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Preparation of a Cube-Textured Ni-7at.%W Based Template Used for Coated Conductors

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Abstract

Although Ni-W substrate with high W content (>5at.%) substrates have been developed successfully, the quality of cube texture and grain boundary, as well as extensive applications in coated conductors should be further improved. In the present work, once intermediate annealing treatment (IAT) at 500˚C for 2 h has been employed to optimize the deformation and recrystallization textures in Ni-7at.%W (Ni7W) substrates. As a result, competitive high cube texture content (<10˚) and low angle grain boundary fraction (<10˚) were realized (98.5% and 91.2%, respectively). A $Gd_2Zr_2O_7$ (GZO) buffer layer with strong cube texture and high-quality surface deposited successfully on the Ni7W substrate using the chemical solution deposition method, demonstrating the advanced GZO/Ni7W template is promising for coated conductors.

Keywords

NiW Substrate, Texture, $Gd_2Zr_2O_7$ Buffer Layer, Coated Conductors

1. Introduction

Ni-W alloys are considered as the most promising substrate materials for high temperature superconducting $YBa_2Cu_3O_{7-\delta}$ (YBCO) coated conductors in terms of rolling assisted biaxial textured substrates (RABiTS) technique [1] [2] [3]. Although over 100-m-long Ni-5at.%W (Ni5W) flexible textured substrates have been prepared commercially, Ni-W substrates with high tungsten content (>5%) could provide higher strength and acceptable magnetic properties. Up to now, the textured Ni-7~9.5at.%W (Ni7~9.5W) alloy substrates have been developed using both powder metallurgy [4] [5] and melting routes [6]-[14]. Since the reduction of stacking fault energy in Ni-W alloy with high tungsten additions, several specific rolling techniques, in particular, the intermediate annealing treatment (IAT), have been applied to produce cube texture in such Ni-W substrates. Gaitzsch et.al reported that a sharp textured Ni-9.5at.%W substrate with cube texture content of 96% (deviated from ideal cube orientation within 10˚) was achieved in terms of the IAT rolling technique [9]. However, this result is not somewhat equivalent to the commercial Ni5W substrate. Thus, more attention should be still paid to fabricating Ni-W alloy (>5at.%W) substrates, especially on the Ni7W substrate which is easier to realize cube texture than the Ni9W substrate, based on the attracting IAT rolling technique.

Recently, a series of work [15] [16] [17] [18] have been focused on the epitaxial growth of $Gd_2Zr_2O_7$ (GZO) buffer layer on Ni5W substrates by means of chemical solution deposition (CSD) method. A promising critical current density J_c of 2.2 $MAcm^{-2}$ at 77K in YBCO superconducting layer based on YBCO/$Ce_{0.9}La_{0.1}O_2$/GZO/NiW architecture has been achieved, using an all-CSD route [17]. In this case, the commercial Ni5W tapes were employed as textured substrates. Thus, it is imperious to verify the feasibility of the Ni7W substrate for the deposition growth of the advanced mentioned buffer layer architecture, which has not been grown on the textured NiW substrates with high W contents (>5at.%).

In the present work, the strong cube-textured Ni7W substrate was fabricated firstly, using once IAT rolling technique with intermediate annealing at 500˚C. Subsequently, a GZO buffer layer was epitaxially grown on the as-obtained Ni7W substrate by CSD method. The crystallographic texture of substrate and the quality of GZO film have been characterized.

2. Experimental Details

Electrolytic nickel pieces (99.95%) and W bulks (99.99%) were melted and then casted into a cylindrical ingot in an induction furnace. After hot forging and hot rolling, the Ni7W rods were cold rolled by applying a 5% reduction per pass to a final thickness of 90 μm, corresponding to a total reduction of 99%. For comparison, the other sample was annealed at 500˚C for 2 h after cold rolling to 90% degree followed by further cold rolling to 90 μm, named as the IAT rolling technique. The explanation on optimum IAT parameters would be discussed systematically as another issue elsewhere. The rolled Ni7W tapes were annealed at 1200˚C in a flowing Ar-4%H_2 atmosphere to obtain the cube orientation. The textured Ni7W substrate was coated with a GZO buffer layer prepared using a propionic acid-based CSD route. The total cation concentration of the GZO precursor solution was 0.6 mol/L and the pulling speed for dip-coating was 20 mm/min. For crystallization of the buffer layer, the sample was held at 1050˚C for 30 min in a quartz tube furnace, in Ar-4%H_2 gas flowing as well. The deformation texture of the substrate and coating layer was characterized by a Bruker D8 X-ray goniometer with Cu Kα radiation. Electron Backscattered Diffraction (EBSD) measurements were carried out using a scanning electron microscope (SEM, Zeiss Supra 35, equipped with a detector from HKL technology). The surface morphologies of the film were evaluated by the same SEM setup, and the surface roughness was analyzed by atomic force microscope (AFM, Micro-Nano D5A).

