

Contents

1	Nanosized Magnetic Materials	1
1.1	Introduction	1
1.2	Synthesis	1
1.2.1	Inert Gas Condensation	2
1.2.2	Water-in-oil Microemulsion Method	3
1.2.3	Organic/Polymeric Precursor Method	7
1.2.4	Sonochemical Synthesis	8
1.2.5	Hydrothermal Synthesis	9
1.2.6	Pyrolysis	10
1.2.7	Arc Discharge Technique	11
1.2.8	Electrodeposition	12
1.2.9	Mechanical Alloying	13
1.2.10	Matrix-mediated Synthesis	15
1.3	Structure-Property Overview	16
1.3.1	Quantum Tunneling	18
1.3.2	Anisotropy	19
1.3.3	Analytical Instrumentation	20
1.4	Theory and Modeling	21
1.4.1	Single-domain Particles	21
1.4.2	Modeling	22
1.5	Applications	23
1.5.1	Magneto-optical Recording	23
1.5.2	Magnetic Sensors and Giant Magnetoresistance	25
1.5.3	High-density Magnetic Memory	25
1.5.4	Optically Transparent Materials	27
1.5.5	Soft Ferrites	27
1.5.6	Nanocomposite Magnets	28
1.5.7	Magnetic Refrigerant	28
1.5.8	High- T_C Superconductor	29
1.5.9	Ferrofluids	29
1.5.10	Biological Applications	30
	References	31
6.1	Introduction	212
6.2	First Stage of Growth	212
6.2.1	Island Density	212
6.2.2	Island Shapes	214
6.3	Growth Modes	216

