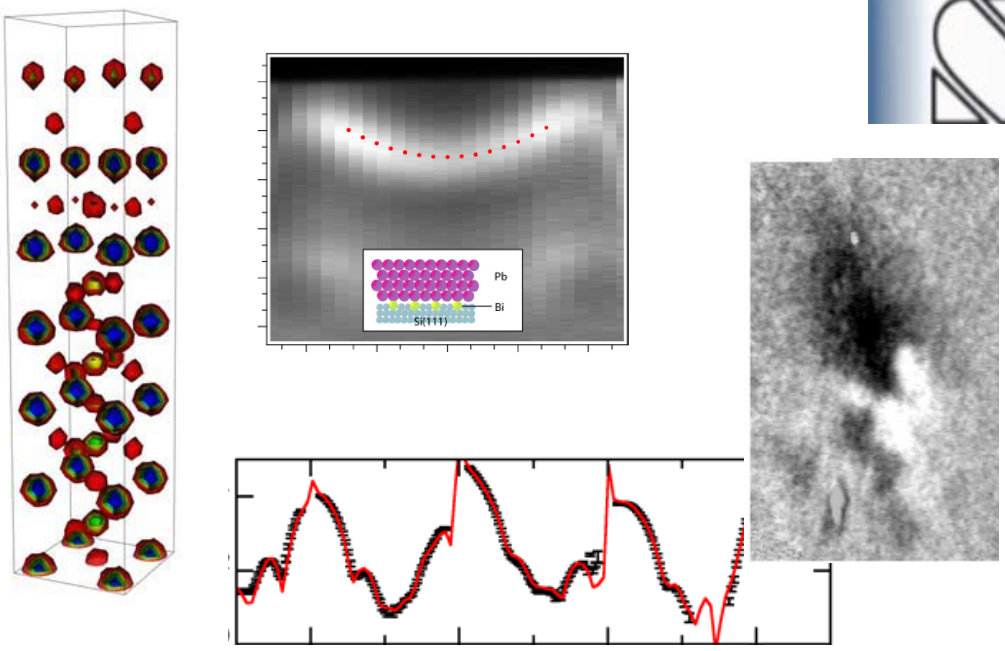

SLS Symposium on

Interfaces

Tuesday, April 13, 2010

10:00 to 12:15, WBGB/019

10:00 Structural Studies of The Interfaces Between Insulating Metal Oxides
S.A. Pauli, M. Björck, S.J. Leake, C.M. Schlepütz, D. Martoccia and P.R. Willmott

10:30 Electronic structure investigations on the conduction mechanism at the $LaAlO_3/SrTiO_3$ interface by Resonant Inelastic X - Ray Scattering
K. Zhou, M. Radovic, J. Schlappa, V.N. Strocov, J. Mesot, L. Patthey and T. Schmitt

11:00 Coffee

11:15 Ultrafast laser-induced spin dynamics in exchange coupled Co/SmFeO3 heterostructure
L. Le Guyader, L. Joly, A. Kleibert, F. Nolting, R. Pisarev, A. Kirilyuk, Th. Rasing and A. Kimel

11:45 Controlling the properties of quantum well states by interface engineering
B. Slomski, F. Meier, J. Osterwalder and H. Dil

Structural Studies of The Interfaces Between Insulating Metal Oxides

S.A. Pauli, M. Björck, S.J. Leake, C.M. Schlepütz, , D. Martoccia, and P.R. Willmott

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The physics responsible for the formation of a highly mobile, two-dimensional, electron gas at the interface of two insulators has been the subject of considerable research and controversy since its discovery in the $LaAlO_3/SrTiO_3$ interface [1,2]. Furthermore, it has been demonstrated that the formation of conductance at the interface only occurs for $LaAlO_3$ films with thicknesses above three monolayers [3]. It is well known that in strongly correlated electron systems even subtle changes in the structure, *i.e.*, in the atomic positions or in the chemical composition, can lead to profound differences in the physical properties. Hence, a structural model of the $LaAlO_3/SrTiO_3$ interface structure with sub-Angstrom resolution is essential in order to understand these phenomena. Surface X-Ray Diffraction (SXRD) is uniquely capable of providing this required accuracy.

