

Contents

List of Contributors XIII

1	Pulsed Laser Deposition for Complex Oxide Thin Film and Nanostructure	1
	<i>Chunrui Ma and Chonglin Chen</i>	
1.1	Introduction	1
1.2	Pulsed Laser Deposition System Setup	2
1.3	Advantages and Disadvantages of Pulsed Laser Deposition	3
1.4	The Thermodynamics and Kinetics of Pulsed Laser Deposition	3
1.4.1	Laser–Material Interactions	4
1.4.2	Dynamics of the Plasma	5
1.4.3	Nucleation and Growth of the Film on the Substrate Surface	5
1.5	Monitoring of Growth Kinetics	8
1.5.1	Introduction and RHEED Studies	8
1.5.2	Growth Kinetics Studies by Surface X-ray Diffraction	9
1.6	Fundamental Parameters in Thin Film Growth	10
1.6.1	Substrate Temperature	10
1.6.2	Background Gas Pressure	10
1.6.3	Laser Fluence and Ablation Area	11
1.6.4	Target–Substrate Distance	11
1.6.5	Post-Annealing	12
1.6.6	Lattice Misfit	12
1.7	Pulsed Laser Deposition for Complex Oxide Thin Film Growth	13
1.7.1	Pulsed Laser Deposition for Superconductor Thin Film	14
1.7.2	Pulsed Laser Deposition for Ferroelectric Thin Films	14
1.7.3	Pulsed Laser Deposition for Ferromagnetic Thin Film	15
1.7.4	Pulsed Laser Deposition for Multiferroics Thin Film	15
1.7.5	Interface Strain Engineering the Complex Oxide Thin Film	16
1.7.5.1	Thickness Effect	16
1.7.5.2	Substrate Effect	17
1.7.5.3	Post-Annealing	21
1.8	Pulsed Laser Deposition for Nanostructure Growth	23

1.8.1	Self-Assembled Nanoscale Structures	23
1.8.2	Geometrically Ordered Arrays	23
1.9	Variation of Pulsed Laser Deposition	24
1.10	Conclusion	24
	References	25
2	Electron Beam Evaporation Deposition	33
	<i>Zhongping Wang and Zengming Zhang</i>	
2.1	Introduction	33
2.2	Electron Beam Evaporation System	35
2.2.1	Heating Principle and Characters of Electron Beams	35
2.2.1.1	Heating Principle of Electron Beams	35
2.2.1.2	Characters of Electron Beams	36
2.2.2	Equipments of Electron Beam Source	37
2.2.2.1	Filament and Electron Emission	37
2.2.2.2	Electron Beam Control	38
2.2.2.3	Power Supply, Crucibles, and Feed Systems	39
2.2.2.4	Source Materials	40
2.2.3	Application of Electron Beam Evaporation	43
2.2.3.1	Cooling of Electron Beam Gun	43
2.2.3.2	Evaporation of Source Materials by Electron Beam	43
2.2.3.3	Vacuum Deposition Process of Electron Beam Evaporation	44
2.2.3.4	Attention and Warning for Electron Beam Evaporation	45
2.3	Characterization of Thin Film	45
2.3.1	Surface Morphology by AFM	46
2.3.2	Thickness Measurement by Spectroscopic Ellipsometry	47
2.4	Summary	53
	Acknowledgments	53
	References	53
3	Nanostructures and Thin Films Deposited with Sputtering	59
	<i>Weiqing Yang</i>	
3.1	Introduction	59
3.2	Nanostructures with Sputtering	60
3.2.1	Oxide Nanostructures	61
3.2.1.1	Needle-Shaped MoO ₃ Nanowires	61
3.2.1.2	Bi ₂ O ₃ Nanowires	64
3.2.2	Nitride Nanostructures	65
3.2.2.1	Graphitic-C ₃ N ₄ Nanocone Array	65
3.2.2.2	InAlN Nanorods	68
3.3	Thin Films Deposited with Sputtering	71
3.3.1	Metal Alloy Thin Films	73
3.3.1.1	LaNi ₅ Alloy Thin Films	73
3.3.1.2	Ni–Mn–In Alloy Thin Films	74
3.3.2	Composite Metal Oxide Thin Films	75

