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Growth and Patterning of Laser Ablated Superconducting $YBa_2Cu_3O_7$ Films on $LaAlO_3$ Substrates

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GROWTH AND PATTERNING OF LASER ABLATED SUPERCONDUCTING $YBa_2Cu_3O_7$, FILMS ON $LaAlO_3$ SUBSTRATES

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ABSTRACT

A high quality superconducting film on a substrate with a low dielectric constant is desired for passive microwave circuit applications. In addition, it is essential that the patterning process does not effect the superconducting properties of the thin films to achieve the highest circuit operating temperatures. We have grown $YBa_2Cu_3O_7$ superconducting films on lanthanum aluminate substrates using a laser ablation technique with resulting maximum transition temperature (T_c) of 90 K. The films were grown on $LaAlO_3$ which was at 775 °C and in 170 mtorr of oxygen and slowly cooled to room temperature in 1 atm of oxygen. These films were then processed using photolithography and a negative photoresist with an etch solution of bromine and ethanol. Results are presented on the effect of the processing on T_c of the film.

I. INTRODUCTION

Laser-ablated, high-temperature superconducting (HTS) $YBa_2Cu_3O_7$ films have been made on many substrates including $SrTiO_3$, MgO, $LaGaO_3$, and ZrO_2.[1-7] These substrates were used because they either had very small interaction with the HTS films during growth or annealing or because the substrates with HTS films had potential electronic applications. In this paper, we report on the growth and patterning of thin $YBa_2Cu_3O_7$ films on $LaAlO_3$ for microwave applications. $LaAlO_3$ was chosen as a substrate because of its relatively low dielectric constant of 22[8] and because of it moderate loss tangent of $8x10^{-5}$ at 10 GHz[9].

Lines varying in width from 10 to 20 μm were patterned using photolithography and wet etching techniques. To determine if the etching or lithography process had influenced the transition temperature of the films. A ring resonator circuit operating at 35 GHz was also fabricated, since the resonator allows the determination of loss and dispersive properties of microstrip transmission line. From the measurement of the quality factor "Q" of a resonator circuit one can determine the microwave losses of the HTS films as compared with those of gold on the same substrates.

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II. Film Growth

The laser ablation technique used to grow the films on substrates of $LaAlO_3$ is similar to the techniques reported in the literature.[1-7] The details of the geometry of the laser ablation is shown in Fig. 1. The substrates (15 by 15 by 0.25 mm) with orientation (001) were mounted onto a stainless steel plate with a diameter of 63 mm. The plate was heated from the backside using a resistive heater made from Kanthal A-1 wire (made by Kanthal, Inc.). The temperature was measured with a type K thermocouple which was welded to the plate. The thermocouple was 2 mm away from the sample. The sample chamber was evacuated to $3x10^{-7}$ torr, or lower, using a liquid nitrogen cold trapped diffusion pump before the sample was warmed up to 500 °C. A continuous flow of oxygen (120 sccm) was then introduced into the chamber, and the sample heated to 775 °C. During deposition the chamber pressure was 170 mtorr; the laser wavelength was 248 nm; the energy density was 1.5 (J/cm^2)/pulse; the pulse rate was 4 pps; and the distance between the target and the sample was 8 cm. The laser beam was rastered up and down 1 cm over the target using an external lens on a translator. The angle between the laser beam and the normal to the target was 45°. The target used was a sintered 25-mm-diameter pellet of $YBa_2Cu_3O_{7-x}$. After deposition the oxygen pressure was raised to 1 atm, and the temperature was lowered to 450 °C at a rate of 2 °C/min. The temperature was held at 450° C for 2 hr before it was lowered to 250 °C at a rate of 2 °C/min. The heater power was then turned off, and the sample was allowed to cool to 40 °C or less before it was removed the chamber.

