

Contents

Preface	xix
Part I LASER FUNDAMENTALS	1
1 Laser Basics	3
1.1 Introduction	3
1.2 Laser Operation	3
1.3 Rules of Quantum Mechanics	3
1.4 Absorption, Spontaneous Emission and Stimulated Emission	4
1.5 Population Inversion	10
1.5.1 <i>Producing Population Inversion</i>	11
1.6 Two-, Three- and Four-Level Laser Systems	11
1.6.1 <i>Two-Level Laser System</i>	11
1.6.2 <i>Three-Level Laser System</i>	12
1.6.3 <i>Four-Level Laser System</i>	14
1.6.4 <i>Energy Level Structures of Practical Lasers</i>	15
1.7 Gain of Laser Medium	16
1.8 Laser Resonator	17
1.9 Longitudinal and Transverse Modes	18
1.10 Types of Laser Resonators	21
1.11 Pumping Mechanisms	23
1.11.1 <i>Optical Pumping</i>	24
1.11.2 <i>Electrical Pumping</i>	28
1.11.3 <i>Other Methods of Pumping</i>	29
1.12 Summary	29
Review Questions	30
Problems	30
Self-evaluation Exercise	31
Bibliography	33
2 Laser Characteristics	34
2.1 Introduction	34
2.2 Laser Characteristics	34
2.2.1 <i>Monochromaticity</i>	34
2.2.1.1 <i>Line-broadening Mechanisms</i>	34
2.2.2 <i>Coherence</i>	36
2.2.2.1 <i>Temporal Coherence</i>	36
2.2.2.2 <i>Spatial Coherence</i>	38
2.2.3 <i>Directionality</i>	39

2.3	Important Laser Parameters	41
2.3.1	<i>Wavelength</i>	41
2.3.2	<i>CW Power</i>	42
2.3.3	<i>Peak Power</i>	42
2.3.4	<i>Average Power</i>	43
2.3.5	<i>Pulse Energy</i>	43
2.3.6	<i>Repetition Rate</i>	43
2.3.7	<i>Pulse Width</i>	44
2.3.8	<i>Duty Cycle</i>	44
2.3.9	<i>Rise and Fall Times</i>	45
2.3.10	<i>Irradiance</i>	45
2.3.11	<i>Radiance</i>	45
2.3.12	<i>Beam Divergence</i>	46
2.3.13	<i>Spot Size</i>	47
2.3.14	<i>M² Value</i>	48
2.3.15	<i>Wall-plug Efficiency</i>	48
2.4	Measurement of Laser Parameters	49
2.4.1	<i>Measurement of Power, Energy and Repetition Rate</i>	49
2.4.1.1	Choosing the Appropriate Sensor	49
2.4.1.2	Choosing the Appropriate Meter	50
2.4.2	<i>Measurement of Spot Size</i>	50
2.4.3	<i>Measurement of Divergence</i>	50
2.4.4	<i>Measurement of M² Value</i>	52
2.4.5	<i>Measurement of Line Width</i>	53
2.5	Laser Beam Diagnostic Equipment	56
2.5.1	<i>Wavelength Meter</i>	56
2.5.2	<i>Laser Spectrum Analyzer</i>	56
2.5.3	<i>Laser Beam Profiler</i>	57
2.5.4	<i>Beam Propagation Analyzer</i>	58
2.6	Summary	59
	Review Questions	60
	Problems	61
	Self-evaluation Exercise	62
	Bibliography	63
Part II TYPES OF LASERS		65
3	Solid-state Lasers	67
3.1	Introduction: Types of Lasers	67
3.2	Importance of Host Material	67
3.2.1	<i>Lasing Species</i>	68
3.3	Operational Modes	68
3.3.1	<i>CW Output</i>	69
3.3.2	<i>Free-running Output</i>	69
3.3.3	<i>Q-switched Output</i>	69
3.3.4	<i>Cavity-dumped Output</i>	72
3.3.5	<i>Mode-locked Output</i>	72
3.4	Ruby Lasers	76
3.5	Neodymium-doped Lasers	78
3.5.1	<i>Nd:YAG Lasers</i>	79
3.5.2	<i>Nd:YLF Lasers</i>	79

