Epitaxy and graphoepitaxy of oxide heterostructures on step edges

M. I. Faley[1], U. Poppe[1], D. Meertens[1], O. M. Faley[2], C. L. Jia[1], R. E. Dunin-Borkowski[1]

1. Institute for Microstructure Research, Jülich Research Centre, Jülich, Germany
2. RWTH Aachen University, Aachen, Germany

Email of corresponding author: m.faley@fz-juelich.de
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Graphoepitaxial growth of high-T_c superconducting $YBa_2Cu_3O_7$ (YBCO) films and heterostructures on MgO substrates and buffer layers is used for making highly sensitive superconducting quantum interference devices (SQUIDs), high-Q microwave resonators, electrical power transmission cables, current leads, fault current limiters, transformers, generators, motors and energy storage devices. For such applications, it is usually important to align the *c*-axis of the YBCO film normal to the substrate surface and to ensure an absence of in-plane-misoriented grains in the films. However, degradation of the MgO surface due to exposure to air leads to the growth of 45^o in-plane-misoriented YBCO grains (Fig.1), reducing the critical current and increasing noise and the spread of parameters in oxide heterostructures and devices made with such films. The realization of graphoepitaxial growth requires fine tuning of the coupling between the YBCO film and the substrate.

For tilted MgO substrates and buffer layers, surface degradation leads to a deviation of the *c*-axis of the YBCO film from the substrate crystallographic direction and its alignment with the substrate surface normal. This effect is advantageous for many applications, such as the preparation of high-T_c step edge Josephson junctions which are used for SQUIDs [1]. The Josephson junction is created on the upper edge of the substrate step where the crystal structure of YBCO undergoes a sharp kink with an angle of 40 degrees (see insert in the Fig.1). SQUID with such Josephson junctions can be combined with high-T_c superconducting multilayer thin-film flux transformers to construct sensitive magnetometers [2] integrated into high-T_c magnetoencephalography measurement systems [3].

Up to now, technology of step edge junctions suffered from poor reproducibility of the junction parameters. High oxygen pressure deposition techniques [4] permits the fine optimization of the growth conditions of the thin-film oxide heterostructures, while different microscopy techniques – optical microscopy, atomic force microscopy, scanning electron microscopy, and sub-Angstrom high resolution transmission electron microscopy provide valuable information about epitaxial or graphoepitaxial growth of the film on the surface of the substrate step edges.

Here we perform an in-depth electron microscopy study and demonstrate that ion beam etching (IBE) of the MgO surface eliminates the growth of misoriented grains and aligns the *c*-axis of the film with the substrate crystallographic direction (Fig.2). The growth spirals on the YBCO film show the orientation of its crystallographic directions: the direction of the *c*-axis of the YBCO film is normal to the terraces of the growth spirals. The *c*-axis of the YBCO film on an MgO surface refreshed by IBE follows the substrate crystallographic direction, which deviates from the substrate surface normal on the slopes.

By controlled exposure of the IBE-refreshed surface of the MgO substrate to air or hydro-carbons before deposition of the YBCO film, it is possible to tune the coupling strength between the substrate and the YBCO and to change the growth of the YBCO film from epitaxial to graphoepitaxial. This approach can be used to achieve controlled deviation of the film *c*-axis from the substrate crystallographic direction and its alignment with the substrate normal, while avoiding the formation of in-plane-misoriented YBCO grains.

References

[1] E. E. Mitchell and C. P. Foley, Supercond. Sci. Technol. **23**, p. 065007 (2010).
[2] M.I.Faley *et al*, IEEE Transactions on Appl. Supercond. **11**, No.1, p. 1383 (2001).
[3] M.I.Faley *et al*, Physics Procedia **27** (2012).
[3] U. Poppe *et al*, J. Appl. Phys. **71**, p. 5572 (1992).