3.3.2.1	BiFeO ₃ /BaTiO ₃ Bilayer Thin Films	75
3.4	Summary	76
	Acknowledgments	77
	References	77
4	Nanostructures and Quantum Dots Development with Molecular Beam Epitaxy	81
	<i>Wen Huang</i>	
4.1	Introduction	81
4.2	Technology of MBE	82
4.2.1	The Physics of MBE	83
4.2.2	MBE Growth Mechanisms	86
4.2.2.1	Two-Dimensional (2D) MBE Growth Mechanism	87
4.2.2.2	Three-Dimensional (3D) MBE Growth Mechanism	88
4.2.2.3	Stranskie–Krastanow 3D Growth Mechanism	90
4.3	Nanoheterostructures Fabricated by Molecular Beam Epitaxy	91
4.3.1	Semiconducting Oxide Heterostructures Grown by Laser Molecular Beam Epitaxy	91
4.3.2	Strain-Induced Magnetic Anisotropy in Highly Epitaxial Heterostructure by LMBE	96
4.4	Quantum Dots Development with Molecular Beam Epitaxy	101
4.5	Summary	103
	Acknowledgments	104
	References	104
5	Carbon Nanomaterials and 2D Layered Materials Development with Chemical Vapor Deposition	105
	<i>Taisong Pan</i>	
5.1	Introduction	105
5.2	Carbon Nanotube Synthesis by Chemical Vapor Deposition	106
5.2.1	Overview of CVD Process of Carbon Nanotube Growth	106
5.2.2	Control of Carbon Nanotube Structure	108
5.2.3	The Alignment of Carbon Nanotube Array	110
5.3	Graphene Synthesis by Chemical Vapor Deposition	112
5.3.1	Overview of CVD Process of Graphene Synthesis	112
5.3.2	Control of Graphene Quality	113
5.4	Metal Dichalcogenide Synthesis by Chemical Vapor Deposition	115
5.4.1	Overview of CVD Process of Metal Dichalcogenides	115
5.4.2	Growth Control of Metal Dichalcogenides in Chemical Vapor Deposition	118
5.5	Summary	119
	References	120

6	Nanostructures Development with Atomic Layer Deposition	123
	<i>Hulin Zhang</i>	
6.1	Introduction	123
6.2	Reaction Mechanisms	125
6.2.1	Thermal ALD	125
6.2.2	Catalytic ALD	127
6.2.3	Metal ALD	129
6.3	Nanostructures Based on ALD	131
6.3.1	Nanolaminates and Nanofilms	132
6.3.2	Nanostructures as Templates	132
6.3.3	Nanostructured Modification	135
6.4	Summary	136
	Acknowledgments	137
	References	138
7	Nanomaterial Development with Liquid-Phase Epitaxy	141
	<i>Weiqing Yang</i>	
7.1	Introduction	141
7.2	Hydrothermal Method	142
7.2.1	Development of Hydrothermal Method	142
7.2.2	Microwave-Assisted Hydrothermal Method	143
7.2.2.1	Microwave-Assisted Preparation of Nanostructures in Aqueous Solution	144
7.3	Nanostructures Fabricated Using LPE	147
7.3.1	Core–Shell Structures	147
7.3.2	The Epitaxial Preparation Methods of Core–Shell Structures	148
7.3.2.1	General Nanochemical Approaches to Prepare Epitaxial Core–Shell UCNPs with a Single Shell Layer	150
7.3.2.2	Layer-by-Layer Approach to Prepare Core–Multishell UCNPs with Monolayer Thickness Precision	153
7.3.2.3	Mesoporous Silica Coating	153
7.3.2.4	Coupling of UCNPs with Plasmonics Using Core–Shell Architecture	154
7.4	Summary	156
	Acknowledgments	156
	References	156
8	Nanostructural Thin Film Development with Chemical Solution Deposition	159
	<i>Yanda Ji and Yuan Lin</i>	
8.1	Introduction	159
8.2	Precursor Solution Preparation	159
8.2.1	Chemical Strategies for Precursor Solutions	160
8.2.2	Sol–Gel Method	160
8.2.3	Metal–Organic Deposition	161

8.2.4	Polymer-Assisted Deposition	161
8.3	Coating	162
8.4	Thermal Treatment	163
8.5	Control of the Microstructures in Thin Films Prepared by CSD Techniques	164
8.5.1	Thermodynamics for CSD-Delivered Thin Films	164
8.5.2	Epitaxial Thin Film Growth	166
8.6	Examples of Nanostructural Thin Films Prepared by CSD Techniques	167
8.6.1	Sol–Gel-Delivered Nanostructured Materials	167
8.6.2	MOD of Nanostructured Materials	168
8.6.3	PAD-Delivered Nanostructured Materials	168
8.7	Summary	174
	References	175
9	Nanomaterial Development Using <i>In Situ</i> Liquid Cell Transmission Electron Microscopy	179
	<i>Xin Chen, Wangfan Zhou, Debiao Xie, and Hongliang Cao</i>	
9.1	Introduction	179
9.2	The Technological Development of <i>In Situ</i> Liquid Cell TEM	179
9.2.1	The Advent of the Modern <i>In Situ</i> Liquid Cell	180
9.2.2	Recent Technological Development of Liquid Cells	180
9.2.3	Commercial Liquid Cells	183
9.3	Nanomaterial Development Using <i>In Situ</i> Liquid Cell TEM Technology	185
9.3.1	Nanomaterial Growth Induced by Electrical Bias	185
9.3.2	Nanomaterial Growth Induced by Irradiation	187
9.3.3	Nanomaterial Formation Induced by Heating	189
9.3.4	Further Nanomaterial Development Results from <i>In Situ</i> Liquid Cell TEM	190
9.4	Summary and Outlook	191
	Acknowledgments	191
	References	192
10	Direct-Writing Nanolithography	195
	<i>Min Gao</i>	
10.1	Introduction	195
10.2	Electron Beam Lithography	195
10.3	Focused Ion Beam Lithography	198
10.4	Gas-Assisted Electron and Ion Beam Lithography	200
10.5	SPM Lithography	201
10.6	Dip-Pen Lithography	205
10.7	Summary	206
	Acknowledgments	207
	References	207

