Parameter Study of In-Situ Grown Superconducting YBaCuO Thin Films Prepared by Laser Ablation

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A parameter study has been made of YBaCuO thin films prepared by laser ablation. The films were deposited on SrTiO₃, MgO, and Si with ZrO₂ buffer layer at substrate temperatures between 600°C - 800°C. With optimization of different parameters like substrate temperature, pulse frequency, target-substrate distance, and oxygen pressure, zero resistivity was derived for the in-situ grown films on SrTiO₃ at 89.5 K, on MgO at 84.6 K, and on Si (ZrO₂) at 83.5 K.

1. Laser Ablation, Experimental details

Several techniques have been used for manufacturing high T_c thin films. Especially, in-situ preparation leads to high-quality films, with c-axis orientation and high critical current densities¹.

In this paper we describe the results of the fabrication of YBa₂Cu₃O_{7-δ} films by means of laser ablation on substrates of SrTiO₃ (100), MgO (100), and Si (111) with ZrO₂.

The experiments were carried out with an excimer laser in the XeCl mode, including an unstable resonator providing a better focus of the laser bundle. The target, mounted on a rotatable table, is a pellet of YBa₂Cu₃O_{7-δ} prepared with the citrate/pyrolysis method² and has a diameter of 16 mm. The spot size of the laser is 2 mm². The energy density was kept at about 2 J/cm². The substrate is attached to a stainless steel plate heated by a NiCr wire and substrate temperatures up to about 800°C, measured by a pyrometer, can be obtained. The distance between target and substrate is adjustable. In the experiments the substrate temperature, the pulse frequency and the target-substrate distance were used as variable parameters. The oxygen pressure during the ablation was about 0.3 mbar and after deposition the sample was cooled down to room temperature in about 1 hour at an oxygen pressure of 1 bar. These in-situ prepared films are superconducting and no anneal procedure is necessary.

2. Results

In order to obtain YBaCuO thin films with the correct stoichiometry, the substrate has to be put on the border region of the plasma. This plasma is influenced by the density of the target, the energy density of the laser beam, and the oxygen pressure in the chamber. With an energy density of 2 J/cm² and an oxygen pressure of 0.3 mbar, good results were obtained with a target to substrate distance of 25 to 35 mm. With these adjustments the deposition rate is typically 1 Å/shot.

FIGURE 1

The influence of the substrate temperature on T_{zero} for SrTiO₃, MgO, and Si + ZrO₂.

Resistivity measurements of YBaCuO films on SrTiO₃, MgO, and Si with ZrO₂ buffer layer show the strong influence of the substrate temperature T_{sub}. All

films have an onset temperature T_{onset} of about 90 K and a zero resistivity temperature T_{zero} strongly dependent on the substrate material and its deposition temperature. In fig. 1 the relation between T_{zero} and T_{subs} is given for a pulse frequency of 2 Hz and a deposition time of 30 min. The typical film thickness is about 300 nm and the films are, even in the Si-ZrO₂ case, c-axis oriented at sufficiently high substrate temperatures.

FIGURE 2

Resistance versus temperature for YBaCuO films on SrTiO₃, MgO and Si+ZrO₂. The T_{zero} values are respectively 89.5, 84.6 and 83.5 K.

Fig. 2 shows the resistance versus temperature for the three different substrates with optimal substrate temperatures. All resistance measurements show a linear behaviour in the temperature range from 300 K to 150 K, given by $R = R_0 + \alpha T$. In fig. 3 the ratio of the residual resistance R_0 and the resistance R_{300} at 300 K versus ($T_{\text{onset}} - T_{\text{zero}}$) is given. We have found an almost linear behaviour, independent of the substrate material.

Critical current measurements have been carried out on the YBaCuO film on SrTiO₃ with a 25 μm bridge of 100 μm length. At 77 K we found a critical current density of $2 \times 10^6 \text{ A/cm}^2$. Critical current measurements on the Si films are in progress.

3. Discussion and conclusions

Laser ablation is a promising technique for in-situ preparation of high-quality high T_c films on various

substrates. Besides our results on (100) SrTiO₃ and (100) MgO, we also have favourable results on Si with 120 nm buffer layer of ZrO₂ with this method.

FIGURE 3

The relation between the superconducting transition width $T_{\text{onset}} - T_{\text{zero}}$ and the resistance ratio R_0/R_{300} .

The substrate temperature is an important parameter to obtain good properties. Especially, in the case of the Si with ZrO₂ buffer layer a strong dependency is found, with an optimum substrate temperature of 725 °C. For MgO this optimum is about 740 °C whereas for SrTiO₃ the condition is less critical and high T_{zero} values can be found in a wide range above 720 °C.

It is known from literature³ that the resistivity of high-quality YBa₂Cu₃O_{7- δ} films behaves directly proportional to the temperature with almost zero residual value when conduction takes place in the ab-plane. As our films are strongly c-axis oriented we may expect this R vs T behaviour and for this reason we believe that the ratio R_0/R_{300} is a proper measure for the film quality. Although the first results on Si are very promising, a further study about the influence of the pulse frequency is necessary to derive the best attainable film quality.

4. References

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