

## Table of Contents

<b>Preface</b> . . . . .	ix
<b>Chapter 1. Nanoscale Cutting</b> . . . . .	1
Rüdiger RENTSCH	
1.1. Introduction. . . . .	1
1.2. Basic elements of molecular dynamics modeling . . . . .	3
1.2.1. Material representation and microstructure. . . . .	3
1.2.2. Atomic interaction . . . . .	4
1.2.3. System dynamics and numerical description . . . . .	7
1.2.4. Boundary conditions . . . . .	8
1.3. Design and requirements for state-of-the-art MD cutting process simulations . . . . .	10
1.4. Capabilities of MD for nanoscale material removal process analysis. . . . .	12
1.4.1. Analysis of microstructure and deformation . . . . .	12
1.4.2. Obtaining cutting forces, stress and temperature. . . . .	15
1.5. Advances and recent developments in material removal process simulation . . . . .	18
1.5.1. Complete 3D surface machining simulation . . . . .	18
1.5.2. Consideration of fluids in MD cutting simulation . . . . .	20
1.6. Summary and outlook. . . . .	23
1.7. References . . . . .	24
<b>Chapter 2. Ductile Mode Cutting of Brittle Materials: Mechanism, Chip Formation and Machined Surfaces</b> . . . . .	27
Xiaoping LI	
2.1. Introduction. . . . .	27
2.2. The mechanism of ductile mode cutting of brittle materials . . . . .	29
2.2.1. Transition of chip formation mode from ductile to brittle . . . . .	29

2.2.2. MD modeling and simulation of nanoscale ductile mode cutting of silicon . . . . .	32
2.2.3. The mechanism of ductile mode chip formation in cutting of silicon. . . . .	32
2.3. The chip formation in cutting of brittle materials . . . . .	35
2.3.1. Material deformation and crack initiation in the chip formation zone . . . . .	35
2.3.2. Stress conditions in the chip formation zone in relation to ductile-brittle mode of chip formation. . . . .	36
2.4. Machined surfaces in relation to chip formation mode . . . . .	38
2.5. References . . . . .	40
<b>Chapter 3. Diamond Tools in Micromachining</b> . . . . .	45
Waqar AHMED, Mark J. JACKSON and Michael D. WHITFIELD	
3.1. Introduction. . . . .	45
3.2. Diamond technology . . . . .	45
3.2.1. Hot Filament CVD (HFCVD). . . . .	46
3.3. Preparation of substrate. . . . .	48
3.3.1. Selection of substrate material . . . . .	48
3.3.2. Pre-treatment of substrate . . . . .	49
3.4. Modified HFCVD process . . . . .	51
3.4.1. Modification of filament assembly. . . . .	51
3.4.2. Process conditions . . . . .	52
3.5. Nucleation and diamond growth . . . . .	53
3.5.1. Nucleation . . . . .	54
3.5.2. Bias-enhanced nucleation (BEN). . . . .	55
3.5.3. Influence of temperature. . . . .	56
3.6. Deposition on complex substrates . . . . .	58
3.6.1. Diamond deposition on metallic (molybdenum) wire. . . . .	58
3.6.2. Deposition on WC-Co microtools . . . . .	58
3.6.3. Diamond deposition on tungsten carbide (WC-Co) microtool . . . . .	59
3.7. Diamond micromachining . . . . .	62
3.7.1. Performance of diamond-coated microtool. . . . .	66
3.8. Conclusions. . . . .	67
3.9. References . . . . .	67
<b>Chapter 4. Conventional Processes: Microturning, Microdrilling and Micromilling</b> . . . . .	71
Wit GRZESIK	
4.1. Introduction. . . . .	71
4.1.1. Definitions and technological possibilities . . . . .	71
4.1.2. Main applications of micromachining. . . . .	72
4.2. Microturning . . . . .	74

