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Application of textured highly alloyed Ni-W tapes for coated conductor architectures

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Abstract: An epitaxial Y_2O_3/YSZ/CeO_2 buffer architecture has been grown using pulsed laser deposition on highly textured Ni-W tapes with W-contents above 5 at.% as well as composite tapes, having a non-ferromagnetic core with high yield strength and a highly textured shell material. The buffer layer growth was studied in detail using X-ray diffraction and EBSD measurements, showing a perfect texture transfer throughout the buffer architecture. Epitaxial YBCO layers were successfully deposited on the buffered tapes showing a superconducting transition temperature T_c of about 90 K with a small transition width on all metal substrates investigated. A critical current density J_c of about 1 MA/cm² was measured at 77 K in self-field. It was found that J_c is mainly limited by the grain boundary network in magnetic fields below 4 T, whereas similar values as on $SrTiO_3$ single crystals were measured at higher fields.

I. INTRODUCTION

At present, considerable basic research work is being directed towards the preparation of $REBa_2Cu_3O_{7-x}$ coated conductors, where RE is either a rare-earth element or yttrium, based on rolling-assisted biaxially textured substrates (RABiTS). The main requirements for the substrates, apart from the strong cube texture, are a sufficient strength for the designated application and reduced ferromagnetism at 77 K, especially for use with ac currents. It was shown that alloying the Ni substrate with elements like W, Cr or V led to strengthened tapes with a high texture quality and reduced ferromagnetism. However, the amount of the alloying element is limited, as the strong cube texture starts to degrade with higher alloying content. So far, optimal substrate properties were achieved using a Ni–5at%W substrate [1]. A further strengthening of the substrate and a reduction in the ferromagnetic properties at low temperature can be achieved using a composite structure with a stronger non-ferromagnetic core material and a shell material which exhibits a high texture quality [2-4]. Recently, also highly textured Ni-7.5at%W substrates have been successfully prepared [5].

II. EXPERIMENTAL

Standard Ni–5at%W (Ni5W), new developed Ni-7.5at%W (Ni7.5W) as well as two composite tapes Ni–3at%W/Ni–10at%Cr–1.5at%Al (Ni3W/Ni10Cr) and Ni–5at%W/Ni–10at%W (Ni5W/Ni10W) were used as substrate materials for the preparation of coated conductor architectures. Selected samples were cut into pieces with dimensions 10 mm × 10 mm, ultrasonically cleaned, and transferred to a high vacuum chamber. The substrates were heated in a hydrogen-containing atmosphere in order to reduce the naturally grown nickel oxide on the substrate surface. A standard buffer architecture composed of 100 nm Y_2O_3, 200 nm YSZ and 50 nm CeO_2 as well as the YBCO layer were deposited by pulsed laser deposition (PLD) on these substrate pieces. The standard thickness of the YBCO layer was about 300 nm for all samples. More details on the deposition conditions have been published recently [6].

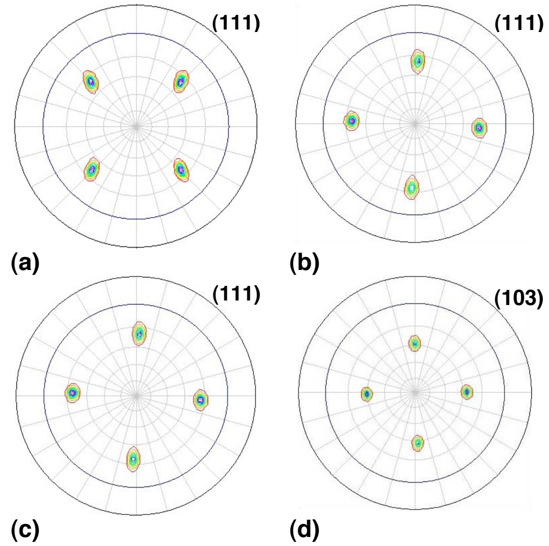

Fig. 1. X-ray pole figures of (a) Ni–7.5W; (b) Y_2O_3; (c) YSZ; (d) YBCO in a complete coated conductor architecture.

III. RESULTS AND DISCUSSION

The different cube texture Ni tapes were used as substrates for the deposition of Y_2O_3/YSZ/CeO_2 buffer layer architecture by PLD. X-ray diffraction experiments revealed perfect epitaxial growth of the subsequent buffer layers as well as the YBCO on the metal tape, as shown for the Ni7.5W substrate in figure 1. Typically, an improvement of the out-of-plane alignment is observed for the buffer layers and the YBCO, whereas the in-plane orientation is slightly broader. EBSD measurements confirm the epitaxial growth on a local scale. FIB cross sections revealed smooth interfaces of the buffer layers and the YBCO. There is an additional thin layer visible at the Ni–Y_2O_3 interface which might be a NiO or $NiWO_4$ layer typically observed in such coated conductor architectures.

