Selective Epitaxial Growth of YBCO by Metal Definition Masks

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Introduction

The superconducting properties of thin films of $YBa_2Cu_3O_{7-\delta}$ (YBCO) are very sensitive to most patterning techniques used. Oxygen outdiffusion is often observed when the sample is heated during (reactive) ion etching, while during wet chemical etching YBCO is brought into contact with chemical substances. Therefore, a patterning technique like Selective Epitaxial Growth (SEG), where no post-deposition patterning is necessary, can be an interesting alternative, especially for structures in the sub-micron range.

In most cases, selective growth of YBCO is accomplished by diffusion of Si into the YBCO-film (1). The minimal dimensions of structures obtainable by this method are limited by the lateral diffusion of the silicon atoms. In our experiments much less-diffusive mask materials were sought, thus trying to obtain SEG not based on diffusion but on either lattice mismatch or on an amorphous layer. This creates the possibility to use very thin buffer layers resulting in smoother films. The electrical, physical and crystallographic properties of YBCO films selectively grown on titanium and tungsten layers have been studied and are presented in this contribution.

Experimental procedure

Metal layers, with a thickness of about 10 nm, have been patterned on YSZ(100) substrates using a conventional lift-off technique. Next, a 80 nm thick layer of YBCO was deposited on the entire substrate using either Pulsed Laser Deposition (PLD) (2) or RF-magnetron sputtering (3). As a final step gold contacts were deposited. The material used (Ti or W) has a relatively high melting point (respectively 1998 K and 3650 K) and is expected to be relatively stable at temperatures of 700-800°C. Due to the oxygen atmosphere in which the deposition of the YBCO-film is done, the layers are at least partially oxidized.

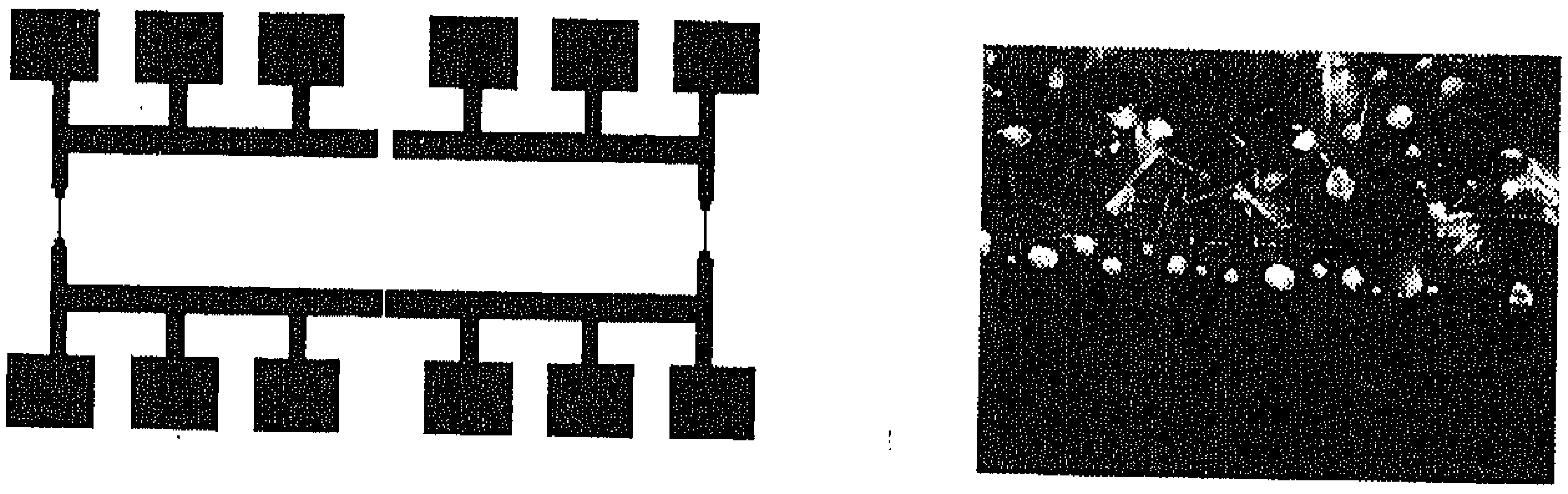

Fig. 1:a) The test structure used. On the left and the right two micro-bridges are present. On the top and the bottom two barriers are created. The squares are used as I and V contacts. b) SEM picture of the border area.

