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Selective Epitaxial Growth of Sub-micron Structures of YBaCuO by Substrate Modification

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Sub-micron structures of high-Tc thin films have been realized with Selective Epitaxial Growth (SEG). Two different techniques to achieve SEG have been studied. First, narrow trenches down to 100 nm are etched into the substrate with a four-layer E-beam lithography technique. Second, amorphous metal layers have been used to define pattern definition masks. Besides the suitability of both techniques, also the potential to combine these techniques is part of this study.

1. INTRODUCTION

Superconducting properties of sub-micron structures of high-Tc thin films deteriorate due to the patterning techniques used. This deterioration is, e.g., caused by oxygen outdiffusion during (reactive) ion etching by local heating or by reactions of the high-Tc thin film with resist and chemicals, needed for the lithographic processes. Selective Epitaxial Growth (SEG), where no post-deposition patterning is necessary, offers new possibilities.

In this study two different techniques to achieve SEG are presented. First, narrow trenches down to 100 nm are etched into the substrate with a four-layer E-beam lithography technique. With this method a pattern etched by SF_6 and O_2 in a Au/Ti(Ox)-thin film on top of an AZ-resist layer is transferred into the substrate by Ar-etching. Second, the pattern needed is defined by locally changing the crystallographic properties of the substrate with pattern definition masks of Ti, used as a reactive agent for local chemical or crystallographic modification of the overlying layer.

2. SELECTIVE EPITAXIAL GROWTH

2.1. Substrate-etching

To reduce the problems of direct etching of a high-Tc thin film, one can etch the less (temperature) sensitive substrate. Steep and well-defined trench-edges are essential for this technique, because there must be no (or bad) electrical contact between in- and outside of the trench. De Nivelle [1] deposited niobium onto a substrate and structured it by a 3-layer EBL (E-beam lithographic) resist method. The Nb-layer served as a mask to structure the substrate by Ar-IBE. Afterwards, the Nb has to be removed by SF_6-RIE followed by an anneal-procedure.

Here, we present an other approach using titanium as an etch-stop. Ti is one of the most resistant materials in Ar-based etching methods as well as in O_2-RIE. On the other hand, the etching of Ti itself can be very difficult due to the reactivity of a 'clean' titanium surface, even at very low background pressures (as low as 10^{-6} Torr). To overcome this problem, the following procedure was used.

On a ($SrTiO_3$) substrate we spin-coated a bottom resist layer (500 nm AZ1518 or PMMA) and prebaked it at 120°C. Afterwards a 40 nm thin Ti-layer is sputter deposited on the resist, in situ followed by a deposition of a 20 nm thin Au-film. The latter protects the titanium from oxidation. Finally, a thin E-beam sensitive resist is spun onto the metallic interlayers.

From extensive studies we achieved the following etch process parameters. Efficient etching of Ti in SF_6-RIE only takes place at low pressure ($<2 \times 10^{-3}$ mbar), admixing oxygen did not result in an increase of the fluorine concentration, and the etch-rate is very sensitive to the exposed area. For small areas (<1 mm^2) the etch-rate stabilized on 6 nm/min at a pressure of 1.8×10^{-3} mbar and a self-bias of -120V.

The anisotropic resist etching by oxygen-RIE is

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very sensitive to process parameters. Although oxygen plasmas are routinely applied to strip resist layers, lateral anisotropic etching is still under study. Good results are obtained by baking the resist at higher temperatures. In our case we want to avoid this, because it limits our lift-off process. Best results were obtained with high O_2 gas flow (14 sccm), input power of 100 W (0.32 W/cm^2), self-bias of -300 V and pressure of 1.5×10^{-2} mbar.

Finally, the pattern is transferred into the substrate by Ar-etching with the TiO_x on top of the resist-Au-Ti-layer as an etch-stop. Afterwards, the resist is removed by lift-off, so no damaging of the substrate-surface takes place and no post-anneal is necessary.

2.2. Definition masks

With standard optical or E-beam lithography a sputter-deposited 10 nm thin Ti layer is structured by lift-off. Next, a 80 nm thin YBCO layer is deposited on the entire substrate. Due to the high deposition temperature and oxygen atmosphere, the Ti-layer will oxidize, forming TiO_x. The diffusion of the Ti is expected to be less, compared to other materials used in literature, like Si or W [2,3]. The diffusion, especially in lateral direction, is the limiting factor is this SEG-process.

Several techniques were used to verify the mechanism that is responsible for ruining the superconducting properties on top of the metal mask. In Figure 1, a crater edge Auger profile of the substrate-Ti-YBCO interface is shown.

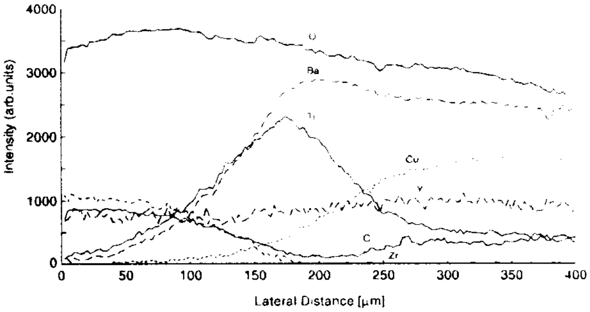

Fig.1 Crater-edge profile of YBCO on Ti-YSZ.

The shown depth-profile is taken as a linescan along the edge of an under grazing angle etched crater. From this profile it can be seen that Ti diffuses only to a small extent into the YBCO-layer. On the other hand, Ba diffuses into the entire Ti-layer, likely forming $BaTiO_3$. This leads to a Ba-deficiency in the first YBCO-layers. SEM pictures show a large density of grains and XRD reveals only c-axis orientations, although in a much lesser extent than the non-covered substrate, indicating a layer with small crystallites. The layer shows a semi-conducting (and by that isolating) behaviour, with a resistivity ρ(100K) =56.5 Ωcm.

The electrical properties (ρ, and IV-characteristics) of a bridge, made with these structuring technique, is given in figure 2. The sub-micron structure is a bridge of 600 nm wide and 300 nm long. The 'zero temperature' (Tc) of the bridge is 88K and the critical current density $J_c=2.7\times10^6$ A/cm^2.

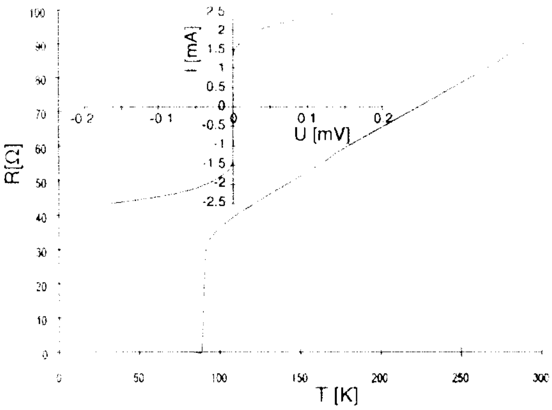

Fig. 2. IV-curve and R versus T for sub-micron structured YBCO bridge

From these measurements we can conclude that the diffusion of Ti into the YBaCuO layer is negligible. This restricts this SEG technique not only to planar structures but makes it also useful in multilayer designs.

A combination of both presented techniques is feasible due to the lift-off possibility after substrate etching.

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