The availability of high-brilliance hard x-ray synchrotron radiation and the advent of novel, photon-counting, area detectors [4] have brought SXRD into a new era. It is now possible to record several thousand structure factors with much improved reliability within reasonable beamtime durations. As a result, structural determination of the surfaces and interfaces of complex crystallographic systems and heterostructures has now become feasible, especially in conjunction with phase-retrieval methods [5].

In this presentation, the evolution of the atomic structure of the interface between $LaAlO_3$ and $SrTiO_3$ as a function of monolayer thickness will be described. The structures were extracted using phase-retrieval algorithms followed by conventional structural refinement.

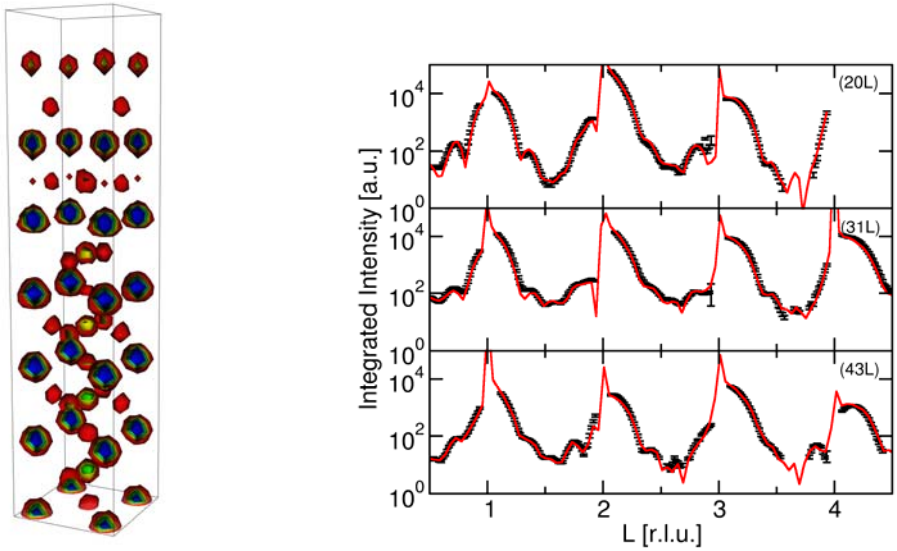

Figure: *Left:* Electron density map of 5 monolayers of $LaAlO_3$ on $SrTiO_3$ recovered by the phase-retrieval algorithm. *Right*: Measured (black) and calculated (red) intensities of 3 crystal truncation rods of the same sample after a conventional structural refinement.

References:

[1] A. Ohtomo and H. Y. Hwang, Nature 427, 423 (2004).
[2] P. R. Willmott et al., Phys. Rev. Lett. 99, 155502 (2007).
[3] S. Thiel, G. Hammerl et al., Science 313, 1942 (2006).
[4] C. M. Schlepütz et al., Acta. Crystallogr. A61, 418 (2005).
[5] M. Björck et al., J.Phys. Condens. Matter 20, 445006 (2008)..

Electronic structure investigations on the conduction mechanism at the $LaAlO_3/SrTiO_3$ interface by Resonant Inelastic X-Ray Scattering

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Oxide heterostructures have been attracting great attention due to extraordinary phenomena occurring at the interface and their potential application for device design employing oxide materials. A particularly fascinating system is the two-dimensional conductive interface between the band insulators $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) which can be even driven to magnetic and superconducting phase at low temperature [1-5]. The 'charge transfer' conduction mechanism was proposed to be due to polar discontinuity created between the polar LAO and non-polar STO. The increased electric potential thereby induces the system to reconstruct by moving half an electron from the surface into the interface then turning some Ti cations from 4+ to 3+ states. However, systematic studies of carrier densities have elucidated that oxygen vacancies (Vo) are also a vital ingredient to the conduction mechanism, although ion intermixing cannot be excluded [6-8]. Since Vo can also bind to Ti ions and create Ti^{3+} states, unravelling the existence of multivalent Ti ions is a key issue for understanding the conduction mechanism.

Resonant Inelastic soft X-ray Scattering (RIXS) is an ideal tool to probe the signature of conduction, the Ti^{3+} state, not only because it is a non-destructive method with bulk sensitivity, but especially since Ti^{3+} states clearly display strong *dd* excitations while Ti^{4+} states exhibit no excitations in the low energy regime. This peculiar feature will unambiguously serve as a fingerprint for small amount of Ti3+ states. In the presentation, RIXS investigations on the modulation of the electronic structure of Ti cations through the LAO/STO interfaces will be shown.

