$YBa_2Cu_3O_7$-CeO_2 superconducting epitaxial thin films: Growth and structural characterization

Sara Martí Sánchez
Facultat de Física, Universitat de Barcelona, Diagonal 645, 08028 Barcelona, Spain.*

Abstract: $YBa_2Cu_3O_7$ 95%- CeO_2 5% nanocomposite thin films on monocrystalline $SrTiO_3$(001) and $LaAlO_3$(001) substrates were obtained using Pulsed Laser Deposition technique. Their crystalline structure, morphology and electrical resistance versus temperature behavior were obtained and compared with conventional (single) $YBa_2Cu_3O_7$ thin films. The nanocomposite samples are c-axis oriented and epitaxial as conventional films, and remarkably have a significatively lower roughness than conventional YBCO samples. $YBa_2Cu_3O_7$-CeO_2 nanocomposite films maintain the superconducting character with high T_c around 88K and they have a narrow transition width of 2K.

I. INTRODUCTION

$YBa_2Cu_3O_7$(YBCO) is one of the most studied of high temperature superconductors. In order to improve the electrical properties (critical current and its dependence with temperature and magnetic fields), CeO_2 nanocrystals can be added to create some defects that can pin the vortex present in type II superconductors[1-2]. Thanks to the vortex pinning at the nanocrystals, J_c can be higher than it would be in conventional YBCO thin films. The objective of this study is based on de deposition and characterization of YBCO doped with 5% CeO_2 thin films on single crystalline substrates and on their comparison with standard (CeO_2 free) YBCO films. We focus here on structural properties and preliminary electrical measurements (R(T)), without investigation of the critical currents.

Thin films were deposited by Pulsed Laser Deposition (PLD). This technique is particulary useful to deposite complex oxides as YBCO, so it has been very common to grow YBCO films using this technique. Due to this fact, physical deposition parameters are already optimized to get high quality films. Two kinds of substrates have been used: $SrTiO_3$ (001) oriented (STO) and $LaAlO_3$ (001) oriented (LAO), because of the similarity on their lattice parameters with YBCO's. STO is cubic with lattice parameter a=3.905Å, LAO is close to cubic with a=3.863Å and YBCO is orthorhombic with a=3.823Å, b=3.887Å and c=11.680Å. The lattice matching between YBCO and the substrate is essential in obtaining good epitaxial films. Because of that, they are the most used substrates to grow this material[3].

The study of the properties of the films includes the characterization of its crystalline structure (analysis of the epitaxy of the films), their morphology and the measurement of the electrical resistance as a function of temperature. This properties are compared with those of YBCO films without CeO_2 doping.

II. EXPERIMENTAL

A. Growth of the samples

All samples were grown by Pulsed Laser Deposition using the equipment of the GECFE group of the UB. It's a Physical Vapour Deposition technique based on the interaction of an intense UV laser beam with a bulk piece of the material (target) in a vacuum chamber. The laser beam is of short wavelength (284nm) and pulsed, and it is focused above a threshold energy density. These conditions cause the ablation of the target and the material is deposited on the substrate. Figure 1 shows the basics of an standard Pulsed Laser Deposition system. It's a poweerful technique to deposite complex oxides because the complex stoichiometry of the materials is mantained[4-5].

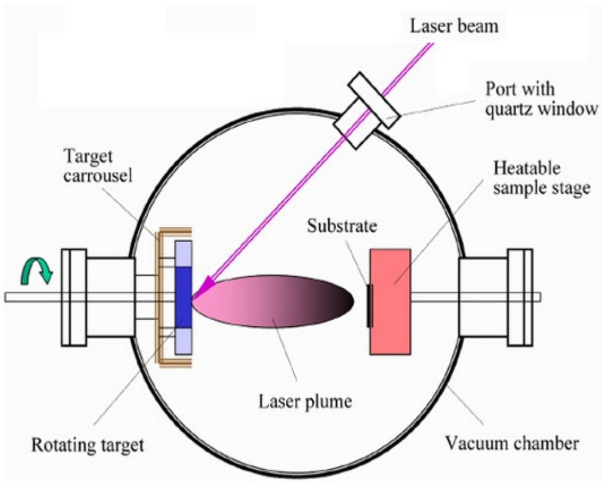

FIG. 1: Standard PLD chamber.

