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Karl F. Renk

Basics of Laser Physics

For Students of Science and Engineering

With 333 Figures

 Springer

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ISSN 1868-4513 e-ISSN 1868-4521
ISBN 978-3-642-23564-1 e-ISBN 978-3-642-23565-8
DOI 10.1007/978-3-642-23565-8
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2011945843

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Printed on acid-free paper

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To Marianne, Christiane, and Peter

Preface

This textbook addresses students of science and engineering. It should be appropriate for a senior level applied physics or engineering course on lasers.

There are many textbooks on lasers. Why may it be useful to have another one? I have tried to unify the description of different types of lasers: gas lasers; solid state lasers, including semiconductor lasers; dye lasers; and free-electron lasers. Semiconductor lasers are described in more detail than in other textbooks on lasers. This may be adequate according to the very different types of semiconductor lasers and the many different applications.

What is the working principle of a laser and how is it realizable in different types of lasers? I introduce a laser as an oscillator (= laser oscillator) that generates coherent radiation via the interaction of radiation with an active medium. An active medium consists of an ensemble of atomic systems with a population inversion.

I make use, on an elementary quantum mechanical basis, of the Einstein coefficients of absorption, spontaneous and stimulated emission of radiation to characterize the interaction of radiation with an atomic system. Einstein coefficients are determinable from quantities that are experimentally accessible. I formulate the working principle of a laser by the use of rate equations, yielding the condition of laser oscillation and other properties of a laser.

The main topics of the book concern: the working principle of a laser; the parts of a laser — like the laser resonator and the active medium; beams of radiation generated by a laser; femtosecond laser pulses; and different types of lasers. Additional topics deepen the understanding of more specific questions concerning, in particular: origin of gain in a titanium–sapphire laser; optical frequency analyzer; theory of gain of radiation in doped glass fibers.

It seems that an important type of laser — the free-electron laser — does not meet the criteria of a laser: classical physics is well suited to analyze operation a free-electron laser. I will, nevertheless, illustrate operation of a free-electron laser by use of an energy-level description. An active medium of a free-electron laser consists of oscillating free electrons. I attribute, to an oscillating free electron, an energy-ladder system. In this description, population inversion occurs in an ensemble of

energy-ladder systems; the concept is known for a particular semiconductor laser — the superlattice Bloch laser (also called Bloch oscillator) — that exists, however, only as an idea based on theoretical work. The energy-level description illustrates similarities of free-electron lasers and conventional lasers as well as differences between them.

A chapter comparing laser oscillators and quasiclassical solid state oscillators provides a connection to textbooks covering the field of microwave oscillators; additionally, the van der Pol oscillator is introduced as a model of a classical oscillator. In contrast to a laser, with a population inversion in an ensemble of quantum systems, a quasiclassical oscillator operates without population inversion: radiation in an active medium interacts with collectives of electrons — the interaction is determined by classical physics but the ability to form appropriate collectives of electrons is of quantum mechanical nature.

A reader may skip, in a first study, several chapters or sections that serve for deepening: Chap. 9 (dynamics of the active medium); Sect. 11.7 (Gouy phase); Sects. 12.9, 12.10, 13.3–13.9 (laser applications); Chap. 17 (physical basis of broadband solid state lasers); Chap. 18 (theory of fiber lasers and amplifiers); Sects. 19.5–19.12 (energy-level description of the free-electron laser); Chap. 21 (theory of semiconductor lasers); Sects. 25.8–25.15 (theory of electromagnetic waves in layered materials); Chap. 26 (discussing quantum well lasers in detail); Chap. 30 (theory of electron waves in semiconductor heterostructures); Chap. 31 (comparing lasers with quasiclassical oscillators); Chap. 32 (Bloch laser); Chaps. 33–35 (laser-related topics). Deepening of topics related to solid state physics (including semiconductor physics) corresponds to my experience in research in solid state spectroscopy. Several other textbooks deepen the discussion of lasers more toward atomic physics or quantum mechanics.

Text illustrations, examples, and exercises should allow a student to follow the main line but also single arguments.

I would like to thank the students who attended my “Laser Physics” course for asking questions about a first manuscript. I thank Alfons Penzkofer for examining a large portion of the manuscript and suggesting many improvements. I am indebted to Al Sievers for very helpful advice with respect to manuscript and exercises. I appreciate many valuable comments from Laurence Eaves, Max Maier, Peter Renk, Jens Siewert, Benjamin Stahl, Herbert Welling, and Ernst Werner. I thank Rupert Huber, Joachim Keller, Tobias Korn, John Lupton, Christoph Strunk, Werner Wegscheider for discussions, and Peter Olbrich for advice on electronic data processing. Ulla Turba has drawn a large part of the figures and has written a large part of the manuscript. I am very grateful for her engagement during preparation of various versions of the manuscript and for allowing me to permanently change text, formula, and drawings. I am indebted to Claus Ascheron for his encouragement to write a book.

