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Microwave properties of $YBa_2Cu_3O_{7-x}$ deposited on MgO substrates

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With pre-annealed treatments, high density of atomic steps were formed on the surface of the MgO substrate. The early-stage microstructure of $YBa_2Cu_3O_{7-x}$ thin films was evolved with a step-flow growth mode by pulsed laser deposition. On the as-polished MgO substrates the Volmer-Weber-type island growth mode was dominant. By means of microstrip line measurement, it was found that the films grown on the pre-annealed substrate not only have a higher critical current densities but also have a lower microwave loss than those of films deposited on as-polished substrate. The distinction existed even when the deposition condition were not optimized.

1. INTRODUCTION

In this report, the effects of microstructure and crystallinity on the microwave properties of the $YBa_2Cu_3O_{7-x}$ (YBCO) films are addressed by using microstrip line resonators. In particular, we have chosen MgO as the substrates owing to its good microwave characteristics and yet large lattice mismatch with YBCO (≈9%) to demonstrate how the surface conditions of the substrates can affect the film microstructure and hence the microwave properties of the films. As has been shown previously, the surface of the MgO substrates can be greatly modified to possess a number of well-aligned atomic-steps when they are annealed with 1atm. oxygen pressure at 1100 °C for 11 hours prior to the pulsed laser deposition [1]. The atomic force microscopy (AFM) studies have shown clear evidence that on the pre-annealed substrates the early-stage microstructure of the films was evolving with a step-flow growth mode whereas on the as-polished MgO substrates a Volmer-Weber-type island growth mode was dominant [1]. In this study, we further demonstrate that, due to the distinct grain morphologies, the YBCO films obtained on the pre-annealed MgO substrates not only have a higher critical current density but also have a lower microwave loss as compared to those of films deposited directly on as-polished substrates. The differences persist even when the deposition conditions were not optimized. However, because of the larger surface roughness of the substrate arising from annealing, the effective zero-temperature penetration depths λ_0 were larger in the former films.

2. EXPERIMENTAL

The YBCO films used in this study were deposited by pulsed laser deposition on both the as-polished and pre-annealed MgO substrates with typical conditions described elsewhere [1]. However, in order to systematically study the effects of microstructure and crystallinity on the microwave properties of the films, we have intentionally changed the substrate temperatures in both cases. Surprisingly, for temperatures in the range of 740-820°C, all the films obtained were apparently with c-axis oriented normal to the film surface. The films were then patterned into microstrip line with dimensions of 0.48mm x 7mm by standard photolithography and wet-etching. After patterning, a 1~2 μm thick of Au layer was deposited on the back side of the substrate to serve as the ground plane. Moreover, in order to avoid the possible oxygen content change-induced degradation, all the samples were annealed at 450°C for 7-8 hours in 1 atm of pure oxygen prior to microwave measurements. The strip lines were then loaded in the HP8510 Network Analyzer™ to measure the temperature dependence of the resonance frequency $f_0(T)$ and to calculate the temperature dependence of unloaded quality factor $Q_0(T)$ and the effective penetration depth $\lambda(T)$[2].

3. RESULTS AND DISCUSSION

The $Q_0^{-1}(T/T_c)$ for several films deposited on both types of substrates with various deposition temperatures are shown in Fig.1. It is evident that, at lower temperatures, the microstrip line resonators made of films deposited on the pre-annealed substrates all have a lower loss (higher $Q_0(T/T_c)$) than those made of films deposited on as-polished ones, even when the substrate temperatures were far from the optimal conditions ($T_s^{optimal} \approx 760$ °C in this case). As mentioned earlier, on the pre-annealed substrates, the step-like surface morphology of the films retains its original all way up to a thickness of 250 nm, leading to a more directionally aligned and larger grain size (85-170 nm) microstructure. While for films grown on the as-polished substrates, the random nucleation and growth mechanism inevitably results in finer and disordered grain structure, especially in the first few layers, as shown in fig.2. However, the surface roughness of both kinds of thin films is almost same, as the thickness is over