4.2.1. Characteristic features and applications . . . . .	74
4.2.2. Microturning tools and tooling systems . . . . .	75
4.2.3. Machine tools for microturning. . . . .	77
4.3. Microdrilling . . . . .	79
4.3.1. Characteristic features and applications. . . . .	79
4.3.2. Microdrills and tooling systems . . . . .	80
4.3.3. Machine tools for microdrilling. . . . .	83
4.4. Micromilling . . . . .	85
4.4.1. Characteristic features and applications. . . . .	85
4.4.2. Micromills and tooling systems. . . . .	87
4.4.3. Machine tools for micromilling. . . . .	89
4.5. Product quality in micromachining . . . . .	92
4.5.1. Quality challenges in micromachining . . . . .	92
4.5.2. Burr formation in micromachining operations . . . . .	92
4.5.3. Surface quality inspection of micromachining products . . . . .	96
4.6. References . . . . .	98
<b>Chapter 5. Microgrinding and Ultra-precision Processes . . . . .</b>	<b>101</b>
Mark J. JACKSON and Michael D. WHITFIELD	
5.1. Introduction. . . . .	101
5.2. Micro and nanogrinding . . . . .	104
5.2.1. Nanogrinding apparatus. . . . .	105
5.2.2. Nanogrinding procedures . . . . .	105
5.3. Nanogrinding tools . . . . .	106
5.3.1. Dissolution modeling. . . . .	109
5.3.2. Preparation of nanogrinding wheels . . . . .	110
5.3.3. Bonding systems . . . . .	112
5.3.4. Vitriified bonding systems . . . . .	113
5.4. Conclusions. . . . .	121
5.5. References . . . . .	122
<b>Chapter 6. Non-Conventional Processes: Laser Micromachining . . . . .</b>	<b>125</b>
Grant M. ROBINSON and Mark J. JACKSON	
6.1. Introduction. . . . .	125
6.2. Fundamentals of lasers . . . . .	126
6.2.1. Stimulated emission . . . . .	126
6.2.2. Types of lasers. . . . .	127
6.2.3. Laser optics . . . . .	128
6.2.4. Beam quality. . . . .	129
6.2.5. Laser-material interactions . . . . .	131
6.3. Laser microfabrication . . . . .	133
6.3.1. Nanosecond pulse microfabrication . . . . .	133
6.3.2. Shielding gas . . . . .	135
6.3.3. Nozzle designs for laser micromachining. . . . .	136

6.3.4. Stages of surface melting . . . . .	138
6.3.5. Effects of nanosecond pulsed microfabrication . . . . .	138
6.3.6. Picosecond pulse microfabrication . . . . .	143
6.3.7. Femtosecond pulse microfabrication . . . . .	146
6.3.8. Effects of femtosecond laser machining. . . . .	150
6.4. Laser nanofabrication . . . . .	151
6.5. Conclusions. . . . .	154
6.6. References . . . . .	154
<b>Chapter 7. Evaluation of Subsurface Damage in Nano and Micromachining . . . . .</b>	<b>157</b>
Jianmei ZHANG, Jiangang SUN and Zhijian PEI	
7.1. Introduction. . . . .	157
7.2. Destructive evaluation technologies . . . . .	158
7.2.1. Cross-sectional microscopy . . . . .	158
7.2.2. Preferential etching . . . . .	159
7.2.3. Angle lapping/angle polishing . . . . .	159
7.3. Non-destructive evaluation technologies . . . . .	160
7.3.1. X-ray diffraction . . . . .	160
7.3.2. Micro-Raman spectroscopy . . . . .	164
7.3.3. Laser scattering . . . . .	167
7.4. Acknowledgements . . . . .	172
7.5. References . . . . .	172
<b>Chapter 8. Applications of Nano and Micromachining in Industry. . . . .</b>	<b>175</b>
Jiawang YAN	
8.1. Introduction. . . . .	175
8.2. Typical machining methods . . . . .	176
8.2.1. Diamond turning . . . . .	176
8.2.2. Shaper/planner machining . . . . .	178
8.3. Applications in optical manufacturing . . . . .	179
8.3.1. Aspheric lens . . . . .	179
8.3.2. Fresnel lens . . . . .	186
8.3.3. Microstructured components . . . . .	193
8.4. Semiconductor and electronics related applications . . . . .	200
8.4.1. Semiconductor wafer production . . . . .	200
8.4.2. LSI substrate planarization . . . . .	202
8.5. Summary . . . . .	203
8.6. Acknowledgements . . . . .	204
8.7. References . . . . .	204
<b>List of Authors . . . . .</b>	<b>209</b>
<b>Index . . . . .</b>	<b>211</b>