Tuned Epitaxy of Oxide Heterostructures

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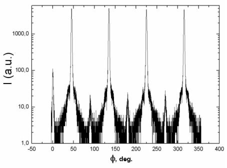
Motivation and objectives

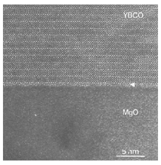
Current development of sensitive high-T_c superconducting quantum interferometers (high-T_c SQUIDs) for magnetoencephalography systems [1,2] is requiring reproducibility of relatively cheap step-edge Josephson junctions on MgO substrates. The main problem here is to provide c-axis oriented growth and absence of in-plane misorientation grain boundaries of $YBa_2Cu_3O_{7-x}$ (YBCO) films on the slide shaped surface of substrate steps. Such c-axis oriented growth of bi-axially textured high-T_c films on tilted MgO buffer layers is required also for making high-T_c superconducting 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. Degradation of the MgO surface, e.g., due to exposure to air helps to realize *c*-axis growth of the YBCO but leads to the growth of 45º in-plane-misoriented YBCO grains, reducing the critical current and increasing noise and the spread of parameters in oxide heterostructures and devices made with such films. This can be avoided by the realization of graphoepitaxial growth of YBCO films, which requires fine tuning of coupling between the YBCO film and the substrate.

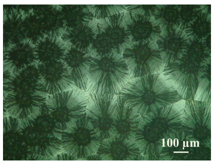
Epitaxy of oxide heterostructures on MgO



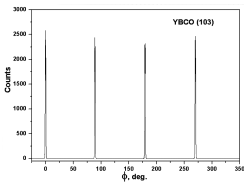
X-ray diffraction ϕ scan for a ~ 1 µm thick YBCO film deposited on old unbuffered MgO (100) substrate after one year storage in air.



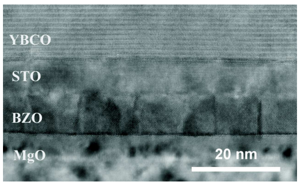
HRTEM of the interface between YBCO and MgO with a 0.5-nm thick amorphous layer of $MgCO_3$ [3].



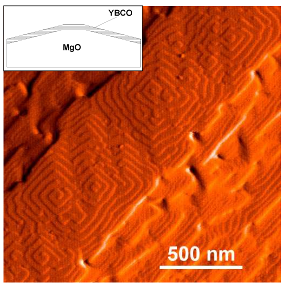
Polarized light images of the surface of an MgO substrate after 5 months storage in air



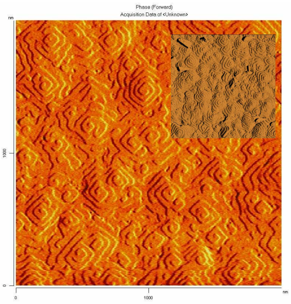
X-ray diffraction ϕ scan for YBCO film deposited on an epitaxially buffered MgO (100) substrate.



Cross sectional HRTEM image of BZO-STO-YBCO heterostructure deposited on a MgO (100) substrate [4].

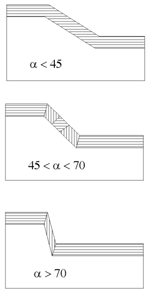


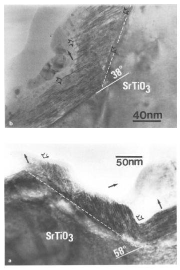
AFM image of a 140 nm thick YBCO film deposited on IBE-cleaned trapezoidal feature on a (100) MgO substrate with about 3 degree slopes. Sketch of the structure is shown in the insert.



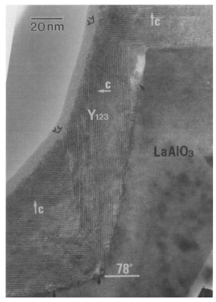
AFM image (2µm x 2 µm) of surface of a 130 nm thick YBCO film on IBE-cleaned MgO. Similar image of YBCO film prepared on as-received MgO is shown in the insert.

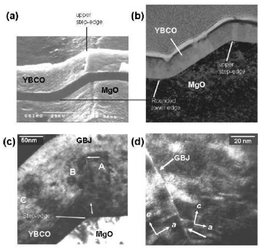
Epitaxy and graphoepitaxy on step edge junctions



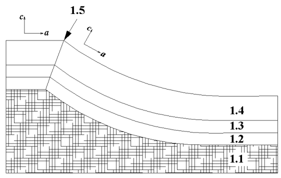


Old type step-edge junctions [5,6].

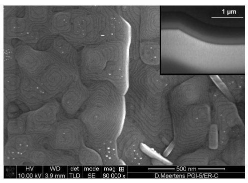




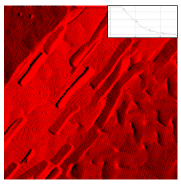
New type step-edge junctions [7,8].



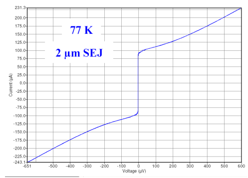
Slide step-edge junction with buffer layers: (1.1) substrate, (1.2) texturing buffer layer, (1.3) anti-epitaxial buffer layer, (1.4) high-T_c film, and (1.5) grain boundary [9].



SEM image of the slide-type step-edge JJ made without graphoepitaxial layer. Cross-section of the structure prepared by FIB is shown in the insert.



AFM image of the slide-type step-edge JJ prepared with graphoepitaxial growth of YBCO. Cross-section of the structure measured by AFM is shown in the insert.



IV-curve of a new type step-edge JJ with graphoepitaxy

Summary

Here we 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. 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 a 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.

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[2] M. I. Faley et al., *Physics Procedia* **31** (2012).

[3] C. Traeholt et al., *Physica C* **230** 297 (1994).

[4] M. I. Faley et al., *Appl. Phys. Lett.* **89** 082507 (2006).

[5] C. L. Jia et al., *Physica C* **175** 545 (1991).

[6] C. L. Jia et al., *Physica C* **196** 211 (1992).

[7] C. Foley, Patent US6514774 (2003).

[8] E. E. Mitchell and C. P. Foley, *SuST* **23** 065007 (2010).

[9] M. I. Faley, Patent PT1.2557 DE102012006825 (2012)