

## Contents

Abstract

Contents

<b>Chapter 1 Introduction.....</b>	<b>1</b>
<b>Chapter 2 Background.....</b>	<b>4</b>
2.1 .....	F
inite different method .....	4
2.1.1 Forward, backward and central differences.....	4
2.1.2 Finite difference calculation .....	5
2.1.3 Derivatives with high order.....	5
2.1.4 Finite method.....	6
2.1.5 Finite different operator.....	6
2.2 The finite element micromagnetic model and dynamic equation.....	7
2.2.1 Free energy concern in micromagnetics.....	10
2.2.1.1 Continuum hyposis.....	11
2.2.1.2 Anisotropy energy.....	11
2.2.1.3 Exchange energy and interaction.....	12
2.2.1.4 Magnetostatic energy.....	13
2.2.1.5 External induced Zeeman energy.....	14
2.2.1.6 Free energy expression.....	14
2.2.2 The dynamic equation.....	14
2.2.2.1 Gyromagnetic prwssion.....	15
2.2.2.2 The Landau – Lifshitz – Gilbert equation.....	15
2.3 Micromagnetic simulation development and current state.....	16

2.4 Exchange Coupled Composite(ECC) media .....	22
<b>Chapter 3 Experiment design and simulation model.....</b>	<b>37</b>
3.1 Experiment flow chart.....	37
3.2 Software and Numerical Micromagnetic model.....	38
<b>Chapter 4 Results and discussions.....</b>	<b>40</b>
4.0.1 Introduction.....	40
4.0.1 Introduction.....	40
4.0.2 Result and discussion.....	40
4.1 Demagnetization field fact in single grain system.....	42
4.1.1 Introduction.....	42
4.1.2 Simulation model detail.....	44
4.1.3 Results and discussions.....	45
4.1.4 Conclusions.....	48
4.2 Modified inter-layer exchange coupling $J$ in single grain system.....	49
4.2.1 Introduction.....	49
4.2.2 Simulation model detail.....	50
4.2.3 Results and discussions.....	51
4.2.4 Conclusions.....	59
4.3 Soft layer number dependence.....	60
4.3.1 Introduction.....	60
4.3.2 Results and discussions.....	60
4.3.3 Conclusions.....	65
4.4 Double grains model.....	69

4.4.1Introduction.....	69
4.4.2 Simulation model detail.....	70
4.4.3 Results and discussions.....	71
4.4.4 Conclusions.....	73
4.5 Seven-grains cluster model.....	74
4.5.1 Introduction.....	74
4.5.2 Simulation model detail.....	74
4.5.3 Result and discussion.....	76
4.5.4 Conclusions.....	83
<b>Chapter 5 Summary.....</b>	<b>84</b>



## List of figures

<b>Figure 2.2.1</b>	The refined meshing near edges and corners.....	9
<b>Figure 2.2.2</b>	The surface charges induced stray field.....	10
<b>Figure 2.3.1</b>	Finite element method of models.....	11
<b>Figure 2.3.2</b>	Damping gyromagnetic precession motion.....	18
<b>Figure 2.3.3</b>	Meshing process.....	20
<b>Figure 2.3.4</b>	Nmag micromagnetic simulation.....	21
<b>Figure 2.3.5</b>	The multi-scale modeling mesh structure.....	22
<b>Figure 2.4.1</b>	The micromagnetic modeling of hard/soft bilayer granular system.....	24
<b>Figure 2.4.2</b>	Magnetization reversal configuration by OOMMF code....	26
<b>Figure 2.4.5</b>	Two materials phase boundary.....	28
<b>Figure 2.4.6</b>	Domain wall spin configuration under an external field.... .....	29
<b>Figure 2.4.7</b>	The homogeneous rotation, curling, and buckling.....	30
<b>Figure 2.4.8</b>	Stereographic projection of the unit-phase on the plane....	31
<b>Figure 2.4.9</b>	The dependence of coupling force and switching field in FePt/FeRh bilayer.....	32
<b>Figure 2.4.10.</b>	Three kinds of hysteresis loop.....	34
<b>Figure 2.4.11.</b>	MH loop and dynamic moment tilting distribution in composite media.....	35
<b>Figure 2.4.12.</b>	1 T bit / $\mu\text{m}^2$ simulation in graded media system.....	36
<b>Figure 3.0</b>	The OXS top level class diagram.....	39

<b>Figure 4.0.1</b>	The demagnetization and spin configuration.....	41
<b>Figure 4.1.1</b>	The derived equation of $\mathbf{D_z}$ and corresponding coordinate System.....	43
<b>Figure 4.1.2</b>	The film structure in section 4.1.....	45
<b>Figure 4.1.3</b>	Hysteresis loops demonstrate the effect of demagnetization consideration.....	46
<b>Figure 4.1.4</b>	Demagnetization field inside the grain.....	48
<b>Figure 4.2.1</b>	Simulation model detail in section 4.2 for film structure...	51
<b>Figure 4.2.2</b>	Hysteresis loops for different coupling strength J.....	52
<b>Figure 4.2.3</b>	The vertical spin configuration inside the grain during the reversal process.....	55
<b>Figure 4.2.4</b>	Inter-spacer exchange energy J is equal to $0.6 \text{ erg/cm}^2$ and $1.2 \text{ erg/cm}^2$ cases.....	56
<b>Figure 4.2.5</b>	The simulation result matches the theory prediction.....	58
<b>Figure 4.2.6</b>	Reversal process for each soft layer.....	59
<b>Figure 4.3.1</b>	Demagnetization curves for different soft numbers.....	60
<b>Figure 4.3.2</b>	The curves of the interface exchange energy across each Pt spacer.....	61
<b>Figure 4.3.3</b>	The domain wall transport mechanism.....	63
<b>Figure 4.3.4</b>	Time resolved demagnetization curve illustrates the upper half soft layers.....	64
<b>Figure 4.3.5</b>	Demagnetization curve for 20 soft layer structure.....	67
<b>Figure 4.3.6</b>	The vertical spin configuration in case of 9nm soft layer thickness.....	69
<b>Figure 4.4.1</b>	Double grains model.....	71
<b>Figure 4.4.2</b>	The corresponding demagnetization curves of single and	

double grains models.....	72
<b>Figure 4.4.3</b> The demagnetization curve of different degree of the grain isolation.....	73
<b>Figure 4.5.1</b> Construction for grain cluster model.....	75
<b>Figure 4.5.2</b> The illustration of 7-grain cluster model.....	76
<b>Figure 4.5.3</b> The demagnetization curve with different mesh sizes.....	77
<b>Figure 4.5.4</b> The measured MH loop for different soft layer number....	78
<b>Figure 4.5.5</b> The demagnetization curve of more complicated 7-grain cluster model-----	79
<b>Figure 4.5.6</b> The spin configuration of more complicated 7-grain cluster model-----	82

