

Semiconductor Lasers

Stability, Instability and Chaos

Bearbeitet von
Junji Ohtsubo

2nd, enlarged ed. Softcover version of original hardcover edition 2008 2010. Taschenbuch. xviii, 475 S.
Paperback

ISBN 978 3 642 09170 4

Format (B x L): 15,5 x 23,5 cm

Gewicht: 753 g

Weitere Fachgebiete > Physik, Astronomie > Elektrodynamik, Optik > Halbleiter- und
Supraleiterphysik

Zu [Leseprobe](#)

schnell und portofrei erhältlich bei

The logo for beck-shop.de features the text "beck-shop.de" in a bold, red, sans-serif font. Above the "i" in "shop" are three red dots of increasing size. Below the main text, the words "DIE FACHBUCHHANDLUNG" are written in a smaller, red, all-caps, sans-serif font.

beck-shop.de
DIE FACHBUCHHANDLUNG

Die Online-Fachbuchhandlung beck-shop.de ist spezialisiert auf Fachbücher, insbesondere Recht, Steuern und Wirtschaft. Im Sortiment finden Sie alle Medien (Bücher, Zeitschriften, CDs, eBooks, etc.) aller Verlage. Ergänzt wird das Programm durch Services wie Neuerscheinungsdienst oder Zusammenstellungen von Büchern zu Sonderpreisen. Der Shop führt mehr als 8 Millionen Produkte.

Contents

1	Introduction	1
1.1	Chaos and Lasers	1
1.2	Historical Perspectives of Chaos in Semiconductor Lasers	3
1.3	Outline of This Book	6
2	Chaos in Laser Systems	11
2.1	Laser Model and Bloch Equations	11
2.1.1	Laser Model in a Ring Resonator	11
2.1.2	Light Emission and Absorption in Two-Level Atoms	13
2.1.3	Maxwell-Bloch Equations	14
2.2	Lorenz-Haken Equations	15
2.2.1	Lorenz-Haken Equations	15
2.2.2	First Laser Threshold	16
2.2.3	Second Laser Threshold	18
2.3	Classifications of Lasers	20
2.3.1	Classes of Lasers	20
2.3.2	Class C Lasers	20
2.3.3	Class B Lasers	23
2.3.4	Class A Lasers	24
3	Semiconductor Lasers and Theory	25
3.1	Semiconductor Lasers	25
3.2	Oscillation Conditions of Semiconductor Lasers	26
3.2.1	Laser Oscillation Conditions	26
3.2.2	Laser Oscillation Frequency	28
3.2.3	Dependence of Oscillation Frequency on Carrier Density	29
3.3	Derivation of Rate Equations	29
3.3.1	Gain at Laser Oscillation	29
3.3.2	Rate Equation for the Field	30
3.3.3	Linewidth Enhancement Factor	32
3.3.4	Laser Rate Equations	33

3.4	Linear Stability Analysis and Relaxation Oscillation	37
3.4.1	Linear Stability Analysis	37
3.4.2	Relaxation Oscillation	38
3.5	Langevin Noises	40
3.5.1	Rate Equations Including Langevin Noises	40
3.5.2	Langevin Noises	41
3.5.3	Noise Spectrum	43
3.5.4	Relative Intensity Noise (RIN)	43
3.5.5	Phase Noise and Spectral Linewidth	44
3.6	Modulation Characteristics	47
3.6.1	Injection Current Modulation	47
3.6.2	Intensity Modulation Characteristics	48
3.6.3	Phase Modulation Characteristics	50
3.7	Waveguide Models of Semiconductor Lasers	51
3.7.1	Index- and Gain-Guided Structures	51
3.7.2	Waveguide Models	53
3.7.3	Spatial Modes of Gain- and Index-Guided Lasers . . .	54
3.7.4	Effects of Spontaneous Emission in Gain- and Index-Guided Lasers	56
3.7.5	Laser Types	58
4	Theory of Optical Feedback in Semiconductor Lasers	63
4.1	Theory of Optical Feedback	63
4.1.1	Optical Feedback Effects and Classifications of Optical Feedback Phenomena	63
4.1.2	Theoretical Model	66
4.2	Linear Stability Analysis for Optical Feedback Systems	68
4.2.1	Linear Stability Analysis	68
4.2.2	Linear Mode, and Stability and Instability in Semiconductor Lasers	73
4.2.3	Gain Reduction Due to Optical Feedback	75
4.2.4	Linewidth in the Presence of Optical Feedback	76
4.3	Feedback from a Grating Mirror	77
4.4	Phase-Conjugate Feedback	79
4.5	Incoherent Feedback and Polarization-Rotated Optical Feedback	82
4.5.1	Incoherent Feedback	82
4.5.2	Polarization-Rotated Optical Feedback	83
4.6	Filtered Feedback	85
5	Dynamics of Semiconductor Lasers with Optical Feedback	87
5.1	Optical Feedback from a Conventional Reflector	87
5.1.1	Optical Feedback Effects	87
5.1.2	Potential Model in Feedback Induced Instability	88

