

Contents

Part I Overview and Fundamentals

1	Introduction	3
1.1	Conventional Laser Processing	4
1.2	Laser Chemical Processing	7
1.2.1	Thermal Activation	7
1.2.2	Non-thermal Activation	9
1.2.3	Local and Large-Area Processing	10
1.2.4	Comparison of Techniques	10
1.2.5	Planar and Non-planar Processing	12
2	Thermal, Photophysical, and Photochemical Processes	13
2.1	Excitation Mechanisms, Relaxation Times	13
2.1.1	Thermal Processes	15
2.1.2	Photochemical Processes	16
2.1.3	Photophysical Processes	17
2.1.4	A Simple Model	17
2.1.5	Chemical Relaxation	18
2.2	The Heat Equation	19
2.2.1	The Source Term	19
2.2.2	Dimensionality of Heat Flow	21
2.2.3	Kirchhoff and Crank Transforms	21
2.2.4	Phase Changes	22
2.2.5	Limits of Validity	23
2.3	Selective Excitations of Molecules	25
2.3.1	Electronic Excitations	26
2.3.2	Infrared Vibrational Excitations	29
2.4	Surface Excitations	35
2.4.1	External Photoeffect	35
2.4.2	Internal Photoeffect	35
2.4.3	Electromagnetic Field Enhancement, Catalytic Effects	37
2.4.4	Adsorbed Molecules	37

3	Reaction Kinetics and Transport of Species	39
3.1	Photothermal Reactions	41
3.2	Photochemical Reactions	43
3.3	The Concentration of Species	45
3.3.1	Basic Equations	45
3.3.2	Dependence of Coefficients on Temperature and Concentration	49
3.4	Heterogeneous Reactions	51
3.4.1	Stationary Equations	52
3.4.2	Transport Limitations	53
3.4.3	Dynamic Solutions	57
3.4.4	Heterogeneous Versus Homogeneous Activation	59
3.5	Combined Heterogeneous and Homogeneous Reactions	59
3.5.1	The Boundary-Value Problem	60
3.5.2	Approximate Solutions	61
3.6	Homogeneous Photochemical Activation	62
4	Nucleation and Cluster Formation	63
4.1	Homogeneous Processes	63
4.1.1	Classical Kinetics	64
4.1.2	Droplets Within a Laser Beam	66
4.1.3	Transport of Clusters, Thermophoresis, Chemophoresis	70
4.1.4	Fragmentation of Particles	70
4.2	Nanoparticle Formation by Pulsed-Laser Ablation	71
4.2.1	Gaseous Ambient	71
4.2.2	Liquid Ambient	76
4.3	Heterogeneous Processes	76
4.3.1	Nucleation in LCVD	77
4.3.2	Condensation of Clusters from Vapor/Plasma Plumes	79
4.3.3	Nanotube Formation by Laser-CVD	82
4.3.4	Shaping of Nanoparticles	83
4.3.5	Cluster Formation Within Solid Surfaces	83
5	Lasers, Experimental Aspects, Spatial Confinement	85
5.1	Lasers	85
5.1.1	CW Lasers, Gaussian Beams	85
5.1.2	Pulsed and High-Power CW Lasers	87
5.1.3	Semiconductor Lasers	89
5.2	Experimental Aspects	90
5.2.1	Micro-/Nanoprocessing	90
5.2.2	The Reaction Chamber; Typical Setup	95
5.2.3	Large-Area Processing	96
5.2.4	Substrates	98
5.3	Confinement of the Excitation	98
5.3.1	The Thermal Field	99
5.3.2	Non-thermal Substrate Excitations	99

5.3.3	Gas-, Liquid- and Adsorbed-Phase Excitations	99
5.3.4	Plasma Formation	100
5.3.5	Material Damages	100
5.3.6	Non-linearities	100
5.3.7	Optical Near-Field and Field-Enhancement Effects . . .	104

