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Improved properties of Pulsed Laser Deposited YBaCuO on $NdGaO_3$ using CeO_2 template layers

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Abstract

$NdGaO_3$ (NGO) is, due to its low loss characteristics, a favourite substrate for high frequency applications [1]. However, problems occur when trying to deposit high quality YBaCuO layers on top of it. The optimum deposition temperature during pulsed laser deposition to obtain high T_c, high critical current values and c-axis orientation on NGO is significantly higher than for standard substrates, like $SrTiO_3$ or YSZ. A disadvantage of this high deposition temperature is the quality of the film surface. The number of outgrowths and precipitates increases rapidly at higher temperatures. To improve the quality of the layers, the effect of a CeO_2 template layer was investigated, leading to remarkable and very promising results. In this paper we focus on the orientation as well as on the surface morphology with and without a CeO_2 template layer on NGO. The orientations were analysed with XRD, the surface morphology with SEM and STM/AFM.

1. Experimental

Thin YBaCuO films (80 nm) were deposited on *$NdGaO_3$ (100)* substrates with the pulsed laser deposition (PLD) technique, using an Excimer-laser in XeCl-mode. The parameters, which were kept constant during this study, are the following: laser energy density of 1.2 J/cm^2, spot size = 1.8×4.0 mm^2, repetition rate = 2 Hz, oxygen pressure of 30 Pa, distance target to substrate 45 mm, PLD-time = 10 min, post PLD pressure = 1 bar, and cooling down procedure within 30 min. The deposition temperature has been varied in a range of 50 degrees around the optimum deposition temperature for $SrTiO_3$ substrates, being in our set-up $T_{dep} = 740°C$ [2]. With the PLD technique it was possible to assemble a CeO_2 template layer prior to the deposition of the YBaCuO film. The PLD parameters of CeO_2 were similar to YBCO, except for the O_2-pressure during deposition (10 Pa), repetition rate of 1 Hz and a PLD-time of 5 min for a 25 nm thin film. In this study, also the deposition temperature of the CeO_2 layer has been varied in the same temperature window as given above. The growth of the CeO_2 layer was followed by the in situ YBaCuO deposition.

The crystallographic orientation of the CeO_2 tem-

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plate layer as well as the YBCO film was studied by XRD-analysis. The electrical properties were analysed using a standard four-probe technique. The surface morphology, which strongly depends on the deposition temperature *and* the use of a template layer, was investigated with scanning electron microscopy. In addition, we looked in more detail to the flatness of the surface, using scanning tunnelling microscopy.

2. Results and discussions

The films deposited on NGO at the optimum growth temperature of $SrTiO_3$ and YSZ, being in our case 740°C, were very smooth, but had a suppressed transition temperature with a T_{c0} of 80 K, or even less. Fig. 1(a) shows a SEM picture of the as-grown film. The surface morphology looks different compared to *c*-axis oriented films on $SrTiO_3$ or YSZ. The rectangular grains indicate *a*-axis growth. Moreover, from XRD-analysis of these films we observe mainly *a*-axis peaks. Fig. 1(b) shows the θ-scan of the (102)/(012)-reflections of YBCO, with $\psi = 56.6°$ in the *c*-direction and 33.4° in the *a*-direction. From these data we can conclude that the films grown on NGO at a 'standard' deposition temperature consist of almost 90% of *a*-axis oriented YBCO. This also explains the reduced T_{c0} of these films [3].

To fulfil the requirements of high T_c values ($T_{c0} = 90$ K) as well as *c*-axis orientation of the deposited YBCO, the deposition temperature has to be increased by 35 to 50 degrees. However, the surface of the layers grown at these high temperatures, shows an increase of outgrowths and precipitates. These irregularities did not proceed from the target due to 'splashing'. By choosing the accurate spot-diameter, laser-intensity and target compactness, these particles density becomes less then 1 per 100 μm^2 [4]. Fig. 2(a) shows a SEM picture of an typical example of such a film, grown at $T_{dep} = 785°C$. The XRD-analysis of such films shows only *c*-axis orientation and no *a*-axis oriented material is found. In Fig. 2(b) the θ scan of the (102)/(012)-reflections of YBCO is given.