3.5.3	<i>Nd:YVO₄ Lasers</i>	82
3.5.4	<i>Nd:Cr:GSGG Lasers</i>	82
3.5.5	<i>Nd:Glass Lasers</i>	84
3.6	Erbium-doped Lasers	85
3.6.1	<i>Er:YAG Laser</i>	85
3.6.2	<i>Er:Glass Laser</i>	85
3.7	Vibronic Lasers	88
3.7.1	<i>Alexandrite Laser</i>	88
3.7.2	<i>Titanium-sapphire Laser</i>	90
3.8	Colour Centre Lasers	90
3.9	Fibre Lasers	91
3.9.1	<i>Basic Fibre Laser</i>	92
3.9.2	<i>Fibre Lasers versus Bulk Solid-state Lasers</i>	93
3.9.3	<i>Operational Regimes</i>	95
3.9.4	<i>Photonic Crystal Fibre Lasers</i>	96
3.9.4.1	<i>Guiding Mechanisms in PCF</i>	97
3.9.4.2	<i>Subclasses of PCFs</i>	97
3.9.4.3	<i>PCF Lasers</i>	98
3.9.5	<i>Applications</i>	98
3.10	Summary	101
	Review Questions	102
	Problems	102
	Self-evaluation Exercise	102
	Bibliography	104
4	Gas Lasers	105
4.1	Introduction to Gas Lasers	105
4.1.1	<i>The Active Media</i>	105
4.1.2	<i>Inter-level Transitions</i>	106
4.1.3	<i>Pumping Mechanism</i>	106
4.2	Helium-neon Lasers	107
4.3	Carbon Dioxide Lasers	111
4.4	Metal Vapour Lasers	115
4.4.1	<i>Helium-cadmium Laser</i>	115
4.4.2	<i>Copper Vapour and Gold Vapour Lasers</i>	116
4.5	Rare Gas Ion Lasers	118
4.6	Excimer Lasers	120
4.7	Chemical Lasers	121
4.7.1	<i>Hydrogen Fluoride/Deuterium Fluoride (HF/DF) Lasers</i>	121
4.7.2	<i>Chemical Oxygen Iodine Laser (COIL)</i>	123
4.7.3	<i>All Gas-Phase Iodine Laser (AGIL)</i>	124
4.8	Carbon Dioxide Gas Dynamic Lasers	125
4.9	Dye Laser	125
4.9.1	<i>Active Medium</i>	126
4.9.2	<i>Pump Mechanisms</i>	127
4.9.3	<i>Wavelength Selection</i>	127
4.10	Free-electron Lasers	127
4.11	X-Ray Lasers	129
4.12	Summary	129
	Review Questions	129
	Self-evaluation Exercise	130
	Bibliography	131

5	Semiconductor Lasers	132
5.1	Introduction	132
5.2	Operational Basics	132
5.3	Semiconductor Laser Materials	135
5.4	Types of Semiconductor Lasers	136
5.4.1	<i>Homojunction and Heterojunction Lasers</i>	136
5.4.2	<i>Quantum Well Diode Lasers</i>	136
5.4.3	<i>Distributed-feedback (DFB) Lasers</i>	138
5.4.4	<i>Vertical-cavity Surface-emitting Laser (VCSEL)</i>	140
5.4.5	<i>Vertical External-cavity Surface-emitting Lasers (VECSEL)</i>	140
5.4.6	<i>External-cavity Semiconductor Diode Lasers</i>	141
5.4.7	<i>Optically Pumped Semiconductor Lasers</i>	143
5.4.8	<i>Quantum Cascade Lasers</i>	145
5.4.9	<i>Lead Salt Lasers</i>	147
5.5	Characteristic Parameters	148
5.5.1	<i>Threshold Current</i>	148
5.5.2	<i>Slope Efficiency</i>	148
5.5.3	<i>Beam Divergence</i>	149
5.5.4	<i>Line Width</i>	151
5.5.5	<i>Beam Polarization</i>	152
5.6	Gain- and Index-guided Diode Lasers	152
5.7	Handling Semiconductor Diode Lasers	152
5.8	Semiconductor Diode Lasers: Application Areas	153
5.8.1	<i>Directed Energy</i>	153
5.8.2	<i>Coherence</i>	153
5.8.3	<i>Monochromaticity</i>	153
5.9	Summary	154
	Review Questions	155
	Problems	155
	Self-evaluation Exercise	156
	Bibliography	157
 Part III LASER ELECTRONICS AND OPTOELECTRONICS		 159
6	Building Blocks of Laser Electronics	161
6.1	Introduction	161
6.2	Linear Power Supplies	161
6.2.1	<i>Constituents of a Linear Power Supply</i>	161
6.2.2	<i>Rectifier Circuits</i>	162
6.2.3	<i>Filters</i>	164
6.2.4	<i>Linear Regulators</i>	166
6.2.4.1	Emitter-follower Regulator	166
6.2.4.2	Series-pass Regulator	167
6.2.4.3	Shunt Regulator	170
6.2.4.4	Linear IC Voltage Regulators	171
6.3	Switched-mode Power Supplies	173
6.3.1	<i>Linear versus Switched-mode Power Supplies</i>	173
6.3.2	<i>Different Types of Switched-mode Power Supplies</i>	174
6.3.2.1	Flyback Converters	174
6.3.2.2	Forward Converter	178
6.3.2.3	Push-pull Converter	178

