

## ***contents***

---

### ***list of contributors***

***preface*** vii

### ***chapter 1 laser fundamentals A. Kestenbaum 2***

<b>1.0 introduction</b>	3
<b>1.1 spontaneous and stimulated emission and absorption</b>	4
<b>1.2 population inversion and pumping</b>	8
1.2.1 Three-Level Laser System	8
1.2.2 Four-Level Laser System	10
<b>1.3 cavity and feedback</b>	13
1.3.1 Threshold Condition	13
1.3.2 Mode Configurations	14
<b>1.4 Q-switching, mode locking, and cavity dumping</b>	21
1.4.1 Description of Q-Switching	21
1.4.2 Q-Switching Techniques	22
1.4.3 Description and Techniques of Mode Locking	26
1.4.4 Cavity Dumping	28
<b>1.5 coherence and interference</b>	29
1.5.1 Temporal Coherence	29
1.5.2 Spatial Coherence	31
<b>1.6 common lasers and their output characteristics</b>	33
1.6.1 Ruby Laser	36
1.6.2 YAG and Neodymium-Glass Lasers	39
1.6.3 Helium-Neon Laser	41
1.6.4 Argon and Other Ion Lasers	44
1.6.5 Carbon Dioxide Laser	46
1.6.6 Helium-Cadmium Laser	49
1.6.7 Water-Vapor Laser	50
1.6.8 Semiconductor Lasers	52
1.6.9 Dye Lasers	57
1.6.10 Brief Survey of Typical Commercial Lasers	58
References	61

### ***chapter 2 interaction of electromagnetic radiation with materials M. A. Saifi 66***

<b>2.0 introduction</b>	67
<b>2.1 radiation field</b>	67
2.1.1 Plane Waves	70
2.1.2 Intrinsic Impedance and Power	74
2.1.3 Elliptically Polarized Wave	75

<b><i>quantum aspects of the radiation field</i></b>	<b>77</b>
2.2.1 Blackbody Radiation	78
2.2.2 Photoelectric Effect	79
2.2.3 Radiation Pressure	82
<b>2.3 <i>theory of solids</i></b>	<b>83</b>
2.3.1 Schrödinger's Equation	83
2.3.2 Energy Levels of an Electron in an Atom	85
2.3.3 Pauli Exclusion Principle	86
2.3.4 Interatomic Bond	86
2.3.5 Space Lattices and Crystal Classes	88
2.3.6 Band Theory of Solids	91
2.3.7 Conductors, Semiconductors, and Insulators	96
2.3.8 Fermi Level	97
<b>2.4 <i>lattice vibrations</i></b>	<b>100</b>
2.4.1 Acoustic Vibrations	100
2.4.2 Optic Vibrations	103
2.4.3 Phonons	104
<b><i>dispersion in solids</i></b>	<b>105</b>
2.5.1 Wave Propagation in Materials	105
2.5.2 Boundary Conditions	108
2.5.3 Reflection and Transmission	110
2.5.4 Dispersion and Absorption in Dielectrics	111
2.5.5 Dispersion and Absorption Due to Free Electrons	116
2.5.6 Optical Properties of Semiconductors	118
<b><i>nonlinear interactions</i></b>	<b>119</b>
2.6.1 Raman Scattering	120
2.6.2 Brillouin Scattering	123
2.6.3 Second Harmonic Generation	125
2.6.4 Absorption Under Intense Radiation	128
<b><i>particle emission</i></b>	<b>130</b>
2.7.1 Electron and Ion Emission	130
2.7.2 Neutral Particle Emission	131
2.7.3 Plasma Production	132
References	133
<b><i>chapter 3 laser processing fundamentals</i></b>	
<i>F. P. Gagliano and V. J. Zaleckas</i>	<b>138</b>
<b>3.0 <i>introduction</i></b>	<b>139</b>
<b>3.1 <i>optics considerations for material processing</i></b>	<b>139</b>
3.1.1 Fundamental Relations	139
3.1.2 Spot Size—Power Density	144
3.1.3 Effective Spot Diameter	145
3.1.4 Material Surfaces	145
3.1.5 Other Considerations	149

