Contents

1. Introduction to Photonic Quantum Dot Nanomaterials and Devices 1

1.1 Physical Properties of Quantum Dots 1
1.2 Active Semiconductor Gain Media 2
1.3 Quantum Dot Lasers 4
1.3.1 Heterostructure lasers 4
1.3.2 Active nanomaterials 5
1.4 Laser Cavities 6
1.4.1 In-plane edge-emitting lasers 7
1.4.2 Vertical-cavity surface-emitting lasers 8
1.4.3 High-power laser amplifiers 9
1.4.4 Coupled-cavity systems 10
1.4.5 Optically excited nano systems 11
1.4.6 QD metastructures 11
References 12

2. Theory of Quantum Dot Light–Matter Dynamics 15

2.1 Rate Equations 19
2.2 Maxwell–Bloch Equations 24
2.2.1 Mesoscopic two-level approach 25
2.2.2 Mesoscopic Maxwell–Bloch description of multi-level quantum dot systems 29
2.2.2.1 Optical field dynamics 30

2.2.2.2 Carrier dynamics within a quantum dot 34
2.3 Quantum Luminescence Equations 38
2.4 Quantum Theoretical Description 42
References 43

3. Light Meets Matter I: Microscopic Carrier Effects and Fundamental Light–Matter Interaction 45
3.1 Dynamics in the Active Charge Carrier Plasma . . . 46
3.1.1 Intra-dot carrier scattering 47
3.1.2 Phonon induced carrier scattering between quantum dots and wetting layer 48
3.1.3 Auger scattering processes involving 0D and 2D carriers 49
3.1.4 Level and gain dynamics 51
3.1.5 Dynamics of carrier scattering rates 54
3.2 Dynamic Level Hole Burning 57
3.3 Ultrashort Nonlinear Gain and Index Dynamics . . . 62
3.4 Conclusion 69
References 69

4. Light Meets Matter II: Mesoscopic Space-Time Dynamics 71
4.1 Introduction: Transverse and Longitudinal Mode Dynamics 71
4.2 Influence of the Transverse Degree of Freedom and Nano-Structuring on Nearfield Dynamics and Spectra 72
4.3 Longitudinal Modes 77
4.4 Coupled Space-Time Dynamics in the Active Area 78
4.4.1 Influence of injection level and geometry . . 79
4.4.2 Influence of disorder: the spatially inhomogeneous quantum dot ensemble . . . 83

4.4.3 Light fluctuations and mode competition in quantum dot cavities 86
4.5 Conclusion 97
References 97

5. Performance and Characterisation: Properties on Large Time and Length Scales 101
5.1 Introduction 101
5.2 Spatial and Spectral Beam Quality 102
5.3 Dynamic Amplitude Phase Coupling 105
5.4 Conclusion 113
References 113

6. Nonlinear Pulse Propagation in Semiconductor Quantum Dot Lasers 115
6.1 Dynamic Shaping of Short Optical Pulses 116
6.2 Nonlinear Femtosecond Dynamics of Ultrashort Light Pulses 118
6.2.1 Self-induced propagation control: tunable propagation speed 118
6.2.2 Propagation control by a second pulse 123
6.3 Conclusion 125
References 125

7. High-Speed Dynamics 127
7.1 Mode-Locking in Multi-Section Quantum Dot Lasers 127
7.2 Dependence of Pulse Duration on Injection Current, Bias Voltage and Device Geometry 129
7.3 Radio Frequency Spectra of the Emitted Light . . . 132
7.4 Short-Pulse Optimisation 134
7.5 Conclusion 136
References 137

8. Quantum Dot Random Lasers 139

8.1 Spatially Inhomogeneous Semiconductor Quantum Dot Ensembles 139
8.1.1 Gain spectra 141
8.1.2 Spatial and spectral hole burning 142
8.2 Coherence Properties 145
8.3 Random Lasing in Semiconductor Quantum Dot Ensembles 150
8.3.1 The physics of random lasing 150
8.3.2 Lasers with strong disorder: incoherent feedback 152
8.3.3 Lasers with weak disorder: coherent feedback 155
8.4 Conclusion 157
References 157

9. Coherence Properties of Quantum Dot Micro-Cavity Lasers 159

9.1 Introduction 159
9.2 Radial Signal Propagation and Coherence Trapping 161
9.3 Influence of Disorder 168
9.4 Conclusions 170
References 170