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Research articles

Influence of cube texture development on magnetic properties of Ni–5 at.% W alloy substrates

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ABSTRACT

The metallic Ni–5 at.%W (Ni5W) substrate with sharp cube texture is found as one of the promising candidates used for fabrication of coated conductors. However, the alternating current (AC) loss, partly contributed by the ferromagnetic Ni5W substrate is unavoidable. In this work, we analyzed the evolution of magnetic properties of Ni5W substrates via the cube texture development. The results revealed that the cube texture has an important impact related to size advantage during recrystallization, leading towards the consumption of the deformation and other orientational grains, and hence giving rise to form a sharp cube texture. Increasing the annealing temperature, the grain size is found to be increased. In the fully developed cube-textured substrate, the grain boundary was replaced by small angle grain boundaries (SAGBs). Also the magnetic domain structure was transformed from 180°-structure to a branched one with the increasing annealing temperature. This transformation is dependent on the increase of grain size, particularly, the SAGBs plays an important role in the formation of perfect domain structure. Increased coercivity and hysteresis loss in the fully textured substrate can be attributed towards the ideal cube texture and perfect complex domain structure. Therefore, a potential solution has been proposed to resolve this limitation of the sharp cube texture and increased hysteresis loss in Ni5W substrates.

1. Introduction

Remarkable advancement has been made in the development of high-temperature superconductors represented by $YBa_2Cu_3O_{7-\delta}$ (YBCO) coated conductors, to be used in electric power devices. Based on the rolling assisted biaxially textured substrate (RABiTS) processing route [1–3], the superconducting current density achieved in YBCO coated conductors is up to 2.5–3.2 MA cm^{-2} in magnetic field at 77 K [4], for which soft magnetic materials (e.g. Ni alloy tapes) are usually employed as substrates. One of the crucial issues regarding their application is the hysteresis loss caused by alternating current (AC) or external magnetic field. The magnetic substrates are found to contribute a considerable hysteresis loss to the total AC loss of the superconducting devices [5–7].

Ni–5 at.%W (Ni5W) substrates have been validated as the most promising substrate candidates for RABiTS coated conductors, at the Curie temperature of 365 K with the specific saturation magnetization of 25 cm^3/g [8]. Due to these parameters, ferromagnetism is declared for Ni5W alloy at 77 K. Therefore, the AC loss is an inevitable issue for Ni5W substrate. Several numerical predicting models have been developed to analyze the relationship between magnetic substrates and working conditions [8–10]. Duckworth [11] investigated more ferromagnetic loss for Ni5W substrate as compared to hysteresis AC loss. Increased AC losses are reported by Suenaga [12] for a superconducting film in perpendicular magnetic fields due to magnetic Ni5W substrate. Erdogan [13] had also studied the ferromagnetic loss induced by a weak ferromagnetic substrate, almost equal to the superconducting loss at the transport current of 75 A and the field frequency of 10 Hz. All the above studies are focused on the contribution of magnetic substrates to the practical applications. However, less attention is paid to the ferromagnetic contribution of Ni5W substrate, determined by processing factors, such as grain size, grain orientations, and residual stresses. It is of great scientific and technical importance to investigate the magnetic properties of Ni5W substrate developed during the fabrication process, which are essential for the deep understanding of the AC loss contributed by magnetic substrates.

