IL NUOVO CIMENTO VOL. 16 D, N. 12 Dicembre 1994

Growth and Magnetic Characterization of YBCO Films (*).

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(ricevuto il 17 Novembre 1994)

Summary. — Epitaxial films of $YBa_2Cu_3O_{7-x}$ were deposited *in situ* on $LaAlO_3$ substrates using single-target 90° off-axis sputtering. The films were characterized by magnetization measurements (M *vs.* T, H), applying the field parallel to c-axis. The observed differences in the T_c and J_c values are attributed to the different oxygen content in the superconducting films.

PACS 74.76 – Superconducting films.
PACS 74.60.Jg – Critical currents.
PACS 74.60.Mj – Material effects on T_c, κ, critical currents (including impurities, ion implantation etc.).
81.15.Cd – Deposition by sputtering.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction.

The thin-film deposition has been receving in the last few years a growing interest in the research of high-T_c superconductors (HTSC), mainly for the possible applications in microelectronics. Technological applications of HTSC require the optimization of the materials with respect both to T_c and J_c, as well as with respect to the surface morphology. Thus in the film deposition the stoichiometric control of the metallic constituents and the correct oxygenation are essential. Besides, measurements of superconducting properties of the films need suitable methods and very sensitive apparatus. Magnetic measurements have the advantage of providing a non-contact method for measuring T_c and estimating J_c (by using the Bean model, which relates the irreversible magnetization to J_c) [1].

In this context we have developed a deposition process for growing YBCO films by sputtering and we have characterized them by a high-sensitivity SQUID magnetometer.

(*) Paper presented at the «VII Congresso SATT», Torino, 4-7 October 1994.

2. – Results and discussion.

2·1. *Films deposition.* – $YBa_2Cu_3O_{7-x}$ films (thickness ≈ 0.1–0.6 μm) were deposited on $LaAlO_3$ (100) substrates, using a planar magnetron sputter gun in a commercial K. J. Lesker deposition system. The sputter gun was mounted in a cryopumped vacuum chamber; the base pressure was $3 \cdot 10^{-8}$ Torr. Stoichiometric 3 in. diameter target was prepared from citrate pyrolis powders [2]. The sputtering atmosphere varied between 40 to 60 mTorr O_2 and 160 to 240 mTorr Ar. An RF power of 100 W generates a cathode self-bias of − 70 V and gives a deposition rate for the off-axis geometry of about 0.1 Å/s, which depends on the total pressure and Ar/O_2 ratio. In our case it ranges from 200 to 300 mTorr with 2% O_2 and 80% Ar. The substrate was bonded by silver paste on the holder. During film growth the substrate block temperature was held constant between 730 and 750 °C. After deposition, the chamber was immediately vented to 20 Torr of pure oxygen and the substrates were allowed to cool slowly to room temperature. Figure 1 shows the sputtering geometry we have used. X-ray diffraction patterns showed the typical reflections of the 123 phase indicating the c-axis orientation perpendicular to the film plane. No spurious phases were detected.

