

Contents

Part I Theory of Light-Matter Interaction

1	Theory of Quantum Light Sources and Cavity-QED Emitters Based on Semiconductor Quantum Dots	3
	Christopher Gies, Matthias Florian, Alexander Steinhoff and Frank Jahnke	
1.1	Introduction	3
1.1.1	QDs Coupled to the Quantized Light Field	4
1.1.2	Characterization of Light	6
1.2	Emission of Single and Few-QD Microcavity Systems	7
1.2.1	Single Photons from a Single and Few QDs in a Cavity	8
1.2.2	Lasing in the Presence of Strong Coupling in a Few-QD System	10
1.2.3	Cavity-Enhanced Emission of Entangled Photon Pairs	14
1.2.4	Single Photons from an Electrical Source with Long Pulses	16
1.3	Carrier Scattering and Dephasing	18
1.4	Non-resonant QD-cavity Coupling	23
1.4.1	Phonon-Assisted Non-resonant Coupling	23
1.4.2	Non-resonant Coupling Mediated by Multi-exciton Transitions	25
1.4.3	Coulomb-Assisted Non-resonant Coupling	27
1.5	Superradiant Emitter Coupling of Quantum Dots in Optical Resonators	29
1.6	Summary and Outlook	35
	References	35

2	Theory of Phonon Dressed Light-Matter Interactions and Resonance Fluorescence in Quantum Dot Cavity Systems	41
	Kaushik Roy-Choudhury and Stephen Hughes	
2.1	Introduction	41
2.2	General Theory for a Single QD Exciton with Exciton-Phonon and Exciton-Photon Interactions.	42
2.2.1	Polaron Master Equation for a QD Exciton in a General Photonic Reservoir	42
2.2.2	Spectrum Definitions	46
2.3	Phonon-Modified Spontaneous Emission and the Breakdown of Fermi's Golden Rule	49
2.3.1	Lorentzian Cavity	50
2.3.2	Slow-Light Coupled-Cavity Waveguide.	52
2.4	Independent Boson Model Lineshape with a Broadened Zero Phonon Line	53
2.5	Cavity-QED Polaron Master Equation: Vacuum Rabi Splitting and Cavity-Assisted Feeding.	54
2.5.1	Phonon Dressed Vacuum Rabi Splitting	58
2.5.2	Off-Resonant Cavity Feeding.	59
2.6	Coherent Driving and Nonlinear Excitation	61
2.6.1	Photoluminescence Lineshapes and Phonon-Mediated Population Inversion	63
2.6.2	Phonon-Dressed Mollow Triplets.	65
2.7	Conclusions and Outlook	70
	References.	71

Part II Excitons and Single Photon Emission

3	Resonantly Excited Quantum Dots: Superior Non-classical Light Sources for Quantum Information	77
	Simone Luca Portalupi and Peter Michler	
3.1	Introduction	77
3.2	Fundamental Optical Properties of Photons: Coherence, Purity, Indistinguishability and Entanglement.	79
3.3	Resonant QD Excitation Methods for Exciton and Biexciton	83
3.3.1	Sources of Decoherence.	83
3.3.2	CW-pumping Methods: Low, Medium and High Excitation Powers	89
3.3.3	Pulsed Resonant Pumping of the Exciton	96
3.3.4	Adiabatic Rapid Passage	102
3.3.5	Spin-Flip Raman Transition.	105
3.3.6	Two-Photon Excitation of the Biexciton	108
3.4	Phonon-Assisted Excitation Methods for Exciton and Biexciton	112

3.4.1	Phonon-Assisted Exciton Excitation	112
3.4.2	Phonon-Assisted Biexciton Excitation	114
3.5	Summary and Outlook	116
	References.	118
4	Coherent Control of Dark Excitons in Semiconductor Quantum Dots	123
	E.R. Schmidgall, I. Schwartz, D. Cogan, L. Gantz, Y. Don and D. Gershoni	
4.1	Bright and Dark Excitons in Quantum Dots	123
4.1.1	The Optical Activity and Oscillator Strength of the Dark Exciton	126
4.2	The Dark Exciton as a Spin Qubit	127
4.3	Experimental Techniques	129
4.3.1	Sample Structure	129
4.3.2	Experimental System	130
4.3.3	Measurement Techniques.	132
4.4	Probing the Dark Exciton State.	134
4.4.1	Optical Observations of the Dark Exciton	134
4.4.2	The Spin-Blockaded Biexciton	135
4.4.3	Probing by Charge Tunneling	137
4.4.4	Probing by Resonant Absorption.	139
4.5	On-Demand Optical Writing of the Dark Exciton Spin State	140
4.5.1	On-Demand Generation Using Resonant Excitation	140
4.5.2	Coherent On-Demand Generation Using Quasiresonant Excitation	142
4.5.3	The Dark Exciton Lifetime	146
4.5.4	The Dark Exciton Coherence Time	147
4.6	Coherent Control of the Dark Exciton Spin State	148
4.7	Controlling the Dark Exciton Eigenstates Using an External Magnetic Field	152
4.8	Optical Reset of the Dark Exciton	156
4.9	Outlook.	160
	References.	161
5	The Mesoscopic Nature of Quantum Dots in Photon Emission	165
	P. Tighineanu, A.S. Sørensen, S. Stobbe and P. Lodahl	
5.1	Fundamentals of Light-Matter Interaction with Quantum Dots.	167
5.1.1	Effective-Mass Theory	167
5.1.2	Excitons.	168
5.1.3	Spontaneous Emission	169

