ESRF	**Experiment title:** Orbital and magnetic order in strained $LaMnO_3$ thin films	**Experiment number**: HE-3123
Beamline: ID08	**Date of experiment**: from: 25/11/2009 to: 01/12/2009	**Date of report**: 25/02/2010
Shifts: 18	**Local contact(s)**: Dr Nicholas BROOKES (e-mail: brookes@esrf.fr)	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Carmela ARUTA* CNR-INFM Coherentia & University of Naples "FedericoII", Italy
Nicholas BROOKES*, ESRF
Alice GALDI* CNR-INFM Coherentia & University of Salerno, Italy
Giacomo GHIRINGHELLI* CNR-INFM & Politecnico di Milano, Italy
Marco MORETTI SALA* CNR-INFM & Politecnico di Milano, Italy
Luigi MARITATO* CNR-INFM Coherentia & University of Salerno, Italy
Pasquale ORGIANI* CNR-INFM Coherentia & University of Salerno, Italy

Report:

The aim of the proposed experiment was the investigation of the magnetic and orbital phase diagram of $La_xMnO_{3-\delta}$ (LMO) thin films grown by Molecular Beam Epitaxy, as a function of several controlled structural parameters. Heavy-ion La/Mn stoichiometric ratio was varied from La-deficient, to 1:1-stoichiometric $LaMnO_3$, and finally to La-rich. Different bi-axial strain was induced by growing LMO films on different substrates: namely $SrTiO_3$ (STO), where the films are expected to experience negligible strain, $NdGaO_3$ (NGO) and $LaAlO_3$ (LAO), where the films are expected to experience compressive strain of -1.2% and 3.0%, respectively. In order to investigate the electronic properties and the local structure of strained and unstrained LMO thin films grown on various substrates and having different thickness, we proposed to do polarization dependent X-ray Absorption Spectroscopy (XAS) and Resonant Inelastic X-ray Scattering (RIXS) characterization (both at the Mn $L_{2,3}$ and O K absorption edges). X-ray Magnetic Circular Dichroism (XMCD) and Linear Dichroism (LD) XAS allowed us the experimental determination of the orbital reconstruction and the magnetic order in manganite films. Complementary, RIXS is sensitive to the variations of the electronic excitation energies related to the tetragonal distortions, thus providing an extremely accurate information about the degree of hybridization of Mn_{3d} and O_{2p}, which depends on the Mn-O distances influenced by substrate-induced strain.

The following $LaMnO_3$ samples on different substrates and with different compositions, i.e. different values of the La/Mn ratio, have been measured:

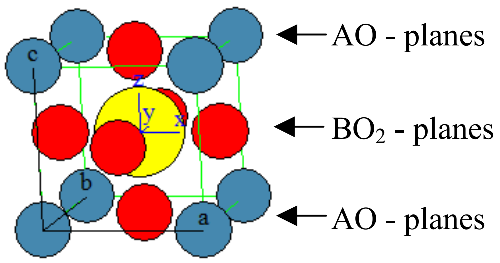
Substrate	**La/Mn ratio**				
	0.76	0.88	0.98	1.05	1.07
STO	ML080711F_STO (sample#06)	ML081013F_STO (sample#13) ML081013L_STO (sample#03)*	ML081014F_STO (sample#05)	ML081216F_STO (sample#09)	ML081218F_STO (sample#04)
LAO	ML090217L_LAO (sample#08)		ML090216L_LAO (sample#02)		ML090218L_LAO (sample#07)
NGO	ML090217L_NGO (sample #12)		ML090216L_NGO (sample#01)*		ML090218L_NGO (sample#11)

