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Fabrication of YBCO/YSZ and YBCO/MgO thick films using electrophoretic deposition with top-seeded melt growth process *

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Superconducting thick films were grown on single crystals MgO and YSZ by electrophoretic deposition with Y_2BaCuO_5(Y211) addition. YBCO thick films were then accomplished by sintering the precursor films above the peritectic temperature. Single crystals of MgO ($3\times3\times0.5\,mm^3$) were used as top-seed to control crystal structure of the thick films. As shown by scanning electron microscopy, the morphologies of YBCO/YSZ and YBCO/MgO thick films are spherulitic texture and platelet type. The critical temperature is ∼89 K for the YBCO/YSZ thick film; the onset transition temperature is 86.4 K and the transition width is ∼3 K for YBCO/MgO thick film. The critical current densities (as determined by Bean model) are, in A/cm^2, 3870 (77 K) for YBCO/YSZ thick films and 2399 (77 K) for YBCO/MgO thick films, which are comparable to the best J_c reported of the thick films prepared by the same method.

Keywords: YBCO thick films, electrophoretic deposition, melt-textured
PACC: 7470V, 7475, 8110F

1. Introduction

Since the high-T_c YBCO superconductor exhibits high critical current density and higher irreversibility field (H_{irr}), it is desirable to use YBCO tapes for a range of electric power applications in the foreseeable future.[1,2] Up to now, two successful methods to fabricate the Y-based tapes are ion-beam-assisted (IBAD) [3] and rolling-assisted bi-axially textured substrates (RABiTS),[4] which prepare suitable buffer layers on polycrystalline flexible tapes. Normally, on the perfectly oriented buffer layers YBCO superconducting coats were deposited by various thin film techniques, such as pulse laser deposition (PLD), metal–organic deposition (MOD) and the MOD method using trifluoroacetates (TFA-MOD), etc.[5−7] The critical current densities of the films prepared by these methods are up to $\sim10^6\,A/cm^2$ (77 K, 0 T). Nevertheless, it is imperative that a simpler approach to Y-based coatings should be studied. Electrophoresis is attractive due to its high growth rate, simple apparatus and the possibility to deposit films on large or irregularly shaped substrates with controllable thickness. Despite that many efforts have been devoted to improving the critical current density of thick films using this method, the value now available is still low.[8−13] So far, the highest critical current density value has been obtained by depositing YBCO on Ag wires. However, there are several drawbacks in using Ag as substrates. First, Ag substrates react with YBCO if the sintering temperature exceeds the peritectic temperature; second, it is difficult to realize epitaxial growth on Ag substrates, i.e. difficult to obtain high quality films; third, the YBCO/Ag wires were always fabricated by multiple deposition with intermediate heat treatment. To overcome these shortcomings, we have prepared the YBCO superconducting thick films on YSZ and MgO single crystal substrates using MgO top-seeded melt growth process with a small amount of Y_2BaCuO_5 (Y211) powder addition. The MgO top seed can lead to *c*-axial grain alignment in the majority part of the YBCO superconducting thick films. The additional Y211 phase is helpful to increase the critical current density J_c. In this paper, the results of experiments with well-textured formation and an increase in J_c are reported. The critical current

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densities have the same order of magnitude with the best values reported of the thick films prepared by the same method.

2. Experiments

The preparation of $YBa_2Cu_3O_{7-\delta}$ (Y123) and Y211 powders were described in another paper of ours.[14] The precursor powder was ground into fine powders of Y123+0.1 mol Y211. The particle size of the powder ranged from 100 nm to 2 μm.

The suspension for electrophoresis was a mixture of precursor powder (Y123+0.1 mol Y211), acetone and a small quantity of iodine, with the mass ratio of about 3:100:0.003. The Ag/YSZ and Ag/MgO substrates were used as the cathodes. A silver plate was used as the anode. During the deposition process, a DC voltage of 950 V was applied between the electrodes and kept for 10 min. In this process, the uniformity of the current density, which is crucial, would affect the homogeneity of the YBCO thick films. The thickness of the YBCO films was controlled by the time of electrophoresis.