<b><i>materials and their properties</i></b>	<b>150</b>
3.2.1 Thermodynamic Considerations	151
3.2.2 Phase Transformations	151
3.2.3 Thermal Diffusivity	154
<b><i>thermal processing models</i></b>	<b>158</b>
3.3.1 Assumptions	158
3.3.2 Solid Phase—Temperature Profiles	159
3.3.3 Melting	164
3.3.4 Vaporization	167
<b>3.4 metallurgical considerations</b>	<b>177</b>
3.4.1 Solidification and Microstructure	181
3.4.2 Grain Growth	185
References	187
<b><i>chapter 4 laser processing</i></b>	<b>F. P. Gagliano and V. J. Zaleckas 190</b>
<b>4.0 introduction</b>	<b>191</b>
<b>4.1 welding</b>	<b>191</b>
4.1.1 Fusion Depth and Weld Geometry	191
4.1.2 Welding Speeds	197
4.1.3 Laser Systems and Their Operating Parameters	198
4.1.4 Advantages of Laser Welding	208
4.1.5 Analyzing and Solving a Welding Problem	214
<b>drilling</b>	<b>227</b>
4.2.1 Beam Characteristics	229
4.2.2 Material Considerations	230
4.2.3 Hole Geometry and Beam Parameters	232
4.2.4 High-Speed Photography	236
4.2.5 Some Practical Considerations and Applications	238
4.2.6 The Study of Drilling Ceramic Material	247
<b>4.3 micromachining</b>	<b>256</b>
4.3.1 Resistor Trimming	257
4.3.2 Capacitor Adjustment and Fabrication	262
4.3.3 Scribing	263
4.3.4 Detailed Analysis and Solution for a Micromachining Application—Silicon Scribing	265
<b><i>miscellaneous applications</i></b>	<b>277</b>
4.4.1 Controlled Fracturing	277
4.4.2 Evaporation	279
4.4.3 Cutting	281
4.4.4 Pattern Generation	286
References	290

**chapter 5 thermally induced changes and  
chemical reactions J. Longfellow 296**

<b>5.0 introduction</b>	<b>297</b>
<b>5.1 heat treating</b>	<b>299</b>
5.1.1 Recovery	300
5.1.2 Recrystallization	300
5.1.3 Grain Growth	301
5.1.4 Quenching	302
5.1.5 Microstructures	302
<b>5.2 diffusion</b>	<b>303</b>
5.2.1 Metals and Insulators	304
5.2.2 Semiconductors	304
<b>5.3 zone melting</b>	<b>305</b>
5.3.1 Conventional Methods	305
5.3.2 Laser Zone Melters	307
5.3.3 Rod Crystals	309
<b>5.4 chemical reactions</b>	<b>310</b>
5.4.1 Thermally Induced Reactions	310
5.4.2 Photochemically Induced Reactions	311
5.4.3 Photolysis	311
References	312

**chapter 6 reflection and scattering R. O. De Nicola 316**

<b>6.0 introduction</b>	<b>317</b>
<b>6.1 reflection of light and its applications</b>	<b>317</b>
6.1.1 General Equations	317
6.1.2 Polarization Components	320
6.1.3 Reflection from Dielectrics	321
x 6.1.4 Reflection from Metals	323
6.1.5 Reflection from Semiconductors	324
6.1.6 Applications of Reflection	326
<b>6.2 scattering</b>	<b>346</b>
6.2.1 General Concepts of Scattering	346
6.2.2 Rayleigh Scattering	348
6.2.3 Raman Scattering	352
6.2.4 Brillouin Scattering	357
References	363

**chapter 7 diffraction L. S. Watkins 366**

<b>7.0 introduction</b>	<b>367</b>
<b>7.1 alignment, surveying, and geodetic systems</b>	<b>368</b>
7.1.1 Alignment Telescopes	368
7.1.2 Accelerator Alignment System	370
7.1.3 Surveying and Geodetic Systems	371