5.1.4	The Dipole Approximation: Oscillator Strength and Density of Optical States	170
5.1.5	Decay Dynamics of Quantum Dots	172
5.2	Light-Matter Interaction Beyond the Dipole Approximation with In(Ga)As Quantum Dots	173
5.2.1	Theory of Light-Matter Interaction Beyond the Dipole Approximation	175
5.2.2	Microscopic Model for Mesoscopic Quantum Dots	179
5.2.3	The Quantum Current Density of Quantum Dots	182
5.2.4	Lattice-Distortion Effects Beyond the Multipolar Theory	183
5.2.5	Quantum Dots as Probes for the Magnetic Field of Light	184
5.3	Single-Photon Superradiance from a Monolayer-Fluctuation Quantum Dot	186
5.3.1	Extending the Concept of Superradiance from Atomic Physics to Solid-State Emitters	186
5.3.2	Deterministic Preparation and Impact of Nonradiative Processes	189
5.3.3	Demonstration of Single-Photon Superradiance	190
5.3.4	Impact of Thermal Effects on Single-Photon Superradiance	192
5.4	Conclusion and Outlook	195
	References	196
6	Single-Photon Sources Based on Deterministic Quantum-Dot Microlenses	199
	T. Heindel, S. Rodt and S. Reitzenstein	
6.1	Introduction	199
6.2	Light Extraction Strategies	201
6.2.1	Micropillar Cavities	202
6.2.2	Photonic Nanowires	203
6.2.3	Microlenses	203
6.3	Numerical Optimization of Photon Extraction Efficiency of Quantum Dot Microlenses	204
6.4	Deterministic Nanophotonic Device Technologies	208
6.5	Fabrication of Deterministic Single Quantum Dot Microlenses	209
6.6	Optical and Quantum Optical Properties of Deterministic Quantum Dot Microlenses	213
6.6.1	High Device Yield and High Photon Extraction Efficiency	213

6.6.2	Single-Photon Emission	215
6.6.3	Generation of Indistinguishable Photons	217
6.6.4	Time- and Temperature Dependent Hong-Ou-Mandel Interferometry	219
6.7	Conclusions and Future Perspectives	226
	References.	228

Part III Biexcitons and Entangled Photon Emission

7	Polarization Entangled Photons from Semiconductor Quantum Dots	235
	Fei Ding and Oliver G. Schmidt	
7.1	Introduction	235
7.1.1	Photon Qubits	236
7.1.2	Entangled Photon Qubits	239
7.2	Semiconductor Quantum Dots Based Entangled Photon Sources	240
7.2.1	Biexciton Cascade and Fine Structure Splitting	242
7.2.2	Manipulation of Fine Structure Splitting	243
7.2.3	Electrical Injection of the Sources	249
7.2.4	Scalability of the Sources	253
7.2.5	Photon Collection Efficiency	258
7.3	Outlook.	260
7.3.1	Entanglement Distribution	260
7.3.2	Hybrid Interfacing with Atoms	261
7.3.3	Telecom Band Sources	262
7.3.4	On-Chip Integration.	262
7.4	Conclusion	263
	References.	264
8	Time-Bin Entanglement from Quantum Dots	267
	Gregor Weihs, Tobias Huber and Ana Predojević	
8.1	Introduction	267
8.2	Photon Degrees of Freedom	269
8.3	Time-Bin Encoding and Entanglement	270
8.4	Time-Bin Entanglement from Single Quantum Emitters	273
8.5	Two-Photon Coherent Excitation of a Quantum Dot.	274
8.6	Time-Bin Entangled Photon Pairs from a Quantum Dot.	278
8.7	Outlook.	281
	References.	283

