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Structural Studies of YBCO Ramp Josephson Junctions for Rapid Single Flux Quantum Circuits

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Ramp-type Josephson junctions with barrier layers of Ga doped $PrBa_2Cu_3O_{7-\delta}$ have been investigated using scanning and transmission electron microscopy. The microstructures have been correlated to the ramp geometry. The junctions exhibited low excess current. This is believed to be due to the uniform thickness of barrier layer deposited on the ion-milled edges. The uniformity of the barrier is presumed to be a result of the smooth ramp, which promoted uniform nucleation and epitaxial growth.

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1. INTRODUCTION

A high-T_c Ramp-edge Josephson junction is a junction with high flexibility. It can, for example, be placed relatively freely on a circuit chip compared with a bicrystal grain boundary junction. To reach high reproducibility it is essential to obtain epitaxial growth and well-defined interfaces between the barrier layer and the superconducting layers. To favour the necessary epitaxial growth of the barrier layer and the subsequent layers, smoothness and uniformity of the ramp-edge is important.

The present work concerns ramp-edge junctions with a barrier layer of $PrBa_2Cu_{2.6}Ga_{0.4}O_{7-\delta}$ (PBCGO). It has a higher normal state resistance than to $PrBa_2Cu_3O_{7-\delta}$ (PBCO) [1]. Junctions made with barrier layers of PBCGO have unaffected critical current compared to junctions with PBCO as the barrier layer [2, 3]. PBCGO is also well lattice matched to $YBa_2Cu_3O_{7-\delta}$ (YBCO) [1]. The aim of this work was to correlate the microstructure of the junction to the ramp-edge geometry.

2. EXPERIMENTAL

The base electrode YBCO, about 100 nm, and the insulating layers, PBCO/$SrTiO_3$/PBCO each with thickness about 20 nm, were deposited by on-axis laser-ablation on a (100) $SrTiO_3$ (STO) substrate. The deposition temperature was 790°C in an oxygen pressure of 0.25 mbar. The films were deposited with a laser energy density of 1.2 J/cm^2 at 10 Hz except for the PBCGO layer where the frequency was 5 Hz. The ramp-edges were made by ion milling during rotation where the incidence angle of the ion beam was 45° with respect to the substrate surface normal. The ramp-edges were patterned along the $[010]_{STO}$. The barrier layer PBCGO, with a thickness of 25 nm, and the top electrode YBCO, 150 nm, were subsequently deposited after the ramp formation. The preparation of the ramp-edge junctions is described in more details elsewhere [4, 5].

The surface morphology of as-received film surfaces was studied by scanning electron microscopy in a JEOL JSM-6301F. Transmission electron microscopy (TEM) cross section samples were made by mechanical grinding, polishing and subsequent ion milling down to electron transparency. They were characterised in a Philips CM 200 with a Field Emission Gun and a Gatan Imaging Filter/EELS system.

3. RESULTS AND DISCUSSION

TEM characterisations of ramp-junctions with low excess current [4] showed a uniform barrier layer in the ramp-edge region. An overview of the ramp-edge region is seen in Fig. 1 and details of the junction area are seen in Fig. 2. The angle of the ion-milled edge was about 30°. The ramp was smooth and this promoted an epitaxial nucleation of PBCGO and a thin film evolution giving a uniform barrier thickness. The subsequent

YBCO top layer grew epitaxially on top of the barrier provided that no secondary phases were present. The interface between the YBCO base layer and the barrier was easier to distinguish than that between the barrier and the top YBCO. This was probably due to an increased amount of dislocations and stacking faults in the YBCO base layer due to the ion milling.

Most of the barrier layers were free from secondary phases and pinholes. In Fig. 2, a small, less than 20 nm, particle has nucleated close to the substrate surface in the barrier layer. Such particles did not to destroy the epitaxial growth of the barrier layer and the subsequent top YBCO layer provided that they were sufficiently small, i.e. enclosed in the layer.

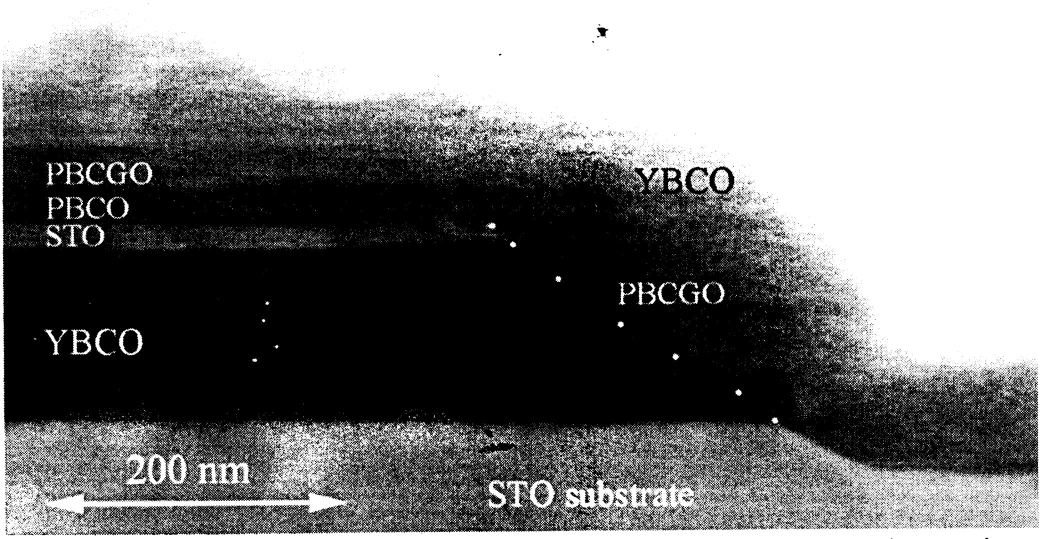

Fig. 1. A TEM micrograph showing an overview of the ramp-edge region. The visible interface between the bottom YBCO layer and the barrier layer is marked with white dots. The interface between the barrer layer and the top YBCO layer is not clearly distinguished due to a relatively large thickness of the TEM specimen. The micrograph was taken with the electron beam incident along the [100]STO.

