The oxides of the transition metals show a rich variety of physical properties due to the interplay of cooperating and competing microscopic degrees of freedom (e.g. charge, orbital, spin, lattice). Heterostructures made from these materials exhibit new physical properties and novel functionalities. Here, the family of oxide perovskites plays a crucial role, since perovskites have only a small lattice mismatch. Thus, this small mismatch allows growing of epitaxial ultra-thin films with a thickness of only a few unit cells (uc).

One interesting system in this material group is LaNiO$_3$: Recent density functional theory has predicted for the novel (1uc/1uc) heterostructure, that by "stretching" the heterostructure, one of the two hybridizing Ni-O $p\sigma$ $e_g$ conduction bands can be pushed up such that it is almost completely depleted [2]. Experimentally, "stretching" ("compressing") can be realized by the epitaxial growth on suitable substrates like, e.g., SrTiO$_3$ (STO, "stretching") or LaSrAlO$_4$ (LSAO, "compressing"). In the "stretching" scenario inclusion of electron-electron interactions within dynamical mean-field theory shifts this band further up above the Fermi level, and the electron is left in only one of the $e_g$ bands. This $x^2$-$y^2$-like band gives rise to a Fermi surface sheet which resembles that of the high-$T_c$ superconducting cuprates. While experimentally it is not yet possible to fabricate the 1/1 heterostructure with the required submonolayer precision, we expect important results from studying [LaAlO$_3$(x u.c.)/LaNiO$_3$(x u.c.)]$_n$ superlattices with various layer thicknesses (4uc//4uc to 2uc//2uc) and on different substrates to get information, whether or not one is on the right route towards an artificially designed cuprate-like Fermi surface with the prospect of superconductivity at high transition temperature.

We have performed Hard X-ray photoemission spectroscopy (HAXPES) at beamline P09 on several [LaNiO$_3$ (x u.c.)/LaAlO$_3$(x u.c.)]$_n$ superlattices grown by pulsed laser deposition at MPI Stuttgart.
(AK Habermeier) on STO and LSAO substrates, respectively. The growth conditions are described in Ref. [1]. The LNO/LAO-bilayers thicknesses were varied between (2uc/2uc) and (4uc/4uc). A sketch of this superlattice is given in Fig. 1. HAXPES is a powerful tool to investigate the electronic structure of the buried interfaces of these superlattices, since the information depth of the emitted photoelectrons is much higher (>5nm) in this energy regime.

![Graph showing Al 1s core level spectra of several LNO-LAO-multilattices grown on STO (left panel) and LSAO (middle panel), respectively. A clear asymmetry indicated by the arrow can be observed. This asymmetry decreases significantly, if the (2uc/2uc) samples are cooled down to low temperatures (right panel).](image)

Figure 2: Al 1s core level spectra of several LNO-LAO-multilattices grown on STO (left panel) and LSAO (middle panel), respectively. A clear asymmetry indicated by the arrow can be observed. This asymmetry decreases significantly, if the (2uc/2uc) samples are cooled down to low temperatures (right panel).

Fig. 2 shows the measured Al 1s core level spectra of several samples grown on STO (left panel) and LSAO (middle panel). A clear asymmetry at higher binding energies can be observed at all samples in respect to the reference spectrum measured on a LaAlO$_3$/SrTiO$_3$, where no asymmetry appears. Furthermore, the asymmetry is increasing with the decrease of the LNO/LAO-layer thickness (4uc/4uc to 2uc/2uc). This might be due to charge leaking from the nickelate to the aluminate layers. Our results show that this charge leaking seems to be independent or only less influenced of the "stretching" ("compressing") mechanism induced by the different substrates.

Optical conductivity measurements in the group of our collaborators at the Max Planck Institute for Solid State Research (Stuttgart, AK Habermeier) hint to a metal-insulator transition around 125K in superlattices with 2 unit cells, possibly due to in-plane charge ordering, stabilized by an intrinsic charge-density wave instability when approaching the 2D limit. The installed endstation at beamline P09 is equipped with a LHHe-cryostat, which enables cooling of the samples down to 20K and performing HAXPES investigations at low temperatures. In Fig. 2 (right panel) first measurements well below the predicted metal-insulator transition (MIT) are shown. Indeed, the asymmetry at the (2uc/2uc) sample decreases significantly. In comparison, the (4uc/4uc) sample shows only a slight change in the line shape due to temperature broadening. This behavior supports the existence of a MIT at low temperatures, since charge leaking should decrease below the critical temperature.

Further investigations on these very exciting oxide superlattices contain measurements of the valence band of samples with different layer thicknesses using the high-resolution post-monochromator, which will be installed soon at beamline P09.

References