5.1.3	Optical Spectrum in Stable and Unstable Feedback Regimes	90
5.1.4	Chaos in Semiconductor Lasers with Optical Feedback	93
5.1.5	Chaotic Bifurcations	95
5.1.6	Dynamics for Injection Current Variations	96
5.2	Dependence of Chaotic Dynamics on the External Mirror Position	101
5.2.1	Periodic Stability Enhancement for Variations of the External Cavity Length	101
5.2.2	Origin of Periodic Stability Enhancement	103
5.2.3	Effects of Linewidth Enhancement Factor	105
5.2.4	Sensitivity of the Optical Phase	107
5.2.5	Chaotic Dynamics for a Small Change of the External Cavity Length	109
5.3	Low-Frequency Fluctuations (LFFs)	112
5.3.1	Low-Frequency Fluctuation Phenomena	112
5.3.2	LFF Characteristics	115
5.3.3	Origin of LFFs	117
5.4	Chaotic Dynamics in Short External Cavity Limit	120
5.4.1	Stable and Unstable Conditions in Short External Cavity	120
5.4.2	Regular Pulse Package Oscillations in Short External Cavity	122
5.4.3	Bifurcations of Regular Pulse Package	124
5.5	Dynamics in Semiconductor Lasers with Grating Mirror Feedback	126
5.6	Dynamics in Semiconductor Lasers with Phase-Conjugate Mirror Feedback	129
5.6.1	Linear Stability Analysis	129
5.6.2	Dynamics Induced by Phase-Conjugate Feedback ...	131
5.6.3	Dynamics in the Presence of Frequency Detuning ...	132
5.6.4	Finite and Slow Response Phase-Conjugate Feedback	132
5.7	Dynamics of Semiconductor Lasers with Incoherent Optical Feedback	134
5.7.1	Dynamics of Incoherent Optical Feedback	134
5.7.2	Dynamics of Polarization-Rotated Optical Feedback .	138
5.8	Dynamics of Filtered Optical Feedback	140
5.8.1	Filtered Optical Feedback	140
5.8.2	External Cavity Modes	142
5.8.3	Frequency Oscillations and Chaotic Dynamics	144
6	Dynamics in Semiconductor Lasers with Optical Injection	147
6.1	Optical Injection	147
6.1.1	Optical Injection Locking	147

6.1.2	Injection Locking Condition	150
6.2	Stability and Instability in Optical Injection Systems	152
6.2.1	Rate Equations	152
6.2.2	Chaotic Bifurcations by Optical Injection	153
6.2.3	Chaos Map in the Phase Space of Frequency Detuning and Injection	157
6.2.4	Coexistence of Chaotic Attractors in Optically Injected Semiconductor Lasers	161
6.3	Enhancement of Modulation Bandwidth and Generation of High Frequency Chaotic Oscillation by Strong Optical Injection	164
6.3.1	Enhancement of Modulation Bandwidth by Strong Optical Injection	164
6.3.2	Origin of Modulation Bandwidth Enhancement	168
6.3.3	Modulation Response by Strong Optical Injection	170
6.3.4	Suppression of Frequency Chirping by Strong Optical Injection	172
6.3.5	Generation of High Frequency Chaotic Oscillation by Strong Optical Injection	174
7	Dynamics of Semiconductor Lasers with Optoelectronic Feedback and Modulation	177
7.1	Theory of Optoelectronic Feedback	177
7.1.1	Optoelectronic Feedback Systems	177
7.1.2	Pulsation Oscillations in Optoelectronic Feedback Systems	179
7.2	Linear Stability Analysis for Optoelectronic Feedback Systems	182
7.2.1	Linear Stability Analysis	182
7.2.2	Characteristics of Semiconductor Lasers with Optoelectronic Feedback	185
7.3	Dynamics and Chaos in Semiconductor Lasers with Optoelectronic Feedback	187
7.3.1	Chaotic Dynamics in Negative Optoelectronic Feedback	187
7.3.2	Chaotic Dynamics in Positive Optoelectronic Feedback	189
7.4	Optoelectronic Feedback with Wavelength Filter	193
7.4.1	System of Optoelectronic Feedback with Wavelength Filter	193
7.4.2	Dynamics of Optoelectronic Feedback with Wavelength Filter	195
7.5	Chaotic Dynamics of Semiconductor Lasers Induced by Injection Current Modulation	198
7.5.1	Instabilities of a Modulated Semiconductor Laser	198