In regions with small steps in ion-milled STO substrate (of the order of unit cell high) the PBCGO grew epitaxially without any particles. Higher steps, around 10-20 nm, promoted nucleation of secondary phases. These small particles were most of the times enclosed in PBCGO. Sometimes, the particles protruded from the PBCGO and then affected the YBCO nucleation and growth.

The PBCGO grew epitaxially on the ion-milled STO substrate. However, some secondary phases and a high concentration of a-axis oriented grains were observed in the top YBCO layer. This top surface had been covered by photoresist during the ion milling. A possible explanation for the presence of secondary phases and a-axis particles is a remaining residue of resist from the patterning procedure, even after cleaning in oxygen plasma. The presence of a-axis particles does not affect the junction properties as the current transport is in the ramp region of the bottom electrode. However, the a-axis particles will affect the performance of the circuits if crossovers are made.

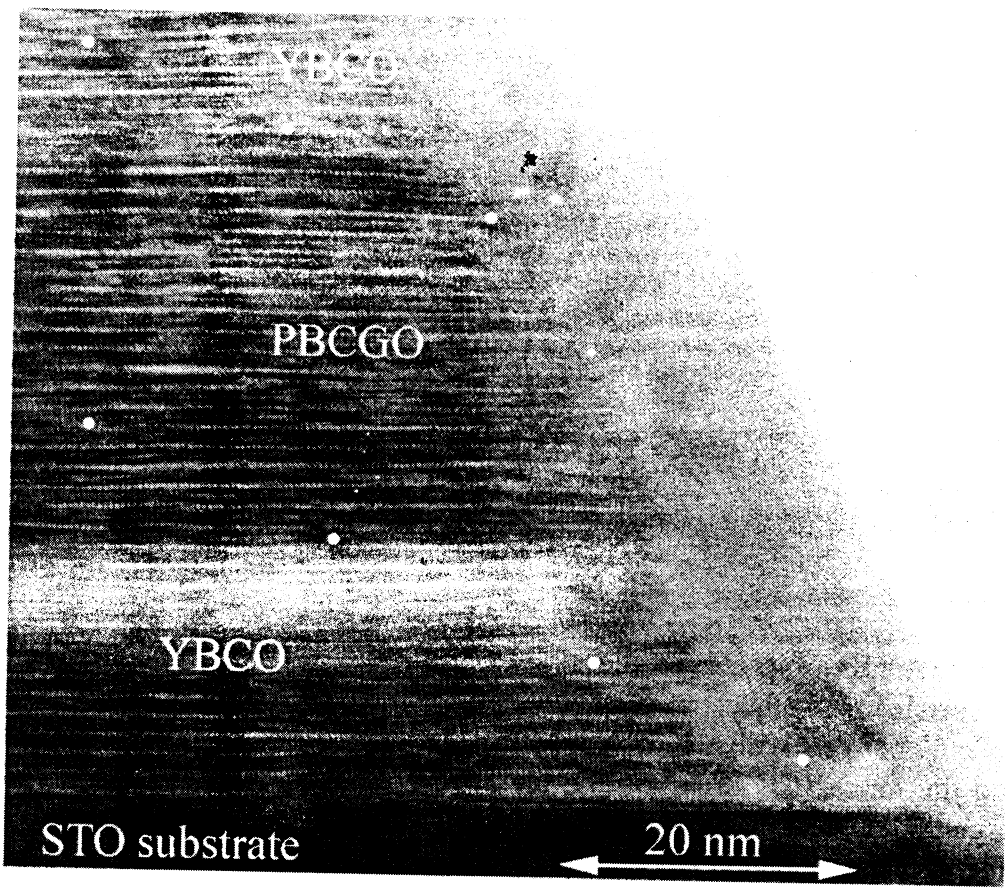

Fig. 2. High-resolution TEM micrograph of the barrier layer in the junction area. The interfaces between the PBCGO layer and the base and the top layer are marked with white dots. A small particle is seen in the barrier layer close to the substrate surface. The $[100]_{STO}$ is parallel to the electron beam.

4. CONCLUSIONS

In summary, we have characterised ramp-edge junctions with a 25 nm thick PBCGO barrier layer. The barrier layer nucleated and grew epitaxially with a uniform thickness on the ion-milled YBCO edges. It was found that small steps of the order of one unit cell of STO resulted in epitaxial the nucleation of PBCGO without secondary phases. Larger steps, however, could give rise to nucleation of small particles, which most often were enclosed in the barrier layer but sometimes protruded into the subsequent YBCO. Protruding particles disrupted the epitaxial growth of the top layer.

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REFERENCES

1. Y. Xu, W. Guan, *Physica C* **206** (1995) 59-66.
2. M. A. J. Verhoeven, G. J. Gerritsma, H. Rogalla, A. A. Golubov, *Applied Physics Letters* **69** (1996) 848-850.
3. M. A. J. Verhoeven, G. J. Gerritsma, H. Rogalla, A. A. Golubov, *IEEE Transactions on Applied Superconductivity* **5** (1995) 2095-2098.
4. M. Q. Huang, Z. G. Ivanov, P. V. Komissinski, P. B. Mozhaev, T. Claeson, The MOS Conference, Stockholm, Sweden (1999).
5. M. Q. Huang, Z. G. Ivanov, P. V. Komissinski, P. B. Mozhaev, T. Claeson, *Manuscript* (1999).