How sharp are atomically sharp interfaces in complex functional oxide heterostructures?

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Complex functional oxide heterostructures have been serving as a multi-directional platform for engineering novel interface functionalities [1,2]. Recent technical improvements of the epitaxial growth techniques enable fabricating high-quality thin films and heterostructures. The phenomena occurring at their interfaces can be tailored depending on the choice of the constituents. However, the key factor dominating the interface functionalities is the control of interface sharpness. Perfect epitaxial grown and structurally sharp interfaces may be rough with respect to its corresponding chemical composition. Therefore, examining the interfacial structure and chemistry is vital for correlating with the physical properties.

Aberration-corrected scanning transmission electron microscopy (STEM)-based investigations reveal that the interface sharpness depends on many factors. Atomic column-resolved electron energy-loss spectroscopy (EELS) and energy-dispersive X-ray spectroscopy (EDX) spectrum imaging and high angle annular dark field (HAADF) and annular bright field (ABF) STEM imaging, a JEOL JEM-ARM200F equipped with a cold field-emission electron source, a probe Cs-corrector (DCOR, CEOS GmbH), and a Gatan GIF Quantum ERS spectrometer has been used. HAADF-STEM images taken from two $LaNiO_3$-La_2CuO_4 multilayers grown on different substrates are presented as examples among numerous further studied oxide heterostructures (Figure 1).

In this lecture, I present investigations on various complex functional oxide heterostructures exhibiting different interface sharpness and, correlatively, different functionalities. Some exciting findings demonstrate the following: i) The growth technique, i.e. pulsed-laser deposition versus atomic layer-by-layer oxide molecular beam epitaxy, has a direct impact on the structural and chemical sharpness of the interfaces [3], ii) two-dimensional doping of La_2CuO_4-based multilayers results in different dopant distribution at both sides of the interfaces which induce different superconducting mechanisms [4,5], iii) the choice of the dopant directly affects the interface sharpness, namely, dopant re-distribution, local octahedral distortions and thereby the interface functionalities [6,7]. The effect of dopant distribution at interfaces on physical properties will be discussed.

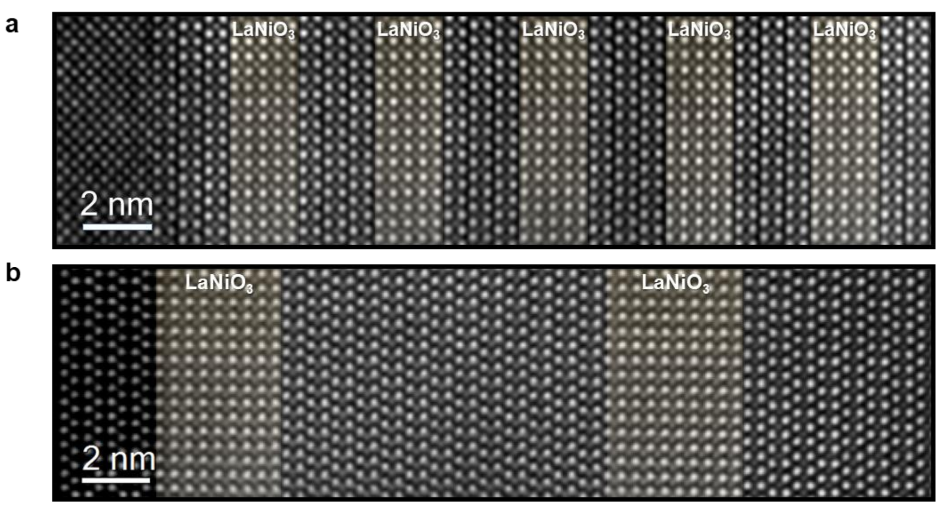

Figure1. HAADF-STEM images taken from $LaNiO_3$-La_2CuO_4 multilayers grown on (a) $(LaAlO_3)_{0.3}(Sr_2TaAlO_6)_{0.7}$ (LSAT) and (b) $LaSrAlO_4$ (LSAO) substrates demonstrate structurally sharp interfaces. The shaded areas mark the $LaNiO_3$ layers in each heterostructure.

References

[1] H. Y. Hwang, Y. Iwasa, M. Kawasaki, B. Keimer, N. Nagaosa, Y. Tokura, *Nat. Mater.* **2012**, *11*, 103.

[2] J. Mannhart, D. G. Schlom, *Science* **2010**, *327*, 1607.
[3] F. Wrobel, A. F. Mark, G. Christiani, W. Sigle, H.-U. Habermeier, P. A. van Aken, G. Logvenov, B. Keimer, E. Benckiser, *Appl. Phys. Lett.* **2017**, *110*, 041606.
[4] F. Baiutti, G. Logvenov, G. Gregori, G. Cristiani, Y. Wang, W. Sigle, P. A. van Aken, J. Maier, *Nat. Commun.* **2015**, *6*, 8586.
[5] Y. Wang, F. Baiutti, G. Gregori, G. Cristiani, U. Salzberger, G. Logvenov, J. Maier, P. A. van Aken, *ACS Appl. Mater. Interfaces* **2016**, *8*, 6763.
[6] Y. E. Suyolcu, Y. Wang, F. Baiutti, A. Al-Temimy, G. Gregori, G. Cristiani, W. Sigle, J. Maier, P. A. van Aken, G. Logvenov, *Sci. Rep.* **2017**, *7*, 453.
[7] Y. E. Suyolcu, Y. Wang, W. Sigle, F. Baiutti, G. Cristiani, G. Logvenov, J. Maier, P. A. van Aken, *Adv. Mater. Interfaces* **2017**, *4*, 1700737.