Doctoral Thesis

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FERROMAGNETIC AND ANTIFERROMAGNETIC DOMAIN CONFIGURATIONS IN THIN FILMS AND MULTILAYERS – TOWARDS A PATTERNED EXCHANGE BIAS SYSTEM

A dissertation submitted to the SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH

for the degree of Doctor of Sciences

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Abstract

Magnetic micro- and nanostructures are of high interest for industrial applications. However, many phenomena employed in magnetic devices require better understanding. For instance, the unidirectional coupling of a ferromagnet to an adjacent antiferromagnet, referred to as exchange bias effect, is not fully understood even though it has been known for five decades. Spatially-resolved magnetic, elemental, and chemical information about the ferro-/antiferromagnetic interface is required in order to solve the exchange bias puzzle. X-ray absorption spectroscopy (XAS) and XAS-based magnetic microscopy techniques such as the photoemission electron microscopy (PEEM) are uniquely able to provide this information.

In the present work, the magnetic domain structure of thin films and multilayers is examined. The main aim of this thesis is to study the role of the magnetic domains in the exchange bias effect. In order to address the complexity of this effect, the studies were carried out in three steps: studying the ferromagnetic (FM) system, the antiferromagnetic (AF) system and finally the AF/FM bilayers.

For the FM studies, cobalt and Permalloy films were deposited as a wedge on top of pre-patterned silicon substrates using dc magnetron sputtering and evaporation, respectively resulting in an array of structures surrounded by a continuous film beneath. The FM domain structure as a function of the film thickness of the continuous and the patterned films was studied using the PEEM. In addition, effects of surface roughness
on the magnetic domain structure are discussed. This work provides important information of how various parameters, such as thickness, substrate roughness or patterning, influence the FM domain structure in thin films.

For the AF studies, thin LaFeO$_3$ films were grown using pulsed laser deposition (PLD) on SrTiO$_3$ substrates. Continuous and patterned LaFeO$_3$ films were studied. The patterning was carried out by either growing the films on pre-patterned substrates or post-patterning (i.e. patterning the film after deposition) using either a combination of electron beam lithography and ion-milling or focused ion beam lithography. The PEEM has been used to determine the orientation of individual antiferromagnetic domains in LaFeO$_3$ thin films. We found the antiferromagnetic axes are tilted by 20° out of the surface plane and have a different sign of the x-ray magnetic linear dichroism compared to previous reports on LaFeO$_3$. Using multiplet calculations, we show that this sign depends on the orientation of the magnetization with respect to the crystalline axes. Furthermore, we found that the AF and crystallographic domains in the LaFeO$_3$ films are one-to-one correlated. Finally, we found that the AF domain structure remains unaffected by the patterning.

We have obtained initial results on a LaFeO$_3$/Co exchange bias system. Indications for pinned uncompensated moments in the LaFeO$_3$ film without Co and for free uncompensated moments in the LaFeO$_3$/Co system were obtained. First measurements of the AF/FM domain correlation were carried out and the ability to perform PEEM measurements in applied magnetic fields was proven.

This work highlights the importance of the magnetic domain structure for the understanding of the exchange bias phenomenon. Our findings shed light on the mystery of the magnetic domain formation in thin films and nanostructures.
Zusammenfassung


Für die FM Studien wurden Kobalt- und Permalloy-Schichten keilförmig auf ein vorstrukturiertes Silizium-Substrat mittels „dc magneto sputtering“ und Verdampfbern aufgebracht. Dadurch entstanden strukturierte Schichten, die von einer kontinuierlichen Schicht umgeben sind. Die Muster der FM Domänen wurden als Funktion der


Diese Arbeit hebt die Bedeutung der magnetischen Domänenmuster für das Verständnis des Exchange Bias Effekts hervor und bringt Licht in das Geheimnis der magnetischen Domänenbildung in dünnen Filmen und Nanostrukturen.