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Superconducting $NdBa_2Cu_3O_{7-\delta}$ Thin Films Grown on Bare $(1\bar{1}02)$ Sapphire by Pulsed Laser Deposition

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Superconducting $NdBa_2Cu_3O_{7-\delta}$ (NBCO) thin films with T_c=89 K have been successfully grown on bare $(1\bar{1}02)$ sapphire substrates by pulsed laser deposition (PLD). The X-ray diffraction results show that the as-grown NBCO films are all c-axis oriented with no observable second phase. The c-axis parameter decreases monotonically with increasing the deposition temperature (T_s), suggesting that the corresponding degradation of T_c for T_s> 790 ^oC might not originate from oxygen deficiency. It is conceived that the film-substrate reaction that occurring at the interface may cause Ba-deficiency and hence enhance Nd-Ba antisite substitutions.

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1. INTRODUCTION

Owing to its high supercoducting transition temperature ($T_c \sim 96$ K), superior magnet-field-dependent critical density (J_c (H)), and very smooth film surface, $NdBa_2Cu_3O_{7-\delta}$(NBCO) has received much research attention very recently [1,2]. For thin film deposition, however, it has been shown that the growth conditions for NBCO are far more restricted than those practiced for depositing YBCO films [3]. For practical applications, especially for microwave devices, sapphire is always substrate of choice for its excellent microwave properties, including low dielectric constant, good mechanical strength and vanishing loss tangent [4]. Thus, it would be an ideal combination to grow superconducting thin films directly on sapphire substrates.

In this paper, we present an attempt towards such effort by depositing NBCO films directly on bare sapphire substrates from a sintered NBCO target using pulsed laser deposition (PLD).

2. Experimental

NBCO films with typical thickness of approximately 350–500 nm were deposited on sapphire ($1\bar{1}02$) single-crystal substrates by conventional on-axis PLD using a KrF excimer laser source with $\lambda = 248$ nm operating at an energy density of 3 J/cm^2. The substrate temperature (T_s) was varied from 750 ^oC to 810 ^oC while keeping the oxygen partial pressure at 0.3 Torr. A sintered target with nominal stoichiometry of Nd:Ba:Cu = 1:2:3 was used. It is noted that the deposition condition used here are somewhat different from those outlined by Cantoni *et al.* [3]. After each deposition, oxygen gas was introduced into the PLD chamber to 1 atm, and was cooled down to room temperature. The film microstructure was studied by X-ray diffraction (XRD), and atomic force microscopy (AFM). The transport properties were measured by standard four-probe method.

3. Results and discussion

Fig. 1 shows typical temperature dependent resistivities for NBCO films deposited at different temperatures. The films all exhibit metallic behavior except that the normal state resistivities are order magnitude larger than those grown on $SrTiO_3$ (100) or $LaALO_3$ (100) substrates. This may be due to the tremendous amount of microstructural defects originated from the large lattice mismatch (>20) between NBCO and sapphire substrate. Nonetheless, the fact that T_c can be as high as 89 K is quite remarkable. Also, the dramatic drop in T_c for T_s> 790^{o}C (inset of Fig. 1) is interesting and demands further discussion. Fig. 2 shows the XRD results of the corresponding NBCO films with T_s ranging from 750 ^{o} C–810 ^{o} C, respectively. A strong c-axis oriented characteristic is evident. There is no observable second phase for all samples. However, if we examine the c-axis lattice parameter as a function of T_s more closely, some interesting features are emerging.

Fig. 3 summarizes the relationships between T_c, T_s and c-axis parameter of NBCO films grown under the different conditions. For comparison , results from NBCO films grown on STO using stoichiometric NBCO and

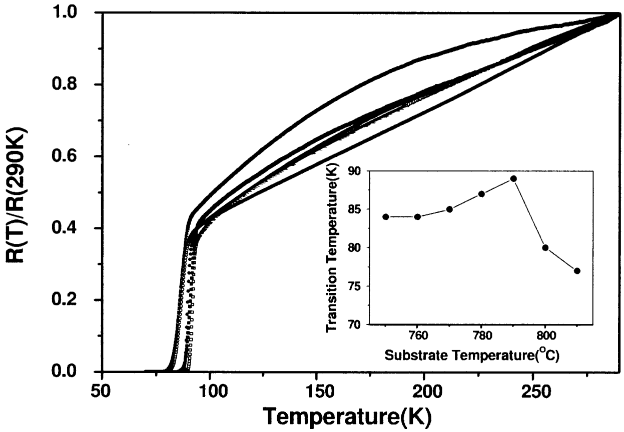

Fig. 1. R-T curves for samples deposited at : T_s = 760 ^{o}C (solid square); T_s = 780 ^{o}C (solid circle); T_s = 790 ^{o}C (open square); T_s = 800 ^{o}C (open circle); and T_s = 810 ^{o}C (solid triangle), respectively. The inset shows T_c vs T_s.

