

# Contents

<b>1. General Principles and Some Common Features</b>	
By L. F. Mollenauer and J. C. White (With 4 Figures) .....	1
1.1 Tunable Lasers and Nonlinear Spectroscopy .....	1
1.2 The Optical Parametric Oscillator .....	2
1.3 Tunable Lasers Based on Vibronically Broadened Bands .....	3
1.4 Optical Gain .....	6
1.5 Laser Efficiency .....	7
1.6 Optical Cavities for Tunable Lasers .....	8
1.6.1 Properties of the Gaussian Mode .....	8
1.6.2 The Astigmatically Compensated Cavity .....	9
1.7 Frequency Selection in Tunable Lasers .....	11
1.7.1 Tuning Elements .....	12
a) Prisms .....	12
b) Diffraction Gratings .....	13
c) Birefringence Plates .....	13
d) Etalons .....	15
1.7.2 Single-Frequency Operation in the Presence of Spatial Hole Burning .....	15
1.8 Mode Locking .....	17
References .....	18
<b>2. Excimer Lasers</b>	
By M. H. R. Hutchinson (With 24 Figures) .....	19
2.1 Introduction .....	19
2.2 Rare-Gas Excimers .....	21
2.2.1 Electronic Structure and Spectroscopy .....	21
2.2.2 Kinetic Models .....	23
2.2.3 Pumping Methods .....	26
a) The Xe <sub>2</sub> <sup>*</sup> Excimer Laser .....	26
b) The Ar <sub>2</sub> <sup>*</sup> Excimer Laser .....	29
2.3 Rare-Gas Halide Excimers .....	29
2.3.1 Electronic Structure and Kinetics .....	30
a) Spectroscopy .....	32
b) Kinetics of Rare-Gas Halides .....	34
2.3.2 Excitation Methods .....	42
a) Electron-Beam Pumping .....	42

b) Self-Sustained Discharges .....	43
c) Electron-Beam Sustained Discharges .....	45
2.3.3 Characteristics of Rare-Gas Halide Excimer Lasers .....	46
a) Frequency Control .....	46
2.4 Rare-Gas Oxide Excimer Lasers .....	51
2.5 Conclusion .....	53
References .....	53
<b>3. Four-Wave Frequency Mixing in Gases</b>	
By C. R. Vidal (With 14 Figures) .....	57
3.1 Background .....	57
3.2 Nonlinear Susceptibilities .....	59
3.3 Fundamental Equations of Nonlinear Optics .....	65
3.4 The Small Signal Limit .....	67
3.4.1 Plane Waves .....	67
3.4.2 Phase Matching .....	69
3.4.3 Gaussian Beams .....	71
3.4.4 Linewidth Dependence .....	74
3.5 The Nonlinear Medium .....	77
3.5.1 General Requirements .....	77
3.5.2 The Heat-Pipe Oven .....	78
3.5.3 Other Systems .....	80
3.6 Experiments in the Small-Signal Limit .....	82
3.7 Onset of Saturation .....	87
3.7.1 General Considerations .....	87
3.7.2 Nonresonant Case .....	88
3.7.3 Two-Photon Resonant Case .....	91
3.7.4 The ac Stark Effect and Multiphoton Ionization .....	94
3.8 High Intensity Saturation .....	96
3.8.1 Conversion Profiles .....	96
3.8.2 Self-(De)Focusing .....	98
3.8.3 Redistribution of Population Densities .....	99
3.8.4 Higher-Order Processes .....	100
3.9 Transient Behaviour .....	102
3.10 Summary .....	103
References .....	107
<b>4. Stimulated Raman Scattering</b>	
By J. C. White (With 43 Figures) .....	115
4.1 Introduction .....	115
4.2 Background Material .....	116
4.2.1 Basic Principles .....	116
4.2.2 Semiclassical Theory of Spontaneous Raman Scattering .....	118
4.3 Stimulated Raman Scattering: Steady State Limit .....	120
4.3.1 Coupled Wave Model .....	121

