YBCO coated conductors on highly textured Pd-buffered Ni-W tape

G. Celentano¹, V. Galluzzi¹, A. Mancini¹, A. Rufoloni¹, A. Vannonzi¹, A. Augieri¹, T. Petrisor², L. Ciontea², and U. Gambardella³

¹ENEA, Frascati Research Center, Frascati, Rome, Italy
²Technical University of Cluj Napoca, Romania
³INFN-LFN, Frascati, Rome, Italy

E-mail: celentano@frascati.enea.it

Abstract. High critical current density YBa₂Cu₃Oₓ₋₅ (YBCO) coated conductors were obtained on cube textured Ni-W. The use of a Pd transient layer as a first buffer led to a sharp out-of-plane grains alignment of the CeO₂/YSZ/CeO₂ buffer layer. YBCO films grown on this template exhibit an out-of-plane orientation with a full width at half maximum of about 3°, less than 50% of the respective starting Ni-W value. Despite the complete interdiffusion between Ni-W and Pd after the YBCO film deposition, the coated conductors exhibit good film adherence as well as a crack free and smooth surface of the YBCO film. YBCO thin films show critical temperature values above than 88 K and a critical current density of 2.1 MA/cm² at 77 K and self field.

1. Introduction

It has been widely shown that high critical current density (Jc) in YBa₂Cu₃Oₓ₋₅ (YBCO) coated conductors is strictly related to the development of a sharp texture in the superconductive film. In the RABiTS approach a cube textured metal tape, such as Ni-based alloys, is used and the texture is transferred to the YBCO film via epitaxy [1]. A buffer layer architecture is necessary to prevent contamination from the substrate to the YBCO layer, to reduce the lattice mismatch and to ensure chemical compatibility. The quality of the buffer layer epitaxial growth, adherence and crack formation are strictly related to the preservation of the metallic surface against oxidation phenomena. For this purpose, the use of a reducing atmosphere during buffer layer deposition on metal substrate has revealed to be a useful approach [2]. Alternatively, epitaxial deposition of a noble metal layer on the substrate surface prior to oxide buffer layer deposition can be used. Among the noble metals, Pd has been shown to grow epitaxially on Ni and/or Ni-alloy substrates in a wide range of deposition conditions, despite the large lattice mismatch with Ni (about 10%); moreover a tendency of texture sharpening with respect to the substrate can be observed [2, 3, 4]. The interdiffusion process between Pd and Ni prior to or during oxide buffer layer deposition has revealed to be critical for the buffer layer architecture development. The structural and morphological quality of the buffer layer is guaranteed as long as the interdiffusion process does not affect the Pd surface during the buffer layer nucleation and growth. On the other hand, at low temperatures, where the interdiffusion is slower and more controllable, the epitaxial growth mechanism of oxide buffer layer onto epitaxial Pd is limited by poor adatom mobility [3]. Nevertheless, the use of Pd as a template layer on Ni-Cr-W alloy has been
shown to be useful to obtain YBCO coated conductors on such a substrate. The crucial key was the possibility of developing buffer layer architecture at low deposition temperature [5].

We report a study on the optimization of Pd layer deposition on Ni-W metallic substrate by electron beam, in terms of structural and morphological properties, and subsequent growth of YBCO/YSZ/YSZ/CeO₃ multilayer. The oxides buffer layer structure CeO₃/YSZ/CeO₃ and the YBCO film, deposited pulsed laser deposition (PLD), preserve the sharp Pd texture through epitaxy. Jc values up to 2.1 MA/cm² were obtained at 77K and self field for YBCO/CeO₃/YSZ/CeO₃/Pd/Ni-W coated conductors.