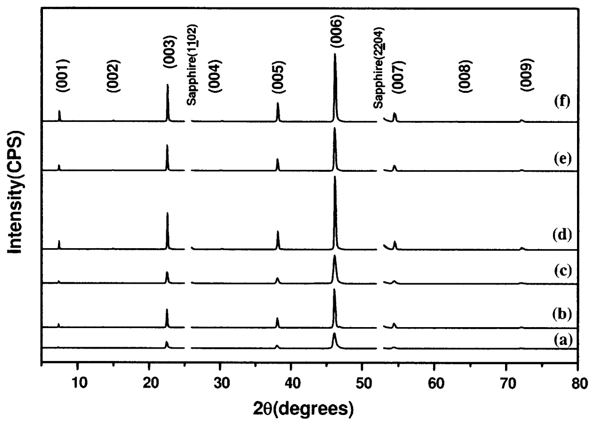

Fig. 2. XRD patterns for NBCO films grown on sapphire substrates at (a) T_s = 750 ^{o}C (b) T_s = 760 ^{o}C (c) T_s = 780 ^{o}C (d) T_s = 790 ^{o}C (e) T_s = 800 ^{o}C and (f) T_s = 810 ^{o}C.

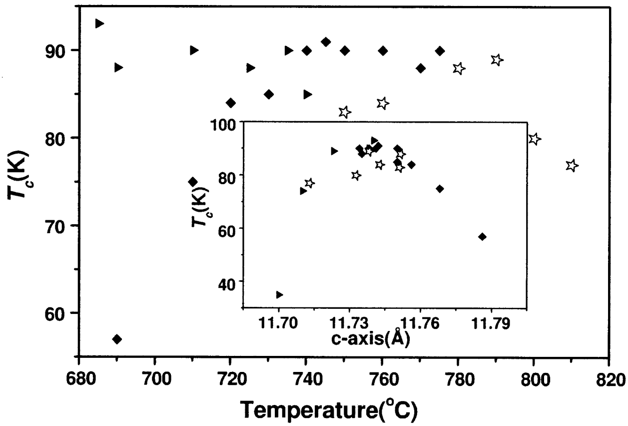

Fig. 3. Relationship between T_c, T_s and the c-axis parameter of NBCO films on sapphire. Data taken from NBCO and $Nd_{1.12}Ba_{1.88}Cu_3O_{7-\delta}$ films on STO[5] are displayed for comparison. The inset shows T_c vs c-axis parameter. Open star : NBCO/sapphire; solid diamond : NBCO/STO; and solid triangle : $Nd_{1.12}Ba_{1.88}Cu_3O_{7-\delta}$/STO

$Nd_{1.12}Ba_{1.88}Cu_3O_{7-\delta}$ targets [5] are also included. It is clear that depending on the target used, the T_c degradation may have resulted from different origins. Since the degradation of T_c in HTSC is always associated with reducing carrier density. For NBCO system, it has been established that both the deficiency of oxygen content and Nd-Ba antisite substitution are the two major mechanisms in reducing available carriers [6,7]. The two, however, are having opposite effect in influencing the c-axis parameter; namely, increasing Nd-Ba substitution would shorten c-axis parameter while oxygen deficiency could lead to c-axis expansion. Thus, it appears that, in the present study, the degradation in T_c occurring at high T_s, might have been a consequence of Nd-Ba substitution. The question is what causes the effect? We believe that, since the c-axis parameter continuously to shorten at higher deposition temperatures, the enhanced interface reaction between NBCO and sapphire to form Ba-Al-O compound may have consumed some Ba ions, leading to an effective increase in Nd content. Thus, in turn, would lead to both T_c and c-axis parameter reductions. The consistent trend seen in the inset of Fig. 3 seems to render strong support to this conjecture.

Indeed, preliminary results using a PBCO buffer layer to block out the interface reaction-induced Ba-deficiency have shown that T_c=91K can be obtained with T_s=800^{o}C [8]. Therefore, it appears that the Nd-Ba substitution is indeed responsible for the degradation of NBCO films grown on sapphire substrate at T_s>790^{o}C.

4. Summary

NBCO films with T_c= 89 K have been successfully deposited on bare sapphire single-crystal substrates by PLD. The correlations between T_c, deposition temperature and c-axis parameter of the films revealed that, at high deposition temperatures, the formation of Ba-Al-O compounds may have effectively reduced Ba concentration and, hence enhanced Nd-Ba substitution, leading to T_c degradation. Indeed, by introducing a PBCO buffer layer, the overall T_c can be improved significantly with no observable degradation even with $T_s \geq 800$ ^{o}C.

5. ACKNOWLEDGMENTS

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