Aberration-corrected scanning transmission electron microscopy (STEM) – electron energy-loss spectroscopy (EELS) study of YBCO/Gd Heterostructures

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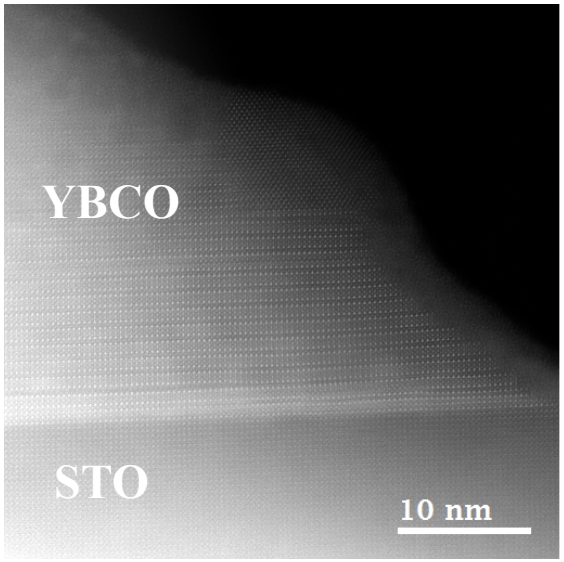
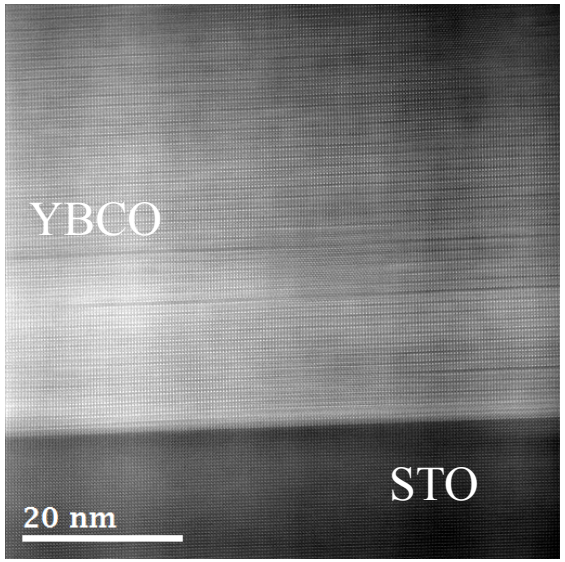
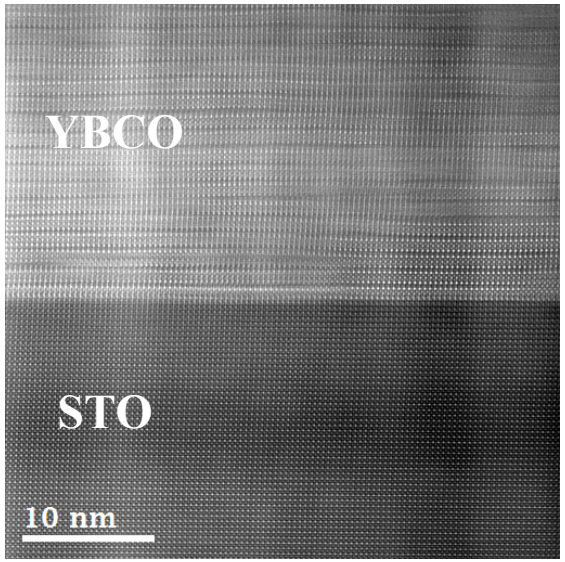
(Samples from UC Davis)
Study carried out in a JEOL ARM200cF operated at 200 kV