Part II Temperature Distributions and Surface Melting

6	General Solutions of the Heat Equation	111
6.1	The Boundary-Value Problem	111
6.1.1	The Attenuation Function, $f(z)$	112
6.1.2	Boundary and Initial Conditions	113
6.2	Analytical Solutions	116
6.3	Pulse Shapes	118
6.3.1	Single Rectangular Pulse	118
6.3.2	Triangular Pulse	120
6.3.3	Smooth Pulse	120
6.3.4	Multiple-Pulse Irradiation	121
6.4	Beam Shapes	122
6.4.1	Circular Beam	122
6.4.2	Rectangular Beam	123
6.4.3	Uniform Illumination	123
6.5	Characteristics of Temperature Distributions	123
6.5.1	Center-Temperature Rise	124
6.5.2	Width of Distribution	124
6.6	Numerical Techniques	126
7	Semi-infinite Substrates	127
7.1	The Center-Temperature Rise	127
7.1.1	Gaussian Beam	127
7.1.2	Circular Laser Beam	128
7.1.3	Rectangular Beam	128
7.2	Stationary Solutions for Temperature-Independent Parameters . .	129
7.2.1	Surface Absorption	130
7.2.2	Finite Absorption	131
7.3	Stationary Solutions for Temperature-Dependent Parameters . .	134
7.4	Scanned CW-Laser Beam	137
7.5	Pulsed-Laser Irradiation	139
7.5.1	Gaussian Intensity Profile	139
7.5.2	Uniform Irradiation	141
7.6	Dynamic Solutions for Temperature-Dependent Parameters . . .	142
8	Infinite Slabs	147
8.1	Strong Absorption	147
8.1.1	Thermally Thin Film	147
8.1.2	Scanned CW Laser	148

8.2	The Influence of Interferences	151
8.3	Coupling of Optical and Thermal Properties	153
9	Non-uniform Media	155
9.1	Continuous Changes in Optical Properties	155
9.2	Absorption of Light in Multilayer Structures	157
9.2.1	Thin Films	157
9.2.2	Two-Layer Structures	159
9.2.3	Three-Layer Systems	160
9.3	Temperature Distributions for Large-Area Irradiation	160
9.3.1	Stationary Solutions for Thin Films	160
9.3.2	Dynamic Solutions	162
9.4	Temperature Distributions for Focused Irradiation	163
9.4.1	Strong Film Absorption	164
9.4.2	Finite Film Absorption	165
9.5	The Ambient Medium	167
9.5.1	Influence on Substrate Temperature	168
9.5.2	Indirect Heating	170
9.5.3	Free Convection	170
9.5.4	Temperature Jump	173
10	Surface Melting	177
10.1	Temperature Distributions, Interface Velocities	178
10.1.1	Boundary Conditions	181
10.1.2	Temperature Dependence of Parameters	186
10.2	Solidification	186
10.3	Process Optimization	189
10.4	Convection	190
10.5	Surface Deformations	192
10.5.1	Surface Patterning	193
10.6	Welding	194
10.6.1	Ultrashort-Pulse Laser Welding	196
10.7	Liquid-Phase Expulsion	196
 Part III Material Removal		
11	Vaporization, Plasma Formation	201
11.1	Energy Balance	203
11.2	One-Dimensional Model	204
11.2.1	Stationary Evaporation	207
11.2.2	Non-stationary Evaporation	212
11.2.3	Optimal Conditions	214
11.3	Knudsen Layer, the Recoil Pressure	215
11.4	Influence of a Liquid Layer	217
11.5	Limitations of Model Calculations	220
11.6	Plasma Formation	221

11.6.1	Ionization	222
11.6.2	Optical Properties of Plasmas	223
11.6.3	Optical Breakdown	225
11.7	Laser-Supported Absorption Waves (LSAW)	227
11.7.1	Laser-Supported Combustion Waves (LSCW): $I_p \leq I \leq I_d$	227
11.7.2	Laser-Supported Detonation Waves (LSDW): $I \geq I_d$	229
11.7.3	Superdetonation	230
11.8	Abrasive Laser Machining	231
11.8.1	Cutting, Drilling, Shaping	231
11.8.2	Non-metals	233
11.8.3	Scribing, Marking, Engraving	234
11.8.4	Comparison of Techniques	234
12	Nanosecond-Laser Ablation	237
12.1	Surface Patterning	238
12.2	Ablation Mechanisms	242
12.2.1	Models	244
12.3	Photothermal Surface Ablation	247
12.3.1	Influence of Screening	249
12.3.2	Post-pulse Ablation	250
12.4	Interactions Below Threshold	251
12.5	The Threshold Fluence, ϕ_{th}	253
12.5.1	Thin Films	256
12.6	Ablation Rates	256
12.6.1	Dependence on Photon Energy and Fluence	256
12.6.2	Dependence on Pulse Duration	259
12.6.3	Influence of Spot Size, Screening	260
12.6.4	Dependence on Pulse Number	261
12.6.5	Influence of an Ambient Atmosphere	263
12.7	Photothermal Volume Decomposition	265
12.8	Photochemical Ablation	266
12.8.1	Dissociation of Polymer Bonds	267
12.8.2	Defect-Related Processes, Incubation	268
12.9	Photophysical Ablation	270
12.9.1	Long Pulses	271
12.9.2	Short Pulses	272
12.9.3	Thermal Versus Photochemical and Photophysical Ablation	272
12.10	Thermo- and Photomechanical Ablation	273
12.10.1	Basic Equations	274
12.11	Material Damage, Debris	276
12.11.1	Strong Absorption	276
12.11.2	Finite Absorption	277
12.11.3	Debris	278