The most relevant deposition parameters that have to taken in control due to their impact on the film properties are the substrate temperature and the partial pressure of O_2. The thickness of the sample can be directly controlled with the number of pulses. In this study, the O_2 presure has been fixed at 0.3mbar and the substrate temperature is 800ºC. The number of pulses has been a variable parameter on the grown samples.

The substrates used to grow YBCO and YBCO-CeO_2 are monocrystalline STO(100) and LAO(100) because the lattice parameter is quite similar to them and it eases the epitaxial growth.

The samples growth for this study and their growth characteristics are shown in TABLE I.

* saramarti92@gmail.com

Material	Substrate	Substrate temperature	pO_2	Thickness
YBCO	STO	800ºC	0.3mbar	80nm
YBCO	STO	800ºC	0.3mbar	120nm
YBCO-CeO_2	STO	800ºC	0.3mbar	120nm
YBCO	LAO	800ºC	0.3mbar	80nm
YBCO	LAO	800ºC	0.3mbar	120nm
YBCO-CeO_2	LAO	800ºC	0.3mbar	120nm

TABLE I: Deposition parameters of the grown samples.

B. Characterization

The samples were characterised using three different techniques. Atomic Force Microscopy(AFM) was used to get information of the morphology: uniformity and roughness of the sample's surface. This measurements have been realised with the GECFE equipment of the University of Barcelona. In AFM, a tip scans the sample giving information about heigh differences. The data adquired of each point is collected in a map of heighs of the surface.

The crystalline structure characterization has been done by X-Ray difractometry (XRD) in the equipment of Centres Científics i Tecnològics de la Universitat de Barcelona (CciTUB). It is based on a X-Ray beam that interacts with the material. Due to its crystalline structure, the material diffracts the beam at certain angles directly related with the atomical positions. 2θ-ω (around symetrical reflections) and Φ(around asymetrical reflections) scans were measured. These scans allow us to get information about out of plane and in plane structure respectively.

The electrical resistance was also measured as a function of temperature for samples grown on STO. In order to determine the critical temperature of the described transition, resistance of the thin film at different temperatures (from 300K to 50K) using a 4-points probes method has been measured. The critical temperature for YBCO thin films it's about 90K, so this is an apropiated range of temperature to study. With this measurements, critical temperature (T_c) and the transition width (Δt_c) can be determined.

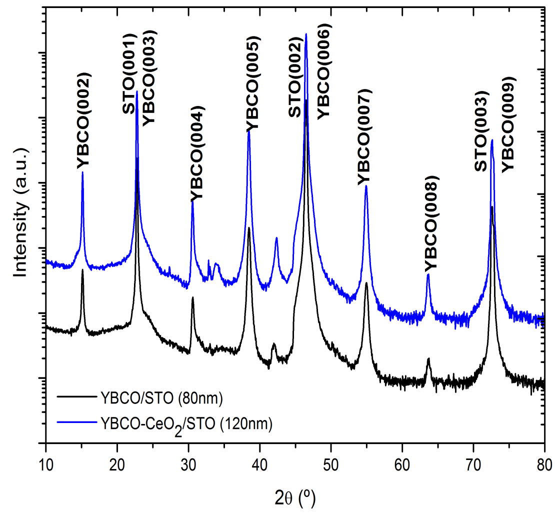

FIG. 2: Diffractograms of 2θ-ω scans of samples grown on STO.

