Scanning transmission electron microscope investigation of $LaAlO_3/SrTiO_3$ bi-interface

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1. SYSTEM

The system investigated is a bi-interface of Lanthanum Aluminate $LaAlO_3$ (LAO) and Strontium Titanate $SrTiO_3$ (STO) composed as follows: LAO layer / STO layer / LAO layer / TiO_2-terminated and [001] oriented STO substrate. This system is an elaboration upon the LAO thin film / TiO_2-terminated STO system, in which a two-dimensional electron gas (2DEG) was unexpectedly found at the interface between these wide gap insulators [1]. More recently such a 2DEG was obtained at an LAO-STO interface [2].

2. RESULTS

3.1 Experimental conditions

The data were collected with a Nion UltraSTEM™ aberration-corrected scanning transmission electron microscope (STEM) at 200 kV for the imaging and at 100 kV for the electron energy-loss analysis.

3.2 High-angle annular dark-field images

The contrast in the image is approximately proportional to $Z^{1.7}$, where Z is the atomic number, and this explains why the LAO layer appears brighter in the high-angle annular dark-field (HAADF) mode, see fig. 1. Dislocation occurrence due to elastic energy release (lattice mismatch $1\text{-}a_{LAO}/a_{STO} \approx 3\%$) is widely observed at the top interface.

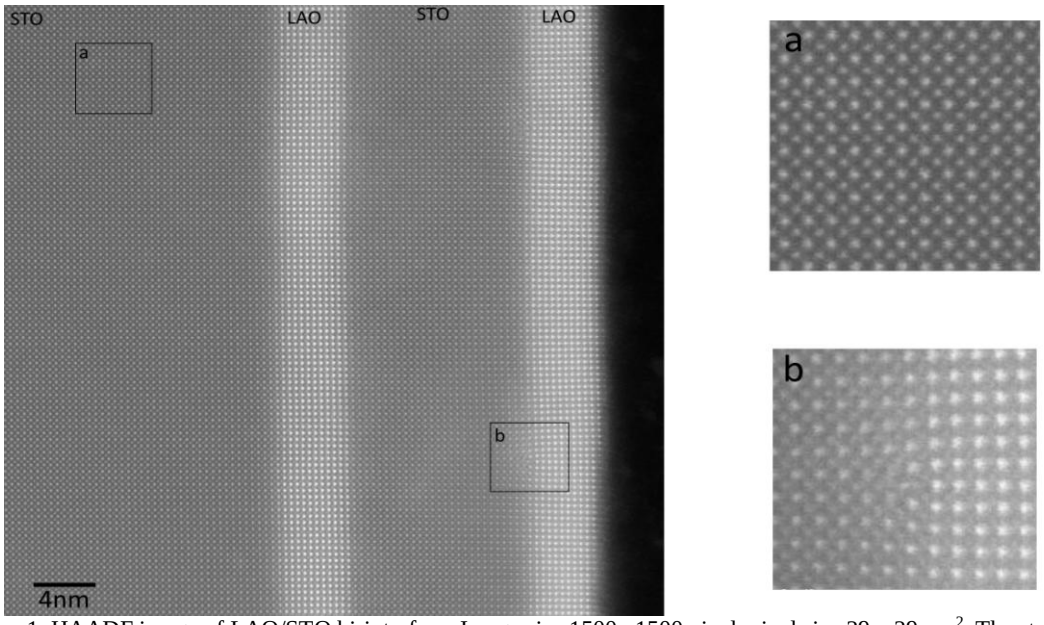

Figure 1. HAADF image of LAO/STO bi-interface. Image size 1500 x1500 pixel, pixel size 29 x 29 pm^2. The structural parameters estimated during the growth of the sample are : LAO 10 unit cells (uc) / STO 12 nm / LAO 10 uc / STO substrate. Insert **(a)** STO lattice, **(b)** dislocation.

3.3 Electron energy-loss spectra

The electron energy-loss spectra (EELS) provide useful information about the structure of the system, especially at the interfaces, where some changes in the chemical structure are expected to explain the occurrence of the 2DEG. The following edges were collected in a single spectrum: La $M_{4,5}$, Al K , Sr $L_{2,3}$, Ti $L_{2,3}$. The separation between the lowest peak (Ti $L_{2,3}$) and the highest (Sr $L_{2,3}$) is approximately 1.5 keV. The Ti chemical map is shown in fig. 2. It suggests a stronger inter-diffusion of Ti at the bottom interface (LAO layer / STO substrate) than at the middle one (STO layer / LAO layer).

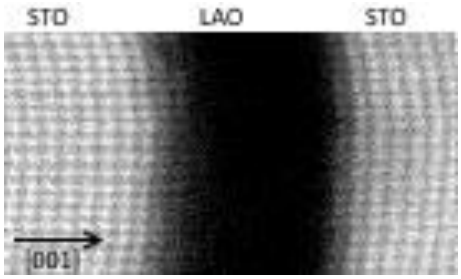

Figure 2. Chemical map of Ti. Growth direction from left to right.

Information about termination planes can be extracted from the chemical maps. The termination planes are key in this system; a LAO thin film/STO substrate heterostructure could have insulating or conductive transport properties when the STO crystal is respectively SrO or TiO_2 terminated [1]. According the profile of chemical maps shown in fig. 3, the middle interface termination planes are AlO_2-SrO and the top interface ones are TiO_2-LaO. The bottom interface termination is unclear.

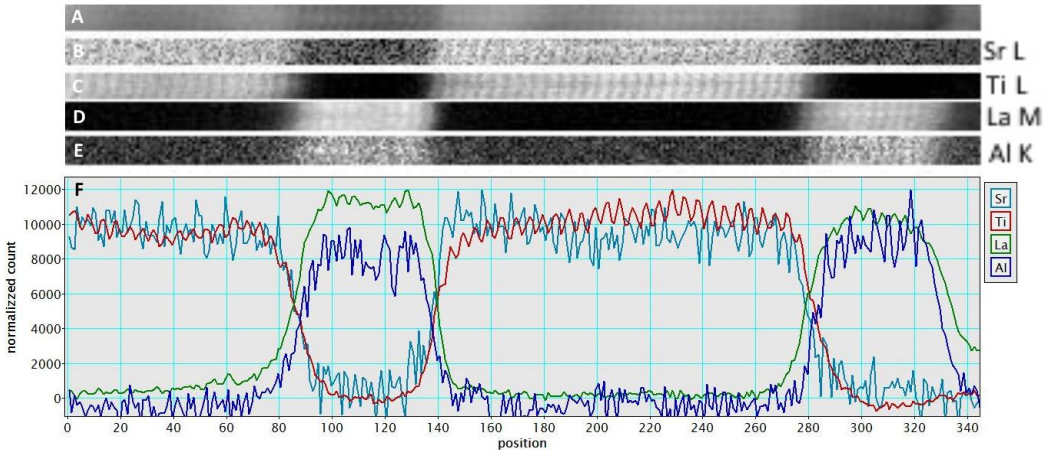

Figure 3 (a) Spectral image (b) Sr $L_{2,3}$ edge (c) Ti $L_{2,3}$ (d) La $M_{4,5}$ (e) Al K (f) profile of the chemical maps normalized and displayed together.

3. CONCLUSIONS

From the presented investigation some results can be reported:

1. The top interface is TiO_2-LaO terminated, the middle interface is AlO_2-SrO terminated
2. The middle interface is sharper than the bottom and top ones
3. Dislocations occur preferentially at the top interface

REFERENCES

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