2. Experimental details
The cube textured Ni 5at%W (Ni-W) substrates with a thickness of about 100 µm were obtained by a cold-rolling process followed by a recrystallization heat treatment, as reported elsewhere [6]. The 200 nm thick Pd buffer was deposited by electron beam technique with a rate of 0.5 nm/s in a background pressure of 10⁻⁶ mbar. The deposition temperature Tsub was varied from room temperature (RT) to 500 °C. The CeO₃/YSZ/CeO₃ buffer layer architecture and the YBCO film were grown by Pulsed Laser Deposition (PLD). The first CeO₃ and YSZ layers were grown at 500 °C in vacuum and 10 mTorr flowing oxygen atmosphere, respectively. CeO₃ cap layer and YBCO films were deposited at 850 °C in 10 and 300 mTorr O₂, respectively. Structural and morphological properties of Pd seed layers and YBCO films deposited on CeO₃/YSZ/CeO₃/Pd/Ni-W architecture were analyzed by means of x-ray diffraction and scanning electron microscopy (SEM). The x-ray θ–2θ and ω-scans were performed using a Rigaku Geigerflex diffractometer with Cu Kα radiation. A Seifert XRD 3003 four circle diffractometer was used to collect pole figures and ϕ-scans. A LEO 1525 field emission-high resolution scanning electron microscope equipped with Oxford INCA Crystal electron backscattering diffraction (EBSD) system was used. Zero-resistance critical temperature Tc, and V-I characteristics at 77 K and self-field were measured by usual DC four-probe method for YBCO films.

3. Pd films
The x-ray θ–2θ spectra of 200 nm Pd films deposited at different Tsub are reported in figure 1. In table 1 the structural properties for the same samples are summarized. Above 200 °C the films show an epitaxial growth, with relative intensities ratio I(002)/(I(111)+I(002)) ranging from 99.8% to 100%. At RT, a preferential (00l) orientation together with a consistent fraction of polycrystalline component are detected. Above 450 °C, a peak broadening in the high angle tail of the (002)Pd reflection is observable. This feature is related to the Pd-Ni interdiffusion. The Pd-Ni solid solution gives rise to a fcc lattice with an parameters value intermediate between the Ni and Pd depending on the compositional fraction. The tail broadening of the (002)Pd peak indicates that deposition temperatures above 450 °C promote a partial substitution of Ni for Pd on the fcc Pd lattice detectable in the x-ray diffraction spectrum. The full width at half maximum (FWHM) of (002)ω-scans in transverse direction (TD) for Pd layer, reported in table 1, reveals a decreasing trend with increasing deposition temperature. A sharpening up to about 60% with respect to the Ni-W substrate is reached at higher

| Tsub (°C) | Pd (°) | Ni-W (°) | % Pd | Ni-W | % |
|----------|--------|----------|-------|-------|---|
| RT       | 6.1    | 8.5      | 28    | 7.8   | 6.7 |
| 200      | 7      | 8.6      | 19    | 6.1   | 6.3 |
| 350      | 4.5    | 8.1      | 44    | 5.7   | 7.1 |
| 450      | 3.5    | 8.2      | 57    | 5.4   | 6.7 |
| 500      | 3.6    | 8.5      | 58    | 5.6   | 6.8 |

Table 1  Principal structural properties of Pd film deposited on Ni-W substrate at different Tsub.

Figure 1 X-ray spectra of Pd film at different Tsub. Star marks Pd-Ni interdiffusion feature.
deposition temperatures. More effective sharpening could be obtained by reducing the surface roughness as reported in the case of pure Ni substrate [3]. φ-scans analyses on (111)Pd and (111)Ni peaks reveal that the improvement of the Ni in-plane alignment induced by Pd is limited at about 18-20%. Pole figures for Pd films deposited at temperatures above 200 °C evidence a strong [001]<100> component with only weak features related to Pd cube twins. EBSD analyses show that above 200 °C Pd films grow epitaxially also on the Ni-W cube twinned regions indicating that the cube twin component in the Pd film textures are strictly related to the fractions of cube twinned grains of the Ni-W substrate.

SEM observations reveal smooth Pd films, with surface morphology reproducing the substrate features. The morphology of 200 nm Pd film regions grown on twinned substrate grains is different from the morphology of Pd grown on the substrate cube grains. The surface in these regions appears rougher, even with some holes, probably because of different growth mechanism induced by the deposition temperature and/or interdiffusion process. In order to test the temperature stability of Pd films, the as-grown samples have been annealed at different temperatures, up to 550 °C for 1 hour in vacuum. Film surface and texture are preserved from Pd-Ni interdiffusion phenomena suggesting that Pd layer on Ni-W can be a suitable template for oxides buffer layer deposition at these temperatures.

