

Contents

1	Introduction	1
2	Fundamental aspects of micromagnetism	7
2.1	Energy terms	8
2.1.1	Exchange energy	8
2.1.2	Magnetostatic energy	9
2.1.3	Zeeman energy	10
2.1.4	Anisotropy energy	10
2.1.5	Effective field	11
2.2	Magnetic structures	12
2.2.1	Characteristic lengths	12
2.2.2	Domains and walls	13
2.2.3	Magnetic vortices	15
2.2.4	Bloch points	19
2.3	Magnetization dynamics	20
2.3.1	Landau-Lifshitz-Gilbert equation of motion	20
2.3.2	Current-induced dynamics	22
2.4	Range of validity of micromagnetic theory	24
3	Finite-element simulations	25
3.1	Mesh generation	27
3.2	Finite-element formulation	28
3.2.1	Shape functions	28
3.2.2	Differentiation	30
3.2.3	Integration	31
3.3	Computation of the effective fields	32
3.3.1	Weak formulation and the exchange field	32
3.3.2	Anisotropy	34
3.3.3	Magnetostatic field	34
3.4	Integration of the equation of motion	37
3.5	Effect of a singularity	37
4	Vortex dynamics	41
4.1	Steady state dynamics	42
4.1.1	The Thiele equation	42
4.1.2	Internal forces acting on a vortex	45
4.1.3	External forces acting on a vortex	48
4.1.4	Vortex motion	49
4.2	Vortex core deformations	52
4.3	Vortex-antivortex interactions	53
4.3.1	Steady-state dynamics	54
4.3.2	Annihilation	54
4.4	Beyond the rigid body approximation	56

CONTENTS

5 Ultrafast vortex core reversal	57
5.1 Experimental observation of the vortex core reversal	58
5.2 Reversal triggered by unipolar field pulses	59
5.2.1 Core reversal mechanism	60
5.2.2 Evolution of the out-of-plane magnetization	60
5.3 Switching field parameters	64
5.4 Energy evolution	66
5.5 Experimental observation of single-pulse induced core reversal	68
5.6 Summary: The fastest field induced switching process	69
6 Ultrafast antivortex dynamics	71
6.1 Antivortex preparation	72
6.2 Field-induced dynamics	73
6.3 Antivortex stability	73
6.4 Experimental investigation	78
6.5 Spin wave generation	80
6.6 Summary	80
7 Current-induced vortex core reversal	83
7.1 Vortex dynamics induced by a spin-polarized current	84
7.2 Core reversal triggered by an alternating current	84
7.3 Core reversal induced by short current pulses	86
7.4 Summary: Resonant versus non-resonant switching	90
8 Energetic origin of the core switch	93
8.1 Core switch triggered at resonance	94
8.1.1 Energy evolution	94
8.1.2 Variations with the applied current	96
8.2 Energy evolution in response to short current pulses	99
8.3 Energy thresholds as a function of intrinsic parameters of the vortex	100
8.4 Energy thresholds in iron	102
8.5 Summary: A local process driven by the exchange field	104
9 Stimulated vortex-antivortex pair production	107
9.1 Pair production in a sample enclosing a vortex	108
9.1.1 Pair production at a distance from the vortex core	108
9.1.2 Pair production in the vicinity of the vortex core	110
9.2 Pair production in a single-domain structure	112
9.3 Current-induced pair production	114
9.4 Summary	115
10 Conclusion	117
Bibliography	120
Publications	139
Acknowledgements	143