11	3D Printing of Nanostructures	209
	<i>Min Gao</i>	
11.1	Introduction	209
11.2	3D Printing Processes	209
11.3	Types of 3D Printing	210
11.3.1	Stereolithography	210
11.3.2	Fused Deposition Modeling	211
11.3.3	Selective Deposition Lamination	212
11.3.4	Selective Laser Sintering	213
11.3.5	3D Inkjet Printing	214
11.3.6	Multijet Modeling	214
11.4	3D Direct Laser Writing by Multiphoton Polymerization	214
11.5	3D Printing Applications	217
11.5.1	Medical Applications	217
11.5.2	Industrial Manufacturing	218
11.5.3	Daily Consumption	219
11.5.4	Limitation of 3D Printing Applications	219
11.6	Summary	219
	Acknowledgments	220
	References	220
12	Nanostructured Thin Film Solid Oxide Fuel Cells	223
	<i>Alex Ignatiev, Rabi Ebrahim, Mukhtar Yeleuov, Daniel Fisher, Xin Chen, Naijuan Wu, and Serekbol Tokmoldin</i>	
12.1	Introduction	223
12.2	Solid Oxide Fuel Cells	223
12.2.1	Thin Film Solid Oxide Fuel Cell Fabrication	225
12.2.2	Thin Film Solid Oxide Fuel Cell Testing	231
12.2.3	Thin Film Fuel Cell Stack Development and Testing	234
12.3	Summary	237
	Acknowledgments	237
	References	237
13	Nanostructured Magnetic Thin Films and Coatings	239
	<i>Goran Rasic</i>	
13.1	Introduction	239
13.2	High-Frequency Devices	240
13.2.1	Ferromagnets	241
13.2.2	Coercivity	242
13.2.3	Magnetic Losses	243
13.2.4	Nanoscale Methods of Loss Reduction	244
13.2.5	Manufacturing Considerations	244
13.2.6	Coercivity Reduction in Surface-Patterned Magnetic Thin Films	245
13.3	Magnetic Information Storage Devices	251

13.3.1	Superparamagnetic Limit	252
13.3.2	Signal-to-Noise Ratio	253
13.3.3	Present-Day Solutions	253
13.3.4	Bit Patterned Media	254
13.3.5	Manufacturing Considerations	255
13.3.6	Patterned Media for Magnetic Data Storage	256
13.4	Summary	261
	Acknowledgments	261
	References	262
14	Phase Change Materials for Memory Application	267
	<i>Liangcai Wu and Zhitang Song</i>	
14.1	Introduction	267
14.2	Ge ₂ Sb ₂ Te ₅ and Its Properties' Improvement	268
14.2.1	Ge ₂ Sb ₂ Te ₅ Phase Change Material	268
14.2.2	N-Doped Ge ₂ Sb ₂ Te ₅ Material	270
14.2.3	C-Doped Ge ₂ Sb ₂ Te ₅ Material	272
14.2.3.1	Film Properties and Microstructure Characteristics	272
14.2.3.2	Reversible Phase Change Characteristics of C-Doped Ge ₂ Sb ₂ Te ₅	274
14.3	High-Speed and Lower-Power TiSbTe Materials	277
14.3.1	Film Properties and Microstructure Characteristics	277
14.3.1.1	Ti-Doped Sb ₂ Te Materials	277
14.3.1.2	Ti-Doped Sb ₂ Te ₃ Materials	278
14.3.2	Reversible Phase Change Characteristics of TST Alloy	280
14.4	Summary	283
	Acknowledgments	283
	References	283
15	Nanomaterials and Devices on Flexible Substrates	285
	<i>Hulin Zhang</i>	
15.1	Introduction	285
15.2	Nanomaterials on Flexible Substrates	286
15.2.1	Nanomaterials Synthesized Directly on Flexible Substrates	286
15.2.2	Nanomaterials Transferred on Flexible Substrates	290
15.3	Devices on Flexible Substrates	292
15.3.1	Printing Electronics on Flexible Substrates	293
15.3.2	Biointegrated Electronics on Flexible Substrates	298
15.4	Summary	300
	Acknowledgments	301
	References	301
	Index	305