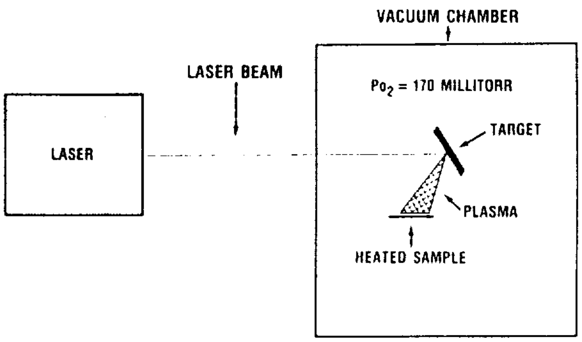

Figure 1. - Schematic of the laser ablation experiment.

The thickness of the HTS films on $LaAlO_3$ was estimated by measuring the thickness of a film grown on quartz plate that was shadow masked. The quartz plate had been placed 1 mm below the bottom of the $LaAlO_3$ on the substrate holder such that the sweep of the plasma plumb was along the line connecting the centers of the quartz and the $LaAlO_3$.

The best film had a T_c of 89.8 K immediately after deposition as determined by a standard four point resistance measurement. Its resistance versus temperature behavior is shown in Fig.2. From the intercept of the extrapolated resistance at 0 K and from the resistance above T_c, one can see that the film is c-axis aligned. This is confirmed by only having the (001) peaks in the x-ray diffraction data (Fig. 3). The surface morphology of the HTS on $LaAlO_3$ is shown in Fig. 4. The surface is very smooth with some small structure. We do not observe large numbers of HTS particulates due to the laser ablation process.

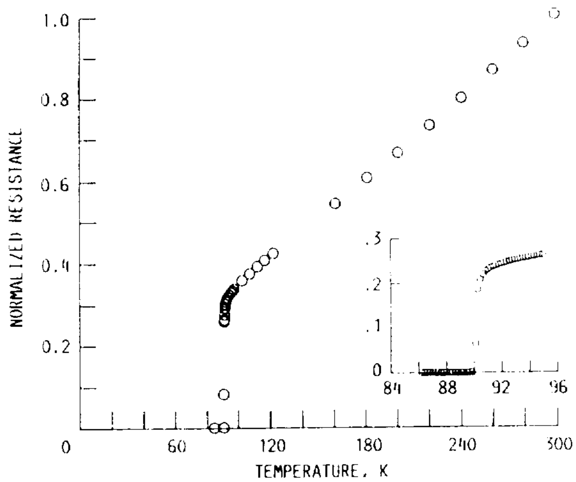

Figure 2. - Normalized resistance of laser ablated $YBa_2Cu_3O_x$ film on $LaAlO_3$.

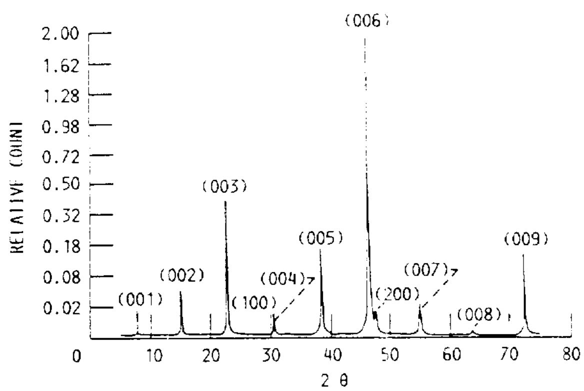

Figure 3. - X-ray diffraction pattern of laser ablated $YBa_2Cu_3O_x$ film on $LaAlO_3$.

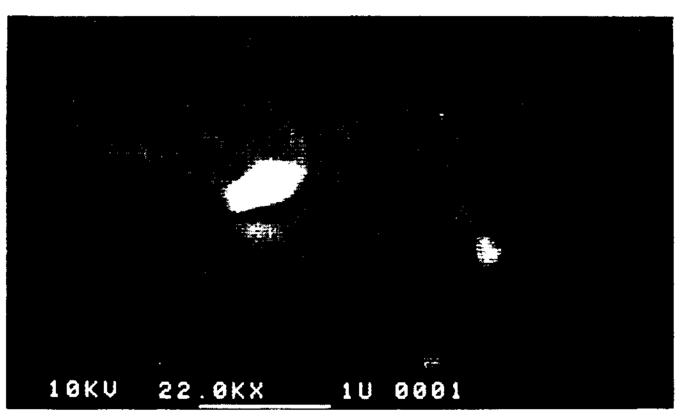

Figure 4. - Scanning electron micrograph of laser ablated $YBa_2Cu_3O_x$ Film on $LaAlO_3$.

