# HIGH CURRENT DENSITY YBCO COATED CONDUCTORS ON STRENGTHENED BIAXIALLY TEXTURED Ni-W SUBSTRATES

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## ABSTRACT

High current density $YBa_2Cu_3O_{7-\delta}$ (YBCO) films were fabricated on rolling-assisted biaxially textured substrates (RABiTS) with a layer sequence of $CeO_2$/YSZ/(dip-coated or e-beam seed)/Ni-W (3 at. %). Electron-beam evaporation was used to deposit $Y_2O_3$ seed layers. A reel-to-reel continuous dip-coating unit was used to deposit $Gd_2O_3$ and $La_2Zr_2O_7$ (LZO) seed layers. Scanning Auger Microprobe analysis of the textured Ni-W substrates indicated the presence of sulfur segregation at the surface. This possibly facilitated the growth of epitaxial e-beam $Y_2O_3$ seed layers *directly* on Ni-W substrates through sulfur c2x2 superstructure. Highly aligned, continuous and crack-free $Y_2O_3$, $Gd_2O_3$, LZO seed layers were obtained. Both YSZ and $CeO_2$ cap layers were deposited on all of these seed layers using *rf*-magnetron sputtering. The YBCO films were then grown on these buffered Ni-W substrates by either pulsed laser deposition (PLD) or ex-situ $BaF_2$ precursor process. A high $J_c$ of 1.9 MA/cm$^2$ at 77 K and self-field was obtained on both $Y_2O_3$ and LZO seed layers. The performance of solution seed layers approached that of the vacuum seed layers.

## INTRODUCTION

In continuation of our efforts to demonstrate the growth of high quality YBCO films on biaxially textured Ni-alloy substrates, we have chosen stronger Ni-W (3 at. %) substrates with reduced magnetism for this study. Here, we report our successful growth of high $J_c$ YBCO films on buffered Ni-W substrates. Biaxially textured Ni-W (3 at. %) substrates were obtained by mechanically deforming the metal rods over 95 % followed by annealing at 1250-1300 °C for 1 h in the presence of forming gas ($Ar/H_2$ (4 %)). The substrates used were 1 cm wide and 50 μm thick. Prior to annealing, the substrates were cleaned by sonification in isopropanol. The annealed Ni-W (3 at. %) substrates are much stronger and have reduced magnetism than pure Ni substrates. The yield strength (YS) at 0.2% strain is 150 MPa. This is comparable to 164 MPa YS for non-magnetic Ni-Cr (13 at. %) substrates. The details of substrate preparation have been reported elsewhere [1].

## EXPERIMENTAL PROCEDURE

The textured Ni-W (3 at. %) substrates were heated in ultra high vacuum (~ $10^{-10}$ Torr) at various temperatures ranging from 200 to 900 °C and the surface features were analyzed using Scanning Auger Microprobe (Physical Electronics Industries, Model 590). The $Y_2O_3$ seed layers were deposited *directly* on biaxially textured Ni-W substrates using reactive e-beam evaporation. An AIRCO Temescal CV-14 10-kW power supply with an e-beam gun was used for the deposition. The chamber was evacuated until the base pressure reached $10^{-6}$ Torr. Forming gas was introduced until the pressure inside the chamber reached to ~ 1 Torr. The Ni-W substrates were pre-annealed at 650-700 °C for 1 h at this pressure. The chamber was then pumped and maintained at a pressure of 4 x $10^{-5}$ Torr using a mixture of forming gas. Yttrium metal in a tungsten crucible was used as the source. The $Y_2O_3$ layers were deposited at 650-700 °C. The background $H_2O$ pressure was maintained around $1 \times 10^{-5}$ Torr during deposition, which was sufficient to oxidize the film to stoichiometric $Y_2O_3$. The deposition rate was 2 Å/sec with the operating pressure of $10^{-5}$ Torr, and the final thickness was around 500 Å.

A reel-to-reel continuous dip-coating unit was used to deposit solution based $Gd_2O_3$ and LZO seed layers *directly* on Ni-W substrates. The coating and annealing were done at different speeds. The details of which will be published elsewhere [2-4]. The *rf*-magnetron sputtering technique was used to grow both YSZ and $CeO_2$ layers on e-beam $Y_2O_3$, and dip-coated $Gd_2O_3$ and LZO seed layers at 780 °C and in 10 mTorr of forming gas. Ex-situ YBCO precursors were deposited on $CeO_2$-buffered YSZ/$Y_2O_3$/Ni-W substrates using electron beam co-evaporation of Y, $BaF_2$, and Cu. The YBCO precursors were then post-annealed at 740 °C and an $O_2$ pressure of 100 mTorr. Details of the experimental conditions have been reported earlier [5]. Pulsed Laser Deposition was also used for YBCO deposition at 780 °C and an $O_2$ pressure of 120 mTorr on dip-coated seed layers.