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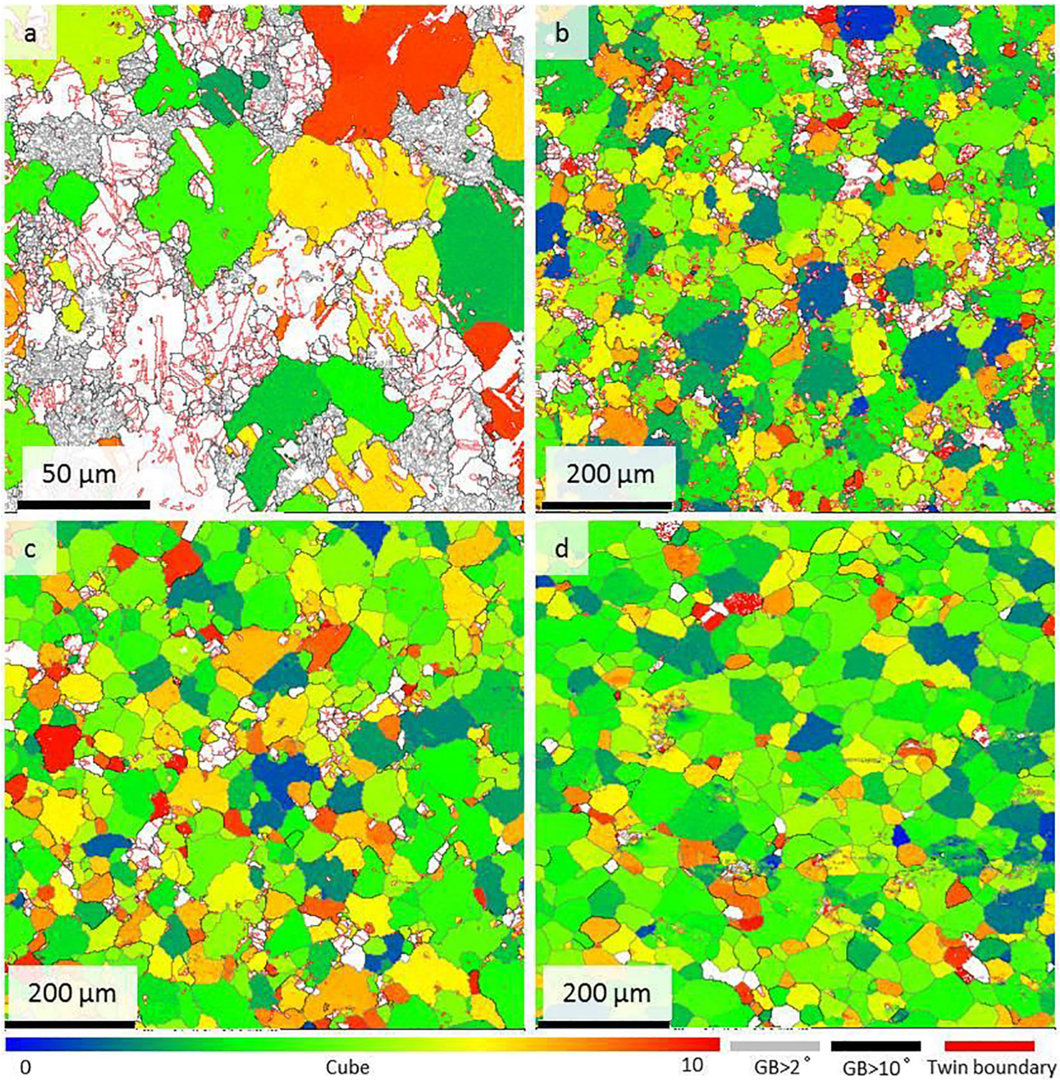

Fig. 1. Distribution maps of grain misorientation and grain boundaries of Ni5W substrates annealed at (a) 700 °C; (b) 800 °C; (c) 900 °C; and (d) 1000 °C, respectively. For substrate annealed at 700 °C, the measured area was 200 µm × 200 µm, with step size of 0.5 µm; for other substrates, the measured areas were 800 µm × 800 µm, with step size of 1 µm. The blue grain represents the grain with ideal cube orientation, the red one stands for the grain with cube orientation deviated at 10°. The gray, black and red lines are the grain boundaries within 2–10°, > 10° and twin boundaries, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The difference between the magnetic domains and hysteresis losses for as-rolled and recrystallized Ni5W substrates has been characterized, and found that the grain size plays an important role on magnetic properties of Ni5W substrates. The development of a very sharp cube texture in Ni5W substrates after primary recrystallization heat treatment, is opening the way to investigate the dependence of magnetic properties on the formation of cube texture. In the present work, we carried out a series of experiments for Ni5W substrates annealed at 700 °C, 800 °C, 900 °C, and 1000 °C, respectively. These samples were characterized for the evolution of grain orientation, grain size, magnetic domain structure and hysteresis loss, in order to illustrate the relationship between magnetic properties and cube texture development in the Ni5W substrates.

2. Experimental details

The Ni5W alloy ingots were fabricated by melting and casting the electrolytic nickel pieces (99.95%) and tungsten bulk pieces (99.99%) in an induction furnace, and then were homogeneously annealed at 1200 °C for 48 h. Hot forging deformation and hot rolling were performed at 1100 °C with rolling reduction of 50%. A 30 mm wide and 10 mm thick, Ni5W strip was obtained after mechanical grinding and polishing. Cold rolling was done at a four-miller rolling machine, with total cold rolling reduction as higher as 99%, where the per pass reduction was below 5%. Finally, 75 µm thick cold-rolled Ni5W metallic substrate tape was obtained. This cold rolled Ni5W substrate was annealed at various temperatures via two-step heat treatment procedure [14]. Firstly, the samples were kept at 700 °C for 30 min before reaching the second-step annealing temperature (which is ranged from 700 °C to 1000 °C for 1 h), in a flowing Ar–4% H_2 protecting atmosphere, to investigate the various degrees of cube texture. The temperature elevating rate was kept as 7 °C/min in the annealing process.

Texture and grain boundary were investigated by electron backscattering diffraction (EBSD) technique (Zeiss Supra 35, equipped with a detector from HKL technology) using “HKL” indexing software. The M–H hysteresis loops were measured by a Quantum Design (PPMS-14LH) magnetometer at 300 K, and a magnetic field of 1000 Oe. The measured plane came out to be parallel to the rolling direction (RD). Additionally, the atomic force microscope (AFM, Micro-Nano D5A, equipped with magnetic model) was utilized to characterize the