7.5.2	Linear Stability Analysis	200
7.5.3	Chaotic Dynamics in Modulated Semiconductor Lasers	204
7.6	Nonlinear Dynamics of Various Combinations of External Perturbations	206
7.6.1	Optically Injected Semiconductor Laser Subject to Optoelectronic Feedback	206
7.6.2	Semiconductor Lasers with Optical Feedback and Modulation	209
8	Instability and Chaos in Various Laser Structures	213
8.1	Multimode Lasers	213
8.1.1	Multimode Operation of Semiconductor Lasers	213
8.1.2	Theoretical Model of Multimode Lasers	214
8.1.3	Dynamics of Multimode Semiconductor Lasers with Optical Feedback	217
8.2	Self-Pulsating Lasers	220
8.2.1	Theory of Self-Pulsating Lasers	220
8.2.2	Instabilities at Solitary Oscillations	223
8.2.3	Instability and Chaos by Optical Feedback	227
8.2.4	Instability and Chaos by Injection Current Modulation	230
8.3	Vertical-Cavity Surface-Emitting Lasers (VCSELs)	232
8.3.1	Theoretical Model of Vertical-Cavity Surface-Emitting Lasers	232
8.3.2	Spin-Flip Model	235
8.3.3	Characteristics of VCSELs in Solitary Oscillations	239
8.3.4	Spatio-Temporal Dynamics in VCSELs	242
8.3.5	Feedback Effects in VCSELs	245
8.3.6	Short Optical Feedback in VCSELs	250
8.3.7	Orthogonal Optical Injection Dynamics in VCSEL	252
8.4	Broad Area Lasers	255
8.4.1	Theoretical Model of Broad Area Lasers	255
8.4.2	Dynamics of Broad Area Semiconductor Lasers at Solitary Oscillations	258
8.4.3	Feedback Effects in Broad Area Semiconductor Lasers	264
8.5	Laser Arrays	266
9	Chaos Control and Applications	269
9.1	General Methods of Chaos Control	269
9.1.1	OGY Method	269

9.1.2	Continuous Control Method	270
9.1.3	Occasional Proportional Method	271
9.1.4	Sinusoidal Modulation Method	272
9.2	Chaos Control in Semiconductor Lasers	273
9.2.1	Continuous Control	273
9.2.2	Occasional Proportional Feedback Control	275
9.2.3	Sinusoidal Modulation Control	276
9.2.4	Optical Control	279
9.3	Controlling Chaos and Noise Suppression	282
9.3.1	Noise Suppression by Sinusoidal Modulation	282
9.3.2	Stability and Instability of LFFs by Injection Current Modulation	286
9.3.3	Chaos Targeting	288
10	Stabilization of Semiconductor Lasers	291
10.1	Linewidth Narrowing by Optical Feedback	291
10.1.1	Linewidth Narrowing by Strong Optical Feedback	291
10.1.2	Linewidth Narrowing by Grating Feedback	294
10.1.3	Linewidth Narrowing by Phase-Conjugate Optical Feedback	295
10.1.4	Linewidth Narrowing by Resonant Optical Feedback	299
10.2	Linewidth Narrowing by Optoelectronic Feedback	301
10.3	Stabilization in Lasers with Various Structures	304
10.3.1	Noise Suppression in Self-Pulsation Semiconductor Laser	304
10.3.2	Stabilization of VCSELs	305
10.3.3	Stabilization of Broad-Area Semiconductor Lasers	308
10.3.4	Stabilization of Laser Arrays	312
10.4	Controls in Nobel Structure Lasers	313
10.4.1	Photonic VCSELs	313
10.4.2	Quantum-Dot Broad-Area Semiconductor Lasers	315
11	Stability and Bistability in Feedback Interferometers, and Their Applications	319
11.1	Optical Feedback Interferometers	319
11.1.1	Bistability and Multistability in Feedback Interferometers	319
11.1.2	Interferometric Measurement in Self-Mixing Semiconductor Lasers	323
11.2	Applications in Feedback Interferometer	325
11.2.1	Displacement and Vibration Measurement	325
11.2.2	Velocity Measurement	328
11.2.3	Absolute Position Measurement	329
11.2.4	Angle Measurement	330