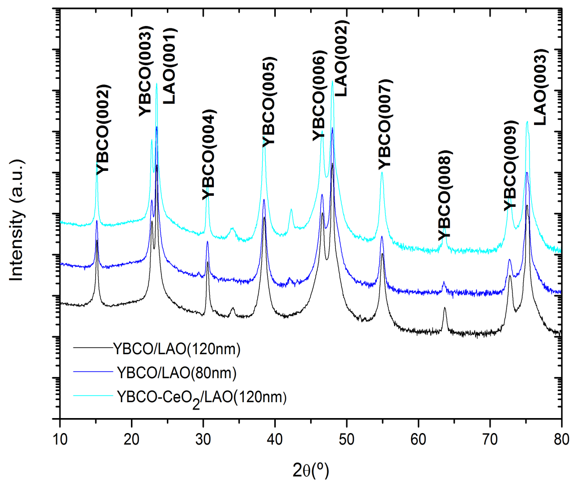

FIG. 3: Diffractograms of 2θ-ω scans of samples grown on LAO.

III. RESULTS AND DISCUSSION

A.Crystalline structure

The θ-2θ scan of samples has given information about the out of plane crystalline structure. This information is shown in the diffractograms shown in t figures 2 and 3.

Figure 2 shows the intensity Bragg peaks of an YBCO sample of 80 nm of thickness (bottom) and YBCO-CeO_2 of 120 nm of thickness (top) on STO(001) substrates. YBCO peaks corresponding to c-orientation are identified in both samples. Figure 3 shows the intensity Bragg peaks of an YBCO sample of 120 nm of thickness (bottom), YBCO of 80nm thickness (middle) and YBCO-CeO_2 120 nm thickness (top) on LAO(001) substrates. On LAO samples can also be identified c-axis oriented YBCO peaks. There are some non-identifyed peaks in all samples, but they don't correspond to any YBCO reflection.These peaks are present in all samples, so the effect of doping doesn't affect the out of plane crystalline structure.

In order to know if films are epitaxial in plane crystalline structure must be analysed by an XRD Φ-scan around asymetrical reflections. This scan has been realised using the YBCO(308) reflection. Figures 4 and 5 show the diffractograms obtained in the measurements.

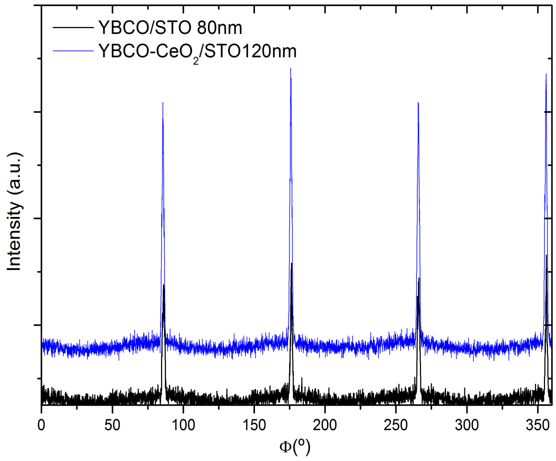

FIG. 4: XRD Φ-scan around asymetrical YBCO(308) reflection for samples grown on STO.

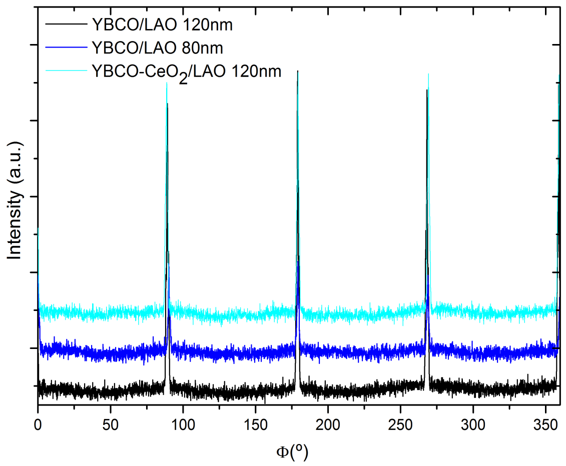

FIG. 5: XRD Φ-scans around asymetrical YBCO(308) reflection for samples grown on LAO.