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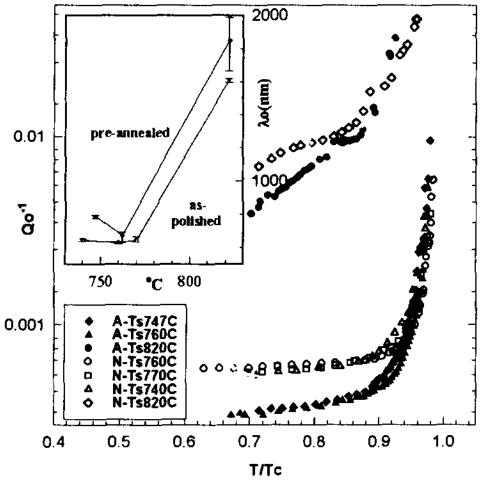

Fig.1 the $Q_0^{-1}(T/T_c)$ of the resonators on both kinds of substrates. The inert show the calculated λ_0. The symbol of A-, and N- represent the pre-annealed and as-polished, respectively

400~500nm. Since the grain boundary scattering of quasiparticles is one of the major causes of microwave loss [3], our results thus are explained plausibly by this scenario. Moreover, it is noted that for the quasi-TEM mode of the microwave propagating along the strip line resonators, the magnetic field and current density are far more concentrated within the first few layers of films in the vicinity of the film-substrate interface[4]. The directionally aligned grains of films grown with a step-flow manner must have provided further advantages in reducing losses due to quasiparticle scattering. It is also interesting that, although the crystallinity of the films should be degraded by high temperature deposition as was reflected to the more severe microwave loss observed for strips made of films deposited at high temperatures (Fig. 1), the effect of grain structure is still retained.

On the other hand, we also consider the important parameter, λ_0, in describing the microwave properties of superconducting films and opposite tendencies were observed. As shown in the inert of Fig. 1, the λ_0's, derived by fitting the temperature dependent resonate frequency $f_0(T)$ with the phenomenological two-fluid model [2], of the strips made of films deposited on pre-annealed substrates were larger in all cases. Since the λ_0 is calculated by taking the whole resonate structure as whole and it is believed to be more sensitive to surface roughness than other structure features. For the pre-annealed substrate, the large surface roughness is essentially coming from the steps formed on the surface during annealing so that the penetration depth of the field may be over estimated.

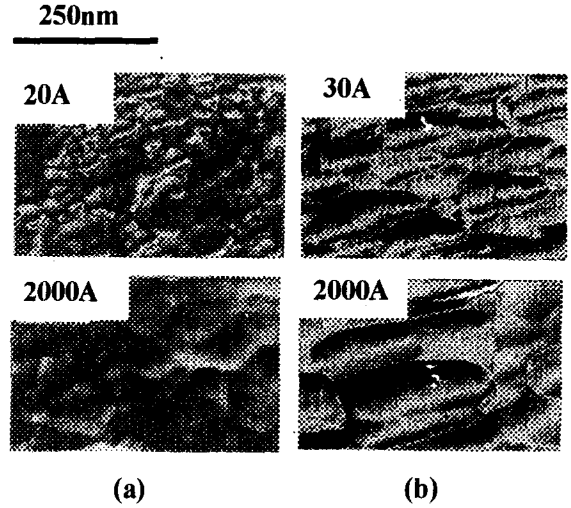

Fig.2. The surface morphologies of the film on MgO substrates revealed by AFM. (a).and (b) are the surfaces of YBCO thin films on the as-polished and pre-annealed substrate, respectively.

4. SUMMARY

By annealing the substrate prior to deposition, the effects of the grain structure in the vicinity of the interface between the MgO substrate and YBCO superconducting thin films can be drastically altered. By comparing the microwave loss, (i.e. the Q-factor), calculated from resonate frequency, a function of temperatures, on the strip lines made of YBCO films deposited on two types of MgO substrates, the effects of film microstructure and crytallinity on both parameters are discussed. This work was supported by the National Science Council of Taiwan, R. O. C., Grants:NSC_85-2112-M-009-035 PH.

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