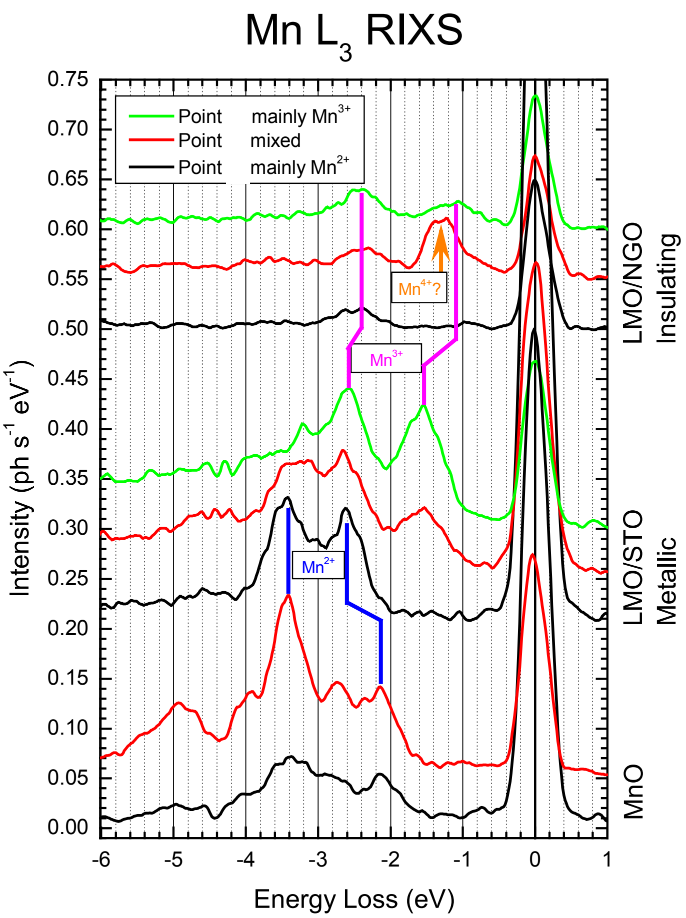
* also measured by RIXS

Linear and circular dichroism (LD and XMCD) have been performed on all samples. The LD on a single crystal of MnO has been also measured as a reference sample. Mn L- and O K- edges LD have been measured in zero-field-cooled (ZFC) at 300K and 10K, both with and without 1T applied magnetic field. Mn L-edge XMCD has been measured at 1T, 300K and 10K, both in Grazing and in Normal Incidence (GI and NI) to check the magnetic anisotropy. In few cases, we have also measured at 5T and 3 T and sample#13 has been measured also in field-cooled (FC) at 100K and 10K. Samples with different La/Mn content on $SrTiO_3$ substrates (negligible-strain case) were investigated. Data are presently under investigation.

The three following LMO samples were selected to be investigated by RIXS:

Sample	*Physical properties*	*Characteristic XAS feature*
ML081013L_STO (sample#03)*	Metallic and Ferromagnetic (T_{MI} = 380K; T_{Curie} = 360K)	presence of Mn^{2+} features
ML090216L_NGO (sample#01)*	Insulating	No Mn^{2+} features
MnO single crystal	Insulating	reference sample





As previuosly said, RIXS spectra provide an extremely accurate information about the degree of hybridization of Mn_{3d} and O_{2p}, which substantially depends on the Mn-O structural arrangement. In the B-site (see figure aside), the atom is tetrahedraly coordinated with 6 oxygen atoms, while in the A-site, the atom has 12 first-neighbors in an almost-spherical coordination. As a consequence, sizeable differences in RIXS spectra are expected to occur (for instance) in these two limit-cases. As a preliminary step, XAS experiments were also performed in RIXS chambers on a metallic and ferromagnetic LMO sample grown on $SrTiO_3$ substrate, and on an insulating LMO sample grown on $NdGaO_3$ substrate (see aside). Three significant energies were selected in the XAS spectra to run RIXS experiments. In particular, the selected energies were at about 640.0eV (E_1), 641.5eV (E_2) and 642.2eV (E_3); the E_1 and E_3 energies correspond to Mn^{2+} and Mn^{3+} transition energies, respectively. E_2 can't be triavially associated to a single Mn characteristic transition energies, but most likely to some a Mn^{2+}/Mn^{3+} mixed characteristics. As a reference, we also decided to perform RIXS experiments on a MnO single crystal. The 3 samples give very different results. The spectra at point A in MnO and LMO/STO are very different, indicating a very different crystal field in the two situations for the Mn^{2+}. Calculation of the RIXS spectra for Mn^{2+} for different crystal field are mandatory to understand experimental data.

By considering the original proposal, all the aimed goals were achieved.