YBCO, as grown

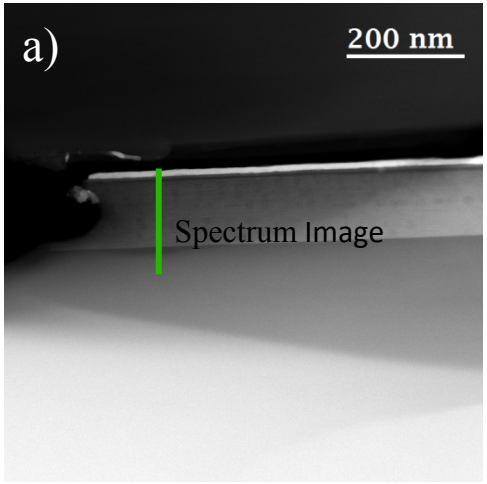


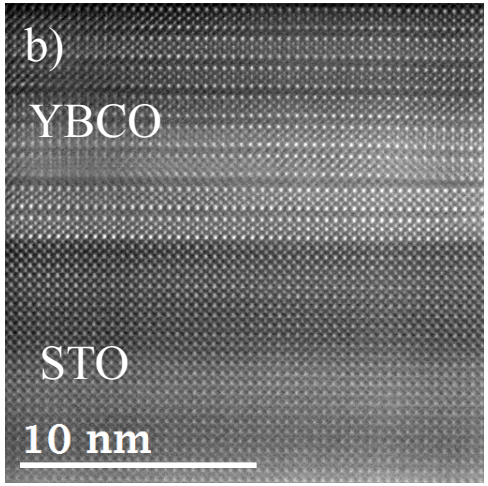


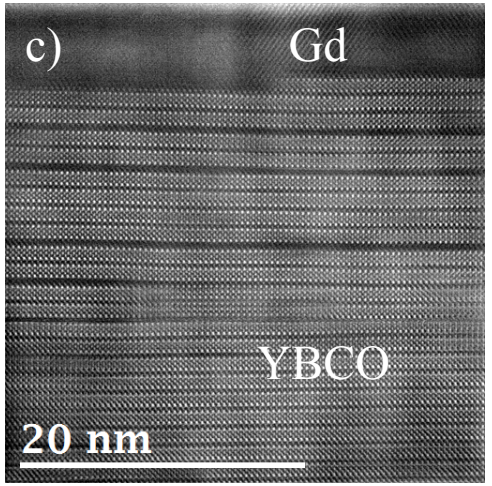


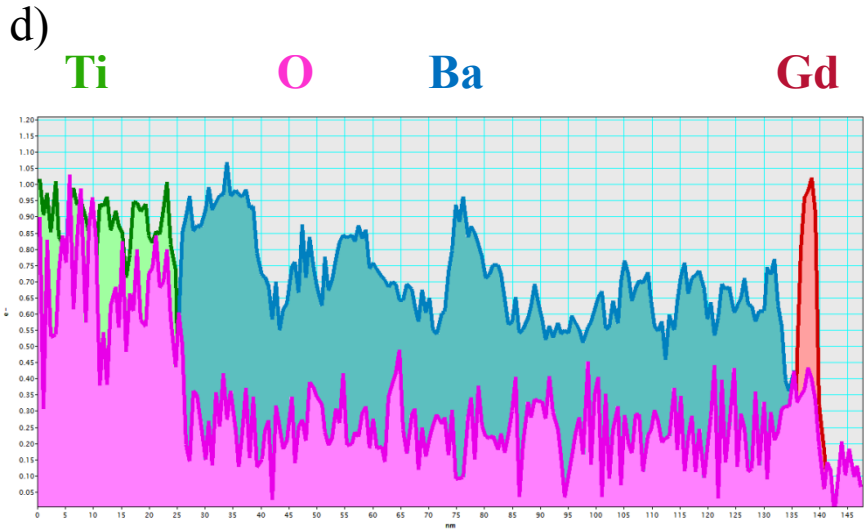
STO/YBCO as grown, with no capping layers (neither Gd nor Au). The quality of the STEM specimens was not the best, they did not come out quite well out of the ion mill. Intermediate magnification high angle annular dark field (HAADF) images of the interphase STO/YBCO exhibit a flat, coherent structure, free of secondary phases. The darker planes in the YBCO layers correspond to the Cu-O chains, just like the Y124 structure. Sometimes they appear doubled (even darker contrast). The density of such defects is not terribly high but in literature they have been ascribed to non optimal oxygenation during growth.