4.3.2 Two-Photon Vector Model .....	125
4.3.3 Stokes/Anti-Stokes Coupling and Higher-Order Scattering .....	128
4.3.4 Self-Focusing Effects .....	135
4.4 Stimulated Raman Scattering: Transient Limit .....	137
4.4.1 Forward Scattering .....	138
4.4.2 Backward Scattering .....	142
4.5 Generation Techniques .....	146
4.5.1 Molecular Systems .....	147
a) Gaseous H <sub>2</sub> .....	147
b) Other Raman Systems .....	161
c) Dimer Lasers .....	166
4.5.2 Atomic Systems .....	169
a) Stokes Generation .....	171
b) Anti-Stokes Generation .....	181
4.5.3 Backward Raman Scattering and Pulse Compression ....	190
4.5.4 Stimulated Hyper-Raman Scattering .....	192
4.6 Further Considerations and Limiting Processes .....	194
4.6.1 Saturation .....	194
4.6.2 Broad-Band Pumping and Dispersion .....	197
4.6.3 Broadening Processes .....	198
4.6.4 Diffraction Effects .....	200
References .....	201
<b>5. Urea Optical Parametric Oscillator for the Visible and Near Infrared.</b> By K. Cheng, M. J. Rosker, and C. L. Tang (With 11 Figures) .....	209
5.1 Background Material .....	209
5.2 Optical Parametric Oscillator .....	210
5.2.1 Experimental Setup and Parametric Oscillator Design Considerations .....	210
5.2.2 Tuning and Linewidth Characteristics .....	213
5.2.3 Threshold and Efficiency Considerations .....	215
5.3 Spontaneous Parametric Fluorescence .....	217
5.4 Conclusion .....	222
References .....	222
<b>6. Color Center Lasers.</b> By L. F. Mollenauer (With 46 Figures) .....	225
6.1 Background Material .....	225
6.2 The Basic Physics and Materials Science of Laser-Active Color Centers .....	229
6.2.1 The F Center .....	229
6.2.2 The F <sup>-</sup> Center .....	231
6.2.3 Creation of F Centers Through Additive Coloration ....	231
6.2.4 Center Creation by Radiation Damage .....	233

6.2.5	Aggregation of F Centers .....	234
6.2.6	The $F_A$ Centers .....	234
6.2.7	Reorientation of $F_A$ (II) Centers .....	237
6.2.8	The $F_B$ (II) Centers .....	238
6.2.9	The $F_2^+$ Center .....	239
6.2.10	Defect Stabilized $F_2^+$ Centers: $(F_2^+)_A$ , $(F_2^+)^*$ , etc. ....	243
	a) The $(F_2^+)_A$ Centers .....	243
	b) The $(F_2^+)^*$ and $(F_2^+)^{**}$ Centers .....	245
6.2.11	The $Tl^0(1)$ Center .....	248
6.2.12	The $F^+$ Center in Alkaline-Earth Oxides .....	252
6.2.13	The $H_3$ Center in Diamond .....	253
6.2.14	Laser-Active Color Centers in Sapphire .....	253
6.3	Some Examples of Color Center Lasers and Associated Hardware .....	254
6.3.1	A Typical cw Color Center Laser .....	254
	a) Optical and Mechanical Design .....	254
	b) Alignment .....	255
	c) Cryogenic Details .....	256
	d) Water Vapor: Effects and Avoidance .....	258
6.3.2	The Burleigh Laser .....	259
6.3.3	Single-Knob Tuning of a Single-Frequency, cw Color Center Laser .....	260
6.3.4	A Ring Cavity Color Center Laser .....	261
6.4	Mode Locking and the Soliton Laser .....	263
6.4.1	Mode Locking by Synchronous Pumping .....	263
6.4.2	The Soliton Laser .....	266
	References .....	275
<b>7.</b>	<b>Fiber Raman Lasers</b>	
	By C. Lin (With 20 Figures) .....	279
7.1	Introduction .....	279
7.2	Stimulated Raman Scattering in Optical Fibers .....	279
7.2.1	Raman Spectra of Optical Fibers .....	279
7.2.2	Loss Characteristics of Optical Fibers .....	281
7.2.3	Raman Gain and Effective Interaction Length .....	281
7.2.4	The Inhomogeneous Nature of Raman Gain .....	283
7.2.5	Considerations for Choice of Fiber .....	284
7.2.6	Picosecond Pulse Raman Interactions in Long Fibers: The Effect of Group Velocity Dispersion .....	285
7.3	Single-Pass Fiber Raman Lasers .....	286
7.3.1	Stimulated Raman Scattering and Broadband Continuum Generation in the Visible Region .....	287
7.3.2	Wide Band Near-IR Generation in Optical Fibers .....	289
7.3.3	Ultraviolet Stimulated Raman Scattering in UV Silica Fibers .....	289

