

# **Lasers**

## **Principles**

### **and Applications**

**J. Wilson**

**J. F. B. Hawkes**

School of Physics

Newcastle upon Tyne Polytechnic



**Prentice Hall**

New York London Sydney Tokyo

# Contents

Preface ix

Glossary of Symbols xi

## 1 Laser Fundamentals 1

- 1.1 The nature of light 1
- 1.2 Emission and absorption of light 9
- 1.3 Interaction of radiation and matter 11
- 1.4 The Einstein relations 13
- 1.5 The gain coefficient 16
- 1.6 Attainment of a population inversion 18
- 1.7 The optical resonator 21
- 1.8 Threshold gain coefficient 24
- 1.9 The lineshape function 26
- 1.10 Laser modes 28
  - 1.10.1 Axial modes 28
  - 1.10.2 Transverse modes 31

Problems 32

References 33

## 2 Operation of Practical Lasers 35

- 2.1 Doped insulator lasers 35
  - 2.1.1 Impurity ion energy levels in solids 36
  - 2.1.2 Pumping methods 39
  - 2.1.3 Fresnel losses 42
  - 2.1.4 The Nd: YAG laser 43
  - 2.1.5 Nd: glass lasers 46
  - 2.1.6 The ruby laser 47
  - 2.1.7 The alexandrite laser 48
  - 2.1.8 Color or 'F' center lasers 50
- 2.2 Semiconductor lasers 52
- 2.3 Gas lasers 63
  - 2.3.1 Atomic lasers 64
    - 2.3.1.1 The HeNe laser 64
    - 2.3.1.2 The copper vapor laser 67

2.3.2	Ion lasers	68
2.3.2.1	The argon ion laser	68
2.3.2.2	The helium–cadmium laser	70
2.3.3	Molecular lasers	71
2.3.3.1	The carbon dioxide laser	71
	Sealed-tube lasers	73
	Gas flow lasers	74
	Gasdynamic lasers	75
	Transversely excited atmospheric (TEA) lasers	75
	Optics	76
2.3.3.2	The nitrogen laser	76
2.3.3.3	The excimer laser	77
2.3.3.4	The chemical laser	78
2.3.3.5	Far infra-red lasers	79
2.4	Liquid dye lasers	80
2.5	The free electron laser	84
	Problems	86
	References	88
<b>3</b>	<b>Properties of Laser Radiation</b>	<b>90</b>
3.1	Laser linewidth	90
3.2	Laser frequency stabilization	94
3.3	Beam divergence	96
3.4	Beam coherence	102
3.5	Brightness	106
3.6	Focusing properties of laser radiation	107
3.7	Q-switching	108
3.7.1	Methods of Q-switching	110
3.7.1.1	Rotating-mirror method	110
3.7.1.2	Electro-optic Q-switching	111
3.7.1.3	Acousto-optic Q-switching	112
3.7.1.4	Passive Q-switching	113
3.8	Mode locking	114
3.8.1	Methods of mode locking	117
3.9	Frequency doubling	119
3.10	Phase conjugation	121
	Problems	125
	References	126
<b>4</b>	<b>Metrological and Scientific Applications</b>	<b>128</b>
4.1	Optical alignment	128
4.2	Measurement of distance	131
4.2.1	Interferometry	131
4.2.1.1	Reversible counting	135
4.2.1.2	Refractive index correction	136

4.2.2	Surface topography and optical component testing	137
4.2.3	Beam-modulation telemetry	142
4.2.4	Pulse-Echo techniques	144
4.3	Laser Doppler velocimetry	145
4.4	Surface velocity measurements using speckle patterns	151
4.5	Angular rotation	153
4.6	Laser spectroscopy	157
4.6.1	Molecular beam spectroscopy	158
4.6.2	Saturation spectroscopy	159
4.6.3	Two-photon spectroscopy	159
4.7	Laser uranium enrichment	160
Problems		162
References		163

## 5 Industrial, Medical and Military Applications 165

5.1	Theoretical analysis	166
5.1.1	Temperature changes assuming no melting or vaporization	168
5.1.2	Melting depths	174
5.1.3	Vaporization depth	175
5.2	Beam transport and focusing	176
5.3	Materials-processing applications	179
5.3.1	Surface hardening	179
5.3.2	Semiconductor processing	182
5.4	Laser welding	184
5.4.1	Microwelding	187
5.4.2	Deep penetrating welding	188
5.5	Laser-assisted machining	189
5.6	Laser cutting	190
5.7	Micromachining	193
5.8	Drilling, scribing and marking	194
5.9	Lasers in medicine	197
5.10	Very high-power laser uses	199
5.10.1	Laser-induced nuclear fusion	199
5.10.2	Laser weapons	201
Problems		201
References		203

## 6 Holography 204

6.1	Introduction	204
6.2	Classification of holograms	207
6.3	A mathematical description of holography	212
6.4	Hologram efficiency	218

<b>6.5 Applications of holography</b>	219	
6.5.1 Holographic interferometry	220	
6.5.1.1 Double exposure holographic interferometry	220	
6.5.1.2 Sandwich holograms	221	
6.5.1.3 Real-time holography	221	
6.5.1.4 Time-average holographic interferometry	223	
6.5.2 Holographic optical components	227	
6.5.2.1 Holographic optical elements (HOE)	228	
6.5.3 Information storage and display	230	
6.5.4 Character recognition	233	
References	233	
<b>7 Optical Information Transmission and Storage</b>	236	
7.1 Optical communication	236	
7.1.1 Light modulation schemes	237	
7.1.2 The optical fiber	241	
7.1.2.1 Intermodal dispersion	246	
7.1.2.2 Graded-index fiber	248	
7.1.2.3 Low-dispersion fibers	249	
7.1.2.4 Fiber losses	252	
7.1.2.5 Fiber materials and manufacture	254	
7.1.3 Optical detectors	258	
7.1.4 Emitters	264	
7.1.5 System design considerations	265	
7.1.6 Future developments	265	
7.1.7 Integrated optics	267	
7.1.8 Optical bistability	270	
7.1.9 Free-space communication	273	
7.2 Laser printing	275	
7.3 Optical disk systems	277	
7.3.1 Recording	281	
7.3.2 Recording media	283	
7.3.3 Data readout from optical disks	287	
7.3.4 Erasable optical disks	289	
Problems	290	
References	292	
<b>Appendix 1</b>	Answers to Problems	294
<b>Appendix 2</b>	Physical Constants	297
<b>Appendix 3</b>	Laser Safety	298
<b>Index</b>	302	