3. Results and Discussion

Figure 1 shows the (111) pole figures of the Ni7W substrates without and with IAT rolling, respectively. Clearly, all of the (111) pole figures reveal the typical characteristics of deformation texture for metal alloys with medium stacking fault energy, *i.e.*, they contain both the Brass-type deformation texture and the Copper-type deformation texture. It also can be seen that the intensity of the Copper-type deformation texture in the IAT sample is stronger than that in cold rolled sample. Meanwhile, the volume fractions of copper (C) and S orientation increase in the IAT sample, whereas the brass (Br) orientation decreases (see Table 1). This is due to the stress relief during IAT annealing, which increases the ability of deformation slipping and transfers the deformation texture from brass-type to copper-type [11]. Meanwhile, the volume fraction of Goss orientation increases slightly from 7.81% to 9.42% in the IAT substrate, which is probably resulted from the recovery occurring at 500˚C. Additionally the cube orientation is no obvious change after the IAT. Consequently, the IAT rolling is beneficial for the formation of copper-type deformation texture in the Ni7W metallic alloy.

The Ni7W substrate with enhanced copper-type deformation texture has been realized a sharp cube texture upon recrystallization, where the area fraction of cube grains deviating from the exact {100} <001> orientation within 10˚ amounts to 98.5% (see Figure 2(a)). However, the fraction in a traditional cold-rolled Ni7W substrate is only 71.8%. Four sharp poles and a weak background intensity are visible from the (111) three-dimensional pole figure (Figure 2(e)), which demonstrates again a high degree of cube texture in the IAT Ni7W substrate. In parallel, the length fraction of low angle grain boundaries (LAGB) within a misorientation angle below 10˚ reaches 91.2% (Figure 2(c)). Although twin boundaries are still evident (merely 2%), the high density of LAGB with misorientation angle less than 4˚ (Figure 2(d)) could ensure a high critical current density in YBCO layer [19]. These results on cube texture and LAGB show that the prepared Ni7W substrate could be equivalent to those of commercial Ni5W substrates, whereas the magnetic and mechanical properties have been improved due to the higher W addition.

Figure 3(a) shows the microstructure of the GZO film grown on the Ni7W

Table 1. Volume fractions of deformation orientations in two substrates calculated using the orientation distribution function. The threshold angle deviated from ideal orientation is 15˚.

	Brass (<15˚) %	Copper (<15˚) %	S (<15˚) %	Goss
CR	37.71	11.68	34.25	7.81
With IAT	29.63	13.91	39.23	9.42

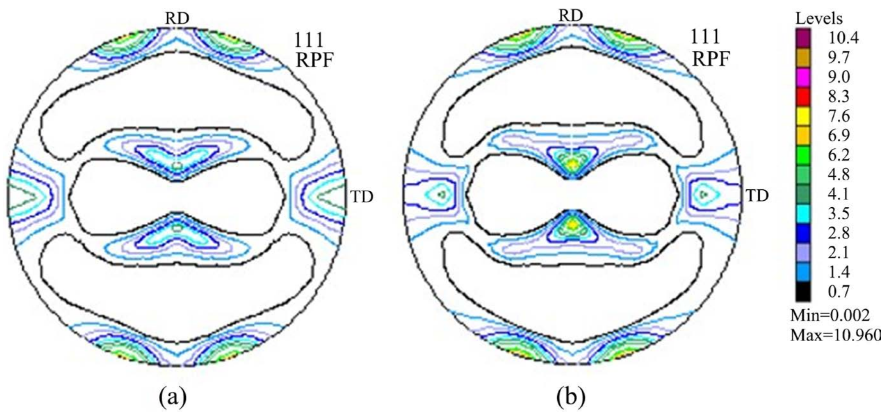

Figure 1. (111) pole figures of Ni7W substrates without (a) and with (b) IAT rolling.