13	Ultrashort-Pulse Laser Ablation	279
13.1	Material Patterning and Damage	279
13.1.1	Wide-Bandgap Materials, Glasses, Polymers	281
13.1.2	Nanostructures	283
13.2	Overview on Interaction Mechanisms	283
13.3	Low Fluence Photoexcitations	285
13.3.1	Thermal Volume Decomposition	286
13.3.2	Thermal Versus Photophysical Ablation	287
13.3.3	Ablation Dynamics	288
13.4	Molecular Dynamics (MD) Simulations	288
13.5	The Two-Temperature Model	292
13.5.1	Electron Transport, Damage Thresholds	296
13.5.2	Melting, Surface Deformation and Ablation	298
13.5.3	Processing of Metals and Semiconductors	301
13.6	Multiphoton- and Avalanche Ionization	302
13.6.1	Dielectrics	303
13.6.2	Coulomb Explosion	306
13.6.3	Processing of Dielectrics	308
13.7	Comparison of Nanosecond and Ultrashort-Pulsed Laser Ablation	311
14	Etching of Metals and Insulators	315
14.1	Photochemistry of Precursor Molecules	317
14.1.1	Halides	317
14.1.2	Halogen Compounds	319
14.2	Concentration of Reactive Species	320
14.2.1	Ballistic Approximation	321
14.2.2	Diffusion	323
14.2.3	Influence of the Reaction Chamber	324
14.2.4	Gas-Phase Recombination	326
14.2.5	Gas-Phase Heating	327
14.3	Dry-Etching of Metals	327
14.3.1	Spontaneous Etching Systems	328
14.3.2	Diffusive Etching Systems	329
14.3.3	Passivating Reaction Systems	329
14.4	Dry-Etching of Inorganic Insulators	332
14.4.1	SiO ₂ Glasses	332
14.4.2	Oxides	333
14.5	Wet-Etching	334
14.5.1	Front-Side Etching	335
14.5.2	Backside Etching	335
15	Etching of Semiconductors	339
15.1	Dark Etching	339
15.2	Laser-Induced Etching of Si in Cl ₂	342

15.2.1	Surface Patterning	342
15.2.2	Photochemical and Thermal Etching	343
15.2.3	Chlorine Radicals	345
15.2.4	Electron–Hole Pairs	346
15.2.5	Crystal Orientation and Doping	348
15.2.6	Nanopatterning	349
15.3	Si in Halogen Compounds	350
15.3.1	Si in XeF ₂	350
15.3.2	Si in SF ₆	351
15.4	Microscopic Mechanisms	352
15.4.1	Photochemical Etching	353
15.4.2	Combined Photochemical and Thermal Etching	354
15.4.3	Thermal Etching	354
15.5	Dry-Etching of Compound Semiconductors	354
15.5.1	III–V Compounds	354
15.5.2	Laser Etching of Atomic Layers	357
15.5.3	Dopants, Impurities, and Defects	357
15.6	Wet-Etching	357
15.6.1	Silicon	358
15.6.2	Compound Semiconductors	359
15.6.3	Interpretation of Results	360
15.6.4	Spatial Resolution, Waveguiding	364