2 Magnetism and Magnetotransport Properties of Transition Metal Zintl Isotypes 37

2.1 Introduction 37

2.2 Structure 38

2.3 Magnetism 41

2.3.1 Alkaline Earth Compounds 43

2.3.2 High-temperature Paramagnetic Susceptibility 43

2.3.3 Ytterbium Compounds 48

2.3.4 Europium Compounds 49

2.4 Heat Capacity 53

2.5 Magnetotransport 54

2.5.1 Alkaline Earth and Ytterbium Compounds 54

2.5.2 Resistivity and Magnetoresistance of the Europium Compounds 57

2.5.3 Comparison with other Magnetoresistive Materials 60

2.6 Summary and Outlook 61

References 61

3 Magnetic Properties of Large Clusters 63

3.1 Introduction 63

3.2 Calculation of the Energy Levels and Experimental Confirmations 65

3.2.1 Calculations 65

3.2.2 Inelastic Neutron Scattering 68

3.2.3 Polarized Neutron Scattering 70

3.2.4 High-field Magnetization 72

3.3 Magnetic Measurements 76

3.3.1 Introduction 76

3.3.2 AC Susceptibility Measurements 77

3.3.3 Cantilever Magnetometry 79

3.3.4 MicroSQUID Arrays 83

3.4 Magnetic Resonance Techniques 85

3.4.1 Introduction 85

3.4.2 HF-EPR 85

3.4.3 Zero-field EPR 87

3.4.4 Low-frequency EPR 88

3.4.5 NMR 89

3.4.6 μ SR 94

3.5 Control of the Nature of the Ground State and of the Anisotropy 97

3.6 Fe₈ – A Case History 99

3.7 Conclusions and Outlook 103

References 104

4 Quantum Tunneling of Magnetization in Molecular Complexes with Large Spins – Effect of the Environment	109
4.1 Introduction	109
4.2 Mn ₁₂ -acetate	110
4.2.1 Experimental Results	110
4.2.2 Basic Model	116
4.3 Fe ₈ Octanuclear Iron(III) Complexes	126
4.3.1 Experimental Results	126
4.3.2 Basic Model	130
4.4 Environmental Effects	137
4.4.1 Experimental Picture	138
4.4.2 Thermally Assisted Tunneling Regime	145
4.4.3 Ground-state Tunneling	154
References	165
5 Studies of Quantum Relaxation and Quantum Coherence in Molecular Magnets by Means of Specific Heat Measurements	169
5.1 Introduction	169
5.2 Experimental Techniques	172
5.3 Theoretical Background	174
5.3.1 Spin-Hamiltonian for Molecular Magnets – Field-dependent Quantum Tunneling	174
5.3.2 Resonant Tunneling via Thermally Activated States	178
5.3.3 Master Equation – Calculation of Γ	182
5.3.4 Calculation of Time-dependent Specific Heat and Susceptibility	185
5.4 Experimental Results and Discussion	186
5.4.1 Superparamagnetic Blocking in Zero Applied Field	187
5.4.2 Phonon-assisted Quantum Tunneling in Parallel Fields	190
5.4.3 Phonon-assisted Quantum Tunneling in Perpendicular Fields	193
5.4.4 Time-dependent Nuclear Specific Heat	197
5.4.5 Detection of the Tunnel Splitting for High Transverse Fields	199
5.5 Effect of Decoherence	202
5.6 Incoherent Tunneling and QC in Molecules with Half-integer Spin	202
5.7 Conclusions	206
References	208
6 Self-organized Clusters and Nanosize Islands on Metal Surfaces	211
6.1 Introduction	211
6.2 First Stage of Growth Kinetics	212
6.2.1 Island Density	212
6.2.2 Island Shapes	214
6.3 Growth Modes	216

6.3.1	Thermodynamic Growth Criterion	216
6.3.2	Microscopic Model	218
6.3.3	Elastic and Structural Considerations	219
6.4	Organized Growth	220
6.4.1	Incommensurate Modulated Layers	221
6.4.2	Atomic-scale Template	222
6.4.3	Self Organization	224
6.4.4	Periodic Patterning by Stress Relaxation	226
6.4.5	Organization on Vicinal Surfaces	227
6.4.6	Low-temperature Growth	227
6.5	Magnetic Properties	228
6.5.1	Magnetism in Low-dimensional Systems	229
6.5.2	Anisotropy in Ferromagnetic Nanostructures	230
6.5.3	Magnetic Domains	232
6.5.4	Superparamagnetism	233
6.5.5	Dimensionality and Critical Phenomena	233
6.6	Magnetic Nanostructures – Experimental Results	234
6.6.1	Isolated Islands	234
6.6.2	Interacting Islands and Chains	238
6.6.3	The 2D Limit	242
6.7	Conclusion and Outlook	246
	References	248
7	Spin Electronics – An Overview	253
7.1	Introduction	253
7.2	The Technical Basis of Spin Electronics – The Two-spin Channel Model	254
7.2.1	2.1 Spin Asymmetry	254
7.2.2	Spin Injection Across an Interface	255
7.2.3	The Role of Impurities in Spin Electronics	256
7.3	Two Terminal Spin Electronics – Giant Magnetoresistance (GMR)	257
7.3.1	The Analogy with Polarized Light	258
7.3.2	CIP and CPP GMR	259
7.3.3	Comparative Length Scales of CIP and CPP GMR	260
7.3.4	Inverse GMR	260
7.3.5	Methods of Achieving Differential Switching of Magnetization – RKKY Coupling Compared with Exchange Pinning	260
7.3.6	GMR in Nanowires	261
7.4	Three-terminal Spin Electronics	261
7.5	Mesomagnetism	263
7.5.1	Giant Thermal Magnetoresistance	263
7.5.2	The Domain Wall in Spin Electronics	264
7.6	Spin Tunneling	266
7.6.1	Theoretical Description of Spin Tunneling	267