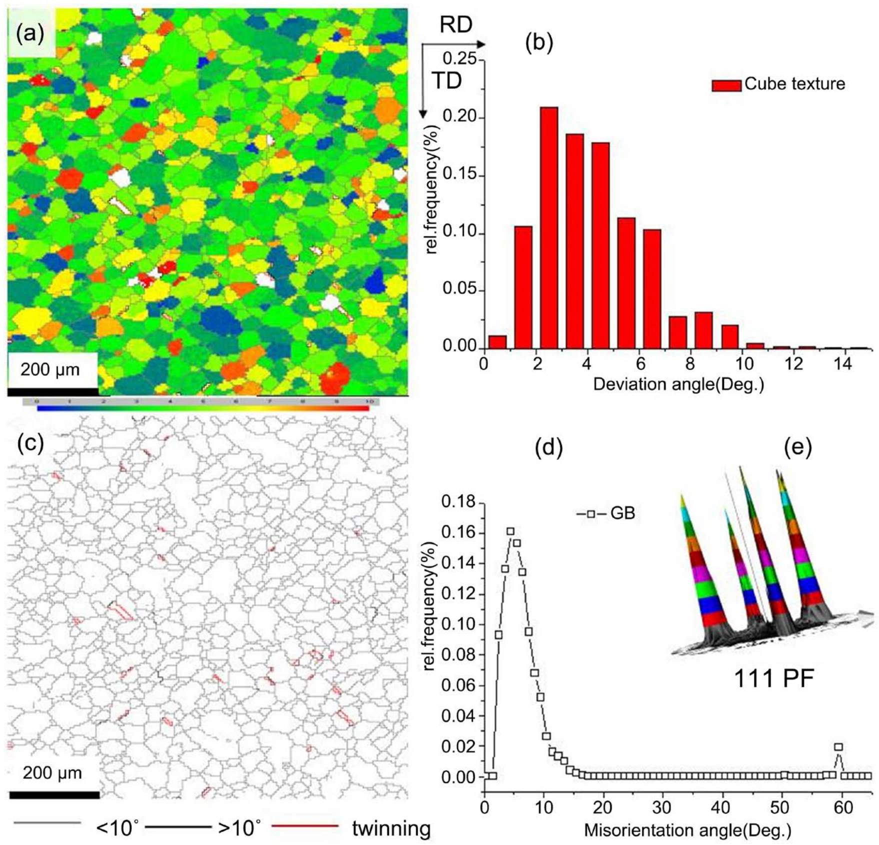

Figure 2. (a) EBSD map of 90-μm-thick Ni7W tape with IAT rolling after recrystallization at 1200˚C for 1 h. The measuring area is 800 × 800 μm^2, with a step size of 1 μm; (b) Cube texture deviated from the ideal orientation; (c) Grain boundary map, where misorientaions between 2˚ and 10˚, >10˚ and twin boundaries are indicated by grey lines, black lines and red lines, respectively; (d) Grain boundary distribution curve; (e) Three-dimensional (111) pole figure calculated from X-ray diffraction.

substrate. The GZO grain size is approximately 20 nm, and the film thickness is about 30 nm. The film is smooth, continuous and crack-free. No apparent grain size and shape variation is visible in the film. Promising results could be observed from that the film is homogeneous as growing across the grain boundaries

