# Preface

## 1. Introduction

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

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
### 3. Modification of Mold Surface Properties

#### 3.1 Introduction

#### 3.2 Thiol-Based Self-Assembled Monolayer
- 3.2.1 Thiol-Based Self-Assembled Monolayer and Deposition Process
- 3.2.2 Experiment Results and Analysis
- 3.2.3 The Changing Properties of SAM at Actual Replication Environment
- 3.2.4 Analysis of Replicated Polymeric Patterns

#### 3.3 Silane-Based Self-Assembled Monolayer
- 3.3.1 Silane-Based Self-Assembled Monolayer and Deposition Process
- 3.3.2 Deposition Process of Silane-Based Self-Assembled Monolayer
- 3.3.3 Self-Assembled Monolayer on Polymer Mold
- 3.3.4 Analysis of Replicated Polymeric Patterns

#### 3.4 Dimethyldichlorosilane Self-Assembled Monolayer

### 4. Micro/Nanoinjection Molding with an Intelligent Mold System

#### 4.1 Introduction

#### 4.2 Effects of the Mold Surface Temperature on Micro/Nanoinjection Molding

#### 4.3 Theoretical Analysis of Passive/Active Heating Methods for Controlling the Mold Surface Temperature
- 4.3.1 Mathematical Modeling and Simulation
- 4.3.2 Passive Heating
- 4.3.3 Active Heating
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
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**

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)**

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**

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