Contents

Part I General Description of a Laser and an Example

1	Introduction	3
1.1	Laser and Light Bulb	3
1.2	Spectral Ranges of Lasers and List of a Few Lasers	4
1.3	Laser Safety	6
1.4	Sizes of Lasers, Cost of Lasers, and Laser Market	6
1.5	Questions About the Laser	8
1.6	Different Types of Lasers in the Same Spectral Range	9
1.7	Concept of the Book	9
1.8	References	11
1.9	A Remark about the History of the Laser	11
	Problems	14
2	Laser Principle	17
2.1	A Laser	18
2.2	Coherent Electromagnetic Wave	18
2.3	An Active Medium	22
2.4	Laser Resonator	26
2.5	Laser = Laser Oscillator	31
2.6	Radiation Feedback and Threshold Condition	32
2.7	Frequency of Laser Oscillation	34
2.8	Data of Lasers	35
2.9	Oscillation Onset Time	38
	Problems	39
3	Fabry–Perot Resonator	43
3.1	Laser Resonators and Laser Mirrors	43
3.2	V Factor and Related Quantities	45
3.3	Number of Photons in a Resonator Mode	46
3.4	Ideal Mirror	47
3.5	Fabry–Perot Interferometer	48

3.6	Resonance Curve of a Fabry–Perot Resonator	50
3.7	Fabry–Perot Resonator Containing a Gain Medium	52
	Problems	53
4	The Active Medium: Energy Levels and Lineshape Functions	55
4.1	Two-Level Based and Energy-Ladder Based Lasers	56
4.2	Four-Level, Three-Level, and Two-Level Lasers	57
4.3	Two-Band Laser and Quasiband Laser	59
4.4	Energy-Ladder Based Laser	61
4.5	Lineshape: Homogeneous and Inhomogeneous Line Broadening	61
4.6	Lorentz Functions	63
4.7	Gaussian Lineshape Function	66
4.8	Experimental Linewidths	67
4.9	Classical Oscillator Model of an Atom	68
4.10	Natural Line Broadening	70
4.11	Energy and Phase Relaxation	70
4.12	Three-Dimensional and Low-Dimensional Active Media	71
	Problems	72
5	Titanium–Sapphire Laser	75
5.1	Principle of the Titanium–Sapphire Laser	75
5.2	Design of a Titanium–Sapphire Laser	77
5.3	Absorption and Fluorescence Spectra of Titanium–Sapphire.....	78
5.4	Population of the Upper Laser Level.....	79
5.5	Heat and Phonons	80
	Problems	80
Part II Theoretical Basis of the Laser		
6	Basis of the Theory of the Laser: The Einstein Coefficients	83
6.1	Light and Atoms in a Cavity	83
6.2	Spontaneous Emission	85
6.3	Absorption	86
6.4	Stimulated Emission	86
6.5	The Einstein Relations	86
6.6	Einstein Coefficients on the Energy Scale	89
6.7	Stimulated Versus Spontaneous Emission	90
6.8	Determination of Einstein Coefficients from Wave Functions.....	92
	Problems	93
7	Amplification of Coherent Radiation	95
7.1	Interaction of Monochromatic Radiation with an Ensemble of Two-Level Systems	96
7.2	Growth and Gain Coefficient	98
7.3	Gain Cross Section.....	101

7.4	An Effective Gain Cross Section	103
7.5	Gain Coefficients	105
7.6	Gain Coefficient of Titanium–Sapphire	107
7.7	Gain Coefficient of a Medium with an Inhomogeneously Broadened Line	109
7.8	Gain Characteristic of a Two-Dimensional Medium	109
7.9	Gain of Light Crossing a Two-Dimensional Medium	111
	Problems	112
8	A Laser Theory	117
8.1	Rate Equations	117
8.2	Steady State Oscillation of a Laser	119
8.3	Balance Between Production and Loss of Photons	121
8.4	Onset of Laser Oscillation	122
8.5	Clamping of the Population Difference	124
8.6	Optimum Output Coupling	125
8.7	Two Laser Equations	127
8.8	Relaxation Oscillation	129
8.9	Laser Linewidth	131
	Problems	133
9	Driving a Laser Oscillation	135
9.1	Maxwell’s Equations	136
9.2	Possibilities of Driving a Laser Oscillation	140
9.3	Polarization of an Atomic Medium	140
9.4	Quantum Mechanical Expression for the Susceptibility of an Atomic Medium	143
9.5	Polarization of an Active Medium	147
9.6	Polarization Current	149
9.7	Laser Oscillation Driven by a Polarization	151
9.8	Laser Equations	160
9.9	Kramers–Kronig Relations	164
9.10	Another Remark about the History of the Laser	165
	Problems	168

