Improvement of the homo-biepitaxial YBCO film fabrication process on Yttrium Stabilized Zirconia.

M P Lisitskiy¹, C Camerlingo¹, M Salvato²*¹, A Vecchione², and M Russo¹

¹ Istituto di Cibernetica “E.Caianiello” del C.N.R., 80078, Pozzuoli (NA), Italy
² Dipartimento di Fisica “E.R.Caianiello”, Universita’ degli Studi di Salerno and INFM-CNR Laboratorio Regionale “Supermat”, 84081 Baronissi (SA), Italy

E-mail: m.lisitskii@cib.na.cnr.it

Abstract. We present the results of the application of the dc magnetron sputtering modulation mode to fabricate YBCO homo-biepitaxial thin film Josephson junctions on Yttrium Stabilized Zirconia substrate. A 45° in-plane rotation of the grown YBCO films with respect to the substrate orientation is realized by using a thin YBCO buffer layer deposited at a temperature (~600 °C) lower than the optimal value (800 °C). The control of the in-plane orientation allows to form Josephson junctions between two YBCO superconducting region of the film with and without buffer layer. We obtained that the modulated deposition mode improves the crystalline in-plane orientation of YBCO on buffer layer/YSZ substrate, increases the grain size and decreases the film stress. The improved homo-epitaxial process was applied for fabrication of dc SQUID devices.

1. Introduction

YBa₂Cu₃O₇₋ₓ (YBCO) is considered as a promising high Tc-superconductor (HTCS) for electronic application. The substrate nature together with deposition conditions control the YBCO in-plane orientation with respect to the substrate crystallographic orientations [1, 2]. Yttria-stabilized ZrO₂ (YSZ) single crystal is a quite unique substrate because of the possibility to have two (0° or 45°) in-plane rotation of the grown YBCO which depends on deposition temperature, thin buffer layer deposition or some particular treatment of the substrate surface [3]. A thin film of YBCO deposited at low temperature can be used as a buffer layer. By controlling the suitable growing conditions for two parts of the substrate, it is possible to grow an YBCO film with two different in-plane orientation (0° on one side, and 45° on the other) creating nearly planar 45° grain boundary and, hence, to form the Josephson weak link in the perpendicular direction to the boundary between two parts of the film. This method named as homo-biepitaxial was successfully applied for fabrication of YBCO Josephson junctions [4]. The homo-biepitaxial junctions are free of topological limitations and can be used for realization of complex HTCS high integrated circuits based on Josephson effect. In addition, the YSZ substrate is cheaper than SrTiO₃ and is not hydrophilic like MgO. Besides of the potential electronic applications, the homo-biepitaxial method is attractive for fundamental investigation. Indeed, d-wave

* Present address: Università degli Studi di Roma "Tor Vergata", Dipartimento di Fisica, 100133 Roma, Italy
nature of YBCO is clearly manifested in $45^\circ$ rotated Josephson junctions as $\pi$-shift of Josephson phase [5]. The home-epitaxial technique seems to be useful for fabricating of bi-dimensional Josephson junction array suitable to flux trapping penetration experiments [6].

One of the main problems with YSZ homo-biepitaxial technique, however, is the control of the in-plane orientation in reproducible manner. The search of a new deposition method may be considered as the key for improvement of the homo-biepitaxial technique. The modulation mode described in [7] consists on periodical modulating of the sputtering power down to a value when the sputtering of a target is practically prevented. A modulation deposition controls the ordering time $t_0$ getting significant effects on the final structure of the film, increasing grain dimensions and decreasing surface roughness.

In the present paper we report on attempt to apply the dc magnetron sputtering in modulation mode for the case of homo-biepitaxial structures, namely, YBCO($800 \, ^\circ C$) film/ YBCO($600 \, ^\circ C$) buffer layer / YSZ substrate. We show how the dc modulation sputtering deposition modifies the YBCO film properties with respect to the conventional dc sputtering process.

### 2. Experimental

The YSZ single crystal of (100) orientation was used as a substrate. YBCO films were deposited by a dc inverted cylindrical magnetron sputtering source with a 50 nm diameter stoichiometric YBCO target. The YBCO buffer layer with a thickness of 20 nm was deposited at temperature $T=600 \, ^\circ C$ while the 200 nm thick YBCO film was deposited at $T=800 \, ^\circ C$. Before YBCO deposition, the substrate was treated by fast atom bombardment (FAB) at an oxygen pressure $P_{O_2}=0.4 \, \text{mTorr}$ at $T=600 \, ^\circ C$. Plasma was ignited in atmosphere of Ar and $O_2$ at total pressure of $700 \div 750 \, \text{Torr}$. Conventional sputtering mode was performed at constant power of 114 W by controlling the plasma ion current. In the modulation mode, the power was kept at 114 W for 126 s and lowered down to 60 W for 22 s. At the full power level the deposition rate was 0.018 nm/s while the sputtering rate at lower level of 60 W could be considered as negligible. After deposition process, the sample was cooled slowly in pure $O_2$. The buffer layer deposition and the YBCO($800 \, ^\circ C$) film were performed as separate fabrication runs.