YBCO/3nm Gd





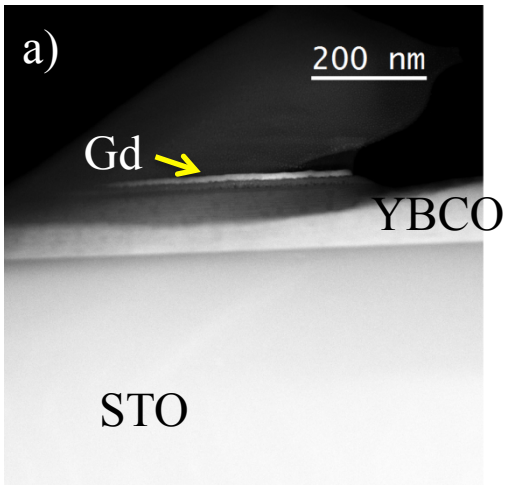


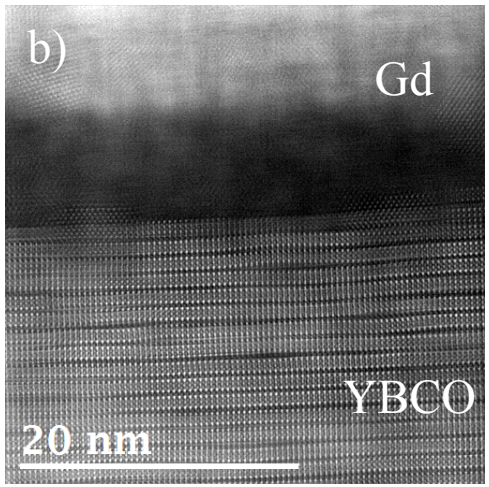


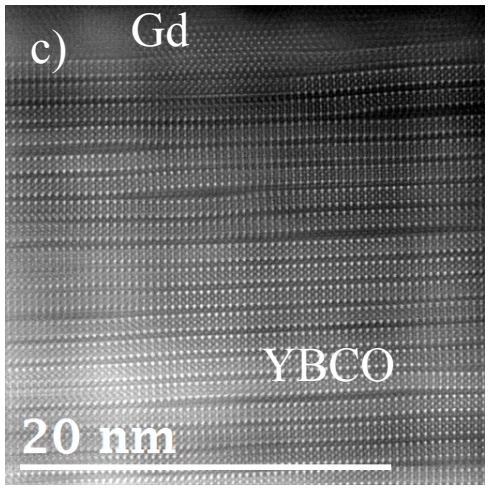
YBCO/3 nm Gd (nominal): This sample presents a capping layer of Gd, nominally 3 nm thick. **Panel (a)** shows is a low magnification image of the structure. Layers are flat and continuous over long lateral distances, no secondary phases are observed.