6.3.2.4	Switching Regulators	181
6.3.2.5	Three-terminal Switching Regulators	183
6.3.3	<i>Connecting Power Converters in Series</i>	184
6.3.4	<i>Connecting Power Converters in Parallel</i>	184
6.4	Constant Current Sources	186
6.4.1	<i>Junction Field-effect-transistor-based Constant Current Source</i>	186
6.4.2	<i>Transistor-based Constant Current Source</i>	187
6.4.3	<i>Opamp-controlled Constant Current Source</i>	189
6.4.4	<i>Constant Current Source Using Three-terminal Regulators</i>	189
6.4.5	<i>Current Mirror Configurations</i>	190
6.4.5.1	Basic Current Mirror	190
6.4.5.2	Widlar Current Source	191
6.4.5.3	Wilson Current Source	191
6.5	Integrated-circuit Timer Circuits	191
6.5.1	<i>Digital IC-based Timer Circuits</i>	191
6.5.2	<i>IC Timer-based Multivibrators</i>	193
6.5.2.1	Astable Multivibrator Using Timer IC 555	194
6.5.2.2	Monostable Multivibrator Using Timer IC 555	195
6.6	Current-to-voltage Converter	197
6.7	Peak Detector	199
6.8	High-voltage Trigger Circuit	200
6.9	Summary	202
	Review Questions	203
	Problems	204
	Self-evaluation Exercise	206
	Bibliography	207
7	Solid-state Laser Electronics	208
7.1	Introduction	208
7.2	Spectrum of Laser Electronics	208
7.2.1	<i>Solid-state Lasers</i>	208
7.2.2	<i>Semiconductor Diode Lasers</i>	209
7.2.3	<i>Gas Lasers</i>	211
7.2.4	<i>Testing and Evaluation of Lasers</i>	212
7.2.5	<i>Laser Sensor Systems</i>	213
7.3	Electronics for Solid-state Lasers	213
7.4	Electronics for Pulsed Solid-state Lasers	214
7.4.1	<i>Electronics for Q-switched Solid-state Lasers</i>	214
7.4.2	<i>Capacitor-charging Power Supply</i>	216
7.4.3	<i>Simmer Power Supply</i>	222
7.4.4	<i>Pseudo-simmer Mode</i>	224
7.4.5	<i>Pulse-forming Network</i>	225
7.4.6	<i>Flashlamp Trigger Circuit</i>	231
7.5	Electronics for CW Solid-state Lasers	233
7.5.1	<i>Arc Lamps</i>	233
7.5.2	<i>Electrical Characteristics</i>	234
7.5.3	<i>Arc Lamp Power Supply</i>	235
7.5.4	<i>Modulated CW and Quasi-CW Operation of Arc Lamp</i>	236
7.6	Solid-state Laser Designators and Rangefinders	237
7.7	Summary	238
	Review Questions	239
	Problems	240