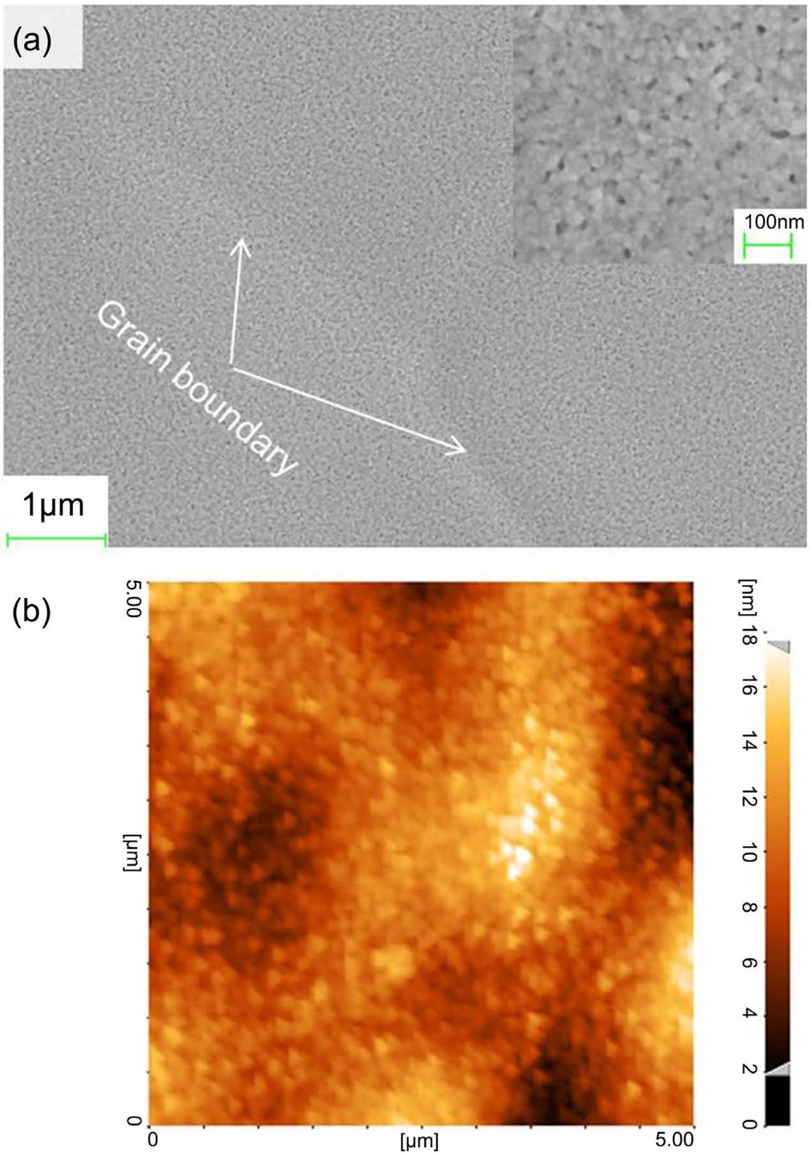

Figure 3. GZO buffer layer deposited on Ni7W substrate tapes: (a) SEM morphology. Inset: high resolution image with 200 K magnification; (b) AFM image, scanning area is 5 μm × 5 μm.

of the Ni7W substrate (shown in **Figure 3(a)**). The AFM result shows that the root mean square roughness is 2.6 nm (**Figure 3(b)**). A strong {001} <100> texture was obtained in the film. The full width at half maximum (FWHM) values for the (222) φ-scan and the (004) ω-scan are 5.95˚and 6.33˚, respectively, demonstrating slight improvement of cube texture compared with that of Ni7W substrate (see **Table 2**). The quality of present grown GZO film is almost identical to that in [17], where a high J_c of 2.2 $MAcm^{-2}$ in YBCO layer has been achieved employing GZO as buffer layer. Thus, it could be concluded that the high quality GZO film deposited on Ni7W substrates produced by once IAT rolling with optimum annealing parameters provides a promising GZO/Ni7W template for further deposition of buffer and superconducting layers.

Table 2. FWHM values (˚) for recrystallized Ni7W substrate and $Ga_2Zr_2O_7$ film.

Materials	φ-scan	ω-scan
Ni7W	6.07	6.77
$Ga_2Zr_2O_7$	5.95	6.33

4. Conclusion

More copper-type deformation texture was formed in the cold-rolled Ni7W substrate prepared by once IAT rolling, resulting in a strong cube texture in substrates upon recrystallization. The fraction of cube orientation (<10˚) is 98.5%, and the length fraction of low angle grain boundaries (<10˚) reaches 91.2%. These values are comparable with that of commercial Ni5W substrates. Furthermore, a $Ga_2Zr_2O_7$ buffer layer has been deposited successfully on the substrate using CSD method. The strong cube texture, as well as the high surface quality of $Ga_2Zr_2O_7$ film, demonstrates that the GZO/Ni7W template has been successfully grown, supporting further deposit the CeO_2 layer and YBCO superconducting layers.

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Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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