Part IV Spin Properties and Integrated Systems

9	A Self-assembled Quantum Dot as Single Photon Source and Spin Qubit: Charge Noise and Spin Noise	287
	Richard J. Warburton	
9.1	A Self-assembled Quantum Dot for Quantum Technology	287
9.2	Photonics of a Self-assembled Quantum Dot	288
9.2.1	The Optical Transition	288
9.2.2	Vertical Tunneling Structures	290
9.2.3	Resonance Fluorescence Detection	291
9.3	Exciton Dephasing	293
9.3.1	The Charged Exciton	294
9.3.2	The Neutral Exciton	298
9.3.3	Locking the Quantum Dot Optical Resonance to a Frequency Standard	301
9.4	Electron Spin Dephasing via the Hyperfine Interaction	303
9.5	Hole Spin Dephasing	312
9.5.1	Coherence Population Trapping on a Single Hole Spin in a Quantum Dot	314
9.5.2	Hole Spin Dephasing	317
9.6	Conclusions	318
	References	319
10	Ultrafast Manipulation of Excitons and Spins in Quantum Dots	325
	Alistair J. Brash, Feng Liu and A. Mark Fox	
10.1	Introduction	325
10.2	Concepts of Coherent Control Experiments	326
10.2.1	The Two-Level Atom Approximation and the Bloch Sphere	326
10.2.2	Rabi Oscillations	328
10.2.3	Damping	332
10.2.4	Coherent Rotations on the Bloch Sphere	334
10.3	Quantum Dots as Coherent Systems	335
10.4	Coherent Control of Excitons	338
10.4.1	Level Structure of Excitons in Neutral Quantum Dots	338
10.4.2	Rabi Flopping	340
10.4.3	Manipulation of Exciton States	342
10.4.4	Two-Qubit Gates	344
10.5	Coherent Control of Spins	345
10.5.1	Energy Level Structure of Charged Dots	346
10.5.2	Spin Initialization	347
10.5.3	Coherent Control of Single Electron Spins	348

10.5.4	Coherent Control of Single Hole Spins	350
10.5.5	Spin Readout	351
10.6	Dephasing: Comparison of Qubits	351
10.7	Outlook	352
	References	353
11	Interfacing Single Quantum Dot Spins with Photons	
	Using a Nanophotonic Cavity	359
	Shuo Sun and Edo Waks	
11.1	Introduction	359
11.2	Theoretical Background	360
11.2.1	Calculation of Spin-Dependent Cavity Reflection Coefficients	361
11.2.2	Resonance Case: A Spin-Photon Quantum Switch	363
11.2.3	Detuned Case: Spin-Dependent Kerr Rotation	364
11.3	Quantum Dot Spins in a Nanophotonic Cavity	365
11.3.1	Micropillar Cavities	365
11.3.2	Photonic Crystal Cavities	366
11.4	Experimental Demonstrations of a Spin-Photon Quantum Switch	366
11.4.1	Device Characterization	367
11.4.2	Spin-Dependent Cavity Reflectivity	368
11.4.3	Coherent Control of Cavity Reflectivity	370
11.4.4	Controlling a Spin with a Photon	372
11.5	Discussions and Outlooks	374
	References	375
12	Entanglement Generation Based on Quantum Dot Spins	379
	Aymeric Delteil, Wei-bo Gao, Zhe Sun and Ataç Imamoğlu	
12.1	Introduction	379
12.1.1	Motivation	379
12.1.2	Quantum Dot Structures	380
12.2	Quantum Dot Spin-Photon Interface	381
12.2.1	Spin-Photon Entanglement Generation Scheme	381
12.2.2	Entanglement Verification	382
12.2.3	Coherence of the Entangled Pair and Spin-Photon Entanglement with Spin-Echo Sequence	386
12.3	Indistinguishability of Photonic Qubits Emitted by Different Dots	388
12.3.1	Generation of Photonic Frequency Qubits	389
12.3.2	Indistinguishability of the Photonic Qubits	390
12.4	Photon to Spin Teleportation	391
12.4.1	Set-Up and Protocol	392

12.4.2	Classical Correlations	392
12.4.3	Quantum Correlations	394
12.5	Distant Entanglement Generation Protocol	395
12.6	Interference of Raman Scattering for Hole Coherence Measurement.	398
12.6.1	Optically Injected Holes as Coherent Spin Qubits	398
12.6.2	Measurement of Spin Coherence Time Using Raman Scattering	398
12.7	Implementation and Characterisation of z -Rotation (Phase) Gate	401
12.8	Experimental Verification of Entanglement.	402
12.8.1	Classical Correlations	402
12.8.2	Quantum Correlations	404
12.8.3	Discussion	405
12.9	Conclusion and Outlook	405
	References.	406
13	Photonic Integrated Circuits with Quantum Dots.	409
	Ulrich Rengstl, Michael Jetter and Peter Michler	
13.1	Introduction	409
13.2	Quantum Computing.	411
13.2.1	Universal Set of Gates.	411
13.2.2	Linear Optics Quantum Computation.	412
13.3	Photonic Waveguides with Integrated Quantum Emitters	414
13.3.1	Types of Photonic Waveguides	415
13.3.2	Integrated Single-Photon Sources.	418
13.3.3	Coupling Between Quantum Dot Emission and Waveguides	419
13.4	Photonic Waveguide Circuits	421
13.4.1	Basic Performance Analysis.	424
13.4.2	Excitation Methods	429
13.5	Perspective of Fully Integrated Photonic Quantum Logic	431
13.5.1	Phase Shifters	431
13.5.2	Electric Field Tuning.	433
13.5.3	Integrated Detectors.	434
13.6	Summary	437
	References.	437
	Index	443

Quantum Dots for Quantum Information Technologies

Michler, P. (Ed.)

2017, XVII, 448 p. 221 illus., 80 illus. in color.,

Hardcover

ISBN: 978-3-319-56377-0