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Emergent Interfacial Magnetism in Superconducting Cuprate-Manganate Superlattices

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The realization of quantum computing via a combination of oxide superconducting and ferromagnetic systems such as *SFS-junctions*, i.e. superconductor/ferromagnet/superconductor heterostructures, inevitably requires crystallographically and chemically sharp interfaces [1]. Such devices would allow the construction of so-called *quiet qubits* that could serve as the main building block in future quantum computers because of their decoupled nature resulting in low-noise levels [2]. As the mechanism at the atomic scale behind these quantum devices has not been well explored until today [1,3], scanning transmission electron microscopy (STEM) is the method of choice to shed light on the chemistry, structure, and physics of the respective SFS-junctions' interfaces [4,5].

For our investigations, we have synthesized ultrathin cuprate-manganate heterostructures via ozone-assisted atomic layer-by-layer molecular beam epitaxy (ALL- Oxide MBE) and determined their physical properties via electrical resistance, mutual inductance, and magnetization vs. temperature measurements. Here, we focus on a newly discovered magnetic phase in the proximity of a superconductor. Superlattices consisting of $La_{1.84}Sr_{0.16}CuO_4$ and $Sr_{2-x}La_xMnO_4$ phases reveal (i) high-temperature superconductivity, (ii) chemically sharp interfaces, and (iii) emergent interfacial magnetism. Structure-property relationships are deduced utilizing STEM techniques such as electron energy-loss spectroscopy (EELS), sub-Ångström-resolved high-angle annular dark-field (HAADF) imaging, and annular bright-field (ABF) imaging at the atomic scale. In particular, EELS fine structure analyses of the O-K edge and the Mn-$L_{2,3}$ edges revealed electronic insights into the unoccupied density of states (DOS) that are directly linked to structural (anti) Jahn-Teller distortions visualized via ABF imaging. The unique combination of structural and electronic characterization in the proximity region of manganite-cuprate systems highlights the state-of-the-art benchmark for investigations of hetero-epitaxial interfaces, linking them to their subsequent physical properties. [6]

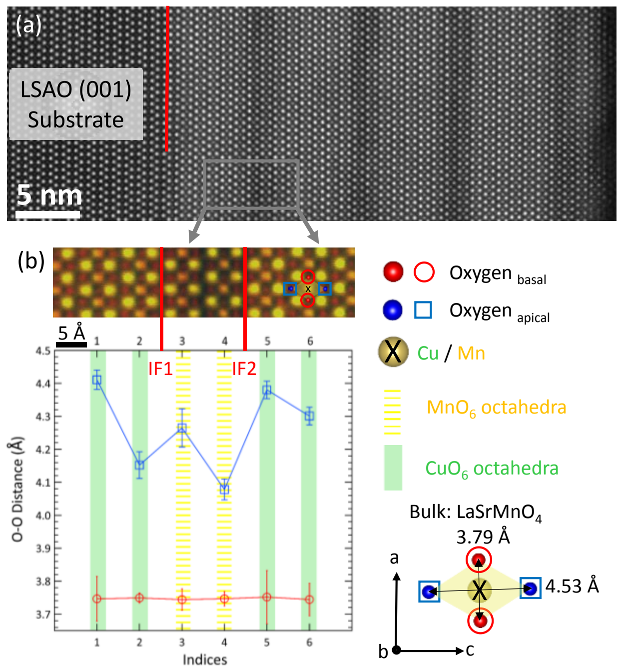

Figure 1. Crystallographic and chemical overview of a 4 x (6 half unit cells $La_{1.84}Sr_{0.16}CuO_4$ + 2 half unit cells $SrLaMnO_4$) + 6 half unit cells $La_{1.84}Sr_{0.16}CuO_4$ superlattice on a $LaSrAlO_4$ (001) substrate. (a) HAADF image of all 8 interfaces of the superlattice as well as the interface to the substrate (red bar). The grey rectangle in (a) shows the area for the overlay of HAADF and inverted ABF images depicting the respective O-O distances of the CuO_6 (green full bars) or MnO_6 (yellow striped bars) octahedra in (b) at the two interfaces, i.e. IF1 and IF2 depicted by two red bars.

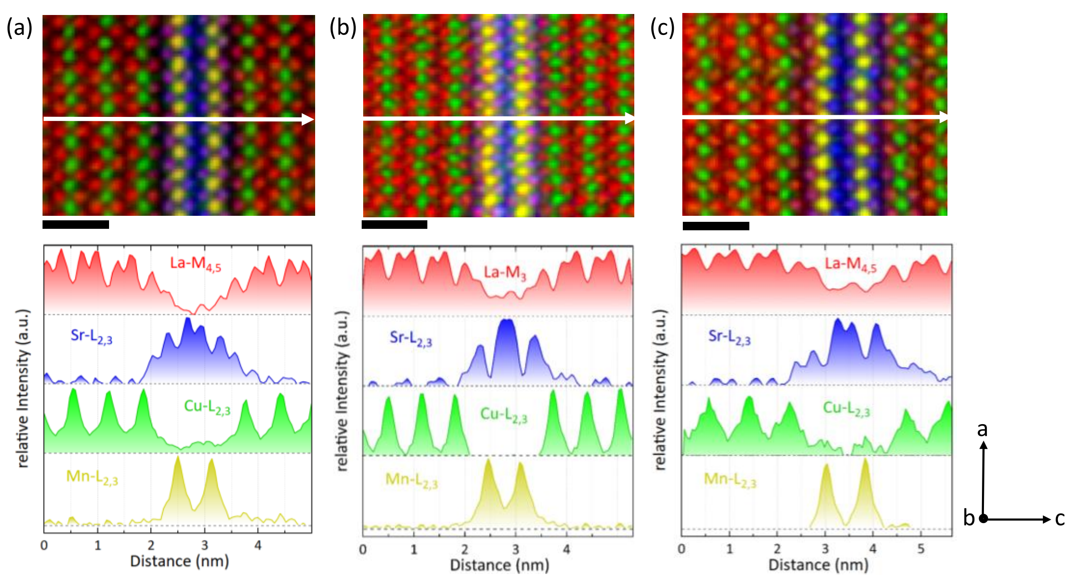

Figure 2. Visualization of elemental distribution at the interface via 2D EELS mapping (top) and 1D profiles (bottom) of all superlattices. (a), (b) and (c) depict the superlattices with Sr_2MnO_4, $Sr_{1.5}La_{0.5}MnO_4$, and $SrLaMnO_4$ unit cells, respectively. White arrows depict the direction of the 1D elemental profiles.

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