The mask pattern used is shown in figure 1a. Six of such structures could be placed onto one substrate. The structure consists of two micro-bridges for measuring the superconducting properties of the film (T_c and J_c) and two barriers (small non-superconducting parts) for measuring the insulating properties of the film. The electrical measurements were carried out using the standard four probe technique. The dimensions of these structures were chosen to be

10, 5 and 2 μm by 100 μm for the bridges. The barriers have the same sizes, but the width and the length are interchanged.

Several techniques were used for determining the mechanism that is responsible for destroying the superconducting properties. First, Auger analysis was carried out for diffusion studies and compositional differences. Second, X-Ray Diffraction studies were performed to study the crystallographic properties of the film. Furthermore, the formation of the metal-oxydes during the heat-up of the substrate and the inlet of oxygen, just before deposition of the YBCO film, was examined.

Results

After deposition of the YBCO, the superconducting and non-superconducting part could easily be distinguished. The first is dark brown to black, while the latter is white-grey or colorless. Scanning Electron Microscopy showed a large density of grains on the surface of the non-superconducting parts, see figure 1b.

Figure 2 shows the resistance versus temperature and critical current at 77K of a Ti patterned YBCO bridge. The width is 5 μm and the thickness of the rf-magnetron sputtered film is 80nm. The bridge has a $T_{c,0}$=89 K and a critical current density $J_c=1.3\times10^6$ A/cm². The normal resistances of all bridges showed, at T=300K, quite a good scaling behavior: respectively 850 Ω, 1.6 kΩ and 4 kΩ for the 10, 5 and 2 micron bridge.

