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Visualizing Interface Effects in Two-dimensionally Doped La_2CuO_4 and La_2CuO_4/ $La_{2-x}Sr_xNiO_4$ Superlattices

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Physics phenomena at interfaces of complex oxide hetero-structures have stimulated intense research activity due to the occurrence of a broad range of electric and magnetic functionalities that do not pertain to the constituting single phases alone. Interface effects have been proven to be a powerful tool for improving or even inducing novel functionalities [1, 2]. In the case of interface superconductivity, the interatomic structure relaxation and charge transfer play a key role.

In this work, we combine atomic-resolved quantitative STEM imaging with analytical STEM-EELS/EDX analysis to investigate interface effects in La_2CuO_4 (LCO)-based hetero-structures, i.e. superlattices of two-dimensionally (2D) Sr-doped LCO, and LCO/$La_{2-x}Sr_xNiO_4$ (LSNO) hetero-structures, both exhibiting T_c up to 40 K, despite its non-superconducting constituents. We lay emphasis on detailed and quantitative STEM analysis to understand the interplay between interface effects (cation and electron hole redistribution, as well as local lattice and oxygen octahedral distortion) and high-temperature interfacial superconductivity.

A detailed study of the cation distribution and concentration at the Sr-doped interfaces was performed by EDXS and EELS analyses. In the case of 2D Sr-doped LCO superlattices, the analysis shows that Sr cations undergo an asymmetric redistribution, as a result of the MBE growth process. Oxygen K-edge fine structure analysis reveals that the hole concentration profile on the downward side of the nominal SrO layer is clearly decoupled from the Sr-profile indicating an accumulation of positive charges compensating the negatively charged SrO planes. In the second example, the cationic intermixing, i.e. La/Sr and Ni/Cu, at the LCO/LSNO interfaces will be discussed.

Atomic-resolved high-angle annular dark-field (HAADF) and annular bright-field (ABF) images, which were simultaneously acquired, were used to evaluate the local lattice and copper-apical-oxygen distortions at these interfaces. As an example, Fig. 2 shows an overlay of HAADF (green) and ABF (red) images of one 2D Sr-doped region, in which the oxygen atomic columns are clearly resolved as dark dots on red background. The interatomic structure analysis shows that the copper-apical-oxygen distance, which is known to be strongly related with T_c, has a remarkable variation near the interface. We observe an anomalous expansion of the apical oxygen–oxygen distance on the downward side of the nominal SrO layer, and a substantial shrinkage of the apical oxygen–oxygen distance on the upward side.

The investigation of the correlation between charge redistribution, local atomic structural changes, and the electrical properties are fundamental for the understanding of interfacial superconductivity in Sr-doped LCO hetero-structures. [3]

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[2] F.Baiutti *et al.*, Nat. Commun. **6** (2015), p. 8586.
[3] The research leading to these results has received funding from the European Union Seventh Framework Program under Grant Agreement 312483-ESTEEM2 (Integrated Infrastructure Initiative I3).

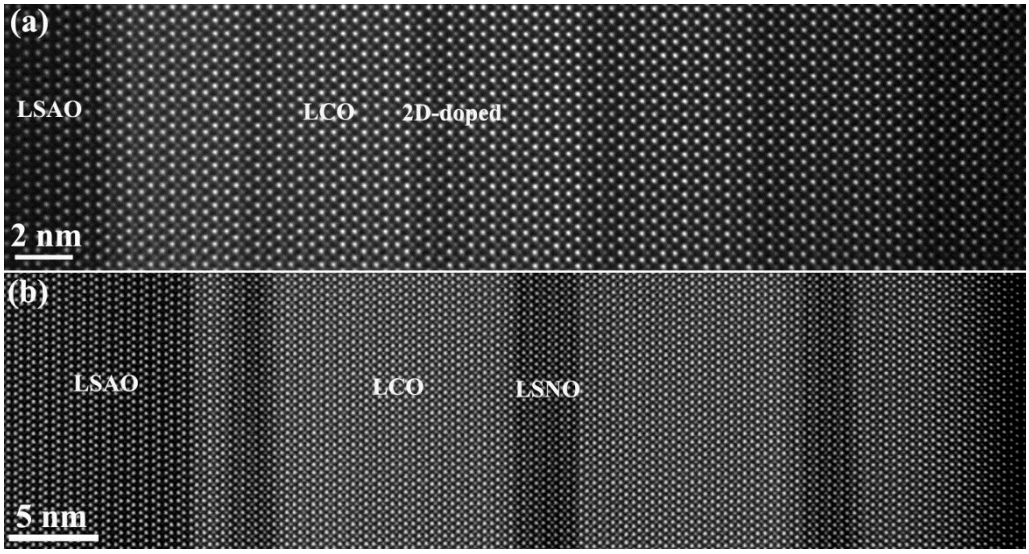

Figure 1. HAADF-STEM image of 2D Sr-doped LCO superlattices (a) and LCO/LSNO heterostructures (b) grown on LSAO (001) substrate. Both images were taken along the crystallographic [100] direction of LSAO.

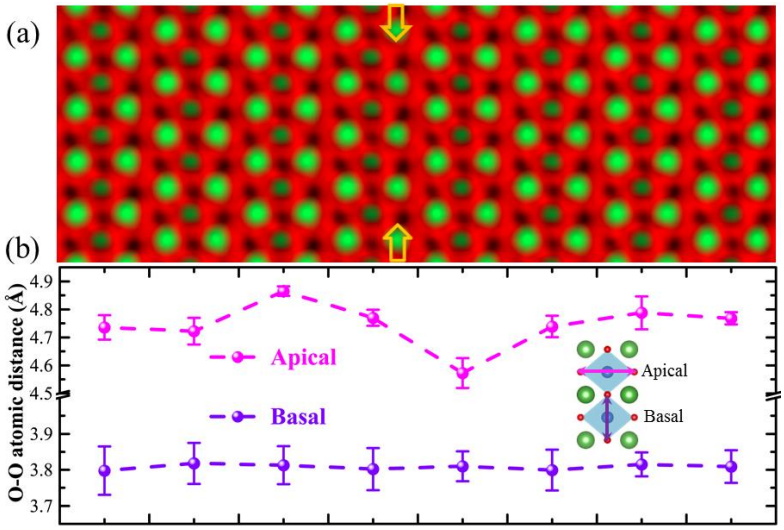

Figure 2. (a) Overlay of simultaneously acquired HAADF (green) and ABF (red) images of one 2D Sr-doped area. The yellow arrows indicate the nominal position of the SrO layer. (b) O–O spacing along apical and basal directions as function of distance from the nominal Sr-doped layer.

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