Part III Operation of a Laser

10	Cavity Resonator	173
10.1	Cavity Resonators in Various Areas	173
10.2	Modes of a Cavity Resonator	174
10.3	Modes of a Long Cavity Resonator	177
10.4	Density of Modes of a Cavity Resonator	179
10.5	Fresnel Number	181
10.6	TE Waves and TM Waves	182
10.7	Quasioptical Arrangement	183
	Problems	183

11 Gaussian Waves and Open Resonators	187
11.1 Open Resonator	188
11.2 Helmholtz Equation.....	190
11.3 Gaussian Wave	192
11.4 Confocal Resonator	199
11.5 Stability of a Field in a Resonator.....	202
11.6 Transverse Modes.....	206
11.7 The Gouy Phase.....	210
11.8 Diffraction Loss.....	215
11.9 Ray Optics.....	217
Problems	222
12 Different Ways of Operating a Laser	225
12.1 Possibilities of Operating a Laser	225
12.2 Operation of a Laser on Longitudinal Modes	226
12.3 Single Mode Laser	226
12.4 Tunable Laser	227
12.5 Spectral Hole Burning in Lasers Using Inhomogeneously Broadened Transitions	228
12.6 Q-Switched Lasers	229
12.7 Longitudinal and Transverse Pumping	231
12.8 An Application of CW Lasers: The Optical Tweezers	231
12.9 Another Application: Gravitational Wave Detector	233
Problems	234
13 Femtosecond Laser	235
13.1 Mode Locking.....	236
13.2 Active and Passive Mode Locking	241
13.3 Optical Frequency Comb	243
13.4 Optical Correlator	248
13.5 Pump-Probe Method.....	249
13.6 Femtosecond Pulses in Chemistry	250
13.7 Optical Frequency Analyzer.....	251
13.8 Terahertz Time Domain Spectroscopy	252
13.9 Attosecond Pulses.....	254
Problems	254

Part IV Types of Lasers (Except Semiconductor Lasers)

14 Gas Lasers	259
14.1 Doppler Broadening of Spectral Lines.....	259
14.2 Collision Broadening	261
14.3 Helium–Neon Laser	262
14.4 Metal Vapor Laser	265
14.5 Argon Ion Laser.....	266
14.6 Excimer Laser.....	267

14.7	Nitrogen Laser	268
14.8	CO ₂ Laser	269
14.9	Other Gas Discharge Lasers and Optically Pumped Far Infrared Lasers	272
	Problems	274
15	Solid State Lasers	279
15.1	Ruby Laser	279
15.2	More about the Titanium–Sapphire Laser	280
15.3	Other Broadband Solid State Lasers	283
15.4	YAG Lasers	284
15.5	Different Neodymium Lasers	286
15.6	Disk Lasers	286
15.7	Fiber Lasers	287
15.8	A Short Survey of Solid State Lasers and Impurity Ions in Solids	290
15.9	Broadening of Transitions in Impurity Ions in Solids	294
	Problems	295
16	Some Other Lasers and Laser Amplifiers	297
16.1	Dye Laser	297
16.2	Solid State and Thin-Film Dye Laser	299
16.3	Chemical Laser	299
16.4	X-Ray Laser	300
16.5	Random Laser	301
16.6	Optically Pumped Organic Lasers	301
16.7	Laser Tandem	301
16.8	High-Power Laser Amplifier	301
16.9	Fiber Amplifier	302
16.10	Optical Damage	302
16.11	Gain Units	303
	Problems	303
17	Vibronic Medium	305
17.1	Model of a Vibronic System	305
17.2	Gain Coefficient of a Vibronic Medium	307
17.3	Frequency Modulation of a Two-Level System	309
17.4	Vibronic Sideband as a Homogeneously Broadened Line	311
	Problems	312
18	Amplification of Radiation in a Doped Glass Fiber	313
18.1	Survey of the Erbium-Doped Fiber Amplifier	314
18.2	Energy Levels of Erbium Ions in Glass and Quasiband Model	315
18.3	Quasi-Fermi Energy of a Gas of Excited-Impurity Quasiparticles	319