7.3.4	Group Velocity Matching in Picosecond Stimulated Raman Scattering in Fibers .....	290
7.4	Tunable Fiber Raman Oscillators .....	291
7.4.1	Fiber Resonator for Raman Oscillation .....	291
7.4.2	Tunability in a Fiber Resonator with Frequency Selective Feedback .....	291
7.4.3	Synchronously-Pumped Fiber Raman Oscillators and Time-Dispersion Tuning .....	292
7.5	Applications of Fiber Raman Lasers .....	295
7.5.1	Dispersion and Bandwidth Studies in Multimode and Single-Mode Optical Fibers in the Near IR .....	295
7.5.2	Applications of Tunable Fiber Raman Oscillators .....	298
7.5.3	Optical Amplification and Pulse Shaping by Stimulated Raman Scattering .....	298
7.6	Conclusion .....	300
	References .....	300
<b>8.</b>	<b>Tunable High-Pressure Infrared Lasers</b>	
	By T. Jaeger and G. Wang (With 15 Figures) .....	303
8.1	Background Material .....	303
8.2	Amplification in High-Pressure Gases .....	304
8.2.1	Gain and Molecular Kinetics in Excited High-Pressure Gases .....	305
8.2.2	Excitation Techniques .....	310
8.2.3	Survey of Molecules for Tunable Lasers .....	312
8.3	Experimental Investigations of Tunable Lasers .....	313
8.3.1	Optically Excited Lasers .....	314
8.3.2	Ultraviolet Preionized TE Lasers .....	319
8.3.3	Electron-Beam Controlled TE Lasers .....	321
8.3.4	Radio Frequency Excited Waveguide Lasers .....	323
8.4	Short Pulse Generation .....	324
8.5	Applications .....	325
8.6	Recent Progress .....	326
8.7	Status and Future Technical Development .....	327
	References .....	328
<b>9.</b>	<b>Tunable Paramagnetic-Ion Solid-State Lasers</b>	
	By J. C. Walling (With 49 Figures) .....	331
9.1	Overview of Fundamentals .....	332
9.1.1	Crystal Field States .....	332
9.1.2	Phonon Modes .....	335
9.1.3	Vibronic Interaction .....	336
9.1.4	Linewidths and Lifetimes .....	338
9.2	Vibronic Laser Kinetics .....	339
9.2.1	Vibronic Laser Gain .....	340
9.2.2	Laser Rate Equations .....	344

a) Ground-State Absorption .....	344
b) Effect of Excited State Absorption .....	345
9.3 Tunable Paramagnetic Ion Lasers: Classes and Characteristics ..	346
9.3.1 Cr <sup>3+</sup> and V <sup>2+</sup> .....	349
a) Ruby, Cr: YAG, Alexandrite, and Emerald .....	350
b) Garnets .....	352
c) Other Materials .....	353
d) V: MgF <sub>2</sub> .....	355
e) Merits of Strong Versus Weak Field Materials .....	356
9.3.2 Ti <sup>3+</sup> and Cu <sup>2+</sup> .....	357
9.3.3 Ni <sup>2+</sup> and Co <sup>2+</sup> .....	359
9.3.4 Ce <sup>3+</sup> .....	362
9.3.5 Sm <sup>2+</sup> and Ho <sup>2+</sup> .....	362
9.4 Alexandrite Material Characteristics .....	363
9.4.1 Alexandrite Crystals .....	364
a) Chromium Concentration .....	364
b) Birefringence .....	365
c) Thermal Lensing .....	366
9.4.2 Optical Cross Sections and Their Role in Laser Performance .....	366
a) Pump Band Absorption .....	366
b) Laser Gain Cross Section .....	368
c) Emission and Excited State Absorption Cross Sections ..	368
d) Ground State Absorption in the Laser Band .....	369
e) Mirror-Site Excited State Absorption .....	369
f) Energy Transfer and the Role of the Inversion Site in Laser Operation .....	372
9.5 Alexandrite Laser Operation and Performance .....	373
9.5.1 Flash Lamp Pumped (Pulsed) Alexandrite Lasers .....	373
a) Basic Oscillator .....	373
b) Q-Switching .....	375
c) Q-Switching on the <i>R</i> -Line .....	379
d) Alexandrite Unstable Resonator Oscillators .....	380
e) Achievement of Low Order Modes .....	382
f) Alexandrite Oscillator-Amplifiers .....	383
g) Zigzag Slab Alexandrite Lasers .....	385
9.5.2 Arc Lamp Pumped (cw) Alexandrite Lasers .....	387
9.5.3 Optical Damage .....	389
9.6 Frequency Conversion .....	391
9.7 Applications .....	393
9.7.1 Photochemistry .....	393
9.7.2 Lidar .....	393
9.7.3 Isotope Separation .....	394
References .....	395
<b>Subject Index .....</b>	<b>399</b>