To avoid outgrowths and precipitates at high deposition temperatures the effect of a CeO_2 template was investigated. The properties, like surface morphology and crystal orientation as given by SEM, AFM and XRD-analysis, of the CeO_2 layer on NGO, were very good in a wide deposition temperature range ($790°C > T_{dep} > 670°C$). However, it appeared that the quality of the in situ deposited YBCO film on top of the CeO_2 layer was strongly dependent on the deposition temperature of this CeO_2 template.

Most remarkable was the fact that the morphology of the YBCO films grown at high deposition temperatures ($T_{dep} = 785°C$), using a CeO_2 template that was deposited at a lower temperature ($T_{dep} = 670°C$), was identical to the films without a template. Again, features, like outgrowth and precipitates, were clearly visible. In Fig. 3(a) a SEM picture is presented. Note the similarity between Fig. 2(a) and Fig. 3(a). The template layer has no effect on the surface morphology and electrical properties ($T_{c0} = 89$ K and $J_c = 2$–3×10^6 A/cm^2, at 77 K).

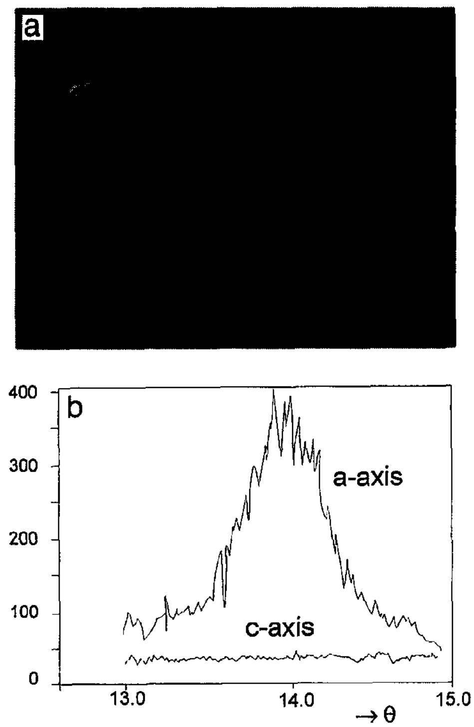

Fig. 1. (a) SEM micrograph (1.0 μm by 0.75 μm) of YBCO on NGO deposited at $T_{dep} = 740°C$. (b) The θ scan of the (102)/(012)-reflections of YBCO, with $\psi = 56.6°$ in *c*-direction and 33.4° in *a*-direction.

The surface quality of the in situ YBCO layer improved significantly by increasing the deposition temperature of the CeO_2 template layer. There was a large correspondence between the results, using a deposition temperature between $T_{dep} = 740$ and 790°C. Fig. 3(b) shows a SEM picture of an YBCO film grown on top of a CeO_2 template, both deposited at $T_{dep} = 785$°C. The superconductor has good superconducting properties ($T_{c0} = 90$ K and $J_c = 3 \times 10^6$ A/cm^2) and a smooth surface.

The surface roughness has also been studied by AFM analysis. Typically height variations were found to be less then 5 nm, which is acceptable for multilayer structures.

In addition to these results we lowered the deposition temperature of the YBCO layer to the standard optimum deposition temperature for $SrTiO_3$ substrates ($T_{dep} = 740$°C) keeping the deposition temperature of the CeO_2 template at $T_{dep} = 785$°C. This reduced temperature had no effect on the superconducting properties or on the surface quality or crystal orientations.

From this we conclude that the growth of YBCO and the occurrence of precipitates is really affected by the surface morphology of the substrate. The effect is clearly visible by covering half of the substrate by a CeO_2 template, which is grown at higher temperatures, followed by the deposition of YBCO at lower temperatures. The covered part has only c-axis oriented YBCO, whereas the YBCO on top of the bare substrate is predominantly a-axis oriented. Furthermore, these results indicate that on NGO selective epitaxy can be obtained by using CeO_2 as a definition mask, especially in a-axis planar devices.