References:

[1] A. Ohtomo and H. Y. Hwang, *Natrue* **427**, 423 (2004).
[2] M. Huijben *et al.*, *Nat. Mater.* **5**, 556 (2006)
[3] S. Thiel *et al.*, *Science* **313**, 1942 (2006).
[4] A. Brinkman *et al.*, *Nature Mater.* **6**, 493 (2007).
[5] N. Reyren *et al.*, *Science* **317**, 1196 (2007) ; A. D. Caviglia *et al.*, *Nature* 456, 624 (2008).
[6] W. Siemons *et al.*, *Phys. Rev. Lett.* **98**, 196802 (2007).
[7] A. Kalabukhov *et al.*, *Phys. Rev. B* 75, 121404 (2007).
[8] P. R. Willmott *et al.*, *Phys. Rev. Lett.* 99, 155502 (2007).

Ultrafast laser-induced spin dynamics in exchange coupled Co/$SmFeO_3$ heterostructure

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The magnetization direction of ferromagnetic (FM) films can be pinned in a given direction by interface exchange coupling with an underlying antiferromagnet (AFM). The resulting heterostructure is one of the key component in nowadays hard drive's read head. It constitutes there the reference magnetic layer, while an additional soft free magnetic layer aligns its magnetization in the stray field of the magnetic recorded information. The resulting alignment of the free layer with respect to the reference layer gives rise to different resistivity, and thus allows one to read the stored information.

The AFM layer in such case is considered a static component. However, the spins dynamics in AFM material is much faster than in FM material, thanks to the strong exchange field governing it. For example, it has been demonstrated recently that a subpicosecond laser-excitation of an antiferromagnetic orthoferrites $RFeO_3$ (R is a rare-earth ion) may result in ultrafast modification of the magnetic anisotropy followed by a reorientation of the antiferromagnetic spins over 90-degrees within a few picoseconds[1]. What would then be the response of an FM-layer in a exchange coupled FM-AFM structure if such an ultrafast spin-reorientation in the AFM takes place? How fast would the FM-layer reorient? Could one turn a read head device into an ultrafast writing head?

Here we report on our investigations of the laser-induced dynamics of Co spins in a exchange coupled Co/$SmFeO_3$ heterostructure[2]. With the help of X-ray magnetic circular dichroism (XMCD) and time-resolved Photoemission electron microscopy, we are able to observe the reorientation of Co-spins which turns out to be faster than 100 ps.

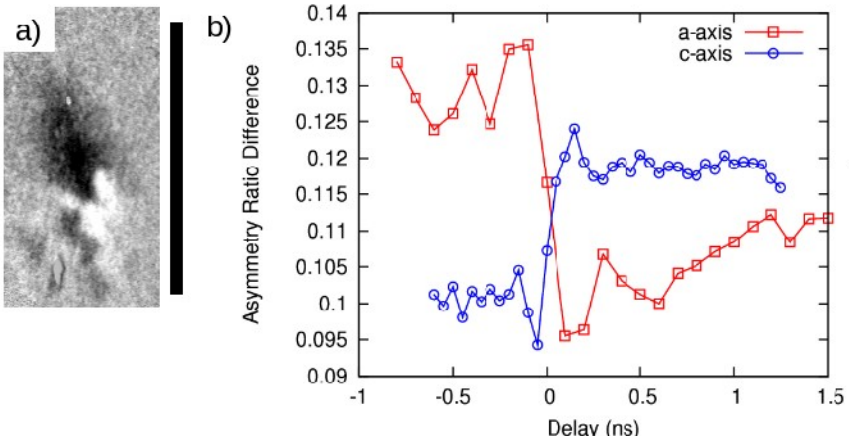

Fig1: a) XMCD image difference between before and after laser overlap, at the Co L_3 edge along the c-axis, showing an increase of magnetic contrast within the laser trace. The scale bar is 100 µm. b) Co magnetic contrast as function of time after the laser overlap, along the a-axis, showing a reduction, and along the c-axis, showing a complementary increase and demonstrating a <100 ps re-orientation of the Co spins.

