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Technique for developing highly strengthened and biaxially textured composite substrates for coated superconductor tapes

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Abstract

The development of reinforced and biaxially textured Ni5W/Ni9W/Ni5W composite substrate for coated conductor applications is presented. The configuration of this substrate is a thin, sharp cubic textured Ni5W outer layer on a Ni9W alloy core that provides the mechanical strength while decreasing the magnetization of the whole substrate. The key technique is to use thin Ag and Cu foils between initial Ni5W and Ni9W alloy pieces to bond them together, followed by cold-rolling and recrystallization. The obtained composite substrate has a very sharp cubic texture on the Ni5W outer layer and its yield strength approaches 200 MPa, thus being 50 MPa higher than commercially used Ni5W substrates. The saturation magnetization of this composite substrate at 77 K was reduced by 75% and 40% compared with pure Ni and Ni5W substrates, respectively. The present results show that this new substrate is suitable for the epitaxial growth of the CeO_2 buffer layers.

Keywords: Ni5W/Ni9W/Ni5W composite substrates; Cubic texture; Coated conductors; Yield strength; Saturation magnetization

1. Introduction

During the past decade, the so-called second generation of superconductors, based on $YBa_2Cu_3O_7$ (Y123) or rare earth metal (Re123) has been paid broad attention worldwide [1–5] due to its high irreversibility field and to low cost of production for practical applications. So far, critical current densities of 1 MA cm^{-2} have been achieved in self fields at 77 K in 100 m lengths of Y123 tapes prepared by the so-called rolling assisted biaxial textured substrates (RABiTS) technique [6,7]. Based on this RABiTS technique route, the corresponding research topics for obtaining a high-quality cubic textured substrate are of great importance, both for the epitaxial growth of high-quality buffer layers on the substrate and the development of long length YBCO coated tapes. In the early work using RABiTS technology, Ni developed a very sharp cubic texture after rolling and annealing [8]. Hence, most of the works to date have used Ni as a base for the substrate material. However, pure Ni has poor mechanical properties and is ferromagnetic (FM), with a high Curie temperature (623 K) and a saturation magnetization of 57.5 emu g^{-1} at $T = 0$ K, which leads to severe limitations in its use for industrial applications such as coated conductors. Recently, it was found that Ni–5 at.% W (Ni5W) alloy substrates are easy to crystallize in a biaxial cubic texture, making it a preferred choice for low-cost substrates for large-scale coated conductor tapes [9,10]. Long lengths of textured Ni5W tapes have been successfully prepared by the RABiTS process and widely used [11,12]. However, they are still ferromagnetic, their Curie temperature being

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339 K. Consequently, Ni alloys with high tungsten (W) content and reduced ferromagnetism have been developed as mechanically stronger substrates for practical applications. Ni–9.3 at.% W (Ni9W) alloy is a potential alternative that can ensure both the strength of the substrate and acceptable magnetic properties. Unfortunately, by investigating a series of Ni–W alloy materials, it was found that a pure cubic texture could not be obtained for W contents higher than 7 at.% in a Ni alloy substrate. To overcome this problem, a new approach to the preparation of composite substrates as materials was reported [13,14]. The key point of this method is the mechanical intercalation of a hard Ni12Cr rod into a Ni–4.5 at.% W (Ni4.5W) tube, followed by hot rolling to a small diameter. After an intermediate annealing, cold-rolling was used to produce a thin tape for use as a substrate for coated conductors. The top layer of this composite tape after annealing presents a {1 0 0} ⟨0 0 1⟩ cubic texture. However, this method produces only a mechanical bond between the outer and inner layers, which inevitably leads to the separation of the three layers during deformation, even when a hot rolling step was employed, thus limiting the production of long length substrate. Moreover, the use of the hot rolling process changes the type of deformation texture in the rolling tape, thus influencing the formation of a high-quality cubic texture in this composite tape after recrystallization.

In this work, a new Ni5W/Ni9W/Ni5W composite configuration has been proposed as a potential weakly magnetic and reinforced substrate, and a technique for developing this kind of composite substrate is demonstrated for the first time to the best of our knowledge. Our goal was to produce a chemically bonded layer between the Ni5W and the Ni9W cores, thereby taking advantage of the formation of a sharp cubic texture in the Ni5W outer layer on the Ni9W core to ensure both the mechanical reinforcement and lower magnetization of the whole substrate. The present work deals extensively with the processing of this composite Ni alloy substrate, highlighting its texture, yield strength and magnetic properties. Moreover, the deposition of high-quality epitaxial CeO_2 buffer layers directly on this composite substrate has shown that the present composite substrate is appropriate to further developments of coated conductor tapes.

