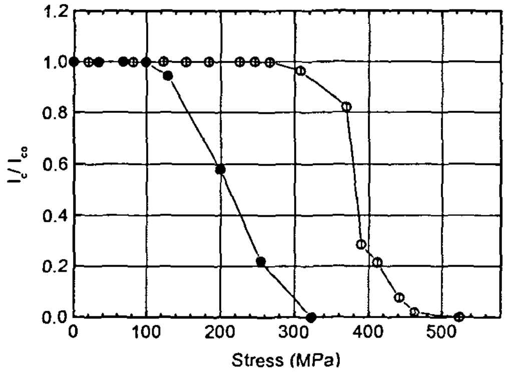

Fig. 5. stress dependence of critical current of YBCO on Ni (solid circle) on NiCr (open circle)

III. Summary

We fabricated YBCO based coated conductors on NiCr RABiTS substrates, whose superconductive quality were comparable to those on Ni. Conditions of fabrication for the growth on such alloys are much different from those on the pure Ni. The deposition of a 20nm thick Ni layer at 500-600 °C temperature is the key point. Critical currents of YBCO on pure Ni remained original one by around 100MPa tensile stress and above this stress, begin to decrease. This occurred at around 270MPa for YBCO on NiCr. The critical tensile stress of YBCO film on NiCr was much larger than that on Ni. We think that this resulted from strengthening Ni with Cr impurities.

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