The dependence of the YBCO film resistance $R$ on temperature $T$ was measured by a four-point dc technique. From the $R(T)$ curve we evaluated the superconducting transition temperature $T_c$, as the temperature at which the resistance falls up to value of $R/2$ where $R$ is the resistance at the beginning of superconducting transition, the superconducting transition width $\Delta T_{90\%-10\%}=T(0.9R_0)-T(0.1R_0)$ and the ratio between the resistance values measured at $T=250 \, \text{K}$ and $T=100 \, \text{K}$ ($R_{250}/R_{100}$). The crystallographic properties, namely, the orientation normal to the substrate surface, lattice constant $c$ along this direction, crystalline grain sizes $d$ and non-uniform strain parameter $\varepsilon=\Delta c/c$ were evaluated from the $\theta-2\theta$ X-ray measurements made by CuK$\alpha_1$ radiation source (wavelength $\lambda=0.154056 \, \text{nm}$).

### 3. Results and discussion

We fabricated YBCO($800 \, ^\circ C$)/YSZ and YBCO($800 \, ^\circ C$)/YBCO buffer layer ($600 \, ^\circ C$)/YSZ samples both by conventional mode and by modulation mode deposition. Figure 1 shows typical $R(T)$ curve measured for the sample YBCO($800 \, ^\circ C$)/YBCO buffer layer ($600 \, ^\circ C$)/YSZ fabricated by modulation mode. Table 1 summarizes the superconducting properties of some films. As can be seen in Table 1, the YBCO films (both with and without YBCO buffer layer) grown by modulation mode exhibit more sharp transition to the superconducting state while the values of $T_c$ and $R_{250}/R_{100}$ are practically identical. All YBCO($800 \, ^\circ C$) films deposited on the YSZ substrate with and without YBCO($600 \, ^\circ C$)
buffer layer are characterized by a well defined crystal orientation, having grains aligned with the \( c \)-axis perpendicular to the substrate plane independently from the deposition mode. The \( c \)-axis lattice constant \( c \) was calculated from the angular position of the reflection peaks on the \( \theta \)-2\( \theta \) X-ray diffraction patterns. The parameters \( d \) and \( \varepsilon \) relate to the reflection peak halfwidth \( \beta \) through the expression \( \beta = 2 \varepsilon \tan \theta + \lambda / d \cos \theta \) [8]. In order to evaluate \( d \) and \( \varepsilon \), \( \beta \cos \theta \) was plotted against \( \sin \theta \) for a number of reflections at low \( \theta \) and fitted by straight line with slope \( 2 \varepsilon \) and \( \gamma \)-axis intercept \( \lambda / d \). The values of \( c \), \( d \) and \( \varepsilon \) are reported in Table 2. The values of \( c \) are closed to that expected in case of fully oxygenated YBCO phase. However some significant difference for \( d \) and \( \varepsilon \) values was observed between the samples fabricated by conventional mode and modulated mode. The modulation deposition mode allows to grow YBCO(800 °C) films with larger grain size and low stress level. This was confirmed by micro-Raman spectroscopy analysis which revealed a low degree of lattice disorder in samples fabricated by modulation mode.

In-plane orientation of the grown YBCO(800 °C) films was evaluated by \( \phi \)-scan of (103) planes and compared with the (111) or (220) plane reflection of the YSZ substrate. A perfect 45° in-plane rotation with respect to YSZ substrate was obtained in case of YBCO(800 °C) films deposited by
modulated mode on YBCO(600 °C) buffer layer (see figure 2). We note that also the buffer layers were deposited by the modulated mode. The presence of the mixed in-plane orientation components of YBCO(800 °C) grown by modulated mode without buffer layer can be eliminated by using of slightly low deposition temperature [3]. Even if this mixed in-plane orientation is not favorable for making a clean grain-boundary Josephson junction, two junctions dc SQUIDs were fabricated by the homo-biopitaxial technique (see insert of figure 3) which clearly demonstrated the interferential Josephson behavior. Figure 3 shows the voltage $V$ versus external applied magnetic flux dependence measured at $T=4.2$ K.

In conclusion, a deposition mode involving a modulation of the sputtering power and consequently of the deposition rate has been employed and investigated in case of YBCO homo-biopitaxial technique. The results indicated that the modulated deposition mode improves the crystalline in-plane orientation of YBCO on buffer layer/YSZ substrate, increases the grain size and decreases the film stress. This structural enhancement is also observed in YBCO films deposited directly on the YSZ substrate even if the problem of a mixed in-plane orientation of YBCO remains still open.

**Acknowledgements**

This work is partially supported by MIUR under the project “Sviluppo di componentistica avanzata e sua applicazione a strumentazione biomedica” and under the project FIRB-RBAU01PYB3.

![Figure 3. $V(\Phi)$ dependence of the dc SQUID shown in insert. $I_{bias}=170$ nA, $T=4.2$ K.](image)

**References**

[1] Phillips J M 1995 Appl. Phys. Lett. 79 1829
[2] Wu X D, Luo L, Muenchhausen R E, Springer K N and Foltyn S 1992 Appl. Phys. Lett. 60 1381
[3] Brorsson G, Olsson E, Ivanov Z G, Stepansov E A, Alarco J A, Boikov Yu, Claeson T, Berastegui P, Langer V and Lofgen M 1994 J. Appl. Phys. 75 7958
[4] Tsai S H, Chi C C, Wu M K 2000 Physica C 339 155
[5] Tsuei C C and Kirtley J R 2000 Reviews of Modern Physics 72 969
[6] Tsuei C C and Kirtley J R 2002 Physica C 367 1
[7] Camerlingo C, Riggiero B, Russo M, Sarnelli E, Del Vecchio A, De Riccardis F, Tapfer L 1997 Journal of Alloys and Compounds 251 34
[8] Jeffery J W 1971 Methods in X-Ray Crystallography (London and New York: Academic Press)