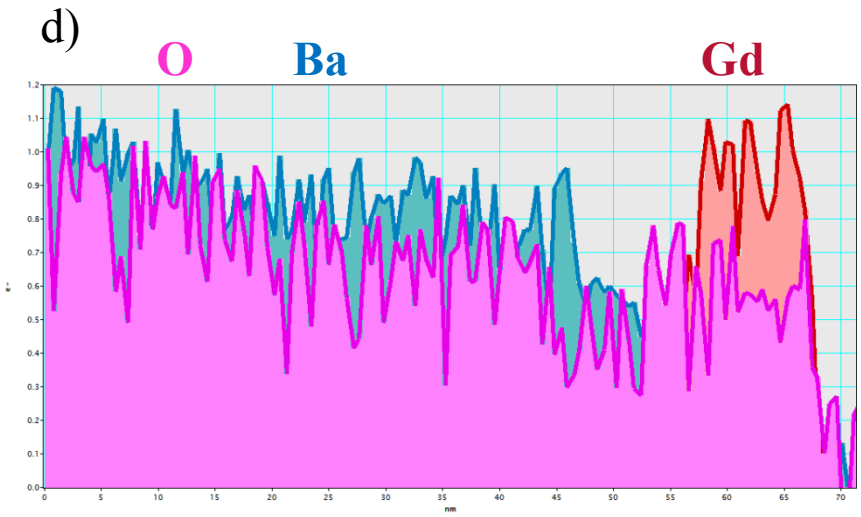
Figure b) exhibits an atomic resolution image of the YBCO/ STO interface. It is coherent, growth is epitaxial. No major defects are observed. Again, some double Cu-O chains are observed (see those extra dark stripes in between bright Ba-O planes, which are exhibit the brightest contrast of the unit cell). (**c)** shows the upper interface, **YBCO /Gd**. Unit cell high steps are observed on the YBCO surface, and it seems like the density of double Cu-O chains is higher near the top surface although we lack the lateral statistics to give an accurate estimation. (**d)** exhibits a profile of the normalized EELS intensities corresponding to the Ti $L_{2,3}$, Ba $M_{4,5}$ and Gd $M_{4,5}$ absorption edges, measured along the line marked with a green line in (a) obtained by EELS. We estimate that the Gd capping layer presents an actual thickness of 7nm. It also seems somewhat oxidized

