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High-resolution mapping of magnetic properties in oxide heterostructures and nanosystems

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Dra. María Varela

Universidad Complutense de Madrid

Complex oxides with a perovskite structure show a wide range of interesting properties due to a strong interplay and competition between lattice, spin, and charge degrees of freedom. This is particularly the case when obtained in the form of thin films or heterostructures, where novel macroscopic functionalities may arise. In this talk we will apply atomic resolution aberration corrected scanning transmission electron microscopy (STEM) and electron energy-loss spectroscopy (EELS) to the study of the structure and properties of magnetic oxide heterostructures. A first example of application involves local measurements of electronic and magnetic properties of ferromagnetic manganite $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) epitaxial ultrathin films grown by high-pressure O_2 sputtering on single crystal $SrTiO_3$ (STO) substrates. We will combine STEM-EELS with density-functional calculations to study local structural distortions and electronic phenomena associated with interfacial magnetism. Atomic resolution images exhibit an increase of the out-of-plane lattice parameter at the LSMO/STO interface plane, pointing to a local reconstruction of the charge density and, hence, physical properties. We use energy-loss magnetic chiral dichroism (EMCD) [1], a technique directly sensitive to the local magnetic moment, to track magnetic quantities across the interface with sub-unit cell resolution. The dichroic signal at both the Mn $L_{2,3}$ and the Ti $L_{2,3}$ edges is enhanced near the interface, pointing to a local increase of the Mn and Ti magnetic moments. These results agree with density-functional theory simulations including interfacial oxygen vacancies, which enhance charge transfer and antiferromagnetic coupling between the Ti and the Mn. A second example can be found in the study of the electronic and magnetic properties of multiferroic interfaces where ultrathin ferroelectric $BaTiO_3$ (BTO) barriers are sandwiched between ferromagnetic LSMO electrodes. Real space measurements of local polarization obtained through the analysis of atomic resolution annular bright field images [3] will be compared to magnetic quantities measured from spatially resolved EMCD. Finally, the magnetic properties of bimagnetic FeO/Fe_3O_4 core/shell nanoparticles will be discussed. In this system the magnetic arrangement at the interface can play a crucial role in the properties and performance of the nanoparticles, with the magnetic moment being largest at the surface and decreasing towards the inner part of the nanoparticle [4].

*[1] P. Schattschneider et al., Nature **441** (2006) pp. 486-488.*
*[2] J. Salafranca et al., NanoLetters **12** (2012), pp. 2499-2503.*
*[4] G. Sanchez-Santolino et al., Nature Nanotechnolgy **12**, (2017) 655-662.*
*[5] D. Del Pozo-Bueno et al., NanoLetters **21** (2021) pp. 6923-6930.*

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