11.2.5	Measurement of Linewidth and Linewidth Enhancement Factor	332
11.3	Active Feedback Interferometer	334
11.3.1	Stability and Bistability in Active Feedback Interferometer	334
11.3.2	Chaos Control in Active Feedback Interferometers	338
12	Chaos Synchronization in Semiconductor Lasers	341
12.1	Concept of Chaos Synchronization	341
12.1.1	Chaos Synchronization	341
12.1.2	Generalized and Complete Chaos Synchronization...	344
12.2	Theory of Chaos Synchronization in Semiconductor Lasers with Optical Feedback.....	347
12.2.1	Model of Synchronization Systems	347
12.2.2	Rate Equations in Unidirectional Coupling Systems	349
12.2.3	Generalized Chaos Synchronization	350
12.2.4	Complete Chaos Synchronization	351
12.2.5	Mutual Coupling Systems.....	351
12.3	Chaos Synchronization in Semiconductor Lasers with an Optical Feedback System	353
12.3.1	Chaos Synchronization – Numerical Examples	353
12.3.2	Chaos Synchronization – Experimental Examples ...	357
12.3.3	Anticipating Chaos Synchronization	359
12.3.4	Bandwidth Enhanced Chaos Synchronization	360
12.3.5	Incoherent Synchronization Systems	362
12.3.6	Polarization Rotated Chaos Synchronization	364
12.4	Chaos Synchronization in Injected Lasers	367
12.4.1	Theory of Chaos Synchronization in Injected Lasers	367
12.4.2	Examples of Chaos Synchronization in Injected Lasers	369
12.5	Chaos Synchronization in Optoelectronic Feedback Systems	370
12.5.1	Theory of Chaos Synchronization in Optoelectronic Feedback Systems	370
12.5.2	Examples of Chaos Synchronization in Optoelectronic Feedback Systems	372
12.6	Chaos Synchronization in Injection Current Modulated Systems	373
12.7	Chaos Synchronization in Mutually Coupled Lasers	374
12.7.1	Chaos Synchronization of Semiconductor Lasers with Mutual Optical Coupling	374

12.7.2	Chaos Synchronization of Semiconductor Lasers with Mutual Optoelectronic Coupling	375
13	Chaotic Communications in Semiconductor Lasers	379
13.1	Message Encryption in a Chaotic Carrier and Its Decryption	379
13.1.1	Chaotic Communications	379
13.1.2	Chaos Masking	381
13.1.3	Chaos Modulation	383
13.1.4	Chaos Shift Keying	383
13.1.5	Chaotic Data Communications in Laser Systems	384
13.2	Cryptographic Applications in Optical Feedback Systems	385
13.2.1	Chaotic Communications in Optical Feedback Systems	385
13.2.2	Chaos Masking in Optical Feedback Systems	388
13.2.3	Chaos Modulation in Optical Feedback Systems	393
13.2.4	Chaos Shift Keying in Optical Feedback Systems	394
13.2.5	Chaotic Communications in Incoherent Optical Feedback Systems	396
13.2.6	Chaos Pass Filtering Effects	396
13.3	Cryptographic Applications in Optical Injection Systems	399
13.4	Cryptographic Applications in Optoelectronic Systems	401
13.5	Performance of Chaotic Communications	404
13.6	Security of Chaotic Communications	408
13.7	Chaotic Carrier and Bandwidth of Communications	410
13.8	Chaos Communications in the Real World	412
13.8.1	Chaos Masking Video Signal Transmissions	412
13.8.2	Chaotic Signal Transmissions through Public Data Link	414
A	Appendix: Chaos	419
A.1	Nonlinear Chaotic Systems	420
A.1.1	Discrete Systems	420
A.1.2	Continuous Systems	422
A.1.3	Delay Differential Systems	424
A.2	Analysis and Characteristic Descriptions for Chaotic Data	425
A.2.1	Phase Space, Attractor, and Poincaré Map	425
A.2.2	Steady State Behaviors	427
A.2.3	Fractal Dimension and Correlation Dimension	430
A.2.4	Lyapunov Exponent	431

A.3 Chaos Control 432

A.4 Chaos Synchronization 437

References 441

Index 469