Figures 4 and 5 show the diffractograms obtained measuring a Φ-scan around asymetrical YBCO(308) reflection for samples grown on STO and LAO respectively. In both diffractograms there are four peaks spaced with a periodicity of 90º, demonstrating in plane order. These scans confirm the epitaxial growth.

B. Morphology

Unsing AFM in contact mode and analysing the results using WSxM software of Nanotec[6] the images shown in figure 6 were obtained. The samples look uniform. There are not many differences between films on LAO and films on STO . The roughness of the surface of samples has been quantificated by the root mean square (RMS) value. The roughness of the samples is quite large, but YBCO thin films usually rough [7]. In our study, the RMS values in YBCO thin films decreases with the thickness of the sample (number of pulses) in STO samples but in LAO samples, the roughness secreases when the thickness of the sample is larger.

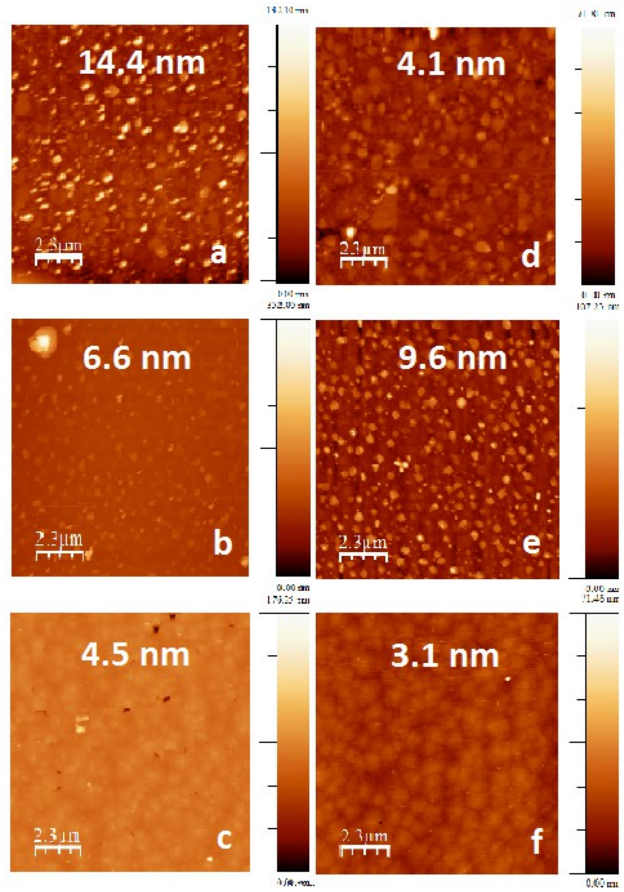

FIG. 6: Morphology and RMS value (top) of a) YBCO 120nm on STO, b) YBCO 80nm on STO, c) YBCO-CeO_2 120nm on STO, d) YBCO 120nm on LAO, e) YBCO 80nm on LAO, f) YBCO-CeO_2 120nm on LAO.

Remarkably, it is found that YBCO-CeO_2 samples have lower RMS values than pure YBCO thin films. It means that with the addition of CeO_2 nanocrystals, we achieve a smoother surface in both substrates.

C. Electrical transport properties

The dependence of the electrical resistance with the temperature is interesting to study because it is the first analysis to study the superconductivity and it allows to determine the critical temperature. The resistance of our samples was measured in a range of temperature between 300K to 50 K because is well known that YBCO in bulk form has it's transition to a superconducting state around a temperature of 90 K. Figure 7 shows the results of the resistance measurements for all the thin films grown on STO substrates.

