

MICRO/NANO REPLICATION

Processes and Applications

SHINILL KANG

 WILEY

CONTENTS

Preface	xiii
1. Introduction	1
1.1 Introduction	1
1.2 Micro/Nano Replication	4
1.3 Application Fields of Micro/Nano Replicated Parts	7
1.3.1 Optical Data Storage Devices	8
1.3.2 Display Fields	11
1.3.3 Other Industries	13
1.4 Required Technologies for Micro/Nano Replication	14
References	19
2. Patterning Technology for Micro/Nanomold Fabrication	22
2.1 Material Removal Process	22
2.1.1 Mechanical Machining	23
2.1.2 Laser Ablation	24
2.1.3 Silicon Etching Process	25
2.1.4 Focused Ion Beam Patterning	28
2.2 Lithography Process	29
2.2.1 Electron Beam Lithography	29
2.2.2 Photolithography	31
2.2.3 Reflow Method	31
2.2.3.1 Fabrication of a Mother Lens	31
2.2.3.2 Empirical Equation for the Volume Change Ratio of a Reflow Lens	39
2.2.3.3 Verification of the Model	40
2.2.4 Laser Interference Lithography	43
2.2.4.1 Theory of Laser Interference Lithography	43
2.2.4.2 Simulation of Laser Interference Lithography	44
2.2.4.3 Experimental Setup	45
	vii

2.2.4.4	Fabrication of Nanostructures Using Laser Interference Lithography under Different Process Conditions	47
2.3	Electroforming Processes	50
2.3.1	Theory of Electroforming Process	51
2.3.2	Electroforming Results	51
2.3.2.1	Metallic Mold for a Microlens Array	51
2.3.2.2	Metallic Mold for Patterned Media	51
	References	54
3.	Modification of Mold Surface Properties	59
3.1	Introduction	59
3.2	Thiol-Based Self-Assembled Monolayer	61
3.2.1	Thiol-Based Self-Assembled Monolayer and Deposition Process	61
3.2.2	Experiment Results and Analysis	63
3.2.3	The Changing Properties of SAM at Actual Replication Environment	64
3.2.4	Analysis of Replicated Polymeric Patterns	70
3.3	Silane-Based Self-Assembled Monolayer	73
3.3.1	Silane-Based Self-Assembled Monolayer	73
3.3.2	Deposition Process of Silane-Based Self-Assembled Monolayer	74
3.3.3	Self-Assembled Monolayer on Polymer Mold	74
3.3.4	Analysis of Replicated Polymeric Patterns	76
3.4	Dimethyldichlorosilane Self-Assembled Monolayer	76
	References	80
4.	Micro/Nano injection Molding with an Intelligent Mold System	82
4.1	Introduction	82
4.2	Effects of the Mold Surface Temperature on Micro/Nano injection Molding	85
4.3	Theoretical Analysis of Passive/Active Heating Methods for Controlling the Mold Surface Temperature	88
4.3.1	Mathematical Modeling and Simulation	90
4.3.2	Passive Heating	94
4.3.3	Active Heating	98

4.4	Fabrication and Control of an Active Heating System Using an MEMS Heater and an RTD Sensor	102
4.4.1	Construction of an Intelligent Mold System	103
4.4.2	Control System for the Intelligent Mold System	108
4.4.2.1	Kalman Filter Observer of the Thermal Plant	111
4.4.2.2	LQGI Controller	113
4.4.2.3	Performance of the Constructed Control System	115
4.5	Replication of a High-Density Optical Disc Substrate Using the Intelligent Mold System	119
	References	120

5. Hot Embossing of Microstructured Surfaces and Thermal Nanoimprinting **123**

5.1	Introduction	123
5.2	Development of Microcompression Molding Process	125
5.3	Temperature Dependence of Anti-Adhesion Between a Mold and the Polymer in Thermal Imprinting Processes	127
5.3.1	Defects in Replicated Micro-Optical Elements	128
5.3.2	Analysis of Polymer in Process Condition of Thermal Imprinting	128
5.3.3	Analysis of Replication Quality Fabricated in Different Peak Temperature	133
5.4	Fabrication of a Micro-Optics Using Microcompression Molding with a Silicon Mold Insert	138
5.4.1	Fabrication of Microlens Components Using Si Mold Insert	138
5.4.2	Analysis of Refractive Microlens	139
5.5	Fabrication of a Microlens Array Using Microcompression Molding with an Electroforming Mold Insert	140
5.5.1	Fabrication of Microlens Components Using Ni Mold Insert	140
5.5.2	Analysis of Replication Quality	143
5.6	Application of Microcompression Molding Process	147
5.6.1	Fabrication of a Microlens Array Using Microcompression Molding	147