7.6.2	Applications of Spin Tunneling	271
7.7	Hybrid Spin Electronics	272
7.7.1	The Monsma Transistor	273
7.7.2	Spin Transport in Semiconductors	274
7.7.3	The SPICE Transistor [55, 56]	274
7.7.4	Measuring Spin Decoherence in Semiconductors	275
7.7.5	Methods of Increasing Direct Spin-injection Efficiency	277
7.8	Novel Spin Transistor Geometries – Materials and Construction Challenges	278
7.9	The Rashba effect and the Spin FET	280
7.9.1	The Rashba Effect	280
7.9.2	The Datta–Das Transistor or Spin FET [68]	280
7.10	Methods for Measuring Spin Asymmetry	281
7.10.1	Ferromagnetic Single-electron Transistors (FSETs)	281
7.10.2	Spin Blockade	284
7.11	Unusual Ventures in Spin Electronics	285
7.12	The Future of Spin Electronics	286
7.12.1	Fast Magnetic Switching	286
7.12.2	Optically Pumped Magnetic Switching	287
7.12.3	Spin Diode	287
7.12.4	Spin Split Insulator as a Polarizing Injector – Application to Semiconductor Injection	288
7.12.5	Novel Fast-switching MRAM Storage Element	288
7.12.6	Quantum-coherent Spin Electronics	288
7.12.7	The Tunnel-grid Spin-triode	290
7.12.8	Multilayer Quantum Interference Spin-stacks	291
7.12.9	Multilayer Tunnel MRAM	291
7.12.10	Quantum Information Technology	292
	References	293
8	NMR of Nanosized Magnetic Systems, Ultrathin Films, and Granular Systems	297
8.1	Introduction	297
8.2	Local Structure	298
8.2.1	Introduction	298
8.2.2	Local Atomic Configuration and Resonance Frequency	299
8.2.3	A Typical Example	301
8.2.4	Summary	303
8.3	Magnetization and Magnetic Anisotropy	303
8.3.1	Principles – Hyperfine Field in Ferromagnets	303
8.3.2	Local Magnetization	305
8.3.3	Local Anisotropy	307
8.4	Magnetic Stiffness – Anisotropy, Coercivity, and Coupling	311
8.4.1	Principles – NMR in Ferromagnets, Restoring Field, and Enhancement Factor	311
8.4.2	Local Magnetic Stiffness	313

8.5	Conclusion	323
	References	324
9	Interlayer Exchange Interactions in Magnetic Multilayers	329
9.1	Introduction	329
9.2	Survey of Experimental Observations	330
9.3	Survey of Theoretical Approaches	333
9.3.1	RKKY Theory	333
9.3.2	Quantum Well Model	333
9.3.3	<i>sd</i> -Mixing Model	333
9.3.4	Unified Picture in Terms of Quantum Interferences	334
9.3.5	First-principles Calculations	334
9.4	Quantum Confinement Theory of Interlayer Exchange Coupling	334
9.4.1	Elementary Discussion of Quantum Confinement	335
9.4.2	Interlayer Exchange Coupling Because of Quantum Interferences	341
9.5	Asymptotic Behavior for Large Spacer Thicknesses	342
9.6	Effect of Magnetic Layer Thickness	345
9.7	Effect of Overlayer Thickness	345
9.8	Strength and Phase of Interlayer Exchange Coupling	346
9.8.1	Co/Cu(001)/Co	347
9.8.2	Fe/Au(001)/Fe	349
9.9	Concluding Remarks	349
	References	350
10	Magnetization Dynamics on the Femtosecond Time-scale in Metallic Ferromagnets	355
10.1	Introduction	355
10.2	Models	358
10.2.1	Heating Metals with Ultrashort Laser Pulses	358
10.2.2	Three-temperature Model of Ferromagnets	360
10.2.3	Model of Spin Dephasing	363
10.3	Magneto-optical Response and Measurement Techniques	364
10.3.1	Magneto-optical Response	364
10.3.2	Time-resolved magneto-optical techniques	367
10.4	Experimental Studies – Electron and Spin Dynamics in Ferromagnets	372
10.4.1	Electron Dynamics	372
10.4.2	Demagnetization Dynamics	375
10.5	Conclusion	381
	References	382
	Subject Index	385