Chapter 1

Introduction

The exploration of the possibility to use the electron's spin-degree of freedom besides the conventionally used charge for storing, processing, and transferring information is currently a major theme in condensed matter research [1]. The possibility to design completely new functional devices based on physical principles that have not yet been exploited has made spintronics one of the most active current fields in physics.

Present-day information technology already utilizes effects based on the electron spin in magnetic materials to process and to store information. Well-known examples are magnetoresistance sensors [2, 3] that make use of the phenomena of giant magnetoresistance (GMR) [4, 5] or tunnelling magnetoresistance (TMR) [6]; they are made of artificial multilayer systems constructed from a sequence of different layers [7]. Similarly, multilayer systems with perpendicular magnetic anisotropy seem to be promising media for 'blue' magneto-optic [8]. Another interesting example of possible future practical applications of thin films multilayer structures is the magnetic random-access memory (MRAM) [9].

Rare-earth metals are of practical interest because of their important role in hard magnetic intermetallics and high-density storage media. The electronic and magnetic properties of lanthanides arise from the unique interplay between the highly localized partially filled 4f shell that provides a large magnetic moment and the valence electrons.

In thin films the band structure undergoes significant modifications. When the coordination number is reduced at the surface, band narrowing and a shift in binding energies of core levels are consequences. Moreover, due to the reduced symmetry at surfaces and interfaces, new electronic states can appear that do not exist in the bulk. In multilayers, the electronic structure of the atomic layers located right at the interfaces plays a key role in mediating the exchange interaction. To explore the microscopic origin of the novel magnetic effects of thin films and multilayers, the electronic structure particularly at surfaces and interfaces needs to be investigated.

Angle-resolved photoelectron spectroscopy (photoemission, PE) serves as a versatile tool to investigate both the valence-band structure and the core levels. Its merits are well known: (i) direct access to the valence-band structure; (ii) high surface sensitivity with tunable information depth by varying the photo-

electron kinetic energy; (iii) element specificity due to characteristic binding energies of core levels; (iv) possibility to identify the nearest-neighbor (n.n.) environment of a photoemitting atom due to the variation of core-level binding energies in different atomic surroundings.

Magnetic dichroism in core-level PE provides atomic-layer-resolved information on magnetic moments at surfaces and interfaces [10], which is hardly possible to obtain by other methods. Yet, analysis of the PE results is relatively complicated through photoelectron-diffraction effects [11–13]. This motivates an investigation of diffraction effects, in particular their manifestation in magnetic dichroism.

A key issue of condensed-matter research for applications in future spintronic devices is the control and manipulation of the electron spin degree of freedom without the need to apply an external magnetic field, since this might become difficult in a densely-packed chip design. Rashba first realized this issue: since an external electric field acts as a magnetic field in the rest frame of a moving electron, one can use static electric fields to manipulate (or polarize) spin-polarized electrons by using an electric rather than a magnetic field [14–16]. This possibility is currently explored exclusively for electrons in semiconductors [17]. However, as we shall demonstrate in the present work, this effect is much more general and exists also at metal surfaces as well as at metal/metal-oxide interfaces.

The concept underlying the Rashba effect can be translated one-by-one to the electronic states at surfaces and interfaces that experience a strong electric field due to the charge potential gradient. In this context, we interpret the previously observed splitting of the surface-state energy dispersion at the Au(111) and W(110) metal surfaces as a consequence of the Rashba effect. A small Rashba constant requires a very fine energy resolution and momentum resolution to observe the effect experimentally. Although present in general, the Rashba splitting is only large, when it can couple to a large intra-atomic spin-orbit coupling. Therefore, one should expect more pronounced effects at the surfaces of high-Z elements, in particular at the surfaces of the rare-earth metals. In particular, the large exchange splitting of a magnetic surface state should allow an independent observation of the two Rashba-split branches. In this work we further develop the idea that the Rashba effect is a general surface and interface phenomenon, using Gd(0001) and Tb(0001) surfaces as examples, as well as their surface monoxide phases.