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## Long-ranged Cu-based order at cuprate/manganite interface

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We present a resonant inelastic and elastic X-ray scattering (RIXS/REXS) study of epitaxial  $\text{YBa}_2\text{Cu}_3\text{O}_7/\text{Nd}_{1-x}(\text{Ca}_{1-y}\text{Sr}_y)_x\text{MnO}_3$  heterostructures (NYN). We show that the Copper charge density wave (Cu-CDW) order of the near optimally doped  $\text{YBa}_2\text{Cu}_3\text{O}_7$  layers can be strongly modified via the hole doping and tolerance factor of  $\text{Nd}_{1-x}(\text{Ca}_{1-y}\text{Sr}_y)_x\text{MnO}_3$ , i.e. by changing  $x$  and  $y$ .

At  $x=0.35$  we observe a quasi-2D Cu-CDW order with  $dx^2-y^2$  orbital character that resembles the one that is commonly found in strongly underdoped bulk YBCO. The strength of the corresponding Bragg peak at  $Q_{\parallel}=0.3$  r.l.u. gets strongly enhanced as the tolerance factor of the manganite layers[1] is decreased and its CE-type antiferromagnetic and charge/orbital ordered (COO) is reinforced[1].

Upon increasing the hole doping of the manganite layers to  $x=0.5$ , we observe a new kind of Cu-CDW order which has a much smaller wave vector of  $Q_{\parallel}=0.1$  r.l.u., a larger correlation length of about 40nm, and a different orbital character, i.e.  $dz^2$  rather than  $dx^2-y^2$ , than the one commonly found in the bulk cuprates[2].

The origin of this new Cu- $dz^2$  charge order is presently not understood, but seems to be rooted in the particular properties of the cuprate/manganite interface. The RIXS and additional x-ray absorption spectroscopy (XAS) data provide evidence for an important role of the orbital reconstruction of the Cu-ions at the interface with the manganite and a related transfer of electrons from the manganite to the cuprate. In particular, they show that the Cu- $dz^2$  orbital of the interfacial Cu ions is strongly shifted up in energy and lies close to the Fermi-level such that it contains a significant part of the hole carriers, which usually mainly reside in the Cu- $dx^2-y^2$  orbital. This orbital reconstruction may well exhibit a lateral modulation along the interface that is linked with the anomalous  $dz^2$ -type Cu-CDW order.

While further studies are required to fully understand the interfacial coupling mechanism(s), the possibility of tuning the Cu-CDW holds great prospects for studying its relationship with high temperature superconductors and hopefully, for future quantum devices.

### References

1. E. Perret et al., Coupled Cu and Mn charge and orbital orders in  $\text{YBa}_2\text{Cu}_3\text{O}_7/\text{Nd}_{0.65}(\text{Ca}_{1-y}\text{Sr}_y)_{0.35}\text{MnO}_3$  multilayers, *Communications Physics* **1**, 45 (2018);
2. R. Gaina et al., Long-ranged Cu-based order with  $dz^2$  orbital character at a  $\text{YBa}_2\text{Cu}_3\text{O}_7$ / manganite interface. *npj Quantum Materials* **6**, 12 (2021);

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