The superconducting properties of the YBCO layers grown on the different Ni-alloy substrates were first measured inductively on unpatterned samples. The prepared films typically showed a superconducting transition between 88 and 90 K, with a transition width T_c of between 0.8 and 1.5 K (Fig. 2). The T_c value, determined by a 90% increase in induced voltage at the warming-up stage, was about 89.5 K for YBCO layers on all Ni–RABiT substrates investigated. Inductive measurements of the critical current density at 77 K in a self-field revealed a homogeneous J_c distribution over the complete sample area. J_c values of up to 1.5 MA cm^{-2} were determined for the YBCO grown on the different Ni substrates.

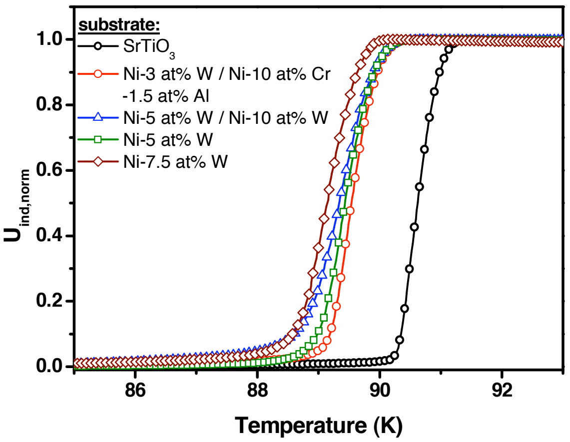

Fig. 2. Inductive measurement of the superconducting transition temperature T_c for YBCO films grown on different substrates.

Resistive measurements were performed on patterned samples to investigate the influence of the substrate in more detail and to determine the dependence on the magnetic field. A critical temperature T_c of about 90 K was measured resistively for the films on Y_2O_3/YSZ/CeO_2 buffer architecture regardless of the substrate. These values are in good agreement with the inductive measurement on the unpatterned samples. The measurement of J_c at zero field and 77 K revealed a value of 0.85 MA cm^{-2} for the YBCO film on the Ni5W substrate and of 0.91 MA cm^{-2} for the Ni5W/Ni10W composite (Fig. 3). The J_c value of 0.65 MA cm^{-2} measured on the Ni3W/Ni10Cr and the Ni7.5W substrate was somewhat lower than on the other substrates. These results generally correlate well with the inductive J_c measurements; the differences might be due to the local grain boundary structure on the 500 µm wide patterned bridge. Nevertheless, the results indicate once again that the prepared composite tapes have a texture quality similar to the standard Ni5W substrates, leading to comparable superconducting properties of the YBCO layer.

The magnetic field dependence plotted in Fig. 3 reveals clear differences between the film on a $SrTiO_3$ single crystal and the YBCO layers on the buffered Ni tapes. The J_c values measured at magnetic fields below 4 T on films deposited on the Ni substrates are significantly lower compared to the film on $SrTiO_3$. The critical current density is mainly limited by the properties of the grain boundary network in this field region [7]. Above this crossover field, the measurement curves on the Ni–5W substrate and on the $SrTiO_3$ merge, indicating similar intra-grain properties of the superconducting layer. This fact underlines once more the quality of the chosen buffer architecture, which prevents the diffusion of Ni into the YBCO layer. The $J_c(B)$ dependence measured for the YBCO films deposited on the different metal substrates shows a similar behaviour. The main differences arise from different values of the irreversibility field, i.e. different pinning properties inside the grains.

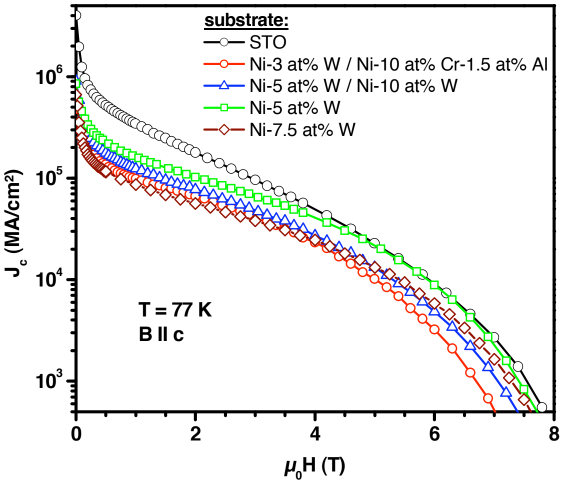

Fig. 3. Magnetic field dependence of the critical current density J_c for YBCO films grown on different substrates.

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