5.6.2	Fabrication of Metallic Nanomold and Replication of Nanopatterned Substrate for Patterned Media	149
	References	154
6.	UV-Imprinting Process and Imprinted Micro/Nanostructures	157
6.1	Introduction	157
6.2	Photopolymerization	158
6.3	Design and Construction of UV-Imprinting System	160
6.4	UV-Transparent Mold	162
6.5	Effects of Processing Conditions on Replication Qualities	165
6.6	Controlling of Residual Layer Thickness Using Drop and Pressing Method	170
6.7	Elimination of Microair Bubbles	171
6.8	Applications	176
6.8.1	Wafer Scale UV Imprinting	176
6.8.2	Diffractive Optical Element	179
6.8.3	Roll-to-Roll Imprint Lithography Process	186
6.9	Conclusion	192
	References	192
7.	High-Temperature Micro/Nano Replication Process	196
7.1	Fabrication of Metal Conductive Tracks Using Direct Imprinting of Metal Nanopowder	196
7.1.1	Introduction	196
7.1.2	Direct Patterning Method Using Imprinting and Sintering	198
7.1.3	Imprinting and Sintering System	199
7.1.4	Defect Analysis and Process Design	203
7.1.5	Analysis of Imprinted Conductive Tracks	204
7.1.6	Conclusions	210
7.2	Glass Molding of Microlens Array	211
7.2.1	Introduction	211
7.2.2	Fabrication of Master Patterns	212
7.2.3	Fabrication of Tungsten Carbide Core for Microglass Molding	215
7.2.3.1	Fabrication Process of Tungsten Carbide Core	215

7.2.3.2	Measurement of Shrinkage After Sintering Process	218
7.2.4	Surface Finishing and Coating Process of Tungsten Carbide Core	219
7.2.5	Comparison of Surface Roughness Before and After Finishing Process	221
7.2.6	Fabrication of Glass Microlens Array by Microthermal Forming Process	225
7.2.7	Measurement and Analysis of Optical Properties of Formed Glass Microlens Array	229
	References	230
8.	Micro/Nano-Optics for Light-Emitting Diodes	233
8.1	Designing an Initial Lens Shape	234
8.1.1	LED Illumination Design	234
8.1.2	Source Modeling	236
8.1.3	Modeling a Spherical Refractive Lens	236
8.1.4	Modeling a Micro-Fresnel Lens	238
8.1.5	Verifying the Micro-Fresnel Lens Performance	240
8.2	Fabrication Results and Discussion	245
8.2.1	Fabrication of the Micro-Fresnel Lens	245
8.2.2	Elimination of Air Bubbles	246
8.2.3	Optimization of the UV-Imprinting Process	247
8.2.4	Evaluation of the Micro-Fresnel Lens for LED Illumination	249
8.3	Conclusions	253
	References	254
9.	Micro-/Nano-Optics for Optical Communications	256
9.1	Fiber Coupling Theory	258
9.2	Separated Microlens Array	259
9.2.1	Design	259
9.2.2	Fabrication	260
9.2.3	Measurement Results	263
9.3	Integrated Microlens Array	266
9.3.1	Design	266
9.3.2	Fabrication	268
9.3.3	Measurement Results	269
9.4	Conclusions	273
	References	274

10. Patterned Media	276
10.1 Introduction	276
10.2 Fabrication of a Metallic Nano Mold Using a UV-Imprinted Polymeric Master	278
10.3 Fabrication of Patterned Media Using the Nano Replication Process	290
10.4 Fabrication of Patterned Media Using Injection Molding	296
10.5 Measurement and Analysis of Magnetic Domains of Patterned Media by Magnetic Force Microscopy	302
10.6 Conclusions	307
References	307
11. Optical Disk Drive (ODD)	310
11.1 Introduction	310
11.2 Improvements in the Optical and Geometrical Properties of HD-DVD Substrates	313
11.3 Effects of the Insulation Layer on the Optical and Geometrical Properties of the DVD Mold	318
11.4 Optimized Design of the Replication Process for Optical Disk Substrates	329
11.5 Conclusions	337
References	339
12. Biomedical Applications	341
12.1 Introduction	341
12.2 GMR-Based Protein Sensors	342
12.2.1 Principle of GMR Protein Sensors	342
12.2.2 Principle of Guided-Mode Resonance Effect	343
12.2.3 Nano Replication Process of a GMR Protein Chip for Mass Production	346
12.2.4 Feasibility Test of GMR Protein Chip	359
12.3 Conclusions	362
References	362
Index	365