2. Experimental

Melted Ni5W and Ni9W ingots with an initial thickness of 10 mm were rolled to 2.5 mm using 10% reduction steps. In the next step, a composite sandwich ingot of Ni5W/Cu/Ag/Cu/Ni9W/Cu/Ag/Cu/Ni5W was prepared by pressing all the layers together according to the given sequence, followed by sintering at 850 °C for 4 h in a flowing Ar (4% H_2) atmosphere. Fig. 1a shows the schematic diagram of the design and processing for preparing the Ni5W/Ni9W/Ni5W composite tapes. Thin Ag and Cu foils were intercalated as a binding layer, thus forming a chemical interface joint between the outer Ni5W and inner Ni9W layers. The sintered composite ingot was then cold-rolled to a thickness of 0.15 mm, the total reduction being larger than 98%. The rolled Ni composite metallic tapes were heat treated through a optimized [15] two-step annealing process by holding the sample at a lower temperature (about 700 °C) for 30 min before reaching a second step annealing temperature of 1100 °C (holding at this temperature for 1 h) in a

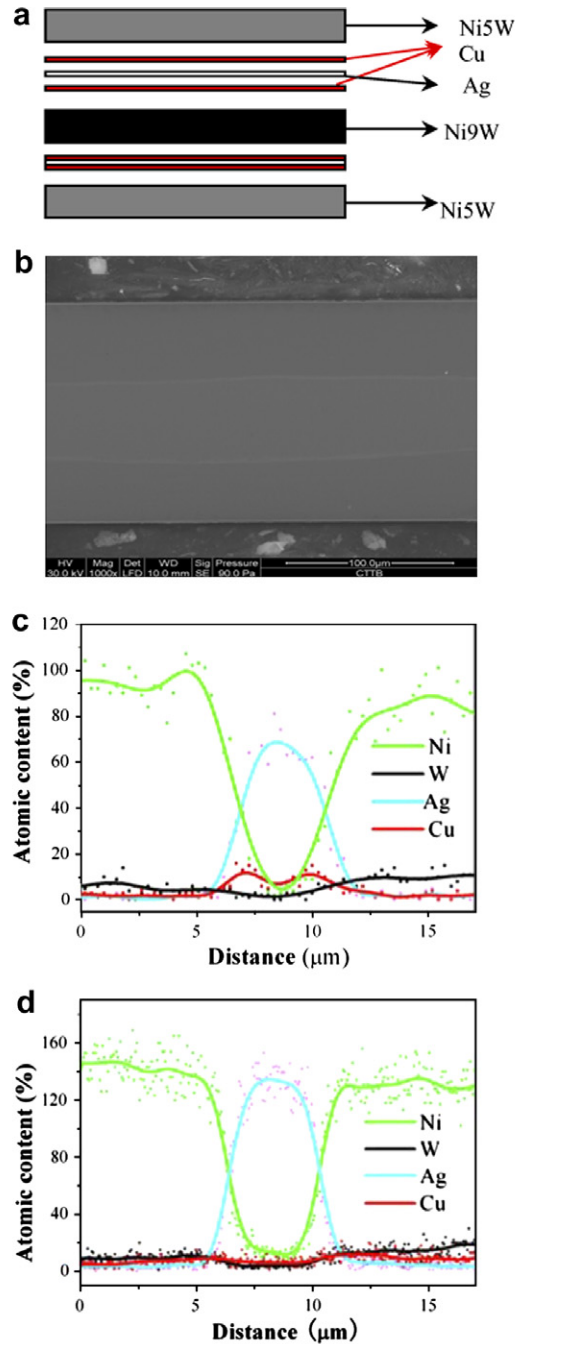

Fig. 1. (a) Schematic diagram of the design and fabrication process of the Ni5W/Ni9W/Ni5W composite tape. (b) SEM backscattered cross-section of a cold-rolled 150 μm thick Ni5W/Ni9W/Ni5W composite tape with two 50 μm thick Ni5W layers on both sides; (c) and (d) are Ni, W, Ag and Cu elemental distributions along the cross-sections of the cold-rolled and annealed composite tapes made by EDAX, respectively.