Part IV Material Deposition

16	Laser-CVD of Microstructures	369
16.1	Precursor Molecules	369
16.2	Pyrolytic LCVD of Spots	370
16.2.1	Deposition from Halides	370
16.2.2	Deposition from Carbonyls	375
16.3	Modelling of Pyrolytic LCVD	375
16.3.1	Gas-Phase Processes	376
16.3.2	The Coupling Between $T(\mathbf{x})$ and $h(\mathbf{x})$	379
16.4	Temperature Distributions on Circular Deposits	382
16.5	Simulation of Pyrolytic Growth	385
16.6	Photolytic LCVD	389
16.6.1	Metals	389
16.6.2	Other Materials	392
16.6.3	Process Limitations	392
17	Growth of Fibers	393
17.1	In Situ Temperature Measurements	394
17.2	Microstructure and Physical Properties	395
17.3	Kinetic Studies	397

17.3.1	Silicon	398
17.3.2	Carbon	398
17.4	Gas-Phase Transport	399
17.4.1	The Coupling of Fluxes	399
17.4.2	Thermal Diffusion (Soret Effect)	402
17.5	Simulation of Growth	405
18	Direct Writing	407
18.1	Characteristics of Pyrolytic Direct Writing	407
18.1.1	Dependence on Laser Parameters and Substrate Material	408
18.1.2	Electrical Properties	410
18.2	Temperature Distributions in Direct Writing	411
18.2.1	Center-Temperature Rise	411
18.2.2	1D Approach, $\kappa^* \gg 1$	413
18.2.3	Numerical Solutions	414
18.3	Simulation of Direct Writing	415
18.3.1	1D Model	415
18.3.2	Comparison with Experimental Data	417
18.3.3	2D Model	421
18.4	Photophysical LCVD	422
18.5	Applications of LCVD in Microfabrication	424
18.5.1	Planar Substrates	424
18.5.2	Non-planar Substrates, 3D Objects	426
19	Thin-Film Formation by Laser-CVD	429
19.1	Direct Heating	430
19.1.1	Stationary Solutions	430
19.1.2	Non-stationary Solutions	434
19.2	Pyrolytic Processing Rates	434
19.2.1	Diffusion	435
19.2.2	Recombination	437
19.3	Photolytic Processing Rates	438
19.4	Metals	439
19.4.1	Deposition from Metal Halides	439
19.4.2	Deposition from Alkyls and Carbonyls	442
19.5	Semiconductors	443
19.5.1	Photodecomposition of Silanes	444
19.5.2	Crystalline Ge and Si	446
19.5.3	Amorphous Hydrogenated Silicon (a-Si:H)	446
19.5.4	Compound Semiconductors	450
19.5.5	Carbon	451
19.6	Insulators	451
19.6.1	Oxides	452
19.6.2	Nitrides	452
19.7	Heterostructures	453
19.8	Comparison of LCVD and Standard Techniques	454

20	Adsorbed Layers, Laser-MBE	457
20.1	Fundamental Aspects	458
20.1.1	Influence of Laser Light	462
20.2	Deposition from Adsorbed Layers	463
20.2.1	Vacuum	463
20.2.2	Gaseous Ambient	466
20.3	Combined Laser and Molecular/Atomic Beams	470
20.3.1	Laser-MBE	471
20.3.2	Laser-ALE	472
20.3.3	Laser-OMBD	473
20.3.4	Laser-Focused Atomic Deposition	474
21	Liquid-Phase Deposition, Electroplating	477
21.1	Liquid-Phase Processing Without an External EMF	477
21.1.1	Thermal Decomposition	477
21.1.2	Electroless Plating	480
21.1.3	Metal-Liquid Interfaces	481
21.1.4	Semiconductor-Liquid Interfaces	483
21.1.5	Further Experimental Examples	484
21.2	Electrochemical Plating	484
21.2.1	Jet-Plating	486
22	Thin-Film Formation by Pulsed-Laser Deposition and Laser-Induced Evaporation	489
22.1	Experimental Requirements	490
22.1.1	Congruent and Incongruent Ablation	493
22.1.2	Targets	494
22.1.3	Uniform Ablation	495
22.1.4	Cross-Beam PLD	497
22.2	Volume and Surface Processes, Film Growth	497
22.2.1	Plasma and Gas-Phase Reactions	498
22.2.2	Substrate Temperature, Laser-Pulse-Repetition Rate	499
22.2.3	Energy of Species	500
22.2.4	Particulates	501
22.2.5	Chemical Composition and Thickness of Films	504
22.3	Overview of Materials and Film Properties	505
22.4	High-Temperature Superconductors	506
22.4.1	Non-reactive Deposition	507
22.4.2	Reactive Deposition	507
22.4.3	Heterostructures	508
22.4.4	Metastable Compounds, Mixed Systems	510
22.4.5	Films with Step-Like Morphology	512
22.4.6	Buffer Layers, Applications	513
22.5	Metals, Semiconductors, and Insulators	515
22.5.1	Metals	515
22.5.2	Semiconductors	515

