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Reversible Laser Patterning of $YBa_2Cu_3O_{7-\delta}$ Microbridges

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Thin films of $YBa_2Cu_3O_{7-\delta}$ on MgO have been patterned using a laser writing technique based on the temperature increase in the focus of a laser beam. The corresponding local increase of the oxygen diffusion velocity can be employed to write reversibly deoxygenated (semiconducting) and reoxygenated (superconducting) patterns, if nitrogen or oxygen, respectively, is chosen as ambient atmosphere. The fully planar microbridges produced in this way have been characterized by electronic transport measurements, scanning probe microscopy and magnetooptics. The processed material exhibits the same superconducting properties as the virgin films.

1. INTRODUCTION

The technique we used for fabricating a microbridge is based on the observation that the electrical properties of $YBa_2Cu_3O_{7-\delta}$ are very sensitive to its oxygen content. In the orthorhombic phase (i.e. $0 < \delta < 0.6$) $YBa_2Cu_3O_{7-\delta}$ behaves like a metallic conductor concerning the electronic transport properties, and below 92 K it becomes superconducting. The tetragonal phase of $YBa_2Cu_3O_{7-\delta}$ (i.e. $0.6 < \delta < 1$) behaves like a semiconductor. The oxygen content can easily be changed by focussed laser heating (Ar-ion cw laser, $\lambda = 488\,\text{nm}$) of the material, thereby causing locally an increase of oxygen diffusion velocity in the YBCO film [1]. The direction of the oxygen diffusion (i.e. into or out of the film) may be controlled by the application of either a reducing or oxidizing atmosphere. In this way oxygen rich (superconducting) regions or depleted (semiconducting) ones can be patterned into the film. The process is planar, noninvasive, reversible, does not require a patterning mask, and does not contaminate the surface of the patterned film.

2. RESULTS

The c-axis oriented, epitaxial $YBa_2Cu_3O_7$ films (thickness ≈ 200 nm) have typical onset transition temperatures around 87 K and a critical current density j_c of about $1.5 \times 10^6\,\text{A/cm}^2$ at 77 K. They were prepared by reactive evaporation onto (100) MgO substrates [2]. The microbridge was patterned in two steps at ambient temperature. The first step was carried out in flowing nitrogen (1 atm). A 140 μm wide and 1 mm long deoxygenated line was written by scanning the focussed gaussian laser beam (full width $w \approx 160\,\mu\text{m}$ at intensity $I/I_0 = 1/e$) across the film surface (laser power ≈ 4.5 W) dividing a stripe (1 mm × 1 cm) in two halves. Each half was electrically contacted with two Ag pads for four-point dc resistance measurements.

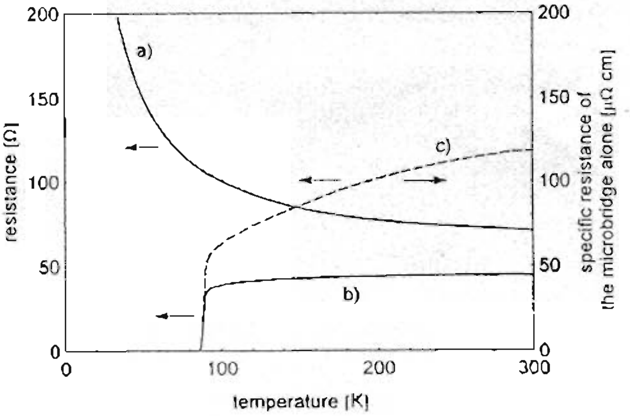

Fig. 1: The resistance vs temperature curve for different situations. a) semiconducting line. b) semiconducting line shunted by a reoxygenated superconducting bridge. c) curve b) with the semiconducting contributions substracted.

Curve a) in Fig. 1 shows a resistance versus temperature curve of a line written by scanning the laser beam with a velocity of 0.8 μm/s across the film surface. The increasing resistance with decreasing temperature points towards a value $\delta > 0.6$ in the written line. By choosing faster scan velocities of the laser beam it was possible to write deoxygenated but still superconducting lines with a T_c that was shifted to lower temperature.