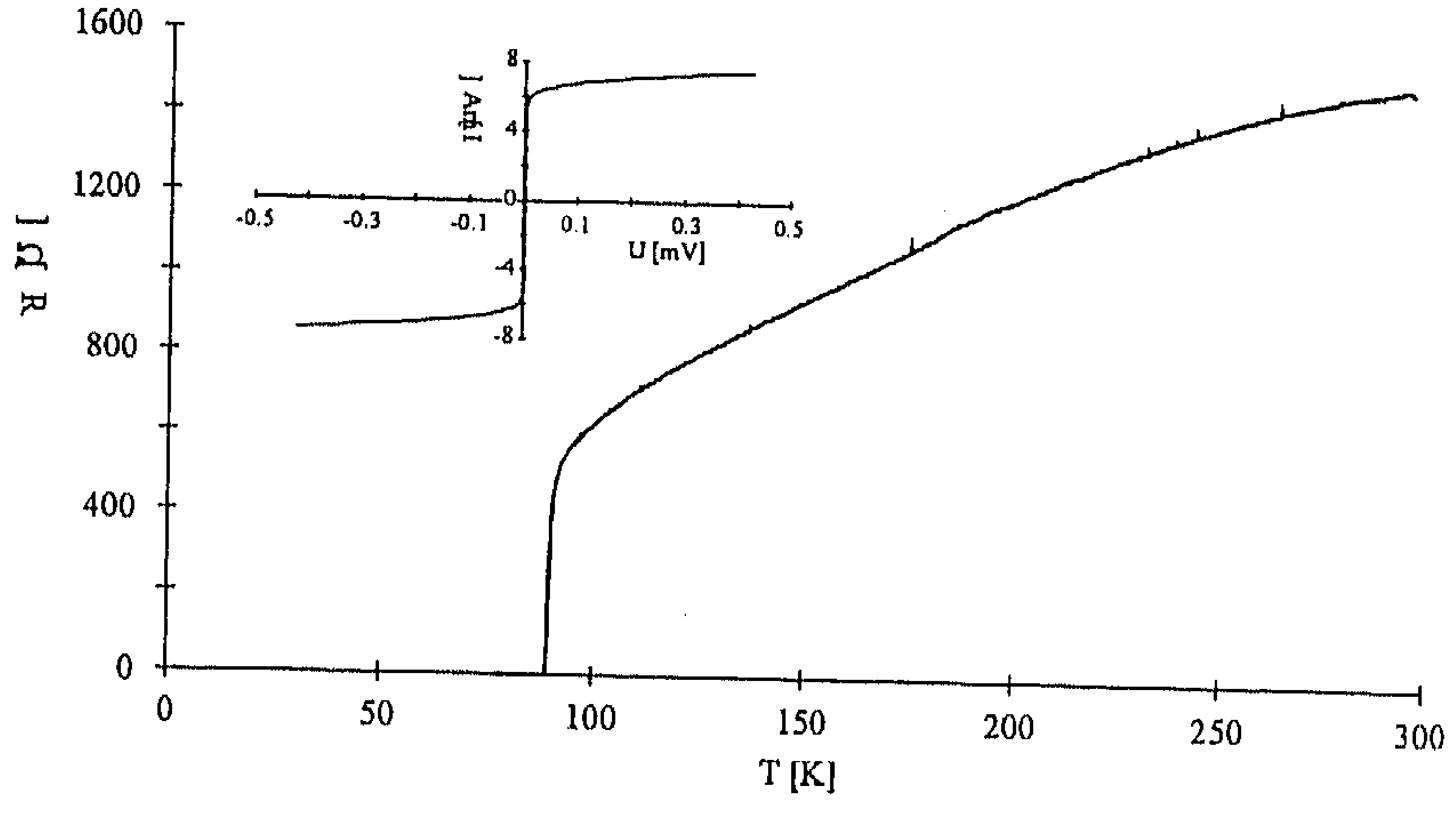

Fig. 2: R versus T and I versus V for a 5μm by 100μm bridge. The film is 80 nm thick and sputtered on a Ti mask.

Besides these bridges, also the barriers (100 μm by 10 μm and 5 μm) were measured. Both barriers indicate a semi-conducting behavior. Figure 3 shows the resistance versus temperature of the 5 μm by 100 μm barrier with R=150Ω at 300K, increasing to 4 kΩ at 77K. At T=89K a small transition can be observed, caused by the superconducting paths leading to the barrier. Also the barrier resistances scaled with its dimensions. In both cases, at T=77 K, a specific resistance of about 0.6 Ωcm was obtained.