The schematic diagram of the crucible is shown in Fig.1. On the bottom of the alumina crucible were placed about 2 g of Y123 powders and over the Y123 powder was put a Pt plate. The YBCO precursor thick films (YBCO/Ag/MgO and YBCO/Ag/YSZ) were laid on the Pt plate. The MgO ($3\times3\times0.5\,mm^3$) crystal seed was placed on the surface of the YBCO thick films. The crucible cover is important for the sintering treatment to avoid the deviation from the Y123 stoichiometric ratio.

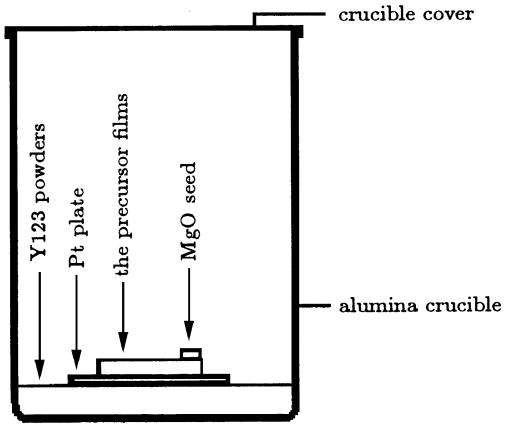


Fig.1. Schematic diagram of the crucible.

In both cases mentioned above, the typical sintering process was carried out as follows: the crucible was put in a muffle furnace and heated up to 1030 °C in 4 h, stabilized at 1030 °C for 30 min, and then the temperature was reduced to 30 °C in 15 h. The YBCO superconducting thick films tightly adhered to the substrates. The experimental process is feasible and reproducible.

3. Results and discussion

The images of surface morphology obtained using scanning electron microscopy (SEM) (Fig.2) illustrate that both YBCO/MgO and YBCO/YSZ thick films are black, textured, planar and compact. A lot of platelet-type structures can be observed in the SEM image of YBCO/MgO superconducting thick film (Fig.2(a)). Figure 2(b) presents the spherulitic textured structures in the SEM image for YBCO/YSZ superconducting thick films.

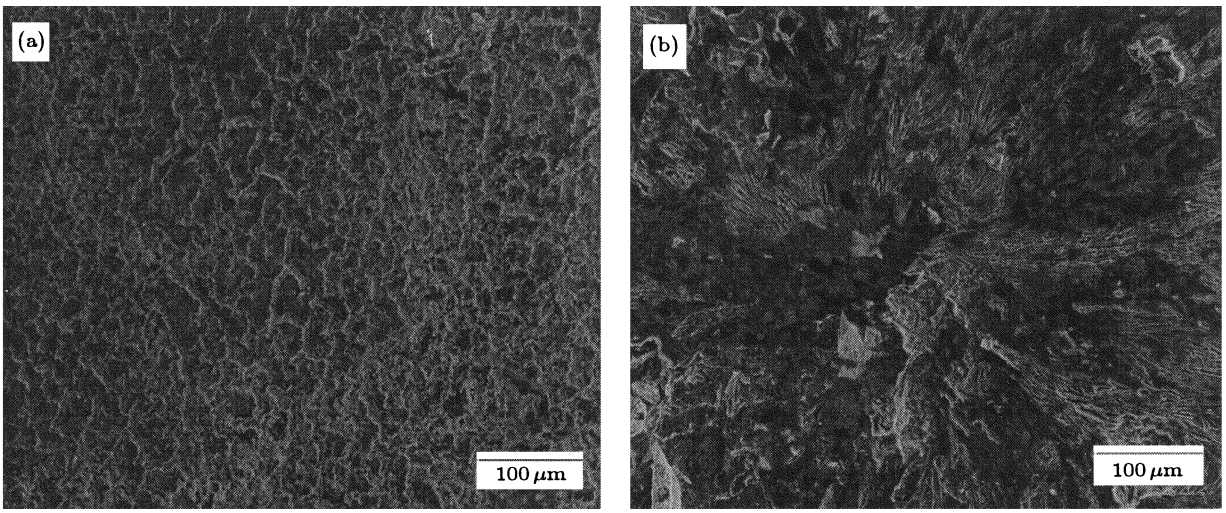


Fig.2. SEM image for YBCO/MgO superconducting thick films (a) and SEM image for YBCO/YSZ superconducting thick films (b).

