Contents

Introduction **xv**

I. Theoretical and Experimental Background 1

1. Magnetic spectroscopy using X-rays **3**
1.1. Classical description of absorption and magnetooptical phenomena 3
1.1.1. Absorption . . . 3
1.1.2. Dielectric tensor and optical effects . . . 4
1.1.3. Link between electrodynamics and quantum mechanics - the Kubo-formula . . . 8
1.2. X-ray absorption spectroscopy (XAS) and its application to magnetism . . . 9
1.2.1. The x-ray absorption process . . . 9

2. Dichroism **11**
2.1. Circular Dichroism . . . 11
2.1.1. X-ray natural circular dichroism (XNCD) . . . 11
2.1.2. X-ray magnetic circular dichroism (XMCD) . . . 11
2.1.3. XMCD sum rules – charge, orbital- and spin-moment . . . 15
2.2. Linear Dichroism . . . 18
2.2.1. Introduction and Terminology . . . 18
2.2.2. X-ray Natural Linear Dichroism (XNLD) . . . 19
2.3. X-ray Magnetic Linear Dichroism (XMLD) . . . 21
2.3.1. X-ray Magnetic Linear Dichroism by exchange-correlation effects . . . 21
2.3.2. XMLD in the presence of orbital degrees of freedom . . . 23
2.3.3. "Anisotropic" XMLD in 3d transition metal compounds . 25
2.3.4. Angular dependence of XMLD - a phenomenological description . . . 28
2.3.5. "Isotropic" XMLD . . . 29
2.3.6. "Anisotropic" XMLD in cubic symmetry . . . 31

3. Transition Metal Oxides - Electronic and magnetic properties 35
3.1. NiO: Electronic structure and magnetic interactions 35
3.2. Antiferromagnetic structure and magnetoelastic domains in NiO . 36
3.2.1. Antiferromagnetic Domain walls 37
3.3. Fe_3O_4: Electronic and magnetic structure 39

4. Experimental Methods 41
4.1. Generation of polarized x-rays – synchrotron radiation 41
4.2. Photoemission microscopy using soft x-rays 42

5. Magnetic Proximity Effect and Related Phenomena 47
5.1. Interfacial exchange coupling and exchange bias 48
5.1.1. Models and their limits 48

II. Experimental results 57

6. Proximity effect in Fe_3O_4 (110)/NiO 59
6.1. Introduction 59
6.2. Sample preparation 59
6.3. Vectorial magnetometry using PEEM microspectroscopy 61
6.3.1. Determination of the substrate magnetization map 62
6.3.2. Coupling of the interfacial Ni-moments to Fe_3O_4 64
6.3.3. Orientation of the spin-axis in NiO – determination of the coupling type 67
6.3.4. Ultrathin proximity zone at the interface 77
6.4. Temperature-dependence of the magnetic contrast 82
6.4.1. Introduction 82
6.4.2. Experimental procedure 82
6.5. Summary 87

7. Influence of interface orientation on the coupling type 89
7.1. Introduction 89
7.2. Sample preparation 90
7.2.1. Substrate and interface conditioning 91
7.2.2. NiO deposition by MBE 96
7.3. Experimental results 97
7.3.1. (110)-interface 97
7.3.2. (001)-interface 97
7.3.3. (111)-interface 101
7.3.4. Amount of uncompensated magnetization in the three orientations 101

7.4. Discussion of the results 104
7.4.1. Magnetoelastic influence on the coupling type 104
7.4.2. Amount of uncompensated magnetization 109
7.5. Summary and Conclusion 109

8. Tailoring antiferromagnetic domain walls and anisotropy 111
8.1. Motivation 111
8.2. Results of the fitting process 113
8.3. Origin of the perpendicular FM orientation 120
8.4. Summary 123

9. Conclusions and Outlook 125

A. Appendix 129
A.1. Epitaxial strain and magnetoelastic distortions in different interface orientations of the Fe_3O_4/NiO system 129
A.1.1. Epitaxial strain of the NiO layer 129
A.1.2. Magnetoelastic coupling 130
A.2. Confusion and conversion – the SI and CGS systems 132

Danksagung 151

Curriculum Vitae 155