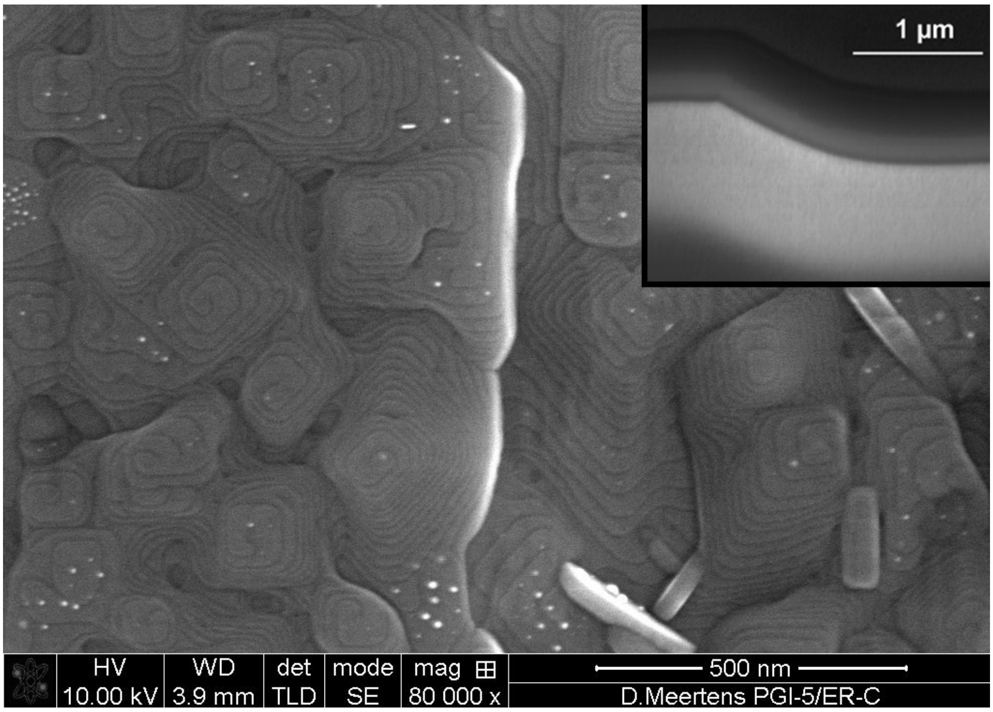

Figure 1. *SEM image of the surface of an YBCO film deposited on an MgO substrate step edge. The inset in the top right corner shows a cross-section of a similar substrate edge structure made by FIB milling.*

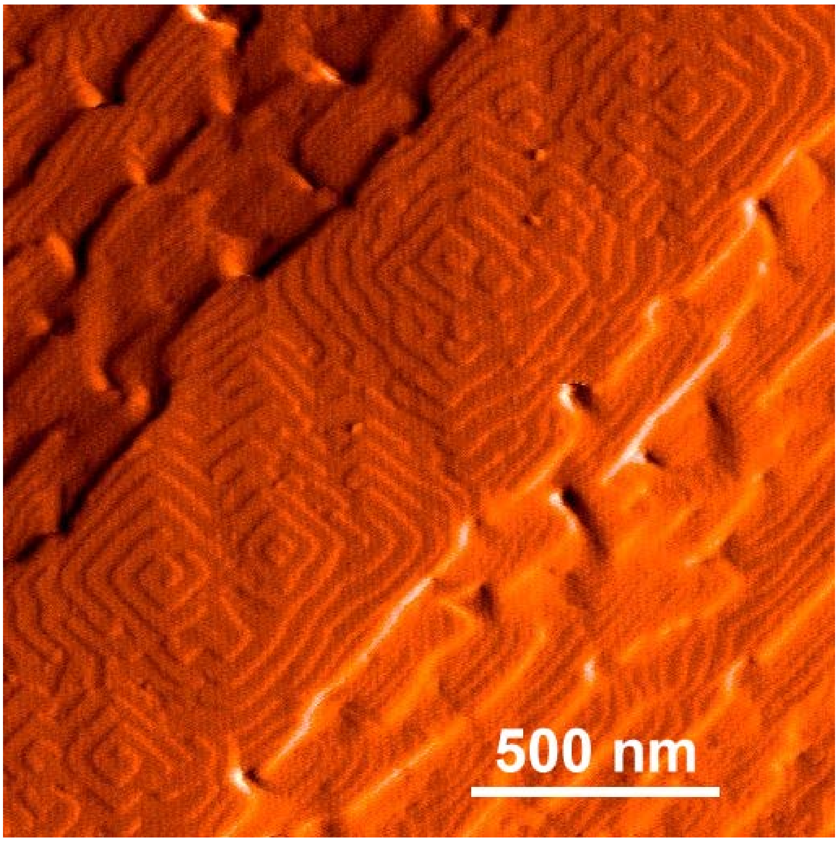

Figure 2. *AFM image of a 140 nm thick YBCO film deposited on an IBE-cleaned trapezoidal feature on a (100) MgO substrate with 3 degree slopes on either side of the ridge.*