MACROSCOPIC PERSISTENT CURRENTS IN LASER ABLATED $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ FILMS

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ABSTRACT

Thin films of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ have been produced in situ by laser ablation. As the condensation of the superconducting film is done onto hot substrates (600 - 780°C) at high oxygen pressures (~ 1 mbar), this technique does not require any special postannealing step. Thus the total process time amounts to less than 10 min. Films were found to be polycrystalline with the c-axis preferentially oriented normal to the substrate plane on single crystalline (001) SrTiO_3 and (random) ZrO_2 , as measured by ion channeling ($\chi_{\min} = 5.5\%$ on SrTiO_3), x-ray scattering and TEM. Complete superconducting transitions above 90 K with transition widths of about 1 K have been observed even on YSZ substrates. Critical current densities, j_c (77 K), of more than 2×10^6 A/cm² could be obtained on SrTiO_3 -substrates. The high quality of the thin films over large areas was demonstrated by the measurement of persistent superconducting current densities at 77 K in the order of 10^3 A/cm² in a 1.5 mm broad ring of 9 mm diameter. No dissipation of this persistent current could be observed during one hour. Measurements of the same film after 8 months in normal air showed a 40 % decrease of j_c and a stronger decrease of j_c with an external magnetic field, suggesting that in the meantime the macroscopic ring current density is dominated by intergranular weak links.

EXPERIMENTAL

Thin film preparation by laser ablation

The commonly used set-up for laser ablation [1] as described earlier [2] was modified in order to achieve homogenous films growth over a larger area. As can be seen from Fig.1 we took advantage of the fact that the laser causes ablation perpendicular to the surface of the target. Thus a cylindrical, rotating target is used. The curved target surface causes ablation into a wider angle. The rectangular laser beam is focussed by a cylindrical lens into a line-shaped area parallel to the axes of the cylinder. Thus the broadness of the beam assures homogenous ablation also in the other lateral dimension of the substrate. The substrates themselves are lying on a heating stage which is located in the middle of the homogenous ablation cloud. The oven can be heated up to 800°C. The surrounding oxygen pressure amounts to several mbar.

Fig. 1: Experimental set-up for laser ablation.

Fig. 2: Sketch of the sample with the vibrating coil geometry.

Cylindrical pellets ($\phi = 15$ mm) made from stoichiometric sintered $\text{YBa}_2\text{Cu}_3\text{O}_7$ were used as targets. In some experiments we employed targets prepared by plasma spraying. The resulting films did not yield as good results as from sintered and more dense targets. In most cases the thin films were condensed onto (001) SrTiO_3 or crystalline ZrO_2 . The pulsed excimer laser used for the ablation has the following parameters: wavelength 248 nm, pulse duration ≈ 40 ns, repetition rate 2 Hz, energy density 2 Joule/cm².

Persistent current measurements

Persistent currents in this sample were determined via the spatial distribution of their magnetic field, as described earlier [3]. The detector was a small, rectangular pick-up coil (length $l = 10$ mm, width $w = 1.5$ mm, thickness = 0.8 mm), which was vibrated by a piezoelectric bimorph in such a mode that mainly the end, A, facing the sample was in motion and the opposite side was nearly at rest (see Fig. 2). In this way the coil acts as a local detector, registering essentially only the magnetic field perpendicular to the sample plane at position A.

For the persistent current measurements a film of 450 nm thickness was evaporated onto a 10×10 mm² substrate of (001) SrTiO_3 . $T_C(R=0)$ was at 88 K, a typical value for such a thick film. Then laser etching removed this film completely in all areas which were not covered by a ring mask resulting in the desired superconducting ring.

RESULTS AND DISCUSSION

In our opinion the preparation of high quality superconducting films requires in-situ processing at elevated substrate temperatures and high O_2 partial pressure in the vacuum chamber. Our best results were obtained at substrate surface temperatures of about 700°C (measured by a thermo-couple glued to the top of the substrate surface) and a base pressure of 1 mbar O_2 . Films with $T_C(R=0) \sim 90$ K, $j_c(77 \text{ K}) > 2 \times 10^6$ A/cm² and thickness of about 200 nm can be obtained within 10 minutes including heating, ventilation and unmounting.

Composition was always found to be within 10 % of the nominal one by RBS-measurements. Good c-axis preferential orientation normal to the substrate plane could be obtained on single crystalline (001) SrTiO_3 and (random) ZrO_2 with optimum temperatures during deposition. Thus for films on SrTiO_3 minimum yield values as low as 5.5% could be measured.

The overall quality of the superconducting films over a large area was checked by the persistent current measurement. A crucial question is whether the persistent currents truly do follow a closed path around the ring or whether they are localized to certain portions of the film. The spatial distribution of the magnetic field of a ring-shaped sample allows to distinguish, unequivocally, between these possibilities [4]. The results prove that the measured field distribution is the expected one for a macroscopic ring current. These persistent currents exist in the textured films at 77 K under different conditions for field-cooled (fc) and zero-field-cooled (zfc) samples. In all cases the following is observed:

- The value obtained for the critical current density of this macroscopic current is $0.9 \times 10^5 \text{ A/cm}^2$.
- The macroscopic ring current does not decay over time periods on the order of hours.

Fig. 3a (open circles) shows the shielding current, I_{shield} , which is induced in the zfc ring when an external field B_{ext} is applied. In small fields a linear relation between I_{shield} and B_{ext} is observed. Saturation occurs at 0.65 A corresponding to the critical current density. This critical persistent current is not affected by the presence of the external magnetic field investigated here ($\leq 50 \text{ G}$, a limit given by the detector's decreasing signal to noise ratio with increasing field). This behavior has changed after

Fig. 3a: The shielding current I_{shield} in a zfc ring at 77 K as a function of the applied external field.

b: The ring current at 77 K and zero external field, plotted vs. B_{ext} to which the sample had been exposed before the measurement. (○ 3/89, ● 11/89).

the sample was stored for 8 months in normal laboratory air (closed circles). The critical current density decreased by about 40 % to 0.35 A, decreased with increasing field and vanished at 16.5 G.

Fig. 3b shows the current in the zfc ring in zero external field after the ring had been exposed briefly to B_{ext} . Thus a flux was trapped in the ring if B_{ext} had exceeded a critical value. This ring current shows a similar field dependence as in Fig. 3a.

Whereas the initial macroscopic current density (about 2 weeks after preparation) does not depend on the presence of $B_{\text{ext}} \leq 50$ G, it decreases with increasing B_{ext} (≤ 16 G) in the aged film (more than 8 months after preparation) like in polycrystalline bulk samples. Here a field of some 10 G is known to destroy the superconducting contacts between the grains [4]. Our method allows the spatially resolved measurement of the magnetic field in different regions of the ring. From these measurements we believe that only one region of weak links occurred in the film which is responsible for the diminished and field dependent critical current values.

These spatially resolved measurements yielded another interesting result. Fig. 4 shows the magnetic field distribution across the center of a homogenous square film (not a ring) on ZrO_2 ($10 \times 10 \text{ mm}^2$) after the ring had been exposed to 1.8 G. A pronounced periodic structure of the trapped magnetic flux is observed. The positions of the different peaks depend on the magnitude of the external field. An explanation for this behavior is still lacking.

Fig. 4: Pick-up signal of the local detector (Fig. 2) versus position across an YBCO film on ZrO_2 ($10 \times 10 \text{ mm}^2$).

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