4. Properties of YBCO film deposited on CeO2/YSZ/CeO2 architecture on Pd buffered Ni-W

YBCO films have been grown on a CeO2/YSZ/CeO2 architecture on Pd-buffered Ni-W. The x-ray θ-2θ spectrum reported in figure 2a, shows a mainly (00l) oriented YBCO film, with a minor fraction of a-axis component. Pd peaks are no more evident indicating that at this stage a complete interdiffusion between Pd and Ni has taken place. At the same time new peaks (marked with stars in figure 2a) compatible with Pd-Ni solid solution emerge. The ω-scans in TD, are reported in figure 2b for (005) YBCO, (002) CeO2, (002) YSZ and (002) Ni-W. The (002) ω-scan for as deposited Pd film are also reported. The FWHM drops from 7.5° of Ni-W to 2.7° of Pd, keeps constant through the oxides buffer layer structure and reaches a value of 2.7° in YBCO. Polar figures analyses reveal single in-plane orientation with the relationship [100]YBCO||[110]CeO2||[110]YSZ||[100]Pd||[100]Ni-W. The FWHM values of the φ-scans for the (113) YBCO peak are of about 6°. Morphological analyses reveal that the YBCO films show a smooth and free of cracks surface, together with a good coalescence among YBCO grains while on substrate twinned grains a tile-roof like morphology is observed, figure 3a. Cross section analysis of fractured samples, figure 3b, show that the whole buffer layer architecture and the YBCO film are dense and compact and the interface between each layer is clean and defined.

The typical zero resistance critical temperature for YBCO film deposited on CeO2/YSZ/CeO2/Pd-Ni-W is about 88.5 K with a transition width of about 2 K. The normal state resistivity exhibits a linear dependence on temperature, with a $\rho(300 \text{ K})/\rho(100 \text{ K})$ ratio of about 3, compatible with highly c-axis oriented YBCO films. $J_c$ measurements were performed on 2 mm wide as-deposited strip at 77 K and zero magnetic field. The $J_c$ values obtained for some samples are listed

![Figure 2](image-url) X-ray spectrum (a) and rocking curve patterns (b) of YBCO/CeO2/YSZ/CeO2 deposited on Pd-buffered Ni-W. In the x-ray spectrum, the stars mark features due to Pd-Ni interdiffusion.
Table 2 Transport properties of YBCO films of different thickness and orientation distribution widths.

| YBCO thickness (nm) | Pd (002) φ−scan FWHM (°) | YBCO (005) φ−scan FWHM (°) | YBCO (113) φ−scan FWHM (°) | Jc MA/cm² |
|---------------------|-----------------------------|-----------------------------|-----------------------------|-------------|
| 280                 | 3                           | 3.2                         | 6                           | 1.35        |
| 280                 | 3                           | 6.3                         | 6.7                         | 0.75        |
| 100                 | 3                           | 3.1                         | 6.1                         | 2.1         |

Figure 3 Surface (a) and SEM cross-section (b) of YBCO film on CeO₂/YSZ/CeO₂ deposited on Pd-buffered Ni-W.

on table 2, for YBCO films of different thickness and orientation distributions. The first sample reported was obtained starting from Pd film deposited at low temperature (200 °C) achieving a FWHM of the out-of-plane orientation distribution around 8°. In the other two samples the Pd film was deposited at 450 °C resulting in a sharper crystalline orientation distributions. Since this difference is transferred to YBCO film, the relatively low Jc value (0.75 MA/cm²) of the first sample can be mainly attributed to the presence of a larger fraction of high misorientation angle YBCO grain boundaries. A Jc value up to 2.1 MA/cm² is obtained for the 100 nm thick sample. This value is comparable with our best results for YBCO film on STO single crystal, showing the potentiality of this structure.

5. Conclusions
We have studied the possibility of using a Pd layer as a template for CeO₂/YSZ/CeO₂ oxide buffer layer deposition on Ni-W substrates for the development of YBCO coated conductor with high Jc performances. Pd films and the whole structure exhibit a sharp texture, with φ−scan FWHM values for the YBCO film even lower than 3°. The buffer layers deposition temperature is low enough to avoid the damages induced by Pd-Ni interdiffusion and at the same time high enough to transfer Pd texture to the subsequent layers by means of epitaxial growth. The morphology of YBCO samples is compact, smooth and no cracks or detached regions of the film can be observed. Tc0 values are above 88 K and Jc on 100 nm YBCO film is more than 2 MA/cm².

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