Self-evaluation Exercise	240
Bibliography	241
8 Gas Laser Electronics	242
8.1 Introduction	242
8.2 Gas Discharge Characteristics	242
8.3 Gas Laser Power Supplies	242
8.4 Helium-Neon Laser Power Supply	244
8.4.1 <i>Power Supply Design</i>	247
8.4.2 <i>Switched-mode Power Supply Configurations</i>	250
8.4.3 <i>Other Possible Configurations</i>	253
8.4.4 <i>Configurations for Special Applications</i>	254
8.4.5 <i>Ballast Resistance</i>	257
8.5 Carbon Dioxide Laser Power Supplies	257
8.5.1 <i>DC-excited CW CO₂ Laser</i>	257
8.5.2 <i>DC-excited Pulsed CO₂ Laser</i>	257
8.5.3 <i>RF-excited CO₂ Lasers</i>	259
8.6 Power Supplies for Metal Vapour Lasers	260
8.7 Power Supplies for Excimer Lasers	261
8.8 Power Supplies for Ion Lasers	262
8.9 Frequency Stabilization of Gas Lasers	263
8.9.1 <i>Dither Stabilization</i>	264
8.9.2 <i>Stark-cell Stabilization</i>	265
8.9.3 <i>Optogalvanic Stabilization</i>	265
8.9.4 <i>Stabilization using Saturation Absorption Dip</i>	266
8.10 Summary	267
Review Questions	268
Problems	268
Self-evaluation Exercise	269
Bibliography	270
9 Laser Diode Electronics	271
9.1 Introduction	271
9.2 Laser Diode Protection	271
9.2.1 <i>Laser Diode Drive and Control</i>	272
9.2.2 <i>Interconnection Cables and Grounding</i>	274
9.2.3 <i>Transient Suppression</i>	275
9.2.4 <i>Electrostatic Discharge</i>	275
9.3 Operational Modes	276
9.3.1 <i>Constant-current Mode</i>	276
9.3.2 <i>Constant-power Mode</i>	277
9.4 Laser Diode Driver Circuits	278
9.4.1 <i>Basic Constant-current Source</i>	278
9.4.2 <i>Laser Diode Driver with Feedback Control</i>	279
9.4.3 <i>Laser Diode Driver with Modulation Input</i>	282
9.4.4 <i>Laser Diode Driver with Protection Features</i>	284
9.4.5 <i>Laser Diode Driver with Automatic Power Control</i>	286
9.4.6 <i>Quasi-CW Laser Diode Driver</i>	289
9.5 Laser Diode Temperature Control	291
9.5.1 <i>Thermoelectric Cooling Fundamentals</i>	292
9.5.2 <i>Thermoelectric Cooler: Performance Characteristics</i>	295

9.5.3	<i>TE Module Selection</i>	297
9.5.4	<i>Heat Sink Selection</i>	299
9.5.5	<i>Thermoelectric Cooler Drive and Control Circuits</i>	301
9.5.5.1	Temperature Sensing Circuits	301
9.5.5.2	Error Amplifier	303
9.5.5.3	Error Signal Processor	303
9.5.5.4	Output Stage	306
9.6	Summary	308
	Review Questions	310
	Problems	310
	Self-evaluation Exercise	312
	Bibliography	314
10	Optoelectronic Devices and Circuits	315
10.1	Introduction	315
10.2	Classification of Photosensors	315
10.2.1	<i>Photoelectric Sensors</i>	315
10.2.2	<i>Thermal Sensors</i>	316
10.3	Radiometry and Photometry	316
10.3.1	<i>Radiometric and Photometric Flux</i>	316
10.3.2	<i>Radiometric and Photometric Intensity</i>	316
10.3.3	<i>Radiant Incidence (Irradiance) and Illuminance</i>	318
10.3.4	<i>Radiant Sterance (Radiance) and Luminance</i>	318
10.4	Characteristic Parameters	318
10.4.1	<i>Responsivity</i>	318
10.4.2	<i>Noise Equivalent Power (NEP)</i>	321
10.4.3	<i>Detectivity and D-star</i>	321
10.4.4	<i>Quantum Efficiency</i>	321
10.4.5	<i>Response Time</i>	322
10.4.6	<i>Noise</i>	323
10.5	Photoconductors	324
10.5.1	<i>Application Circuits</i>	326
10.6	Photodiodes	329
10.6.1	<i>Types of Photodiodes</i>	330
10.6.1.1	PN Photodiodes	330
10.6.1.2	PIN Photodiodes	331
10.6.1.3	Schottky Photodiodes	331
10.6.1.4	Avalanche Photodiodes	331
10.6.2	<i>Equivalent Circuit</i>	331
10.6.3	<i>I–V Characteristics</i>	333
10.6.4	<i>Application Circuits</i>	334
10.6.5	<i>Solar Cells</i>	336
10.7	Phototransistors	340
10.7.1	<i>Application Circuits</i>	341
10.8	Photo- FET, SCR and TRIAC	343
10.8.1	<i>Photo-FET</i>	343
10.8.2	<i>Photo-SCR</i>	343
10.8.3	<i>Photo-TRIAC</i>	344
10.9	Photoemissive Sensors	345
10.9.1	<i>Vacuum Photodiodes</i>	345
10.9.2	<i>Photomultiplier Tubes</i>	345
10.9.3	<i>Image Intensifiers</i>	346