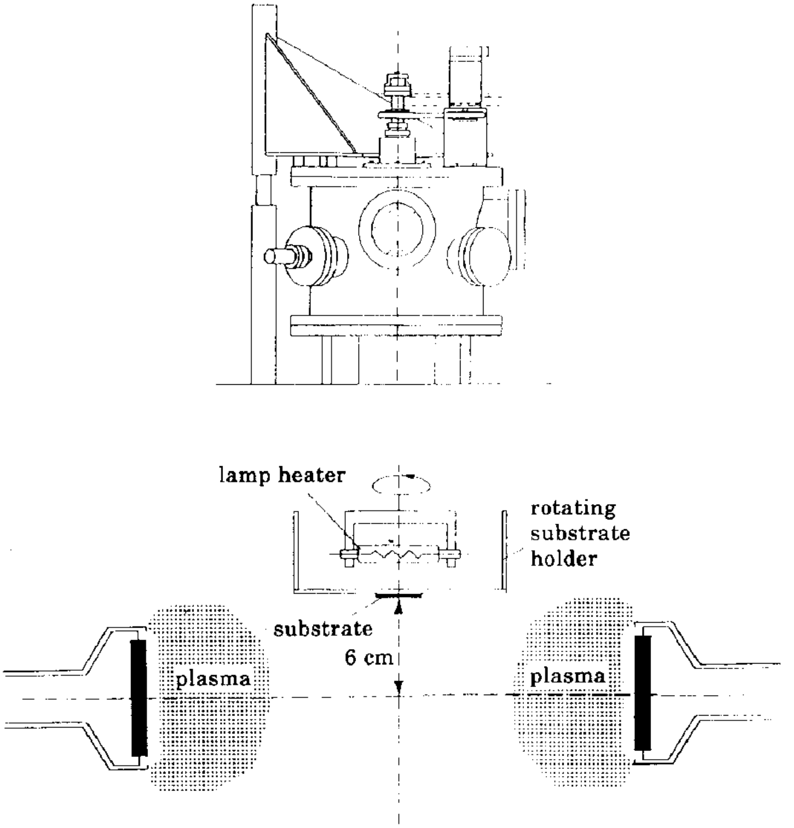

Fig. 1. – Schematic view of the deposition chamber and of the off-axis RF magnetron sputtering equipment.

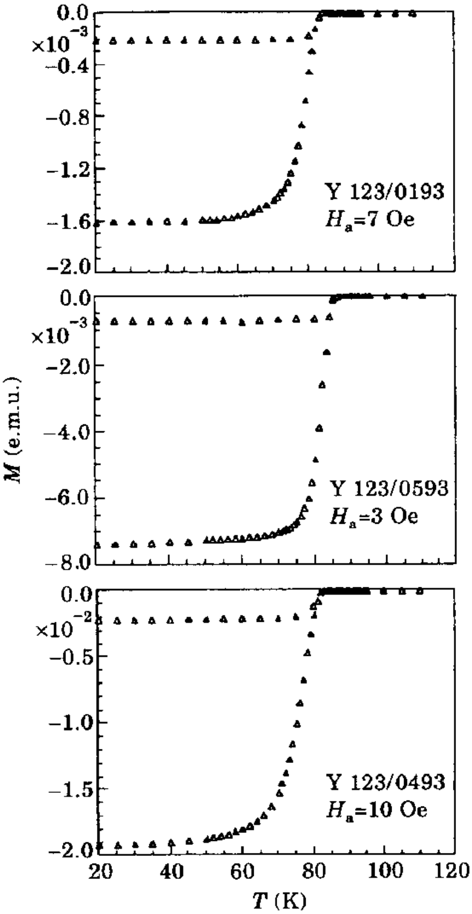

Fig. 2.

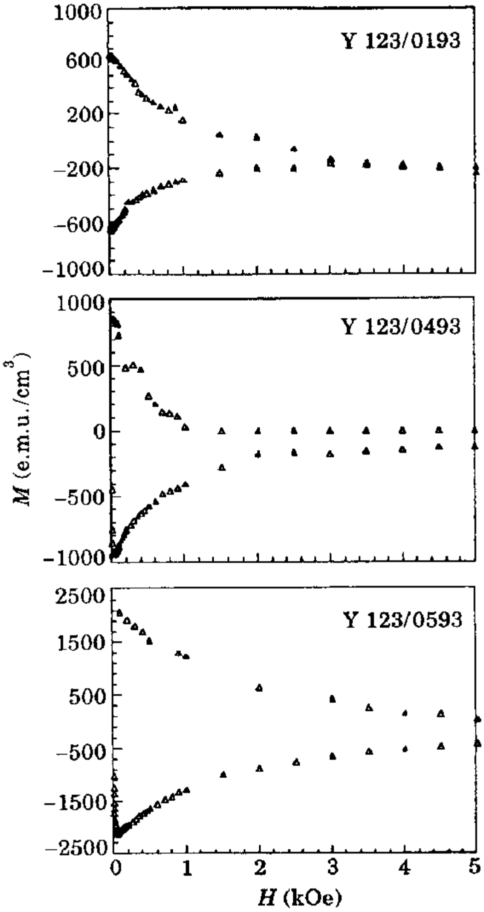

Fig. 3.

Fig. 2. – Temperature dependence of the magnetization. Upper and lower curve: FC and ZFC magnetization, respectively.

Fig. 3. – Hysteresis cycles at $T = 77$ K.