22.5.3	Carbon Films	517
22.5.4	Insulators	519
22.5.5	Heterostructures	521
22.6	Nanostructured Materials	521
22.6.1	Nanoparticle films	522
22.6.2	Nanocomposites	522
22.7	Organic Materials	524
22.7.1	MAPLE	527
22.8	Laser-Induced Forward Transfer	528
22.8.1	Transfer films	530

Part V Material Transformations, Synthesis and Structure Formation

23	Material Transformations, Laser Cleaning	535
23.1	Transformation Hardening	535
23.2	Laser Annealing, Recrystallization	537
23.2.1	Ion-Implanted Semiconductors	537
23.2.2	Thin Films	540
23.3	Glazing	541
23.4	Shock Hardening	542
23.5	Surface Polishing	542
23.6	Transformations Within Bulk Materials	544
23.6.1	Non-erasable Marking	545
23.6.2	Gratings	545
23.6.3	Waveguides	546
23.6.4	3D-Optical Storage	547
23.7	Laser Cleaning	549
23.7.1	Adhesion Forces	550
23.7.2	Dry Cleaning	552
23.7.3	Steam Cleaning	557
23.7.4	Wet Cleaning	558
23.7.5	Matrix Cleaning	559
24	Doping	561
24.1	Solid-Phase Diffusion	562
24.2	Liquid-Phase Transport	565
24.3	Sheet Doping	565
24.3.1	Silicon	566
24.3.2	Compound Semiconductors	569
24.4	Local Doping	570
24.5	Laser Implantation	571
25	Cladding, Alloying, and Synthesis	573
25.1	Laser-Assisted Cladding and Sintering	573
25.1.1	3D Rapid Prototyping	575
25.2	Alloying	575

25.2.1	Laser–Surface Alloying	575
25.2.2	Formation of Metastable Materials	576
25.2.3	Silicides	576
25.3	Synthesis	577
25.3.1	Thin Films	577
25.3.2	Fibers	578
26	Oxidation, Nitridation, and Reduction	581
26.1	Basic Mechanisms	582
26.1.1	Very Thin Films	583
26.1.2	Thin Films	583
26.1.3	Thick Films	585
26.1.4	Influence of Laser Light	585
26.2	Metals	587
26.2.1	Photothermal Oxidation	587
26.2.2	Photochemical Contributions	589
26.2.3	Oxidation by Pulsed-Laser Plasma Chemistry	590
26.2.4	Nitridation	591
26.3	Elemental Semiconductors	592
26.3.1	Photothermal Oxidation of Si	592
26.3.2	Photochemically Enhanced Oxidation of Si	594
26.3.3	Nitridation of Silicon	596
26.4	Compound Semiconductors	596
26.4.1	Summary	597
26.5	Oxide Transformation, Reoxidation	597
26.5.1	Silicon Oxide	597
26.6	Reduction and Metallization of Oxides	598
26.6.1	Qualitative Description	599
26.6.2	Oxidic Perovskites and Related Materials	600
26.6.3	Superconductors	602
27	Transformation and Functionalization of Organic Materials	605
27.1	Surface Modification of Polymers	605
27.1.1	Laser-Enhanced Adhesion	605
27.1.2	Swelling, Amorphization, Crystallization	607
27.1.3	Photochemical Exchange of Species	608
27.1.4	Chemical Degradation	609
27.2	Chemical Transformations Within Thin Films and Bulk Materials	611
27.2.1	Laser Lithography	613
27.2.2	Maskless Techniques	616
27.2.3	Decomposition of Precursor Films	617
27.2.4	3-D Photopolymerization	619
27.3	Laser-LIGA, LAN	620

