Magnetic order and interfacial coupling in oxide thin films and heterostructures probed with soft x-ray dichroism

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The combination of novel magnetic properties induced by reduced dimensionality and strong magnetic interactions across interfaces leads to intriguing new properties in magnetic hetero- and nanostructures not observed in the constituent materials in bulk form. It is the careful optimization of the characteristics of the individual layers as well as the magnetic coupling across the interface that allows us to control the magnetic properties and tailor them for devices, e.g., in information storage and processing technology.

Soft x-ray magnetic spectroscopies can make unique contributions to improving our understanding of complex magnetic nanostructures since these techniques provide elemental, valence- and site-symmetry specific information with high sensitivity and tunable probing depth. X-ray magnetic circular dichroism (XMCD) is sensitive to (unidirectional) ferromagnetic order, while x-ray magnetic linear dichroism (XMLD) can also detect (uniaxial) antiferromagnetic order. A crystalline electric field with cubic symmetry induces only a weak angular dependence in XMCD spectra [1] but can cause a very pronounced anisotropy in XMLD spectra [2]. Furthermore, non-magnetic sites with a distorted local cubic symmetry can give rise to an x-ray linear dichroism (XLD). In this presentation, we discuss how to distinguish between the individual contributions to soft x-ray dichroism spectra in order to extract the wealth of information about magnetic thin films, interfaces and hetero- and nanostructures contained in the data [3, 4, 5]

We determined the magnetic structure of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) / $La_{0.7}Sr_{0.3}FeO_3$ (LSFO) superlattices with 6 unit cell thick sublayers using soft x-ray magnetic dichroism [5]. Circular dichroism was employed to study the characteristics of the ferromagnetic LSMO layer indicating a reduced magnetic ordering temperature of 200 K compared to the bulk value of 360 K. Linear dichroism is used to analyze the antiferromagnetic order in the LSFO layers which persists up to the bulk Néel temperature near 400 K. Our experiments clearly show that when the magnetization of the LSMO layer is aligned with a magnetic field, a torque is created on the Fe moments in the

LSFO layer through exchange coupling at the interface realigning the Fe moments as well. Through comparison with theoretical calculations we are able to show that independent of the LSMO magnetization direction in the sample surface plane, the Fe moments are always oriented perpendicular to the Mn moments. This perpendicular alignment is due to the frustrated exchange coupling at the interface and the weak anisotropy in the thin LSFO layer.

Revisiting previous XMLD studies of the Co/NiO(001) interface taking the impact of the crystal electric field on the XMLD into account for the first time, we show that NiO(001) exhibits a crystallographic and magnetic domain structure near the surface that is identical to that of the bulk. Upon Co deposition perpendicular coupling of Co and Ni moments is observed [2, 3] that persists even in the presence of uncompensated interface moments.

We also measured the asphericity and the energy splitting of the 4*f* states in EuO thin films [4] – a material with fascinating properties and of technological importance for spintronics applications – using XMLD. Our measurements, which are confirmed by multiplet calculations, show that there is significant 4*f* anisotropy. This suggests that pinning of the *f* states by the local environment becomes feasible and can be tuned by external conditions, chemical doping, and strain for use in device applications.

Moreover, we will discuss the impact of epitaxial strain on the magnetic properties and XMLD spectra of complex oxide thin films.

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