Analysis of both YBCO/YSZ and YBCO/MgO superconducting thick film surfaces using x-ray diffraction (XRD) (Fig.3) shows a majority of orientated peaks of Y123 phase and a few small peaks of Y211 phase. The values of the relative intensity of (003), (005), (006) peaks in Y123 phase are obviously greater than other peaks present in the XRD patterns. This indicates a preferred 00l direction perpendicular to the surfaces of the YBCO/MgO and YBCO/YSZ thick films.

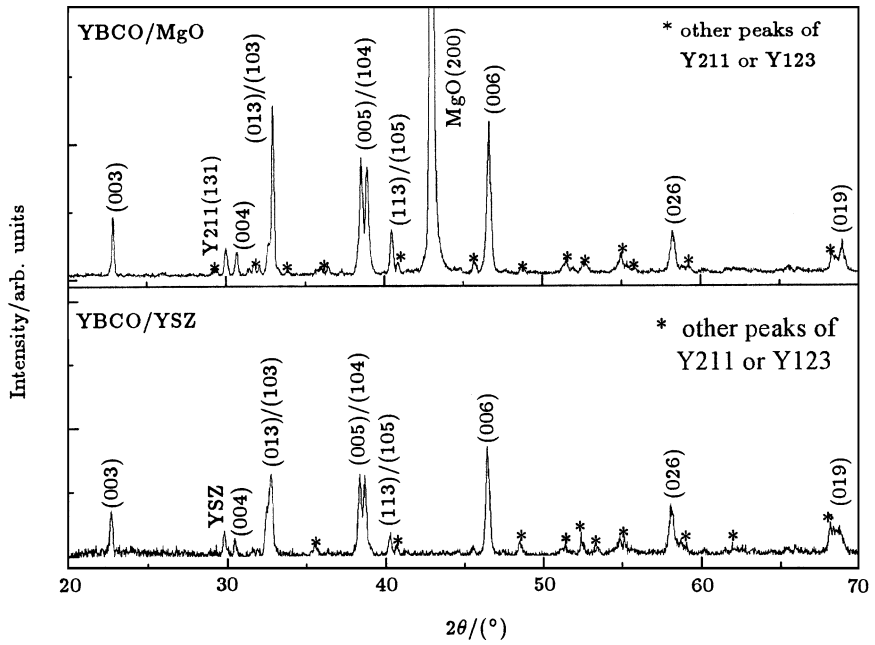


Fig.3. XRD patterns for YBCO/YSZ and YBCO/MgO superconducting thick films.

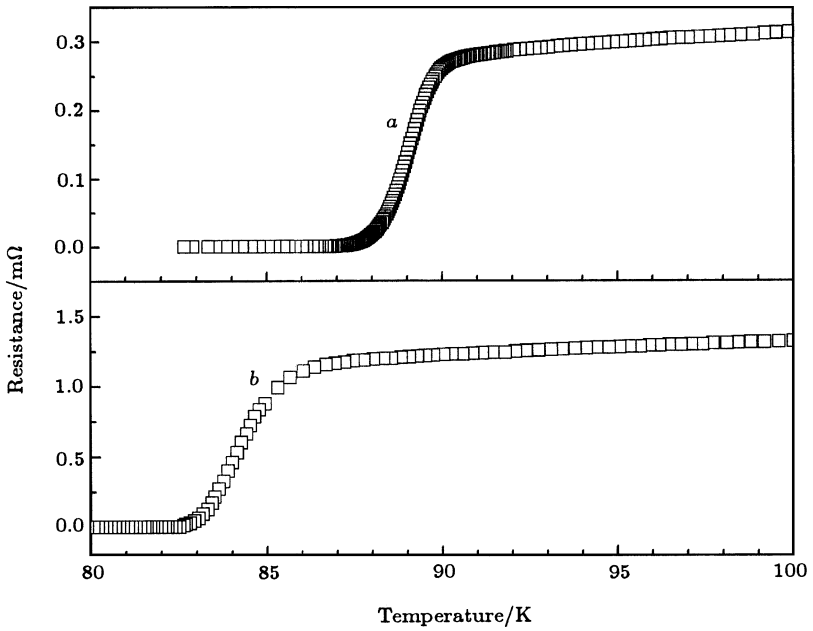


Fig.4. Resistance versus temperature for the YBCO/YSZ (curve a) and YBCO/MgO (curve b) superconducting thick films.