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PATTERNING

Films on $LaAlO_3$ and $SrTiO_3$ were patterned using photolithography and wet etching. The negative photoresist (752), its developer (802), and the associated rinse (n-butyl acetate) used were obtained from KTI. The photoresist strippers used were Losalin IV (from E.C. Merke), acetone, toluene, and ethanol. Each step of the process was checked to see if it had an effect on the T_c of the HTS films. The results of the different processing steps on T_c are shown in table I. The full process of patterning the HTS films was to spin on the negative photoresist to a thickness of 2 μm, followed by a soft bake at 90° C for 1 hr, and then to expose the photoresist. After developing the photoresist, the film was etched for 500 s in 1 percent molar of bromine in ethanol. After etching, the films were rinsed in ethanol and the photoresist was removed with the Losalin IV photoresist stripper which was at 70 °C. We did not observed any drop in the T_c of the HTS films.

Table I Effect of Photolithography Process on T_c of $YBa_2Cu_3O_x$ Films

Exposure to negative photoresist	None
Soft baking of photoresistat 90 °C for 1 hr)	None
Exposure to photoresist developer and rinse	None
Exposure to different stripping solvents after patterning[a]:	
Boiling ascetone (58 °C) for 10 min	None
Boiling ethanol (78 °C) for 10 min	None
Boiling toluene (111 °C) for 10 min	None
Losalin IV (760 °C) for 5 min	None

[a]Only boiling ethanol and Losalin IV sucessfully removed exposed phoresist.

The films used to determine the effect of the various fabrication steps had transition temperatures between 77 and 85 K. Fig. 5 shows the effect of exposing the film directly to the photoresist stripper Losalin IV at 70° C. No change in T_c occurred, but the slope of the resistance versus temperature curve did change. Fig. 6 shows the T_c of the film on $LaAlO_3$ before patterning and after it was patterned into a ring resonator, that had operated at 33 GHz, and after it had

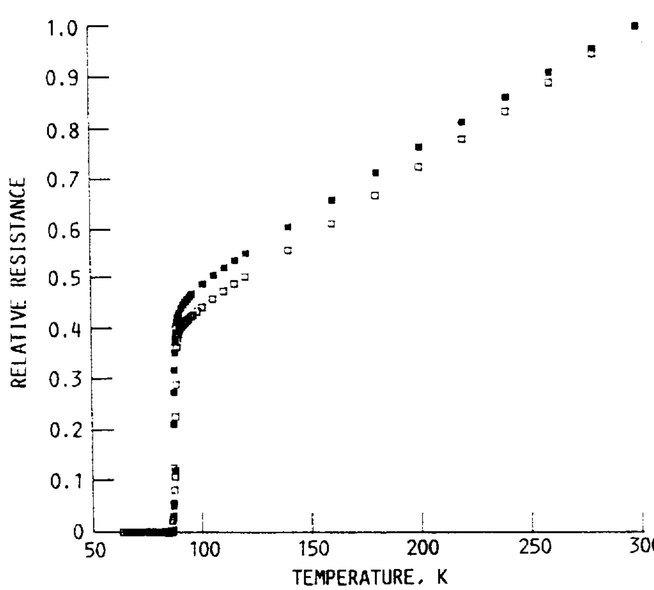

Figure 5. - Normalized resistance of a laser ablated $YBa_2Cu_3O_x$ film on $SrTiO_3$. The film □ is before processing while the film ■ is after exposure to negative photoresist.