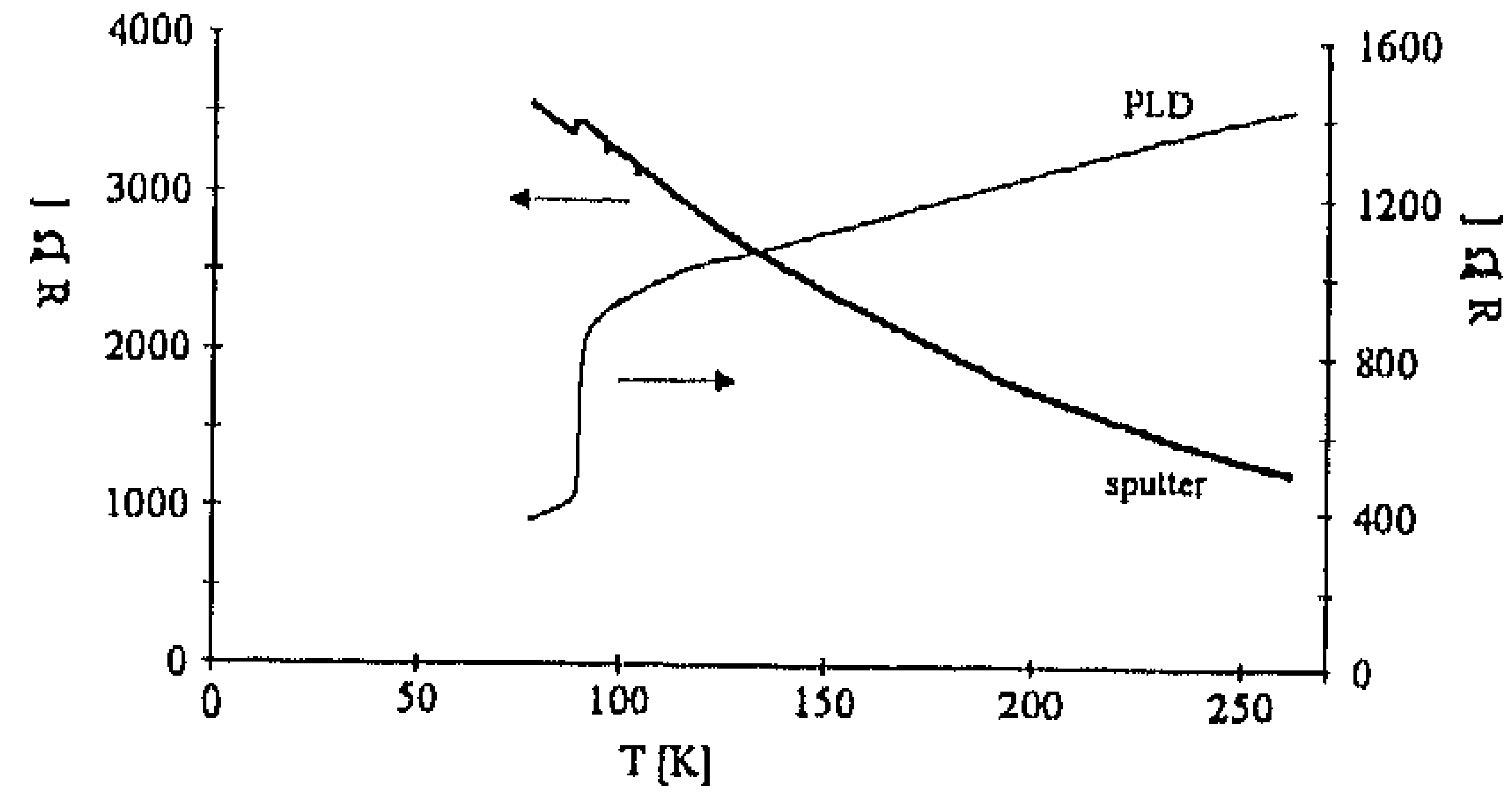

Fig. 3: The temperature dependent resistance of the non-superconducting barrier. The barrier is 100 μm by 5 μm. The YBCO has been deposited by rf-magnetron sputter and pulsed laser deposition (PLD).

The films deposited on Ti with the pulsed laser deposition technique showed a different behavior, see also figure 3. The resistance at T=300K is still comparable with the sputtered film, but has a metal-like temperature dependency. Again, there is drop at 90K, which is caused by the current leads. The electrical properties of the SEG-grown PLD bridges show a similar behavior as the rf-sputtered films, although the resistance at T=300K is decreased by the parallel resistance of the Ti-YBCO layer. These results can be explained by the different deposition rates of both techniques (sputter deposition takes more than 1 hour; PLD only 15 min.).

To study the diffusion in detail, a depth profile of the film on the metal-mask was made. To avoid charging effects, which hamper the sensitivity of the measurements, the technique of crater edge profiling was applied. Using this technique a crater is etched in the film and then a linescan is taken along an edge of this crater. The advantage is that the measurement can take as long a time as needed and can thus be done with much lower electron beam intensities. The crater edge profile along a crater made on the Ti mask part of the film is shown in figure 4.