The standard four-probe method is used to measure the resistance of the YBCO superconducting thick films. Curve a and curve b are the super-normal transition temperature curves for YBCO/YSZ superconducting thick film and YBCO/MgO superconducting thick film, respectively (Fig.4). For YBCO/YSZ superconducting thick film, the onset transition temperature is 90.3 K and the narrow transition width is ~1.8 K. For YBCO/MgO superconducting thick film, the onset transition temperature is 86.4 K and the transition width is ~3 K. Both the widths of the transition temperature of the YBCO thick films fabricated in this work are narrow, as compared with the values ever obtained by the same method. In contrast, the thick films prepared by the same procedure without MgO seed do not exhibit superconductivity.

The measurements of M–H loops at 77 K have been carried out to deduce the critical current density. The applied magnetic field is vertical to the surface of the YBCO superconducting thick films. Using hysteresis loops and the Bean model, the critical current density versus the magnetic field is shown in Fig.5. Zero field transport critical current density is 3.870×10^3 A/cm^2 for YBCO/YSZ superconducting thick films and 2.399×10^3 A/cm^2 for YBCO/MgO superconducting thick films at 77 K. The relatively low critical current density, which is compared with the films fabricated by other methods (PLD, TFA-MOD, MOD, etc), is related to the defects in the thick films and the nonuniformity of oxygen content. Our results and those developed by electrophoresis which were reported in other papers are listed in Table 1 for comparison.

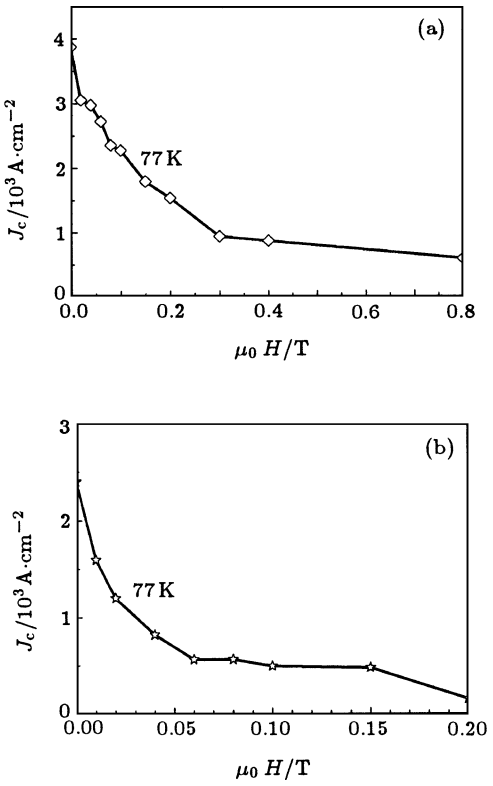


Fig.5. Field dependence of transport critical current density at 77 K for the YBCO/YSZ (a) and YBCO/MgO (b) superconducting thick films.

Table 1. Comparison of the critical current densities for the YBCO superconducting thick films prepared by electrophoresis.

Data source	J_c/A·cm^{-2} (77 K)	Film thickness/μm	Substrates	Year
Ref.[8]	6	~80	Ag/MgO	1991
Ref.[9]	500	On the order of 10	Ag	1992
Ref.[10]	646	35	Ag wire	1995
	420	30		
Ref.[11]	1649	25	Ag wire	1996
	1557	20		
	1233	10		
Ref.[12]	700	30–80	Ag/Al_2O_3	2000
	1458	30–80	Ag wire	2000
Ref.[13]	760	~50	Ag	2002
This work	2399	30	Ag/MgO	2003
This work	3870	25	Ag/YSZ	2003

4. Conclusions

In conclusion, for the purpose of controlling the crystal structure and improving the critical current density in high-T_c superconducting films, we have established a higher growth rate process to grow the YBCO superconducting thick films for YBCO-coated tapes. The well-textured crystal formations are observed both in YBCO/YSZ and YBCO/MgO superconducting thick films obtained by the improved technique. The maximum value of the critical current density of YBCO/YSZ superconducting thick film is 3870 A/cm^2 (77 K).

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