
Contents

Symbols	XVII
1 Introduction	1
1.1 Review of Certain Historic Magnetic Concepts	2
1.1.1 Magnetic Susceptibility	2
1.1.2 Classification of Magnetic Materials	3
1.1.3 The Concept of Magnetic Pole	5
1.1.4 Magnetic Dipoles	6
1.2 Origins of Magnetism on an Atomic Scale	6
1.2.1 The Importance of Angular Momentum	7
1.2.2 Magnetic Moment of a Sample of N Atoms	8
1.2.3 Crystal Field vs. Spin–Orbit Coupling	9
1.2.4 Magnetocrystalline Anisotropy	10
1.2.5 Magnetostriction	10
1.3 Structure-Dependent Micromagnetism	11
1.3.1 Division into Magnetic Domains	12
1.3.2 Formation of Domain Walls	12
1.3.3 Types of Domain Walls	13
1.3.4 Significance of Magnetic Domains and Domain Walls ..	14
1.4 Towards Technological Advancements	15
1.4.1 Design of New Magnetic Materials	15
1.4.2 Magnetic Quantum Dots	15
References	16
2 Barkhausen Noise as a Magnetic Nondestructive Testing Technique	19
2.1 Introduction	19
2.2 A Basic Definition of Magnetic Barkhausen Noise	20
2.2.1 Types of MBN Experiments	20
2.2.2 Where does MBN Originate?	21
2.2.3 Formation of Magnetic Domains	22
2.2.4 MBN and 180° Domain Walls	23

2.3	Stress Effects	24
2.3.1	Elastic Stress Causes Changes in Bulk Magnetization	24
2.3.2	Magnetic Domains Respond to Stress	24
2.3.3	Magnetic Anisotropy and MBN	25
2.3.4	Some Parameters Used in MBN Analysis	25
2.3.5	Elastic Stress Influences on Magnetic Anisotropy	27
2.3.6	Plastic Deformation and Magnetic Anisotropy	27
2.3.7	Effects of Residual Stresses	28
2.3.8	Influence of Dislocations	30
2.3.9	Selective Wall Energy Increases at Pinning Sites	30
2.3.10	Roll Magnetic Anisotropy	31
2.3.11	Limits in MBN Signal Increase with Plastic Stress	32
2.4	Effects of Microstructure on MBN	33
2.4.1	Variations in Grain Size	33
2.4.2	Compositional and Phase Influences	34
2.4.3	MBN Behavior in Different Materials	34
2.5	Competitiveness of MBN in Nondestructive Evaluation	36
2.5.1	Usefulness of MBN for MFL	36
2.5.2	Need for Calibration of MBN as NDT	37
	References	38
3	Combined Phenomena in Novel Materials	41
3.1	The Interest in Magneto-optical Media	41
3.1.1	Conventional vs. Continuous Media	42
3.1.2	The Basis of Magneto-optical Effects	43
3.1.3	Composite Films Used in Magneto-optical Recording	43
3.1.4	Magnetic Recording and Optical Readout	44
3.1.5	Quality of Magnetic Recording	44
3.1.6	Overcoming Noise Problems	45
3.1.7	The MO Sony Disk	46
3.1.8	Magnetically Induced Super Resolution	47
3.1.9	Nondestructive Optical Readout	47
3.1.10	Double and Multilayer MO Disks	48
3.1.11	Domain Wall Displacement Detection	49
3.1.12	Magnetic Bubble Domains	50
3.1.13	Generation of a Bubble Bit of Memory	50
3.1.14	Driving Force for Wall Displacement	50
3.2	Magnetoelectric Materials	51
3.2.1	The Magnetoelectric Effect	51
3.2.2	Oxides, Boracites, Phosphates, etc.	52
3.2.3	Layered Composite Materials	52
3.2.4	Product, Sum and Combination Properties	53
3.2.5	PZT and Magnetostrictive Materials	53
3.2.6	Avoiding Ferrites	54
3.2.7	Undesired Effects of Sintering	54

3.2.8	Variations in Signal Due to Mechanical Coupling	55
3.2.9	Laminated Composites	55
3.2.10	Voltage Coefficient α	56
3.2.11	Obtaining Improved Voltage Coefficients	57
3.2.12	ME and Nanostructures	57
3.2.13	Effects on a Nanoscale	58
3.2.14	Residual Stresses and Strains in Nanostructures	60
3.2.15	Multiferroics	61
3.2.16	Using Terfenol-D	61
3.2.17	Multiferroic Transformers	61
3.2.18	Multiferroic Sensors for Vortex Magnetic Fields	63
3.2.19	Enhancing Multiferroicity through Material Design	63
3.2.20	Identifying Multiferroics	64
	References	64
4	Magnetoresistance and Spin Valves	71
4.1	Introduction	71
4.2	A Simple Way of Quantifying Magnetoresistance	72
4.3	What is Responsible for GMR?	72
4.4	Deskstar 16 GP	73
4.5	“Spin-down” vs. “Spin-up” Scattering: Magnetic Impurities	73
4.6	Fabrication of GMR Multilayers: Thin Films and Nanostructures	74
4.7	Spin Valves	75
4.8	The Role of Exchange Bias	75
4.9	Ni-Fe Alloys	76
4.10	Ternary Alloys	77
4.11	Ni-Fe Alloys with Higher Fe Content	77
4.12	Basic Principles of Storing Information Magnetically	78
4.13	Materials for spin valve Sensors	80
4.14	The Need for Proper Sensor Design	81
4.15	Magnetic Tunnel Junctions	82
4.16	Anisotropic Magnetoresistive Sensors	82
4.17	Extraordinary Magnetoresistance	83
4.18	GMR Sensors with CPP Geometry	83
4.19	Dual Spin Valves	84
4.20	Some GMR Multilayer Material Combinations	85
4.21	Ferromagnetic/Nonmagnetic Interfaces	86
4.22	The Nonmagnetic Spacer	86
4.23	Magnetic Tunneling	87
4.24	The Magnetic Tunnel Transistor	87
4.25	Some Special Types of Ferromagnets	88
4.26	Colossal Magnetoresistance	89
4.27	CPP Geometry Preferred in Sensors	90
4.28	Spin Valves in Commercial Applications	91
	References	93