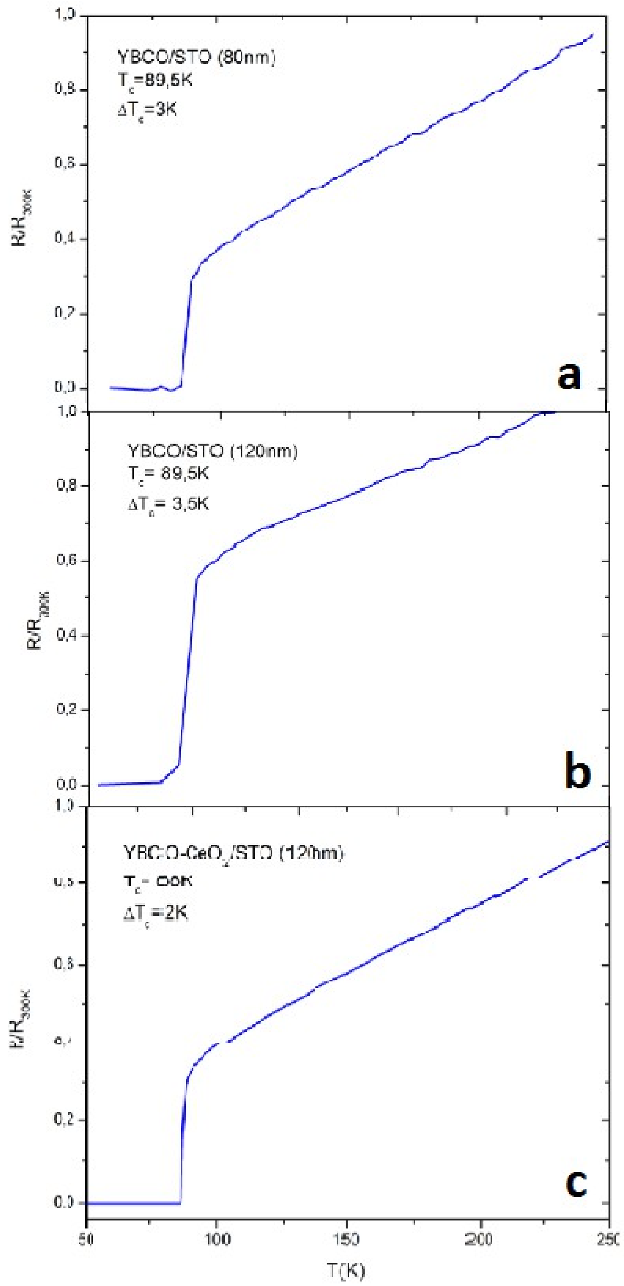

FIG. 7: R(T) measurements of a) YBCO 80nm, b)YBCO 120nm, c) YBCO-CeO_2 120nm

All samples have the transition to superconductor at temperatures closely below 90 K and with narrow transitions of about 2 K. Table II collects de results of critical temperatures and the width of the transitions.

Sample	T_c(K)	ΔT_c(K)
YBCO/STO 80nm	89.5	3,0
YBCO/STO 120nm	89.5	3,5
YBCO-CeO_2 120nm	88.0	2,0

TABLE II. T_c and ΔT_c of samples grown on STO.

The critical temperature had not decreased significantly I YBCO-CeO_2 nanocomposite thin film. It has only decreased 1.5 K, that it's insignificant if the width of the transition (determined by ΔT_c) is considered, because transition of YBCO-CeO_2 becomes narrower than YBCO's.

IV. CONCLUSIONS

YBCO-CeO_2 nanocomposite films have been successfully grown STO(001) and LAO(001) using Pulsed Laser Deposition mantaining and even improving some of YBCO's properties. Epitaxial growth was confirmed by the XRD measurements and no differences were appreciated between the nanocomposites and pure YBCO thin films, however, surface structure has significantly changed. AFM scans analysis have revelated a decrease of the surface roughness in nanocomposite films in comparison with single YBCO films. The electrical transport properties measured have not changed adding CeO_2 to YBCO: YBCO-CeO_2 films are still superconducting below a temperature of 90 K.

In summary, the efect of adding CeO_2 does not degrade YBCO's properties. It would be interesting to study if criticall current J_c is higher in those samples as it increases in samples when CeO_2 nanocrystals are added, but this study has not been realised yet.

Acknowledgments

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