18.4	Condition of Gain of Light Propagating in a Fiber	321
18.5	Energy Level Broadening.....	322
18.6	Calculation of the Gain Coefficient of a Doped Fiber.....	324
18.7	Different Effective Gain Cross Sections	327
18.8	Absorption and Fluorescence Spectra of an Erbium-Doped Fiber.....	328
18.9	Experimental Studies and Models of Doped Fiber Media	330
	Problems	331
19	Free-Electron Laser	333
19.1	Principle of the Free-Electron Laser	334
19.2	Free-Electron Laser Arrangements.....	337
19.3	Frequency of Free-Electron Oscillations	339
19.4	Free-Electron Laser Theory	343
19.5	Data of a Free-Electron Laser	345
19.6	High Frequency Transverse Polarization and Current	347
19.7	Free-Electron Oscillations	349
19.8	Saturation Field of a Free-Electron Laser.....	353
19.9	Optical Constants of a Free-Electron Laser Medium	356
19.10	Bunching of Electrons in a Free-Electron Laser.....	357
19.11	Energy-Level Description of a Free-Electron Laser Medium.....	360
19.12	Comparison of a Free-Electron Laser with a Conventional Laser	365
19.13	A Remark about the History of the Free-Electron Laser.....	366
	Problems	366

Part V Semiconductor Lasers

20	An Introduction to Semiconductor Lasers	371
20.1	Energy Bands of Semiconductors	372
20.2	Low-Dimensional Semiconductors	374
20.3	An Estimate of the Transparency Density	375
20.4	Bipolar and Unipolar Semiconductor Lasers	376
20.5	Edge-Emitting Bipolar Semiconductor Laser	377
20.6	Survey of Topics Concerning Semiconductor Lasers	378
20.7	Frequency Ranges of Semiconductor Lasers	380
20.8	Energy Band Engineering	381
20.9	Differences Between Semiconductor Lasers and Other Lasers	381
	Problems	382
21	Basis of a Bipolar Semiconductor Laser	383
21.1	Principle of a Bipolar Semiconductor Laser.....	384
21.2	Condition of Gain of Radiation in a Bipolar Semiconductor	385

21.3	Energy Level Broadening.....	389
21.4	Reduced Density of States.....	390
21.5	Growth Coefficient and Gain Coefficient of a Bipolar Medium.....	392
21.6	Spontaneous Emission.....	395
21.7	Laser Equations of a Bipolar Semiconductor Laser.....	396
21.8	Gain Mediated by a Quantum Well.....	399
21.9	Laser Equations of a Quantum Well Laser.....	404
21.10	What is Meant by “Bipolar”?.....	406
	Problems.....	408
22	GaAs Quantum Well Laser.....	411
22.1	GaAs Quantum Well.....	412
22.2	An Active Quantum Well.....	413
22.3	GaAs Quantum Well Laser.....	420
22.4	Threshold Current of a GaAs Quantum Well Laser.....	422
22.5	Multi-Quantum Well Laser.....	424
22.6	High-Power Semiconductor Laser.....	424
22.7	Vertical-Cavity Surface-Emitting Laser.....	425
22.8	Polarization of Radiation of a Quantum Well Laser.....	427
22.9	Luminescence Radiation from a Quantum Well.....	427
	Problems.....	428
23	Semiconductor Materials and Heterostructures.....	429
23.1	Group III–V and Group II–VI Semiconductors.....	429
23.2	GaAlAs Mixed Crystal.....	431
23.3	GaAs Crystal and Monolayer.....	431
23.4	GaAs/GaAlAs Heterostructure.....	432
23.5	Preparation of Heterostructures.....	433
23.6	Preparation of Laser Diodes.....	434
23.7	Material Limitations.....	434
23.8	Energy Bands and Absorption Coefficients of GaAs and AlAs.....	434
	Problems.....	436
24	Quantum Well Lasers from the UV to the Infrared.....	439
24.1	A Survey.....	439
24.2	Red and Infrared Laser Diodes.....	439
24.3	Blue and UV Laser Diodes.....	441
24.4	Group II–VI Materials of Green Lasers.....	442
24.5	Applications of Semiconductor Lasers.....	443
	Problems.....	444
25	Reflectors of Quantum Well Lasers and of Other Lasers.....	445
25.1	Plane Surface.....	445
25.2	Coated Surface.....	446
25.3	External Reflector.....	446
25.4	Distributed Feedback Reflector.....	447

