Very recently, investigation of transport properties of YBCO nano-wires (i.e. lateral width down to 50nm) has revealed a peculiar in-plane anisotropy of the superconducting critical current density $J_c$ when the film is grown on suitable substrates (e.g. [110]-oriented MgO). Such an in-plane anisotropy has been tentatively correlated to the in-plane structural features of the YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) films.

Here we report our results on atomic resolution Transmission Electron Microscopy (TEM) studies and nanodiffraction experiments performed on superconducting (001)YBCO/(110)MgO thin films prepared for TEM analysis in different geometries.

In Figure 1a a representative bright field plan-view TEM image of the YBCO film is shown. The film has typical domain structure, which is a characteristic fingerprint of the “c-axis” spiral growth mode of YBCO. Domains have an average size of about 50-100 nm, with boundaries along both the in-plane directions. Plan-view nanodiffraction experiments confirmed the “c-axis” growth of the film which is indeed [001]-oriented with the respect to the electron beam only exhibiting the characteristic h00 and the 0k0 diffraction spots. Figure 1b shows a representative nanodiffraction in the [001] zone axis of the film. The diffraction spots of the film are indexed in the presence and the presence of additional spots (pointed by arrows) is also observed with spacing compatible with the 002 diffraction spots of MgO. By taking the substrate as a reference, we determined that the film and the substrate have a (010)(100)YBCO//(2,-2,0)(0,0,2)MgO orientation relationship. Interestingly, no evidence of twin domains is found within the film.

Cross-sectional HRTEM analyses were also performed across the two in-plane directions of the film. Figure 2a and 2b show bright field HRTEM images taken with the electron beam parallel to the[010] and [100] YBCO crystallographic directions, respectively. Interestingly, a pronounced waving of the YBCO lattice planes along the two in-plane crystallographic directions is observed, with a different wave-periodicity depending on the relative film/substrate crystallographic orientation. We associate the emergence of this feature to an inhomogeneous strain induced by the bared (110)MgO substrate in the two in-plane directions, speculating on the relationship between these structural properties and the high critical current measured in these specimens.

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Fig. 1: a) Plan view Bright field TEM image of the YBCO film ([001] film zone axis). b) Nanodiffraction taken in the [001] zone axis of the film. In the pattern, diffraction spots of YBCO are indexed and additional spots, compatible with the 002 diffraction spots of MgO, are pointed by arrows. c) Nanodiffraction of the MgO substrate in the [110] zone axis.

Fig. 2: HRTEM cross sectional images taken (a) in the [010] and (b) [100] zone axes of the YBCO film. In both the cases a waveness of the YBCO lattice planes is observed.