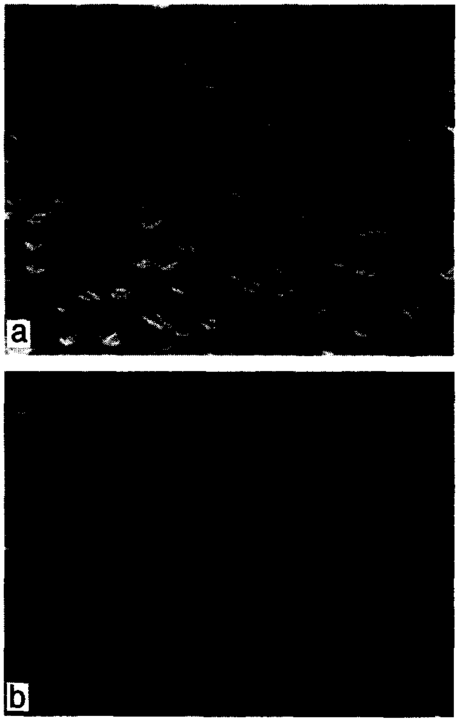

Fig. 3. (a) SEM micrograph (5.0 μm by 3.0 μm) of YBCO, deposited at $T_{dep} = 785$°C, with a CeO_2 template layer, deposited at $T_{dep} = 670$°C, on NGO (001). (b) SEM micrograph (5.0 μm by 3.0 μm) of YBCO with a CeO_2 template layer, both deposited at $T_{dep} = 785$°C, on NGO (001).

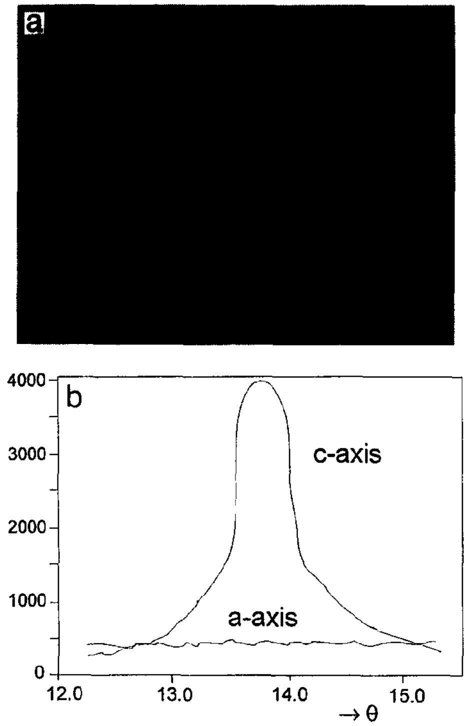

Fig. 2. (a) SEM micrograph (5.0 μm by 3.0 μm) of YBCO on NGO deposited at $T_{dep} = 785$°C. (b) The θ scan of the (102)/(012)-reflections, with $\psi = 56.6°$ in c-direction and 33.4° in a-direction, of YBCO on NGO deposited at $T_{dep} = 785$°C.

3. Conclusions

The optimum deposition temperature, in the sense of high T_c, high critical current and c-axis orientation, of YBCO on NGO substrates is significantly higher than with the use of standard substrates like $SrTiO_3$ or YSZ. The roughness of the surface, however, is much worse, due to an increase of outgrowths and precipitates at these higher deposition temperatures. The YBCO films deposited at standard temperatures are mainly a-axis oriented. Using a CeO_2 template, deposited at temperatures $T_{dep} >$ 740°C, the YBCO surface becomes very smooth and c-axis oriented, even at lower deposition temperatures. These results indicate that on NGO selective epitaxy can be obtained by using CeO_2 as a definition mask.

References

[1] D. Terpstra, A.J.H.M. Rijnders, F.H.G. Roesthuis, D.H.A. Blank, G.J. Gerritsma and H. Rogalla, J. Alloys Comp. 195 (1993) 719.

[2] D.H.A. Blank, D.J. Adelerhof, J. Flokstra and H. Rogalla, Physica C 167 (1990) 423.

[3] C.B. Eom, A.F. Marshall, R.D. Jacowitz and T.H. Geballe, Science 249 (1990) 1549.

[4] D.H.A. Blank, R.P.J. IJsselsteijn, P.G. Out, H.J.H. Kuiper, J. Flokstra and H. Rogalla, Mater. Sci. Eng. B 13 (1992) 67.