In a second step, in which pure oxygen was passed through the cell (1 atm), a superconducting oxygen-rich $14\,\mu$m wide microbridge was patterned by scanning the laser beam, now focussed to a 1/e-width of $16\,\mu$m, perpendicular to the semiconducting line. In this case a scanning velocity $0.08\,\mu$m/s and a laser power 0.42 W led to good results.

The resistance versus temperature data for the semiconducting line shunted by a superconducting microbridge is plotted in Fig. 1 curve b). Curve c) shows the calculated resistance of the superconducting microbridge alone without the contribution of the semiconducting line.

The laser-written microbridge exhibited a superconducting transition ΔT_c about 3 K wide (10-90%) with T_{c0} at 86 K, and a critical current density j_c of about $1.3 \times 10^6\,\mathrm{A/cm^2}$ at 77 K. For the I_c measurements, we used a $1\,\mu$V criterion. The T_{c0} of the microbridge stored at room temperature and air did not change over a period of at least 6 weeks after patterning.

The contrast in the optical reflection micrograph (Fig. 2) between the deoxygenated parts of the film and the oxygenated ones is caused by a decreasing absorption coefficient in the visible part of the spectrum when $YBa_2Cu_3O_{7-\delta}$ is losing oxygen [3].

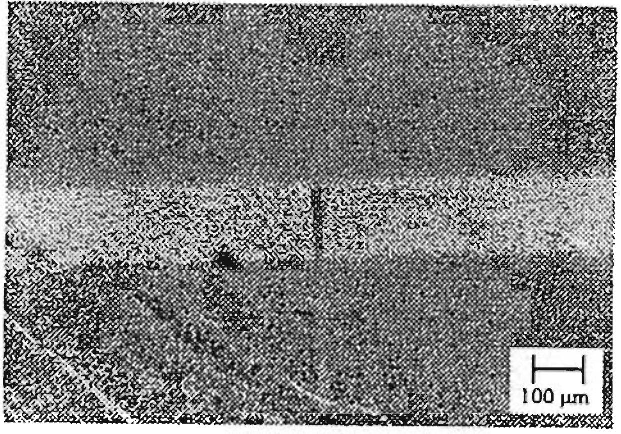

Fig. 2: Optical reflection micrograph of the $YBa_2Cu_3O_{7-\delta}$ film after patterning the microbridge (centre of the picture).

By contrast, scanning electron microscopy (SEM) images showed no difference between oxygenated and deoxygenated lines. The oxygen content dependence of screening an applied magnetic field could be visualised by magnetooptics. Recent investigations of the laser patterned structures by means of a surface acoustic near field microscope (SNAM) demonstrate a significant increase of the work function at the deoxygenated parts of the YBCO film surface [4].

3. DISCUSSION

The oxygen diffusion under our specific experimental conditions can be estimated by considering the film thickness and the time during which the YBCO film surface has to be heated to reach equilibrium, i. e. to become semiconducting or metallic, respectively.

By using $\langle x^2 \rangle = 2 \cdot D \cdot t$ and setting $\sqrt{\langle x^2 \rangle}$ equal to the film thickness of 200 nm and t equal to the heating time $t \approx 200\,\mathrm{s}$ of a certain spot on the film surface a diffusion coefficient $D \approx 1 \times 10^{-12}\,\mathrm{cm^2/sec}$ was estimated [5]. This value lies between the values determined by Krauns et al. and Yamamoto et al. [6] for oxygenating the film at a temperature $T \approx 500°\mathrm{C}$. Apart from different laser energy densities and thermal conductivities of the film substrates also the surface microstructure of the YBCO film should have a strong influence on appropriate scan velocities.

4. CONCLUSIONS

We have demonstrated that the laser annealing technique is suitable for patterning microbridges by just changing the ambient atmosphere from nitrogen to oxygen and using the reversibility of the process. Compared to conventional patterning techniques we see the major advantage of the used technique in its reversible properties.

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