# Preface

Spintronics is the child of magnetoelectronics, which was born with the discovery of the "*half-metallic ferromagnets*" in 1983 by Robert de Groot for NiMnSb and by Jürgen Kübler for $Co_2MnAl$ and $Co_2MnSn$. Peculiar for this type of ferromagnets is that only electrons with one kind of spin take part in the electronic transport properties. This leads to the idea that electronic devices can be built where not the charge but the spin of the electron transports the signal and is thus free of "ohmic" energy dissipation. The exceptional property that the materials exhibit 100 % spin polarization at the Fermi energy makes them ideal candidates for spin injection devices to be used in spin electronics that is spintronics.

Spintronics is an emerging technology exploiting the spin degree of freedom and has proved to be very promising for new types of fast electronic device. Amongst the anticipated advantages of spintronics technologies, researchers have identified the non-volatile storage of data with high density and low energy consumption as particularly relevant. This monograph examines the concept of half-metallic compounds perspectives to obtain novel solutions, and discusses several oxides as well as the intermetallic Heusler compounds. Such materials can be designed and made with high spin polarization and, especially in the case of Heusler compounds, many material-related problems present in current-day 3d metal systems, can be overcome. From materials design by theoretical methods and the preparation and properties of the materials to the production of thin films and devices, this monograph provides an insight into the current research on Heusler compounds and double perovskites. It offers a general understanding of structure–property relationships, including the influence of disorder and correlations on the electronic structure and interfaces. Last not least, spintronics devices such as magnetic tunnel junctions (MTJs) and giant magnetoresistance (GMR) devices, with current perpendicular to the plane, in which $Co_2$ based Heusler compounds are used as new electrode materials, are also introduced.

The way from materials design to applications and devices is reviewed in 17 chapters by experts in the field. An introduction to Heusler compounds (Chaps. 1–3) and double perovskites (Chap. 4) as materials for spintronics is given in the first four chapters. In the following four chapters, the basic theoretical considerations for materials design of the half-metallicity of Heusler compounds (Chaps. 5–7) and double perovskites (Chaps. 5 and 8) are given. Next five chapters are devoted to the application of new and well established experiments to investigate the materials and devices (Chaps. 9–13). Finally, four chapters (14–17) review the successful use of the new materials in thin films and devices.

The first part is devoted to new materials from the classes of Heusler compounds and double perovskites. Chapter 1 gives an overview on functionalities and applications of Heusler compounds. The following Chap. 2 reports on new Heusler compounds and their properties starting with material design from the viewpoint of a chemist based on optimization and tuning of the Fermi energy by chemical substitution. Details of crystallographic order and disorder phenomena in Heusler compounds are discussed in Chap. 3. These phenomena are important for an understanding of the structure to property relations. Substitution effects in double perovskites are reported in Chap. 4, which investigates the influence of electron and hole doping in half-metallic $Sr_2FeReO_6$.

The second part reviews the design of new materials by theoretical methods. Chapter 5 deals with the theory of the half-metallic materials and reviews the half-metallic ferromagnets and ferrimagnets found in the classes of Heusler compounds and double perovskites. The special focus of this chapter is on electronic structure, nature of the magnetic moments and physics of the energy gap for a single spin channel. Chapter 6 is about correlation and chemical disorder in Heusler alloys with a special emphasis on spectroscopic studies. It is shown that effects of local electronic correlations and alloying on the properties of the Heusler compounds need an equal treatment of static and dynamic correlations. More details of the electronic structure of the half-metallic, transition metal based Heusler compounds are reviewed in Chap. 7. It reports on calculation of electronic structure and properties by means of ab-initio band structure methods for ordered, substituted and disordered Heusler compounds. The theory of the electronic structure of complex oxides is reported in Chap. 8, which discusses—based on dynamical mean field theory—the electronic structure, magnetic properties, and metal–insulator transitions in transition metal oxides.

The third part is devoted to new experimental methods and their application to the investigation of new materials. Chapter 9 is about the experimental investigation of the local structure of highly spin polarized Heusler compounds revealed by nuclear magnetic resonance spectroscopy (NMR). It shows that NMR, as a local probe, is a suitable tool to reveal structural contributions and foreign phases in spin polarized materials which are very difficult to detect with other methods. Chapter 10 reports on the investigation of new materials with high spin polarization by X-ray magnetic circular dichroism. It explains in an element specific way the spin and orbital magnetic moments of $Co_2YZ$ (bulk and films) and confirms experimentally the tailoring of the Fermi level in quaternary substituted compounds. As a very young experimental method, hard X-ray photoelectron spectroscopy is applied in Chap. 11 to explore the electronic structure of new materials, thin films, and buried layers in MTJs. In Chap. 12, the surface electronic properties of $Co_2Cr_{1-x}Fe_xAl$ are characterized by spin resolved photo emission with low photon energies to discriminate bulk and surface states. Magneto-optical experiments and ion beam-induced modification of Heusler compounds are reported in Chap. 13 that reports on investigations of magnetic exchange stiffness, magnetic anisotropy, magnetization reversal, and magneto-optical Kerr effect in Co-based Heusler compound thin films.

The last part demonstrates the successful use of new spintronics materials in thin films and devices. Chapter 14 is devoted to a special material ($Co_2Fe(Al_{1-x}Si_x)$) and its application in spintronics. It reports on the structural and magnetic properties of epitaxial thin films and their applications to magnetic tunnel junctions (MTJs), giant magnetoresistive (GMR) devices and spin transfer magnetization switching. It reveals that the use of Heusler compounds is an effective way to reduce the switching current density in MTJs. Chapter 15 is about the transport properties of $Co_2$(Mn, Fe)Si thin films. Especially it is shown that the normal Hall effect undergoes a transition from a hole-like charge transport in $Co_2MnSi$ to an electron-like transport in $Co_2FeSi$. Chapter 16 reports on the preparation, barrier-interface engineering, and investigation of $Co_2Cr_{1-x}Fe_xAl$ thin films for MTJs with $AlO_x$ tunneling barriers. The tunnel magnetoresistance in tunnel junctions with $Co_2MnSi$ as Heusler alloy electrode and MgO as barrier is investigated in Chap. 17. This completes the way from material design to successful use in spintronics devices.

Mainz, Dresden

Claudia Felser
Gerhard H. Fecher

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