2·2. *Magnetic characterizations.* – The films were characterized by means of magnetic measurements using a SQUID magnetometer ($2 < T < 400$ K; $H_{\max} = 5.5$ T). The magnetic field was applied parallel to the c-axis. Low-field ($H \leqslant 10$ Oe) magnetization measurements as a function of the temperature allowed us to derive the critical temperature T_c, taken as the onset of the diamagnetic transition. In fig. 2 low-field M *vs.* T measurements are reported. They were performed as follows: the sample was first cooled in zero field, then a field was applied and the measurements were performed with increasing temperature (ZFC, *i.e.* zero-field–cooled curve); subsequently the sample was cooled in the same field down to the lowest temperature and then it was warmed up again and the measurements were performed again (FC, *i.e.* field-cooled curve). A sharp transition is observed in the ZFC curves confirming, qualitatively, the epitaxial nature of the superconducting film. The low signal in the

TABLE I.

Sample	Thickness (Å)	Size (mm^2)	T_c(K)	J_c^{ab}(A/cm^2)
FY0193	1000	2.0 × 2.7	80	$2.8 \cdot 10^4$
FY0493	5000	4.0 × 3.5	83	$1.7 \cdot 10^4$
FY0593	6000	3.5 × 2.6	86	$1.3 \cdot 10^5$

FC curve, which levels off just below T_c, and the large separation from the ZFC curve, reflect a strong flux trapping by pinning.

The measurements of the hysteresis cycles (fig. 3) allowed us to estimate the critical current density J_c from the width of the hysteresis cycles using the Bean critical state model [1], which for a platelet geometry predicts

$$J_c = 10\,\Delta M/a_2(1 - a_2/3a_1),$$

where ΔM is the width of the cycle and $2a_1$, $2a_2$ ($a_1 > a_2$) are the film dimensions perpendicular to the applied field.

In table I J_c^{ab} ($T = 77$ K, $H = 1$ kOe) and T_c are reported for three films, together with their thickness and size. The T_c values are lower than the characteristic value ($T_c \approx 90$ K) for the stoichiometric compound ($YBa_2Cu_3O_7$). This should be due to a reduced number of charge carriers in the CuO_2 planes [3]. Therefore, the observed differences in the T_c values should be ascribed to a different oxygen stoichiometry, T_c increasing with increasing it. We have not, however, determined the oxygen content in our films. J_c is about one order of magnitude higher for the sample FY0593, having the highest T_c. With increasing T_c the field-dependence of J_c decreases: for the sample FY0193 ($T_c = 80$ K) the cycle closes at about 3kOe, whereas for the other two samples it remains open up to 5 kOe (fig. 3). Moreover, for the sample FY0593 ($T_c = 86$ K) J_c decreases more slowly than for the sample FY0493 ($T_c = 83$ K) (fig. 4).

The fact that J_c increases and its field dependence decreases with increasing T_c suggests that J_c also is ruled by the oxygen content. It is well known indeed that with increasing oxygen content both T_c and J_c increase [3, 4]. The increase of J_c in this case should be due to a stronger coupling between the CuO_2 planes, determined by the higher oxygen content, which reduces the actual anisotropy of the superconducting

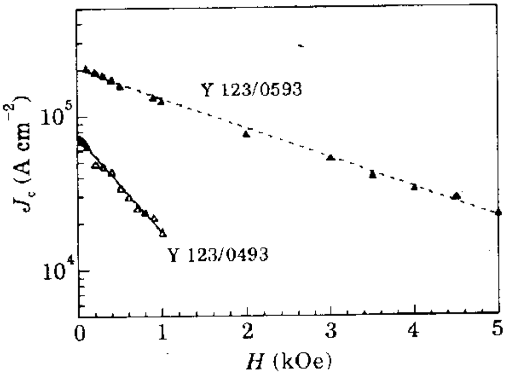

Fig. 4. – Field dependence of J_c at 77 K for two films (FY0493 and FY0593).

material. We cannot exclude, however, in the absence of further detailed structural investigations, that a different density of twin planes, which are known to act as pinning centres, can also play an important role in determining the observed J_c differences.

3. – Conclusions.

We have reported the growth, by sputtering, of epitaxial YBCO films and their characterization by magnetization measurements. The observed T_c ($80 < T_c < 86$ K) and J_c (*e.g.*, $2 \cdot 10^4 < J_c^{ab}$ (77 K, $H = 1$ kOe) $< 1 \cdot 10^5$ A/cm^2) differences are attributed to a different oxygen content.

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