References:

[1] A.V. Kimel et al., Nature **429** 850 (2004)
[2] L. Joly et al., J. Phys.: Condens. Matter **21** 446004 (2009)

Controlling the properties of QWS by interface engineering

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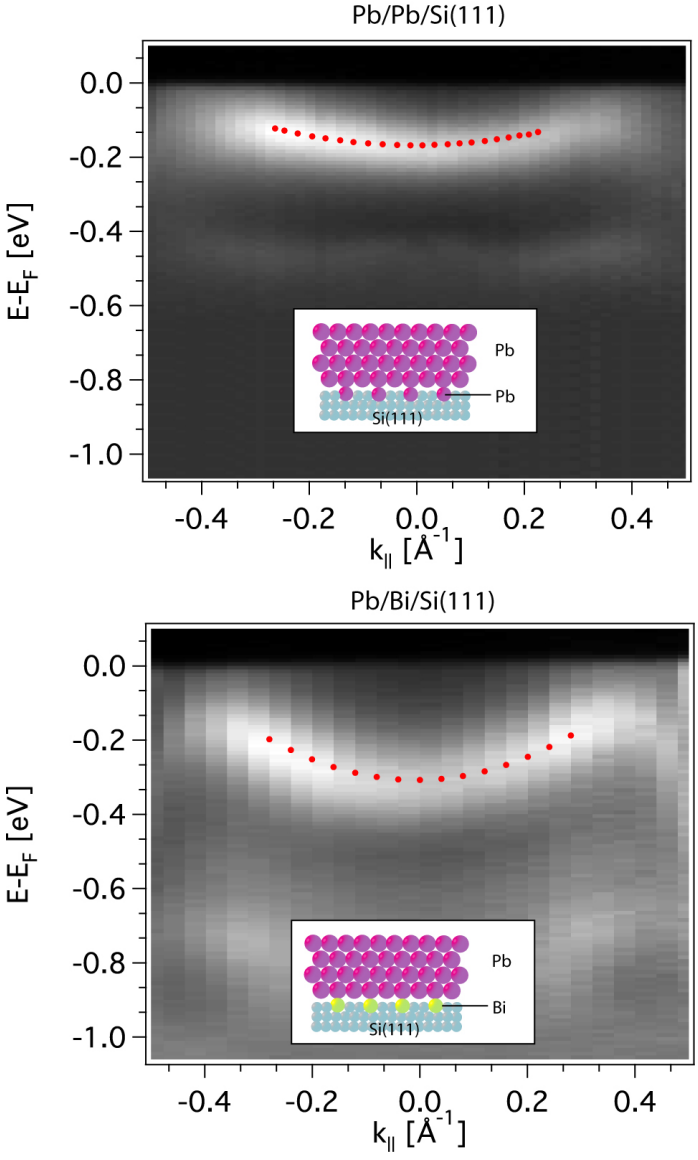
The fabrication of materials with adjustable physical properties is an intriguing field in surface science and a key issue towards functional materials. By means of heteroepitaxy it has become possible to grow flat metal films on semiconductor substrates, with perfect non-intermixing interfaces. Such systems show indeed interesting phenomena such as monolayer dependent oscillations of superconducting temperature or of magnitude and sign of hall resistivity - these properties are influenced by the thickness of the deposited metal. Here we will explore the influence of the interface on the electronic properties of quantum well states (QWS).



With angle-resolved photoemission spectroscopy we have measured the band structure of Pb QWS either on a Pb or Bi interface on top of n-doped Si(111), see Figure. Although both interfaces form equivalent surface reconstructions, namely (√3x√3)R30°, the dispersion of the QWS alter significantly. Whereas in Pb/Pb/Si(111) the effective mass can reach 10 m_e, we find in Pb/Bi/Si(111) effective masses up to 4 m_e.

The high effective mass in Pb/Pb/Si(111) may arise from a lower degree of orbital overlap and is a result of the complex interplay between total energy minimization of the film and the interaction with the substrate, which lead to a favored atomic arrangement.

Figure 1

a) In-plane dispersion of Pb QWS on Pb terminated Si(111) with an effective mass of 5.6 m_e.

b) Dispersion of Pb QWS on Bi terminated Si(111) with an effective mass of 2.6 m_e.