Chapter 6

Conclusion

In this work, it was shown that Sp-STM can be used to image one well-defined in-plane component of the spin polarization of a sample surface with high lateral resolution. This was achieved by the proper choice of a Sp-STM electrode, namely a ring. The magnetization at the tunneling part of the ring lies in the plane of the sample surface. The plane of the ring defines the direction which the ring is sensitive to. Thus, a well-defined in-plane component can be imaged. By choosing either a ring or a tip electrode, the in-plane or the out-of-plane component of the spin polarization can be measured with the Sp-STM. The functionality of the new Sp-STM electrode was tested on a well characterized system, 180° domain walls at the surface of Fe-whiskers.

The capability of the Sp-STM was used to measure the spin arrangement of antiferromagnetic surfaces with a high lateral resolution of at least 1 nm. The main part of this work deals with the investigation of thin layer-wise antiferromagnetic ordered Mn films which are in direct contact to a ferromagnetic Fe(001) substrate. In addition, measurements were performed on thin layer-wise antiferromagnetic ordered Cr films on Fe(001). In the Sp-STM images, clearly the layer-wise antiferromagnetic order of adjacent Mn and Cr layers is visible. For Mn films, this behavior was observed up to about 20 ML where Mn undergoes a phase transition.

Magnetically frustrated regions were found at the surface of Mn films on Fe(001). The magnetic frustrations are explained by the interface roughness between Mn and Fe. When Mn is overgrowing a monatomic Fe substrate step, the Mn layer thickness is different by one atomic layer on both sides of the step. Assuming the same magnetic coupling between Mn and Fe on both sides of the step edge, the layer-wise antiferromagnetic order within the Mn film cannot be fulfilled on both sides of the step without creating a magnetic frustration. The investigation of the spin arrangement influenced by monatomic steps has been beyond the resolution limit of the established magnetic imaging techniques. Here, Sp-STM provides an ideal tool to probe the behavior of single, laterally confined magnetic frustrations. The possibility to image the topography and the magnetic signal simultaneously allows the correlation between magnetic structures and specific topographic features.

The Sp-STM experiments showed that a magnetic frustration appeared predominantly at the Mn film surface above a buried monatomic Fe substrate step. This suggests that a magnetic frustration is formed through the entire Mn film induced by a topological defect line. These kind of magnetic frustrations are different from natural bulk domain walls though they also show the rotation of the spin polarization by 180° from one side to the other. In contrast to bulk walls, the magnetic frustrations are pinned along substrate step edges and it was found that they are very narrow for thin Mn films. By investigating the width of these magnetic frustrations as a function of the Mn film thickness, a linear widening with increasing Mn thickness was observed. A width of the magnetically frustrated region between 1 nm (between the second and third ML Mn) and 7 nm (between the 18 and 19 ML Mn) was found.

The experimental finding of the widening of the magnetic frustration with increasing Mn film thickness was compared to two model descriptions of this effect, a continuum model and calculations based on a Heisenberg model. Both models reproduced the observed widening of the magnetic frustration at the Mn surface with increasing Mn film thickness rather satisfying. However, the behavior within the Mn films is significantly different for both models. Since Sp-STM is a surface sensitive technique, only the behavior at the Mn film surface could be investigated.

The Sp-STM experiments showed that the difference of the spin-dependent tunneling current measured between two oppositely spin-polarized Mn surface layers on Fe(001) depends on the bias voltage. The sign of the spin contrast changed in the investigated voltage range of +0.8 V to -1.4 V. In the case of Cr films on Fe(001), a constant spin contrast was found except for an enhancement close to the Fermi level. Likely, in both systems the highest spin contrast was observed near spin-polarized surface states. In the case of Mn, the behavior of the spin contrast as a function of the bias voltage was compared to calculations. Two different theoretical descriptions showed different mechanisms which could be responsible for the observed spin contrast. It was pointed out that a spin polarization at an antiferromagnetic surface can be explained solely by bulk states. Therefore, no spin-polarized surface states are needed to obtain a spin polarization at the surface of antiferromagnetic Mn films.

The presented Sp-STM measurements showed real space studies of magnetic frustrations caused by the influence of monatomic steps at an interface between two exchange coupled systems. Qualitatively, our results should hold also for other layered antiferromagnets in contact to a ferromagnet.