<b>7.2</b>	<b><i>far-field diffraction effects</i></b>	<b>372</b>
7.2.1	Fresnel Zones	374
7.2.2	Diffraction by a Rectangular Aperture	378
7.2.3	Fresnel-Kirchhoff Diffraction Formula	383
7.2.4	Fraunhofer Diffraction Pattern by a Lens	387
7.2.5	Fraunhofer Diffraction Pattern of a Circular Aperture	388
7.2.6	Fraunhofer Diffraction Pattern of a Narrow Slit	389
7.2.7	Babinet's Principle	391
7.2.8	Diffraction and Measurement of Objects Other than Slits	392
7.2.9	Laser Requirements	395
7.2.10	Reconstruction of Slit Profiles	395
<b>7.3</b>	<b><i>spatial filtering</i></b>	<b>397</b>
7.3.1	Fourier Transform Property of a Lens and Its Electronic Analogue	397
7.3.2	Illumination	397
7.3.3	Spatial Filtering Arrangement	398
7.3.4	Optical Processing	399
7.3.5	Examples of Other Spatial Filtering Arrangements and Operations	399
7.3.6	Defect Detection	406
7.3.7	Use of a Directional Filter	409
7.3.8	Phase Contrast and Schlieren Effects	410
7.3.9	Spatial Frequency Spectrum of Periodic Patterns	411
7.3.10	Types of Filtering: Periodic Stop Filters	413
7.3.11	Periodic Transmission Filters	420
7.3.12	Auxiliary Filters	420
7.3.13	Limitations	421
7.3.14	Practical Inspection System	424
7.3.15	TV Detection System	426
<b>7.4</b>	<b><i>complex spatial filter</i></b>	<b>427</b>
7.4.1	Matched Filter	427
7.4.2	Constructing Matched Filters	428
<b>7.5</b>	<b><i>Fresnel correlation</i></b>	<b>430</b>
7.5.1	Step and Repeat Measurement	431
	References	433

## ***chapter 8 interferometry and holography***

*R. J. Klaiber* 436

<b>8.0</b>	<b><i>introduction</i></b>	<b>437</b>
<b>8.1</b>	<b><i>temporal and spatial coherence</i></b>	<b>437</b>
<b>8.2</b>	<b><i>interference</i></b>	<b>438</b>
8.2.1	Interference of Two Coherent Plane Waves	438
8.2.2	Interference of Two Angularly Separate Plane Waves	440

<b>9.5 heat detectors</b>	<b>560</b>
9.5.1 Bolometers	560
9.5.2 Thermopile Devices	563
9.5.3 Pyroelectric Detectors	567
<b>9.6 attenuation and beam-sampling techniques</b>	<b>569</b>
9.6.1 Neutral Density Filters	570
9.6.2 Optical Interference Filters	570
9.6.3 Silicon Attenuators	571
9.6.4 Integrating Spheres	572
9.6.5 Diffraction Grating	572
9.6.6 Diffuse Reflectors	573
9.6.7 Beamsplitters	573
References	574
<b>chapter 10 laser safety J. F. Carr</b>	<b>578</b>
<b>10.0 introduction</b>	<b>579</b>
<b>10.1 why the laser is a unique hazard</b>	<b>579</b>
<b>10.2 laser hazards</b>	<b>581</b>
10.2.1 Research on Laser Hazards	581
10.2.2 Biological Effects of Laser Radiation	584
10.2.3 Specular and Diffuse Hazards	586
10.2.4 Eye and Skin Exposure Levels	591
10.2.5 Possible and Probable New Hazards	591
10.2.6 Associated Hazards—Equipment and Materials	593
<b>10.3 safety programs</b>	<b>593</b>
10.3.1 Hazard Evaluation and Measurement	594
10.3.2 Manufacturing	595
10.3.3 Research and Development	601
10.3.4 Protective Equipment	601
<b>10.4 medical surveillance</b>	<b>605</b>
<b>10.5 government regulations</b>	<b>607</b>
10.5.1 Federal	607
10.5.2 State	608
References	608
<b>appendix 10-a sample calculations</b>	<b>609</b>
<b>appendix 10-b eye examination protocol</b>	<b>612</b>
<b>appendix 10-c medical surveillance for possible skin damage from exposure to lasers</b>	<b>613</b>
<b>glossary—optical components and definitions</b>	<b>616</b>
<b>Index</b>	<b>631</b>