Sample YBCO/7nm Gd



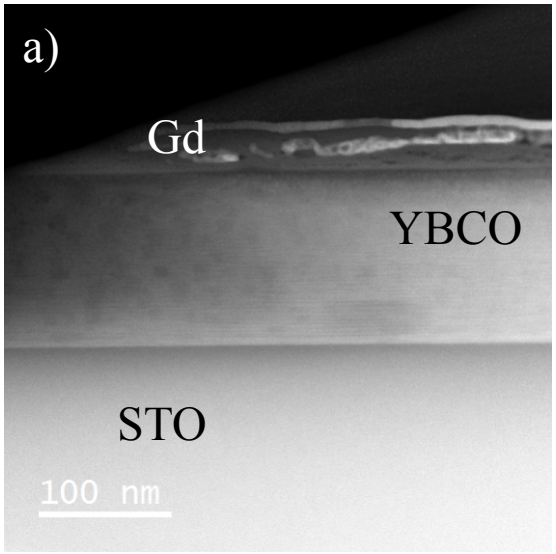


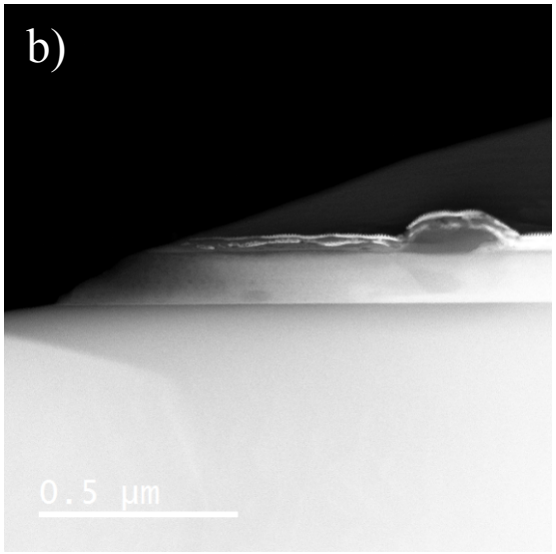


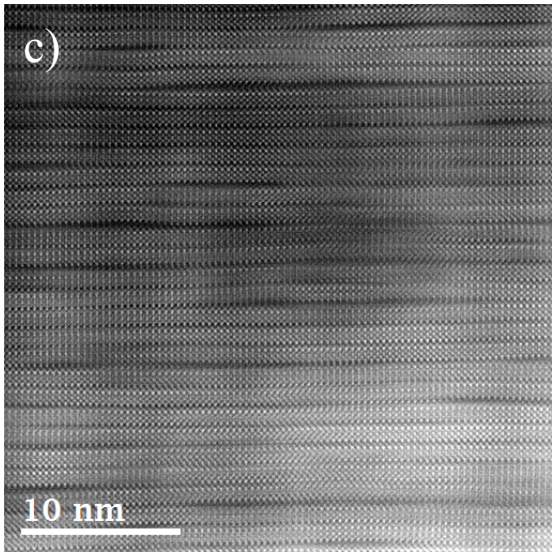


YBCO/ Gd 7 nm. **Figure a)** shows a low magnification HAADF (Z-contrast) image of the structure, heavy elements appear brighter. Layers are again flat and continuous over long lateral length scales, of the order of a micron .The uneven contrast is a thickness related artifact (derived from the ion mill).
Figures b) and **c)** show the interface between the YBCO and Gd. Double Cu-O chains are present and give rise to stacking faults and strain fields.
Figure d) exhibits a chemical profile traced across the structure obtained by EELS only including the Ba $M_{4,5}$ and Gd $M_{4,5}$ signals. The Gd capping layer presents a thickness of 17nm.

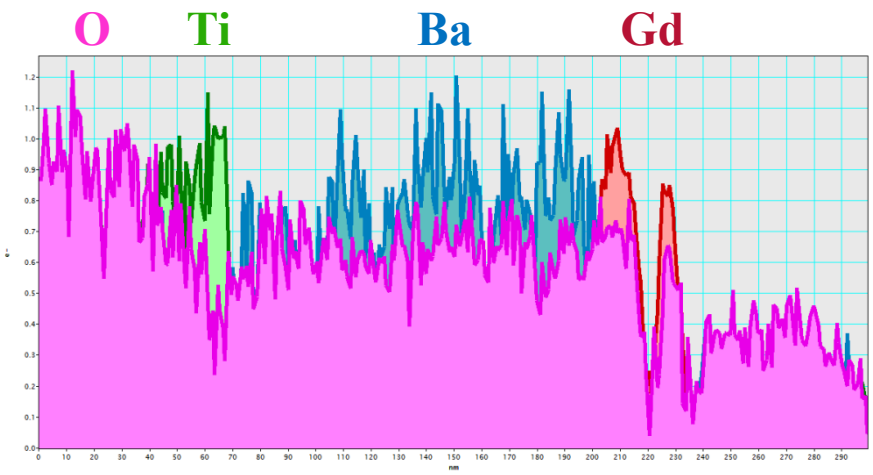
Sample YBCO/20nm Gd







d)



YBCO/ Gd 20 nm (nominal). Figures a) and **b)** exhibit low magnification HAADF images of the structure. The thicker capping layer appears altered and it seems that the Au deposited on top of the Gd has somehow got mixed with the Gd and diffused into the center of the capping layer. In **b)** it is also noticeable the presence of surface inhomogeneities bump that alter the lateral integrity of the capping.
Figure c) shows a high magnification image of the YBCO layer , again denoting the presence of oxygen vacancies and double Cu-O chain layers. Heavy distortions of the lattice are also present in this structure mostly related to the laterally discontinuous double Cu-O chain layers. **Figure d)** shows a chemical profile traced across the structure obtained by EELS. The Gd capping layer presents a real thickness of 34nm.

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Summary

1. Al samples studied are epitaxial and the YBCO/ STO interface is coherent.
2. The YBCO O stoichiometry may be slightly compromised. Noticeable densities of double CuO chains are observed in all samples. These give rise to a local structure more similar to the Y124 one than the nominal Y123.
3. The structure of the double CuO chains is uneven laterally and gives rise to strain fields and distortions in the YBCO lattice. These tend to be less pronounced close to the STO but get worse near the top Gd interface.
4. The density of distortions appears to increase with the amount of Gd deposited on the capping layer. Maybe less O goes into the YBCO for thicker Gd cappings?
5. The Gd capping layer always present a thickness roughly double of the nominal value. Is it also heavily oxydized?
6. All samples present flat layers in low magnification except for the last one (thickest Gd capping) where an inhomogeneous Gd / Au distribution is observed.