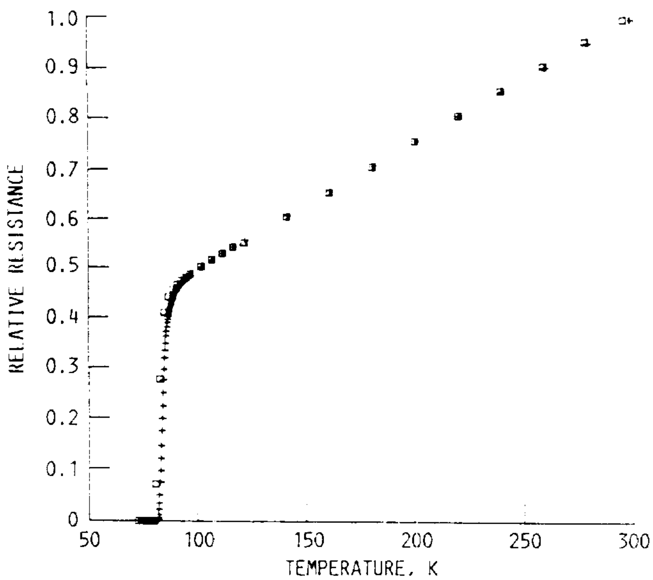

Figure 6. - Comparison of normalized resistance of a laser ablated $YBa_2Cu_3O_x$ film on $LaAlO_3$ before processing □ and after being fabricated into a 35-GHz ring resonator +.

silver contacts evaporated onto it and annealed at 500° C for 1 hr. There is no apparent difference in the T_c or the resistance versus temperature behavior between the film before and after processing.

To test the laser ablation technique's ability to produce uniform film thickness and the variation of T_c across the film, Hall bars with silver contacts were fabricated (Fig. 7). The width of the bar is 10 μm. The film thickness is not very uniform over the 5- by 10-mm area. The time needed to etch the film until the substrate was exposed varied by a factor of 2 from one edge to the other edge of the substrate. However, the T_c did not vary from region to region (table II).

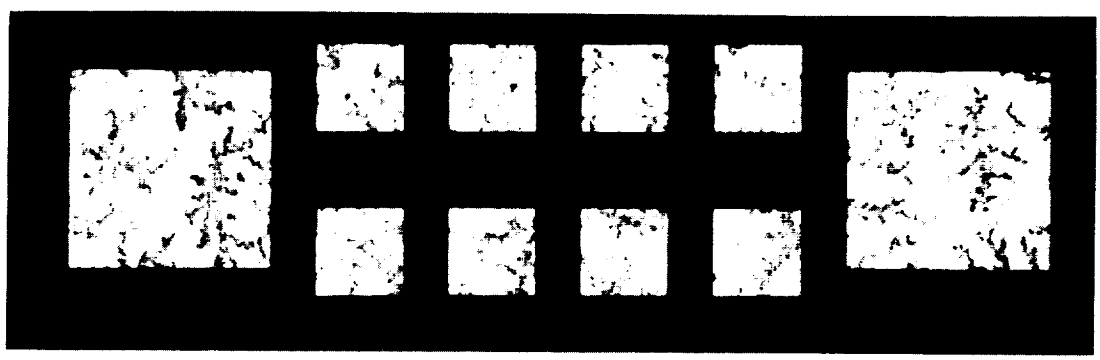

Figure 7. - Finished Hall bar of $YBa_2Cu_3O_x$ film on $SrTiO_3$ substrate.

Table II Variation of on $SrTiO_3$ as Measured With Patterned Hall Bars

Before patterning	70.6 K
10- μm lines after patterning	71.0, 71.5, 72.5 K
20- μm lines after patterning	75.3, 75.5, 76.5 K

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Conclusions

Laser-ablated, high-temperature superconducting films on $LaAlO_3$ and $SrTiO_3$ have been grown. The best films had a T_c of 90 K and have their c-axis aligned to the substrate. There is no variation of T_c across the films, but there is a variation of film thickness. These films have been patterned with negative photoresist and a bromine/ethanol etch. There is no detectable degradation of T_c by any step of the fabrication process even though the films were heated to 122° C in toulene.

This fabrication process should be able to be used to make most of the passive and one layer structures without any degradation of the transition temperature.

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