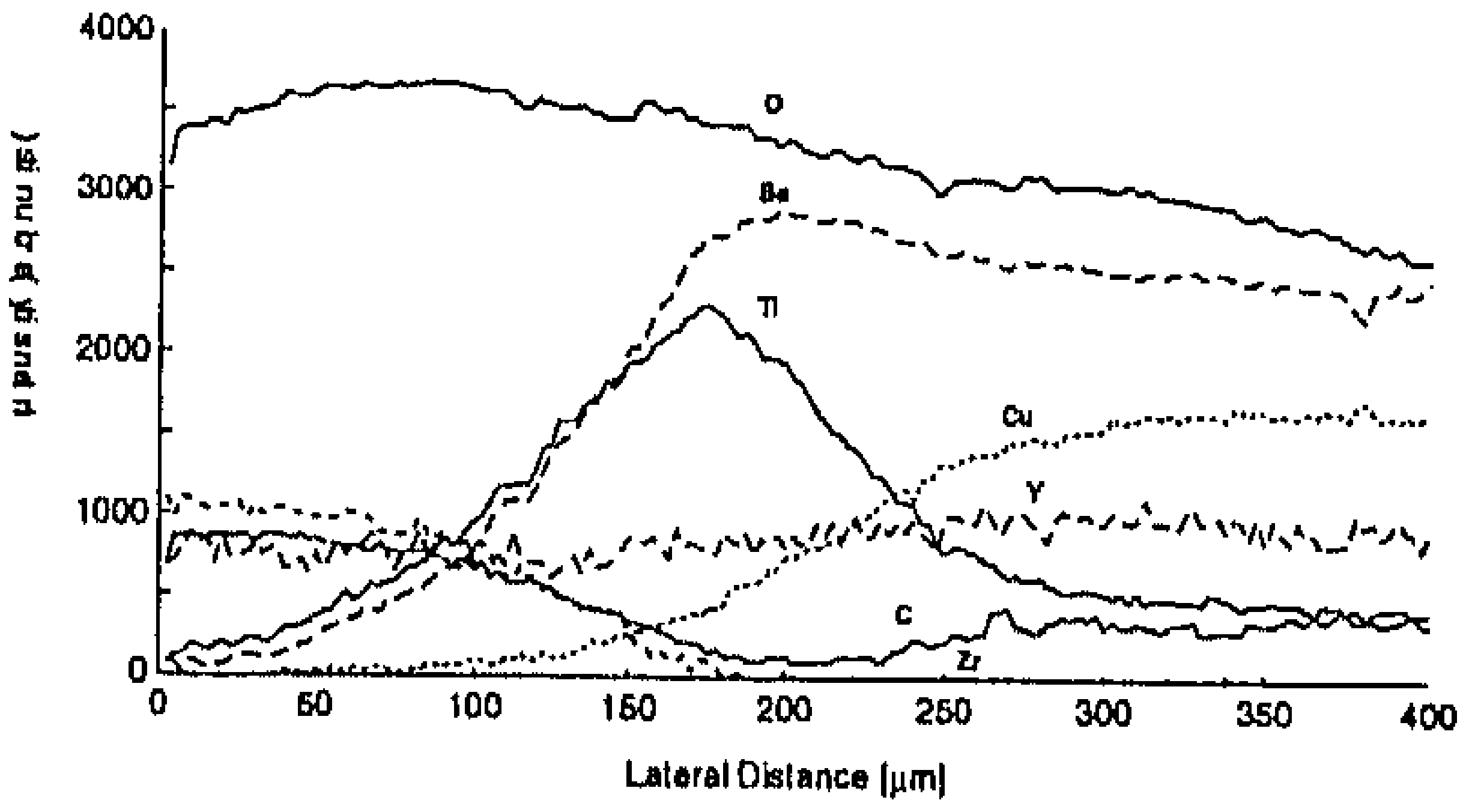

Fig. 4: Auger crater edge profile, showing a depth analysis of the interfaces between the substrate (YSZ), the Ti mask layer and the sputtered YBCO film.

From this profile some remarks about the diffusion process can be made. First, it can be seen that Ba diffuses into the Ti mask layer and that, likely, $BaTiO_3$ is formed. Zr and Cu diffuse to a small extent into the Ti layer. The Y-signal is nearly constant throughout the entire profile. The YSZ-substrate used contained about 9% Y_2O_3, so the Y must have diffused either from the substrate or from the film into the Ti layer. Compared to the Cu and Zr signal it can be

concluded that Y diffused to about the same extent as those two compounds. Finally it is shown that Ti atoms diffuse to a little extent into the YBCO film.
The diffusion of Ti into YBCO is not necessarily responsible for the destruction of the superconducting properties. On the surface of the film no Ti could be detected, so that the diffusion is not throughout the entire film. From literature it is known that small amounts of Ti substitution for Cu do not degrade the superconducting properties of YBCO films(4).

The electrical properties, like T_c and J_c, of the micron bridges made on tungsten masks look similar to those made by titanium. The resistances at room temperature were significant smaller, probably originating from leakage currents. The electrical properties of the W-barriers confirm this. The resistances all have a metal-like temperature dependency with a superconducting transition. The 5 μm wide barrier even had a critical current of 3 mA at 77K. Crater edge profiling shows no W concentration at the interface between sputtered YBCO and YSZ substrate. With the PLD, only a small amount of W could be found.

Conclusions

Titanium, and to a lesser extent tungsten, is a good candidates for selective epitaxial growth of YBCO. Depending on the deposition process, structures down to 2 μm can be made, which have comparable electrical properties as etched structures. The sputtered *barriers* on tungsten become superconducting, and thus less suitable for SEG. The degradation of the superconducting properties on Ti is, i.a., caused by crystal mis-orientation and diffusion of Ba into the Ti-layer and less by poisoning of the YBCO by Ti-atoms. The amorphous Ti layer oxidizes to TiO_2, as confirmed by measuring the volume change of the mask material during oxidation. For structures in the sub-micron range, however, less diffusive mask materials have to be used. First experiments with TiN, which is known as a diffusion stop, show very promising results. The patterning technique as presented in this paper has its merits in combination with other non-etching structuring techniques, like substrate trenches (5).

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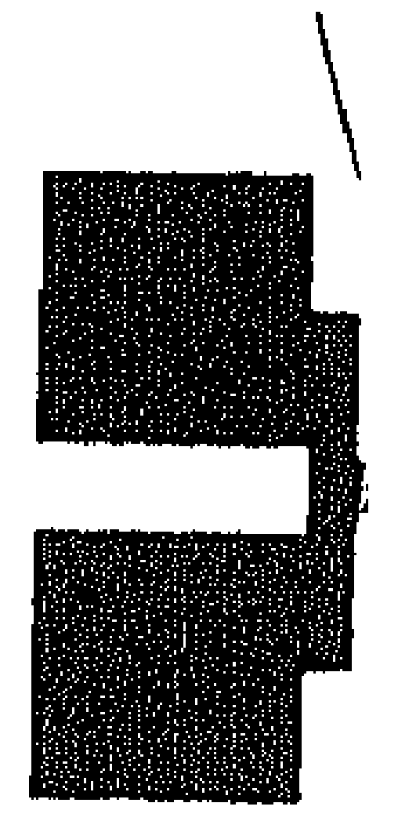

Fig.1a: Cc

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