10.10 Thermal Sensors	347
10.10.1 Thermocouple and Thermopile	347
10.10.2 Bolometer	348
10.10.3 Pyroelectric Sensors	348
10.11 Displays	350
10.11.1 Display Characteristics	350
10.11.2 Types of Displays	350
10.12 Light-emitting Diodes	351
10.12.1 Characteristic Curves	352
10.12.2 Parameters	354
10.12.3 Drive Circuits	354
10.13 Liquid-crystal Displays	356
10.13.1 Construction	356
10.13.2 Driving LCD	357
10.13.3 Response Time	358
10.13.4 Types of LCD Displays	358
10.13.5 Advantages and Disadvantages	361
10.14 Cathode Ray Tube Displays	361
10.15 Emerging Display Technologies	362
10.15.1 Organic Light-emitting Diodes (OLEDs)	362
10.15.2 Digital Light-processing (DLP) Technology	363
10.15.3 Plasma Display Panels (PDPs)	363
10.15.4 Field Emission Displays (FEDs)	363
10.15.5 Electronic Ink Displays	363
10.16 Optocouplers	363
10.16.1 Characteristic Parameters	364
10.16.2 Application Circuits	366
10.17 Summary	370
Review Questions	372
Problems	373
Self-evaluation Exercise	374
Bibliography	377
Part IV LASER APPLICATIONS	379
11 Lasers in Industry	381
11.1 Introduction	381
11.2 Material-processing Applications	381
11.2.1 Classification	381
11.2.2 Important Considerations	382
11.2.2.1 Material Properties: Absorption Length and Diffusion Length	382
11.2.2.2 Laser Parameters	382
11.2.3 Common Material-processing Applications	383
11.2.4 Advantages	385
11.3 Laser Cutting	385
11.3.1 Basic Principle	385
11.3.2 Laser Cutting vs Plasma Cutting	387
11.3.3 Laser Cutting Processes	387
11.3.4 Machine Configurations	388

11.4	Laser Welding	390
	11.4.1 Laser Welding Processes	390
	11.4.2 Welding Lasers	390
	11.4.3 Advantages	392
11.5	Laser Drilling	393
	11.5.1 Basic Principle	393
	11.5.2 Laser Drilling Processes	394
	11.5.3 Lasers for Drilling	395
	11.5.4 Advantages of Laser Drilling	396
11.6	Laser Marking and Engraving	396
	11.6.1 Principle of Operation	396
	11.6.2 Laser Marking Processes	397
	11.6.3 Lasers for Marking and Engraving	398
	11.6.4 Advantages	399
11.7	Laser Micromachining	401
	11.7.1 Laser Micromachining Operations	402
	11.7.2 Lasers for Micromachining	403
	11.7.3 Laser Micromachining Techniques	404
11.8	Photolithography	407
	11.8.1 Basic Process	408
	11.8.2 Lasers for Photolithography	411
11.9	Rapid Manufacturing	411
	11.9.1 Additive Versus Subtractive Manufacturing	412
	11.9.2 Rapid Manufacturing Technologies	412
	11.9.3 Lasers for Rapid Manufacturing	413
	11.9.4 Advantages	414
11.10	Lasers in Printing	414
	11.10.1 Laser Printing Process	415
	11.10.2 Anatomy of Laser Printer	415
	11.10.3 Choice Criteria	416
	11.10.4 Laser Printers vs Inkjet Printers	417
11.11	Summary	418
	Review Questions	419
	Self-evaluation Exercise	420
	Bibliography	421
12	Lasers in Medicine	422
12.1	Introduction	422
12.2	Light–tissue Interaction	422
	12.2.1 Light–tissue Interaction for Diagnostic Applications	423
	12.2.1.1 Fundamental Interaction Mechanisms	423
	12.2.1.2 Optical Properties of Tissues	425
	12.2.1.3 Fluence Rate Distribution	426
	12.2.2 Light–tissue Interaction for Therapeutic Applications	427
	12.2.2.1 Photochemical Effects	427
	12.2.2.2 Photothermal Effects	428
	12.2.2.3 Photomechanical Effects	429
12.3	Laser Diagnostics	430
	12.3.1 Basic Principle	431
	12.3.2 Comparison with Other Techniques	431
	12.3.3 In Vivo Optical Diagnostic Techniques	432
	12.3.3.1 White Light Imaging	432