28	Instabilities and Structure Formation	623
28.1	Coherent and Non-coherent Structures	623
28.1.1	Equations	624
28.1.2	Stability	625
28.1.3	Coherent Structures	626
28.1.4	Non-coherent Structures	626
28.2	Ripple Formation	626
28.2.1	Interference Pattern	627
28.2.2	Distribution of Energy	632
28.2.3	Feedback	634
28.2.4	Comparison of Experimental and Theoretical Results	635
28.2.5	Ripples Generated by Ultrashort-Laser Pulses	638
28.2.6	Embedded Periodic Structures	643
28.3	Spatio-Temporal Oscillations	644
28.3.1	Zero Isoclines	645
28.3.2	Instabilities in Laser-Induced Oxidation	646
28.3.3	Explosive Crystallization	647
28.3.4	Exothermal Reactions	648
28.3.5	Instabilities in Direct Writing	649
28.3.6	Discontinuous Deposition and Bistabilities	652
28.4	Instabilities and Structure Formation in Laser Ablation	655
28.4.1	Fundamental Aspects	655
28.4.2	Conical and Columnar Structures	659
28.5	Hydrodynamic Instabilities	664
28.5.1	Kelvin–Helmholtz Instabilities	664
28.5.2	Rayleigh–Taylor Instabilities	666
28.5.3	Surface Corrugations, Droplets	668
28.6	Stress-Related Instabilities	671
28.7	Technological Aspects	676

Part VI Diagnostic Techniques, Plasmas

29	Diagnostic Techniques	681
29.1	Characterization of Laser-Beam Profiles	681
29.2	Homogenization of Laser Beams	681
29.2.1	Diffraction Methods	682
29.2.2	Reflective Methods	682
29.2.3	Refractive Methods	683
29.3	Deposition, Etch, and Ablation Rates	683
29.3.1	Optical Techniques	683
29.3.2	Other Techniques	686
29.4	Temperature Measurements	689
29.4.1	Photoelectric Pyrometry	689
29.4.2	Other Optical Techniques	693
29.4.3	Other Techniques	693

29.5	Analysis of Surfaces and Thin Films	694
29.5.1	Surface Topologies, Microstructures	694
29.5.2	Transport Measurements	695
30	Analysis of Species and Plasmas	697
30.1	Precursor and Product Species	697
30.1.1	Optical Spectroscopy	697
30.1.2	Mass Spectrometry	699
30.1.3	MALDI, LAESI	701
30.2	Species in Vapor and Plasma Plumes	702
30.2.1	Species at Subthreshold Fluences	702
30.2.2	Atomic and Molecular Neutrals	703
30.2.3	Electrons and Ions	704
30.2.4	Plasma Radiation, X-Rays	705
30.2.5	Clusters and Fragments	705
30.3	Plume Expansion in Vacuum	706
30.3.1	Spherical Plume	706
30.3.2	Elliptical Plume	707
30.3.3	Mass- and Ion-Flux Measurements	708
30.4	Plume Expansion in Gases, Shock Waves	708
30.4.1	Point Blast Model	710
30.4.2	Combined Propagation of Plume and SW	711
30.4.3	Formation of Nanoparticles	713
30.4.4	Comparison with Experimental Investigations	715
30.5	Optical Breakdown in Liquids, Cavitation	719
30.5.1	Absorbing Targets	720
30.5.2	Transparent Media	721
 Part VII Lasers in Medicine, Biotechnology and Arts		
31	Lasers in Medicine and Biotechnology	727
31.1	Medical Applications	728
31.1.1	Ophthalmology	728
31.1.2	Dermatology and Surgery	728
31.1.3	Photodynamical Therapy	729
31.1.4	Prosthesis	729
31.2	Biotechnology	729
31.2.1	Laser Microdissection	729
31.2.2	Micro-/Nanosurgery and Manipulation	730
31.2.3	Biopolymers	730
31.3	Interaction Mechanisms	731
31.3.1	Chemical Effects	733
32	Restoration and Conservation of Artworks	735
32.1	Cultural Heritages	735
32.1.1	Metal Artworks	736
32.1.2	Oil-paintings, Frescos	736

32.2	Analysis and Origin of Artworks	737
32.3	Architecture, Modern Artwork	737
Appendix A	Definitions and Symbols	739
A.1	Symbols and Conversion Factors	739
A.2	Abbreviations, Acronyms	745
Appendix B	Mathematical Functions and Relations	749
Appendix C	Tables	757
References	783
Index	843

Laser Processing and Chemistry

Bäuerle, D.W.

2011, XXII, 851 p., Hardcover

ISBN: 978-3-642-17612-8