

Table of Contents

Foreword	xi
Jörge DE SOUSA NORONHA	
Introduction	xvii
Michel BRILLOUËT	
Chapter 1. X-ray Lithography: Fundamentals and Applications	1
Massimo TORMEN, Gianluca GRENCI, Benedetta MARMIROLI and Filippo ROMANATO	
1.1. Introduction.	1
1.2. The principle of X-ray lithography	5
1.2.1. The irradiation system for XRL	7
1.2.2. Properties of synchrotron radiation	9
1.2.3. High Resolution and Deep XRL	12
1.2.4. Examples of X-ray lithography beamlines	12
1.2.5. Scanner/stepper	18
1.2.6. The mask.	19
1.3. The physics of X-ray lithography.	25
1.3.1. How phase and intensity of X-rays are altered by interaction with matter.	25
1.3.2. X-ray lithography as a shadow printing technique	27
1.3.3. X-ray absorption in a resist and physical mechanisms involved in its exposure	30
1.3.4. Physical model of electron energy loss in resists	35
1.3.5. Diffraction effects in X-ray lithography.	40
1.3.6. Coherence of synchrotron radiation from bending magnet devices	41

1.3.7. Basic formulation of diffraction theory for a scalar field.	44
1.3.8. Rayleigh–Sommerfeld formulation of diffraction by a planar screen	47
1.3.9. An example of diffraction effects: Poisson’s spot in X-ray lithography	51
1.4. Applications	55
1.4.1. Optimal photon energy range for high resolution and deep X-ray lithography	55
1.4.2. Diffraction effects on proximity lithography.	56
1.4.3. High resolution 3D nano structuring.	61
1.4.4. 3D polymer structures by combination of NanoImprint (NIL) and X-ray lithography (XRL)	64
1.4.5. Micromachining and the LIGA process.	66
1.4.9. Micro-optical element for distance measurement	77
1.5. Appendix 1	79
1.6. Bibliography	79
Chapter 2. NanoImprint Lithography	87
Stefan LANDIS	
2.1. From printing to NanoImprint.	87
2.2. A few words about NanoImprint	90
2.3. The fabrication of the mold	96
2.4. Separating the mold and the resist after imprint: de-embossing	100
2.4.1. The problem	100
2.4.2. Adhesion	102
2.4.3. Adhesion and physico-chemical surface properties	103
2.4.4. Surface treatment of the mold	107
2.4.5. Treatment of the resist	114
2.4.6. Characterization of the demolding process.	114
2.5. The residual layer problem in NanoImprint.	118
2.5.1. The residual layer: a NanoImprint specific issue	118
2.5.2. Is the thickness of the residual layer predictable?	120
2.5.3. How can the process impact the thickness of the residual layer?	125
2.6. Residual layer thickness measurement.	132
2.6.1. Macro-scale approach: coherence between film color and thickness	134
2.6.2. Microscopic approach	136

2.7. A few remarks on the mechanical behavior of molds and flow properties of the nanoimprint process	148
2.8. Conclusion	157
2.9. Bibliography	157
Chapter 3. Lithography Techniques Using Scanning Probe Microscopy	169
Vincent BOUCHIAT	
3.1. Introduction.	169
3.2. Presentation of local-probe microscopes.	170
3.3. General principles of local-probe lithography techniques.	171
3.4. Classification of surface structuring techniques using local-probe microscopes	173
3.4.1. Classification according to the physical nature of the interaction	174
3.4.2. Comparison with competing advanced lithography techniques	176
3.4.3. Industrial development perspectives.	177
3.5. Lithographic techniques with polymer resist mask.	179
3.5.1. Electron beam exposure of resists by scanning probe microscopes	180
3.5.2. Development of a resist dedicated to AFM nano-lithography.	182
3.5.3. Lithography using mechanical indentation	184
3.6. Lithography techniques using oxidation-reduction interactions	185
3.6.1. Direct fabrication by matter deposition induced by STM microscopy	186
3.6.2. Local anodization under the AFM tip	188
3.7. “Passive” lithography techniques	198
3.7.1. Dip-pen lithography	198
3.7.2. Alignment technique by means of a mechanical masking (stencil mask).	200
3.8. Conclusions and perspectives	200
3.9. Bibliography	201
Chapter 4. Lithography and Manipulation Based on the Optical Properties of Metal Nanostructures	207
Renaud BACHELOT and Marianne CONSONNI	
4.1. Introduction.	207
4.2. Surface plasmons	208
4.2.1. Definition of a volume plasmon	208

4.2.2. Delocalized surface plasmons	209
4.2.3. Localized surface plasmons	212
4.2.4. Application to lithography	216
4.3 Localized plasmon optical lithography	216
4.3.1. Near-field optical lithography by optical edge effect	217
4.3.2. Use of nanoparticle resonances	220
4.4. Delocalized surface plasmon optical lithography	222
4.4.1. Coupling between nanostructures and delocalized surface plasmons	223
4.4.2. Surface plasmon launch and interferences	224
4.5. Conclusions, discussions and perspectives	225
4.6. Bibliography	226
Chapter 5. Patterning with Self-Assembling Block Copolymers	231
Karim AISSOU, Martin KOGELSCHATZ, Claire AGRAFFEIL, Alina PASCALE and Thierry BARON	
5.1. Block copolymers: a nano-lithography technique for tomorrow?	231
5.2. Controlling self-assembled block copolymer films	233
5.3. Technological applications of block copolymer films	237
5.4. Bibliography	244
Chapter 6. Metrology for Lithography	249
Johann FOUCHER and Jérôme HAZART	
6.1. Introduction	249
6.2. The concept of CD in metrology	250
6.2.1. CD measurement after a lithography stage: definitions	250
6.2.2. What are the metrological needs during a lithography step?	251
6.3. Scanning electron microscopy (SEM)	254
6.3.1. SEM principle	254
6.3.2. Matter–electron interaction	258
6.3.3. From signal to quantified measurement	263
6.3.4. Provisional conclusion on scanning electron microscopy	266
6.4. 3D atomic force microscopy (AFM3D)	266
6.4.1. AFM principle	267
6.4.2. Three-dimensionnal AFM (AFM3D) special features	275
6.4.3. Provisional conclusion on AFM 3D	286
6.5. Grating optical diffractometry (or scatterometry)	286
6.5.1. Principle	287

6.5.2. Example: ellipsometry characterization of post development lithography	290
6.5.3. Pros and cons	296
6.5.4. Optical measurements analysis	297
6.5.5. Specificities of scatterometry for CD metrology	305
6.5.6. Scatterometry implementation: R&D versus production	307
6.5.7. New fields for scatterometry	310
6.6. What is the most suitable technique for lithography?	310
6.6.1. Technique correlation	313
6.6.2. Technique calibration	313
6.6.3. Process development	314
6.6.4. Evaluation of morphological damage generated by the primary electron beam from CD-SEM	314
6.7. Bibliography	316
List of Authors	321
Index	323