12.3.3.2	Diffuse Optical Spectroscopy	434
12.3.3.3	Elastic Scattering Spectroscopy	434
12.3.3.4	Optical Coherence Tomography	435
12.3.3.5	Confocal Imaging	438
12.3.3.6	Fluorescence Spectroscopy and Imaging	438
12.3.3.7	Raman Spectroscopy	441
12.4	Therapeutic Techniques: Application Areas	442
12.5	Ophthalmology	443
12.5.1	<i>Refractive Surgery</i>	444
12.5.2	<i>Treatment of Glaucoma</i>	447
12.5.3	<i>Cataract Surgery</i>	448
12.5.4	<i>Treatment of Retinal Detachment (Retinopexy)</i>	449
12.5.5	<i>Treatment of Proliferative Diabetic Retinopathy</i>	449
12.6	Dermatology	449
12.6.1	<i>Portwine Stains</i>	450
12.6.2	<i>Pigmented Lesions and Tattoos</i>	451
12.6.3	<i>Hair Removal</i>	452
12.6.4	<i>Lasers for Dermatology</i>	453
12.7	Laser Dentistry	453
12.7.1	<i>Considerations in Laser Dentistry</i>	453
12.7.2	<i>Lasers for Dentistry</i>	454
12.8	Vascular Surgery	455
12.8.1	<i>Conventional Treatment of Angioplasty: PTA</i>	455
12.8.2	<i>Laser Angioplasty</i>	456
12.9	Photodynamic Therapy	456
12.9.1	<i>Important Considerations</i>	458
12.9.2	<i>Applications of PDT</i>	458
12.10	Thermal Therapy	459
12.10.1	<i>Treatment of Haemorrhages of Peptic Ulcers</i>	459
12.10.2	<i>Treatment of Cancer</i>	460
12.11	Summary	460
	Review Questions	462
	Self-evaluation Exercise	463
	Bibliography	465
13	Lasers in Science and Technology	466
13.1	Introduction	466
13.2	Optical Metrology	466
13.2.1	<i>Interferometers</i>	466
13.2.1.1	Michelson Interferometer	467
13.2.1.2	Twyman–Green Interferometer	468
13.2.1.3	Mach–Zehnder Interferometer	468
13.2.1.4	Fabry–Pérot Interferometer	469
13.2.1.5	Sagnac Interferometer	471
13.2.2	<i>Length Metrology</i>	471
13.2.3	<i>Time and Frequency Metrology</i>	472
13.2.3.1	Optical Clock	474
13.2.4	<i>Measurement of Line Width</i>	474
13.2.5	<i>Infrared Thermometer</i>	476
13.3	Laser Velocimetry	478
13.3.1	<i>Laser Doppler Velocimetry</i>	478
13.3.1.1	Operational Principle	478
13.3.1.2	Advantages	480