The films were analyzed by x-ray diffraction techniques. SEM micrographs were taken using a Hitachi S-4100 field emission microscope. The thicknesses of both buffers and YBCO films were determined by Rutherford backscattering spectroscopy (RBS) and alpha step profilometer scans. The resistivity and transport critical current density, $J_c$, were measured using a standard four-probe technique. The voltage contact spacing was 0.4 cm. Values of $J_c$ were calculated using a 1 μV/cm criterion.

## RESULTS AND DISCUSSION

The data obtained from the Auger analysis of the textured Ni-W substrates are shown in Fig. 1. At 200 °C, the observation of C (18 at. %) and $O_2$ (32 at. %) indicates the presence of hydrocarbons and possibly $WO_3$ or NiO at the surface. After heating the substrate to 550 °C for a very short time, the C peaks disappeared and $O_2$ was decreased to 10 at. % but the presence of S (20 at. %) was observed. Further heating (≥ 600 °C) increased the sulfur segregation to 22 at. % and $O_2$ was completely absent. Similar surface features were observed previously on Ni [6].

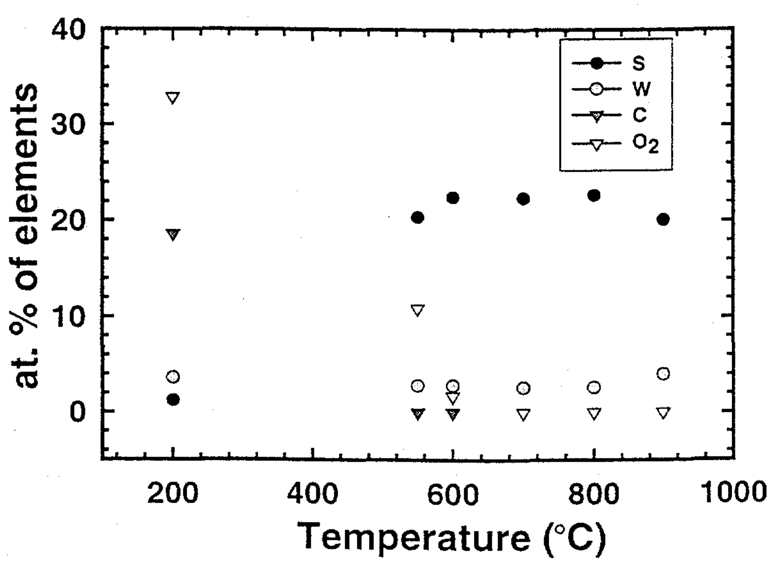


Fig. 1. Scanning Auger Microprobe analysis containing various atomic % of elements present at the textured Ni-W (3 at. %) surface, by annealing at each temperature for 60 min in ultra high vacuum.

Detailed XRD studies indicated the presence of epitaxial $Y_2O_3$, $Gd_2O_3$, and LZO seed layers on Ni-W substrates. The field dependence of $J_c$ for YBCO films deposited on the seed layers with sputtered YSZ and $CeO_2$ cap layers are shown in Figure 2. A high $J_c$ of 1.9 $MA/cm^2$ at 77 K and self-field was obtained on both $Y_2O_3$ and LZO seed layers. $J_c$ at 0.5 T is 21% of the zero-field $J_c$ for $Y_2O_3$ seed layers.

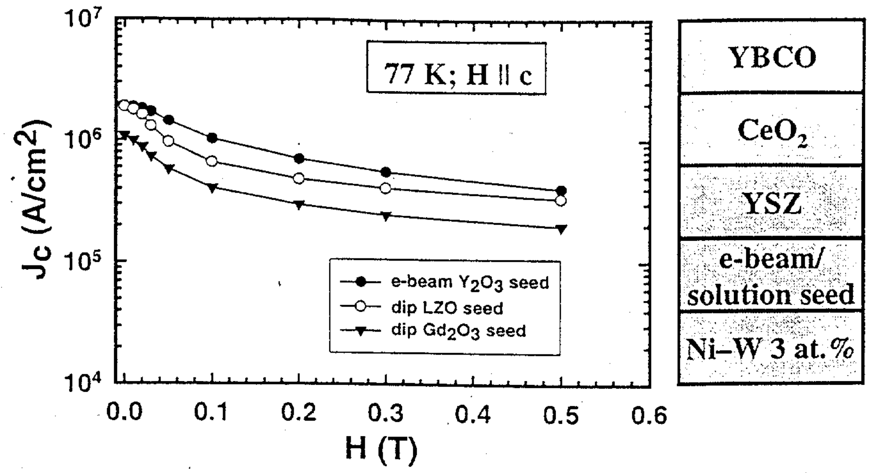


Fig. 2. The field dependence of critical current density, $J_c$, for YBCO films grown on various seed layers. The architecture is shown on the right.

In summary, we have demonstrated the growth of high $J_c$ YBCO films on strengthened, textured Ni-W (3 at. %) substrates. The performance of the solution seed layers approached that of the vacuum seed layers.

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