

Contents

| | | |
|----------|---|----|
| 1 | Introduction | 1 |
| 1.1 | Light-Matter Interaction in Semiconductors | 1 |
| 1.2 | Semiconductor Lasers | 4 |
| 1.3 | Semiconductor Lasers as Dynamical Systems | 6 |
| 1.4 | Semiconductor Quantum-Dots | 7 |
| 1.5 | Outline of the Thesis | 9 |
| | References | 10 |
| 2 | Theory of Quantum-Dot Optical Devices | 13 |
| 2.1 | Introduction | 13 |
| 2.2 | Charge-Carrier Scattering in Quantum-Dot Structures | 14 |
| 2.2.1 | Coulomb-Scattering of Charge Carriers | 16 |
| 2.2.2 | Electron-Hole Picture | 20 |
| 2.2.3 | Detailed Balance | 21 |
| 2.2.4 | Carrier-Phonon Scattering | 23 |
| 2.3 | Light-Matter Interaction | 25 |
| 2.3.1 | Electric Field Dynamics | 26 |
| 2.3.2 | Maxwell–Bloch Equations | 29 |
| 2.4 | Quantum-Dot Laser Rate Equations | 32 |
| 2.4.1 | Maxwell–Bloch Laser Rate Equations | 32 |
| 2.4.2 | Adiabatically Eliminated Polarization | 37 |
| 2.4.3 | Modeling of Spontaneous Emission | 39 |
| 2.4.4 | Carrier-Induced Gain and Refractive Index Changes | 41 |
| 2.5 | Quantum-Dot Laser Carrier-Heating Model | 43 |
| 2.5.1 | Charge-Carrier Energy and Temperature | 43 |
| 2.5.2 | Carrier Heating by Auger-Scattering Processes | 45 |
| 2.5.3 | Energy Balance Equations | 46 |
| | References | 47 |

| | | |
|----------|--|-----------|
| 3 | Quantum-Dot Laser Dynamics | 53 |
| 3.1 | Introduction | 53 |
| 3.2 | Laser Dynamics—Relaxation Oscillations | 54 |
| 3.2.1 | Relaxation Oscillations in Two-Variable Laser Equations | 55 |
| 3.2.2 | Turn-On Dynamics of Quantum-Dot Lasers. | 58 |
| 3.2.3 | Influence of Charge-Carrier Scattering | 63 |
| 3.3 | Minimal Model for Quantum-Dot Laser Dynamics | 66 |
| 3.3.1 | Linearization and Eigenvalue Problem | 68 |
| 3.3.2 | Asymptotic Analysis—Relaxation Oscillations. | 71 |
| 3.4 | Modulation Response of Quantum-Dot Lasers | 76 |
| 3.4.1 | Small-Signal Response | 76 |
| 3.5 | Amplitude-Phase Coupling in Quantum-Dot Lasers | 82 |
| 3.5.1 | The Linewidth-Enhancement Factor α | 83 |
| 3.5.2 | Charge-Carrier-Induced Susceptibility in Quantum-Dot Lasers. | 84 |
| 3.6 | Dynamics Under Optical Injection | 89 |
| 3.6.1 | Quantum-Dot Laser Model with Optical Injection | 90 |
| 3.6.2 | Injection Locking of Quantum-Dot Lasers. | 92 |
| 3.6.3 | Dependence on the Quantum-Dot Structure and Pump-Current | 97 |
| 3.6.4 | Evaluation of the α -Factor from Optical Injection. | 101 |
| 3.6.5 | Comparison with α -Factor-Based Models | 104 |
| 3.7 | Optical Injection—Numerical Path Continuation. | 111 |
| 3.7.1 | Quantum-Dot Laser Model Simplification | 112 |
| 3.7.2 | Path Continuation Results | 117 |
| 3.7.3 | Dependencies on Scattering and Reservoir Loss Rates | 120 |
| 3.7.4 | Summary | 122 |
| 3.8 | Dynamics Under Optical Feedback | 123 |
| 3.8.1 | Quantum-Dot Laser Model with Optical Feedback | 123 |
| 3.8.2 | Quantum-Dot Laser Dynamics Under Optical Feedback | 125 |
| 3.9 | Small-Signal Frequency Response of Quantum-Dot Lasers | 131 |
| 3.9.1 | Evaluation of the Frequency and Amplitude Modulation Indices. | 131 |
| 3.9.2 | Numerical Evaluation of FM/AM Measurements | 132 |
| 3.9.3 | Influence of Scattering Rates and Reservoir Losses | 135 |
| 3.10 | Conclusion | 137 |
| | References | 139 |

| | |
|--|------------|
| 4 Quantum-Dot Optical Amplifiers | 147 |
| 4.1 Introduction | 147 |
| 4.2 Quantum-Dot Semiconductor Optical Amplifier Model | 148 |
| 4.2.1 Electric Field Propagation | 149 |
| 4.2.2 Quantum-Dot Material Equations | 150 |
| 4.2.3 Modeling of Spontaneous Emission | 152 |
| 4.3 Large-Signal Amplification in Quantum-Dot Amplifiers | 154 |
| 4.3.1 Calculation of Amplified Spontaneous Emission Spectra | 155 |
| 4.3.2 Gain Saturation | 159 |
| 4.3.3 Amplification of Optical Data Streams | 161 |
| 4.4 Multi-State Operation of Quantum-Dot Amplifiers | 164 |
| 4.5 Coherent Transients in Quantum-Dot Amplifiers | 169 |
| 4.5.1 Rabi-Oscillations in Quantum-Dot Semiconductor Amplifiers | 171 |
| 4.5.2 Comparison with Experimental Measurements | 175 |
| 4.6 Conclusion | 180 |
| References | 182 |
| 5 Summary and Outlook | 187 |
| Appendix A | 191 |

<http://www.springer.com/978-3-319-25803-4>

Nonlinear and Nonequilibrium Dynamics of
Quantum-Dot Optoelectronic Devices

Lingnau, B.

2015, XIII, 193 p. 88 illus., 25 illus. in color., Hardcover

ISBN: 978-3-319-25803-4