13.3.1.3 Applications	480
13.3.2 Particle Image Velocimetry	480
13.4 Laser Vibrometry	482
13.4.1 Operational Principle	482
13.4.2 Types of Laser Doppler Vibrometers	484
13.4.3 Applications	484
13.5 Electronic Speckle Pattern Interferometry	484
13.5.1 Operational Principle	485
13.5.2 Measurement Configurations	486
13.5.2.1 Out-of-plane Displacement Measurement	486
13.5.2.2 In-plane Displacement Measurement	487
13.5.2.3 In-plane Displacement Gradient Measurement	487
13.5.2.4 Three-dimensional (3D) Measurement	488
13.5.2.5 Vibration Measurement	490
13.6 Satellite Laser Ranging	490
13.6.1 Operational Principle	491
13.6.2 Lasers for SLR	492
13.6.3 SLR Telescopes and Stations	492
13.6.4 SLR Applications	493
13.7 Lasers in Astronomy	494
13.7.1 Adaptive Optics	494
13.7.2 Laser Guide Star	494
13.7.3 Laser Guide Star Mechanisms	496
13.7.3.1 Rayleigh Guide Star	496
13.7.3.2 Sodium Beacon Guide Star	496
13.8 Holography	496
13.8.1 Basic Principle	498
13.8.2 Types of Hologram	499
13.8.2.1 Amplitude- and Phase-modulated Holograms	499
13.8.2.2 Transmission and Reflection Holograms	499
13.8.2.3 Thin and Thick Holograms	500
13.8.2.4 Other Commonly Encountered Holograms	501
13.8.3 Applications	502
13.9 Summary	503
Review Questions	504
Self-evaluation Exercise	505
Bibliography	507
14 Military Applications: Laser Instrumentation	508
14.1 Introduction	508
14.2 Military Applications of Lasers	508
14.3 Laser-based Instrumentation	512
14.3.1 Laser Aiming Modules	512
14.3.2 Laser Rangefinders	513
14.3.2.1 Time-of-Flight Technique	514
14.3.2.2 Triangulation Technique	515
14.3.2.3 Phase Shift Technique	516
14.3.2.4 FM-CW Range-finding Technique	516
14.3.2.5 Lasers for Laser Rangefinders	518
14.3.2.6 Applications and Related Devices	519
14.3.3 Laser Target Designators	520
14.3.4 Laser Proximity Sensors	520
14.3.5 Laser Bathymetry Sensors	524

14.3.6	<i>Laser Radar (Ladar) Sensors</i>	526
14.3.7	<i>Forward-looking Infrared (FLIR) Sensors</i>	528
14.4	Guided Munitions	532
14.4.1	<i>Guidance Techniques</i>	532
14.4.1.1	Beam Rider Guidance	532
14.4.1.2	Command Guidance	533
14.4.1.3	Homing Guidance	536
14.4.1.4	Navigation Guidance	538
14.4.1.5	Ring Laser Gyroscope	540
14.4.1.6	Fibre-optic Gyroscope	545
14.4.2	<i>Electro-optically Guided Precision Strike Munitions</i>	546
14.4.2.1	Laser-guided Munitions: Operational Basics	549
14.4.2.2	IR-guided Missiles: Operational Basics	554
14.5	Laser Communication	556
14.5.1	<i>Advantages and Limitations</i>	556
14.5.2	<i>Free-space Communication</i>	557
14.5.3	<i>Fibre-optic Communication</i>	559
14.6	Summary	561
	Review Questions	562
	Problems	563
	Self-evaluation Exercise	564
	Bibliography	565
15	Military Applications: Directed-energy Laser Systems	566
15.1	Introduction	566
15.2	Laser Technology for Low-intensity Conflict (LIC) Applications	566
15.2.1	<i>Importance of Laser Technology in LIC Applications</i>	566
15.2.2	<i>Detection of Chemical and Biological Warfare Agents</i>	567
15.2.2.1	Detection of Chemical Warfare Agents	567
15.2.2.2	Detection of Biological Agents	568
15.2.3	<i>Detection of Explosive Agents</i>	570
15.2.4	<i>Detection of Optical and Electro-optic Devices</i>	573
15.2.5	<i>Disposal of Unexploded Ordnances</i>	574
15.2.6	<i>Non-lethal Laser Dazzlers</i>	576
15.3	Electro-optic Countermeasures	580
15.3.1	<i>Need and Relevance</i>	580
15.3.2	<i>Passive and Active Countermeasures</i>	580
15.3.3	<i>Types of EOCM Equipment</i>	581
15.3.4	<i>Infrared Countermeasures</i>	584
15.4	Directed-energy Laser Weapons	585
15.4.1	<i>Operational Advantages and Limitations</i>	587
15.4.2	<i>Operational Scenario</i>	588
15.4.3	<i>Components of Directed-energy Weapon Systems</i>	589
15.4.4	<i>International Status</i>	590
15.5	Summary	592
	Review Questions	595
	Self-evaluation Exercise	596
	Bibliography	598
	Appendix A: Laser Safety	599
	Index	605