5	Some Basic Spintronics Concepts	99
5.1	Encoding Information: Emergence of Spintronics	99
5.2	Spin Injection	100
5.2.1	Minority vs. Majority Spin Carriers	100
5.2.2	Spin Injection Rate	100
5.2.3	Spin Polarization and Spin Transfer	101
5.2.4	CPP vs. CIP Geometry	102
5.2.5	Spin Accumulation, Spin Relaxation, and Spin Diffusion Length	103
5.2.6	No Spin Accumulation in CIP Geometry	103
5.2.7	Half-Metallic Ferromagnets	104
5.2.8	Some Epitaxial Growth Techniques	104
5.2.9	ME Materials and Spintronics	105
5.2.10	Spontaneous Band Splitting	106
5.2.11	Spin Valves	106
5.2.12	Poor Injection Efficiency	107
5.2.13	Additional Layer Between Ferromagnet and Spacer	107
5.2.14	III–V Magnetic Semiconductors	107
5.2.15	Obtaining Spin-Polarized Magnetic Semiconductors	108
5.2.16	Light vs. Electric-Field-Induced Carrier Enhancement	108
5.2.17	Giant Planar Hall Effect	109
5.2.18	Maintaining Spin Polarization	109
5.2.19	The Future of Spin Injection	111
5.3	Control of Spin Transport	111
5.3.1	The Need for Long Spin Relaxation Times	111
5.3.2	Organic Semiconductor Spacers	112
5.3.3	Spin Transport in Organic Semiconductor Spin Valves	113
5.3.4	Nanoscale Effects at Ferromagnet/Organic Semiconductor Interface	113
5.3.5	Carbon Nanotubes	114
5.3.6	GMR vs. TMR	114
5.3.7	The Parallel Resistor Model	116
5.3.8	Effects at Adjacent Interfaces in GMR	116
5.3.9	Scattering at Bloch Walls	117
5.3.10	Importance of Materials Choice	118
5.3.11	Spin Control Through Electric Fields	118
5.4	Spin Selective Detection	119
5.4.1	Detecting Single Spins	119
5.4.2	Detecting Spin Polarization of an Ensemble of Spins	119
5.4.3	The Datta and Das Spin Field Effect Transistor	121
5.4.4	The Future of Spintronics Devices	121
	References	121

6	Trends in Magnetic Recording Media	129
6.1	The Popularity of Magnetic Tapes	129
6.1.1	Quality of Magnetic Tapes	130
6.1.2	The Pressure for Higher Capacity Magnetic Tapes	131
6.1.3	Constraints Imposed by Thermal Stability	131
6.1.4	Forming a Bit	132
6.1.5	Influence of Magnetic Anisotropy	133
6.1.6	Choice of Materials	133
6.2	Bit Patterned Magnetic Media	134
6.2.1	Bit-Cells	134
6.2.2	Minimizing Errors	135
6.2.3	Some Disadvantages of Patterned Bits	136
6.2.4	Solutions for Patterning Bits Efficiently	136
6.2.5	Materials for Bit Patterned Magnetic Media	137
6.2.6	Maintaining Competitiveness	138
6.2.7	Going Nano and Beyond	138
6.3	Self-assembly and Magnetic Media	139
6.3.1	Alumina Templates	139
6.3.2	Guided Self-assembly as a Solution to Long-Range Ordering	142
6.3.3	Chemically vs. Topographically Guided Self-assembly ..	144
6.3.4	Biological Self-assembled Templates	144
6.3.5	The Versatility of Block Copolymers	144
6.3.6	Inorganic Templates May Still Be Competitive	145
6.4	Present Alternatives for Discrete Media Production	145
6.4.1	Patterning with Stampers and Masks	145
6.4.2	Cleanliness Concerns	146
6.4.3	Obtaining High Aspect Ratios	147
6.4.4	Types of Nanopatterning Processes	147
6.4.5	Emerging Fabrication Techniques	148
6.4.6	Discrete Track Media	149
6.4.7	Identifying Track Locations	149
6.4.8	Parallel Writing of Data	150
6.4.9	Magnetic Lithography for Mass Data Replication	150
6.4.10	Magnetic Disk Drives vs. Semiconductor Processing	151
6.4.11	Head Performance	151
6.4.12	Spin Valves and Giant Magnetoresistive Heads	152
6.4.13	Looking Back and into the Future	152
	References	153
7	Concluding Remarks	161
	Reference	161
	Index	163