

Introduction

The last two decades were showing an inspiringly fast development of the field of magnetism, essentially initiated by the application of magnetic storage devices in information technology. The breathtaking evolution of this revolutionizing technology is characterized by a sustained miniaturization tendency and it inspired intense research on the magnetism of thin films. These scientific results have accelerated the technological innovation even more up to the present time. From this mutual stimulation of basic research and technological application, a rich variety of novel experimental techniques and stunning scientific discoveries have evolved, like the giant magneto-resistance effect, spin-torque transfer or spin-current induced magnetic switching on the scientific side. From the application point of view, this process led to the new technology of spintronics. Most of these phenomena and applications are connected to magnetic properties of interfaces or systems with strongly reduced spatial dimensions, which show significant deviations from the well-known bulk magnetic behavior of the applied materials. A reduction of the spatial extension causes a strict cut-off of the various magnetic interactions acting at different length scales. Therefore, a reduced dimensionality allows to tune the magnetic properties of a system and thereby offers interesting technological perspectives. Consequently, the challenge for the future is to understand and control the magnetism on very small length and time scales. For these reasons, the study of magnetic surface and dimensionality effects has become a fascinating field in basic condensed-matter research. The development of spintronic devices, in particular the application of the giant magneto-resistance and exchange-bias effects has led to a renewed interest in magnetic semiconductors and antiferromagnets.

While the altered magnetic behavior due to strong spatial limitations is well documented in the literature for the important ferromagnetic materials, comparably little is known about the thickness dependence of the magnetic properties of antiferromagnetic systems. Experiments on antiferromagnets are challenging since macroscopically measurable quantities are of weak signal. No macroscopic magnetization reflects the microscopic order, and the divergence of the susceptibility at the ordering temperature is less pronounced than in ferromagnets. Therefore, such studies typically require a high magnetic sensitivity. Since antiferromagnetic structures arise from competing distance-dependent spin-spin coupling mechanisms, spatial limitations might not only affect the macroscopic properties like the ordering temperature, but also the energetically favorable spin arrangement, i.e. the magnetic structure itself can become a function of the spatial dimension of the sample. Therefore, the study of ultra-thin antiferromagnetic samples requires knowledge of the microscopic details of the magnetic structure, even if macroscopic properties are addressed. Such information can be obtained by magnetic scattering techniques.

The present thesis explores the effect of reduced spatial dimensions and surfaces on the magnetic properties of antiferromagnetic metals and semiconductors by means of resonant magnetic soft x-ray scattering, a new technique that has become complementary to the well-established method of magnetic neutron scattering. Resonant soft x-ray scattering is characterized by large magnetic and surface sensitivity and is therefore well suited to examine the magnetic properties of ultra-thin films and inter-

faces. The experimental challenge of resonant soft x-ray scattering consists in the strong absorption of soft x rays in air, which prevents the use of commercial diffractometers and requires a scattering apparatus that operates at least in high vacuum. Within the framework of this thesis, a completely new scattering apparatus was developed and built. This novel apparatus provides excellent UHV conditions, which allow the in-situ preparation of high-quality samples, even of extremely reactive materials. The construction of a two-stage rotary feedthrough as the central part of this diffractometer permits the straightforward application of complex detectors and analyzers, as demonstrated in this thesis by the use of a novel position sensitive detector, that can be rotated in the UHV chamber. The scientific results obtained demonstrate the excellent performance of the new setup and also the potential of resonant soft x-ray scattering. In particular, studies of ultra-thin films of the magnetic semiconductor EuTe quantified magnetic surface and dimensionality effects with unprecedented detailedness. This includes temperature-dependent magnetization profiles with atomic-layer resolution across an entire EuTe film, and a thickness-dependent dimensional crossover inferred from distinct changes in the behavior of the short-range magnetic correlations that persist above the ordering temperature. These correlations could be examined from distances of approximately 1000 Å down to correlation lengths of the order of the nearest-neighbor spacing at temperatures well above the ordering temperature.

The main results of this work include (i) a detailed study on the influence of surfaces on the magnetic behavior of antiferromagnets and (ii) the development of a novel apparatus for soft x-ray scattering. This apparatus was successfully employed in the experiments presented here, but also in several collaborations. This thesis describes both aspects of the accomplished work. It is organized as follows: The first part summarizes essential theoretical predictions and experimental results from literature concerning the altered magnetic behavior at surfaces (chapter 1), the general magnetic properties of the studied materials (chapter 2), as well as the basics of x-ray diffraction and resonant scattering (chapter 3). The subsequent part introduces the experimental aspects of the present studies and focuses on a detailed presentation of the scattering apparatus (chapter 4) and the samples studied (chapter 5). The last part describes the scientific results obtained from thin holmium metal films (chapter 6) and from the magnetic semiconductor EuTe (chapter 7).