25.5	Distributed Bragg Reflector	447
25.6	Total Reflector	447
25.7	Bragg Reflector	448
25.8	Photonic Crystal	448
25.9	Photonic Crystal Fiber	450
25.10	Remark About Photonic Crystals	451
25.11	Plane-Wave Transfer Matrix Method Characterizing an Optical Interface	451
25.12	Thin Film Between Two Media	452
25.13	Dielectric Multilayer	453
25.14	One-Dimensional Photonic Crystal	454
25.15	Bragg Reflection as Origin of Energy Gaps	459
	Problems	460
26	More About the Quantum Well Laser	463
26.1	Electron Subbands	463
26.2	Hole Subbands	466
26.3	Modification of the Gain Characteristic by Light Holes	468
26.4	Gap Energy of a Quantum Well	468
26.5	Temperature Dependence of the Threshold Current Density of a GaAs Quantum Well Laser	469
26.6	Gain Mediated by a Quantum Well of Inhomogeneous Well Thickness	469
26.7	Tunability of a Quantum Well Laser	470
26.8	Anisotropy of a Quantum Well	470
	Problems	470
27	Quantum Wire and Quantum Dot Laser	471
27.1	Quantum Wire Laser	471
27.2	Quantum Wire	472
27.3	Gain Mediated by a Quantum Wire	475
27.4	Multi-Quantum Wire Laser	476
27.5	Quantum Dot	478
27.6	Quantum Dot Laser	479
27.7	One-Quantum Dot Laser	480
	Problems	482
28	A Comparison of Semiconductor Lasers	483
28.1	Gain of Radiation in a Bulk Semiconductor	484
28.2	Double-Heterostructure Laser	486
28.3	GaAs Junction Laser	487
28.4	Junction Lasers in the Infrared	488
28.5	Bipolar Semiconductor Lasers: A Comparison	488
28.6	Development of Semiconductor Lasers	490
28.7	Terahertz Gap	492
	Problems	493

29	Quantum Cascade Laser	495
29.1	Principle of the Quantum Cascade Laser	496
29.2	Infrared Quantum Cascade Laser	497
29.3	Semiconductor Superlattice and Minibands	498
29.4	Transport in a Superlattice	499
29.5	Far Infrared Quantum Cascade Laser	499
	Problems	500
30	Electron Waves in Semiconductor Heterostructures	501
30.1	Electron in a One-Dimensional Square Well Potential	501
30.2	Energy Bands of Electrons in a Periodic Square Well Potential	504
30.3	Plane-Wave Transfer Matrix Method Characterizing a Semiconductor Interface	507
30.4	Minibands	509
30.5	Quantum Well	512
30.6	Double-Quantum Well	512
	Problems	512
31	A Comparison of Laser Oscillators and Quasiclassical Solid State Oscillators	515
31.1	Interaction of Radiation with an Active Medium of a Laser or a Quasiclassical Oscillator	516
31.2	Solid State Oscillators	517
31.3	Semiconductor Superlattice Oscillator	518
31.4	Model of a Solid State Oscillator	520
31.5	Dynamics of Gain Mediated by a Semiconductor Superlattice	524
31.6	Balance of Energy in a Superlattice Oscillator	529
31.7	Resonant-Tunneling Diode Oscillator	531
31.8	Van der Pol Oscillator	532
	Problems	536
32	Superlattice Bloch Laser: A Challenge	539
32.1	Principle of a Superlattice Bloch Laser	540
32.2	Bloch Oscillation	542
32.3	Esaki–Tsu Characteristic	546
32.4	Bloch Gain	548
32.5	Saturation Field of a Bloch Laser	553
32.6	Synchronization of Bloch Oscillations to a High Frequency Field	554
32.7	Energy-Level Description of the Superlattice Bloch Laser	556
32.8	Possible Arrangements of a Bloch Laser	560
32.9	References to the Bloch Laser and Discussion	560
	Problems	562

Part VI Laser Related Topics

33	Optical Communications	567
33.1	Principle of Optical Communications.....	567
33.2	Glass Fiber	568
33.3	Pulse Distortion due to Dispersion.....	569
33.4	Erbium-Doped Fiber Amplifier	570
33.5	Detector	571
33.6	Transfer Rates	571
	Problems	572
34	Light Emitting Diode and Organic Laser	573
34.1	LED Preparation and Market.....	573
34.2	Illumination	574
34.3	Organic LED	575
34.4	Organic and Polymer Lasers	577
	Problems	578
35	Nonlinear Optics	579
35.1	Optics and Nonlinear Optics	579
35.2	Origin of Nonlinear Polarization	580
35.3	Optical Frequency Doubler.....	581
35.4	Difference Frequency Generator	582
35.5	Optical Parametric Oscillator.....	583
35.6	Third-Order Polarization	584
35.7	Four-Wave Mixing and Optical Frequency Analyzer	585
35.8	Stimulated Raman Scattering.....	587
	Problems	587
	Solutions to Selected Problems	589
	References	601
	Index	611