

Contents

1	Quantum Dynamics of Polariton Condensates	1
	Fabrice P. Laussy	
1.1	Introduction	2
1.2	Modeling of the Polariton Dynamics	7
1.3	Formation of Coherence in a Gas of Boson (2D Polaritons)	9
1.4	Formation of Coherence in a Fully Quantized System (0D Polaritons)	19
1.5	Propagation of Polariton Wavepackets (1D Polaritons)	26
1.6	Summary and Outlooks	35
	References	37
2	Polariton Nonlinear Dynamics: Theory and Experiments	43
	Vladimir D. Kulakovskii, Sergei S. Gavrilov, Sergei G. Tikhodeev, and Nikolay A. Gippius	
2.1	Introduction	44
2.2	Giant Stimulated LP–LP Scattering Under CW Excitation	44
2.3	Semiclassical Theory of Microcavity Nonlinearities	47
2.4	Kinetics of Stimulated Polariton Scattering: Hysteresis Behavior of LP–LP Scattering and Experimental Evidence for Dynamic Self-Organization	51
2.5	Polariton Multistability in a “Spinor” Polariton System	57
2.6	Conclusion	63
	References	64
3	Vortices in Spontaneous Bose–Einstein Condensates of Exciton–Polaritons	67
	Benoît Deveaud-Plédran and Konstantinos G. Lagoudakis	
3.1	Introduction	67
3.2	Basics of Polaritons	68

3.3	Bose–Einstein Condensation of Exciton–Polaritons	69
3.4	Vortices in Polariton Condensates	72
3.5	Half Quantum Vortices in Polariton Condensates	73
3.6	Dynamics of Vortices in Polariton Condensates	77
3.7	Conclusions and Outlook	82
	References	83
4	The Berezinskii–Kosterlitz–Thouless Phase Transition in Exciton–Polariton Condensates	85
	Georgios Roumpos and Yoshihisa Yamamoto	
4.1	Introduction	86
4.2	Two-Dimensional Bose Gas and Superfluidity	87
4.2.1	Order Parameter, Spontaneous Symmetry Breaking, and Long-Range Order	88
4.2.2	Superfluidity	90
4.2.3	Quantized Vortices	92
4.2.4	Low Dimensions and the Hohenberg– Mermin–Wagner Theorem	94
4.2.5	Two-Dimensional Bose Gas	96
4.2.6	The Berezinskii–Kosterlitz–Thouless Transition	100
4.3	Basic Characterisation of the Sample and Condensate	104
4.3.1	Major Scientific Instruments	104
4.3.2	Real-Space and Momentum-Space Spectroscopy	105
4.3.3	Condensation Characteristics	109
4.3.4	Comparison of Pumping Schemes	112
4.4	Power-Law Decay of the Spatial Correlation Function	112
4.4.1	Condensate in Real Space	113
4.4.2	Michelson Interferometer Setup	115
4.4.3	Short-Distance Decay	118
4.4.4	Long-Distance Decay	121
4.4.5	Different Detunings and Orthogonal Prism Orientation	124
4.4.6	Nonequilibrium Model	125
4.4.7	Conclusion	127
4.5	Single Vortex–Antivortex Pair	128
4.5.1	Condensate Shape in Real Space	129
4.5.2	Pinned Vortex–Antivortex Pair	131
4.5.3	Mobile Vortex–Antivortex Pair	133
4.5.4	Different Condensate Shapes	137
4.5.5	Vortex-Pair Dynamics Described by Open-Dissipative Gross–Pitaevskii Equation	139
4.6	Future Directions	142
	References	143

5	Coexisting Polariton Condensates and Their Temporal Coherence in Semiconductor Microcavities	147
	D.N. Krizhanovskii, David M. Whittaker, M.S. Skolnick, K.G. Lagoudakis, and M. Wouters	
5.1	Coexisting Non-equilibrium Polariton Condensates	148
5.1.1	Introduction	148
5.1.2	Experimental Technique and Sample	149
5.1.3	Real and Momentum Space Imaging of Coexisting Condensates	149
5.1.4	Gross-Pitaevskii Formalism of Non-equilibrium Polariton Condensates	153
5.1.5	Conclusion	156
5.2	Effect of Interactions on Temporal Coherence of Polariton Condensates	157
5.2.1	Introduction	157
5.2.2	Measurement of the First-Order and the Second-Order Correlation Functions of Non-resonantly Pumped Condensates	159
5.2.3	Quantum Optical Treatment of Temporal Coherence in Non-equilibrium Polariton Condensates	161
5.2.4	Temporal Coherence of a Polariton Condensate Excited in the Optical Parametric Oscillation Configuration	163
5.2.5	Conclusion	169
	References	170
6	Vortices in Polariton OPO Superfluids	173
	Francesca M. Marchetti and Marzena H. Szymańska	
6.1	Introduction	173
6.2	A Very Short Introduction to Microcavity Polaritons	175
6.2.1	Exciton–Exciton and Exciton–Photon Interaction	176
6.3	Optical Parametric Oscillator Regime	178
6.3.1	Polariton Parametric Scattering and Optical Parametric Amplification	179
6.3.2	Bistability and OPO in the Plane-Wave Approximation	180
6.3.3	Numerical Modelling	186
6.3.4	Vortex Phase and Profile	190
6.3.5	Stable Vortices in a Small-Sized OPO	190
6.4	Triggered Optical Parametric Oscillator Regime	195
6.4.1	Theoretical Description of the TOPO	197
6.4.2	Experiments	199
6.5	Triggered Metastable Vortices as a Diagnostic of the OPO Superfluid Properties	200
6.5.1	Theory and Experiments	201
6.5.2	Onset and Dynamics of Vortex–Antivortex Pairs	203

6.6	Stability of Multiply Quantised Vortices	206
6.6.1	TOPO Regime	207
6.6.2	OPO Regime	208
6.7	Vortices in Other Polariton Fluids	209
6.7.1	Spontaneous Vortices in Trapped Incoherently Pumped Polaritons	209
6.7.2	Resonantly Pumped-Only Polaritons	209
	References	210
7	Superfluidity and Hydrodynamic Topological Excitations of Microcavity Polaritons	215
	A. Amo and A. Bramati	
7.1	Introduction	215
7.2	Superfluidity According to the Landau Criterion	217
7.2.1	Resonant Excitation of the Lower Polariton Branch	219
7.2.2	Non-resonant Excitation	221
7.3	Hydrodynamic Effects	223
7.4	Free Flow Around a Large Obstacle	225
7.4.1	Non-equilibrium Hydrodynamics	228
	References	230
8	Spin Effects in Exciton–Polariton Condensates	233
	Alexey Kavokin	
8.1	Introduction	233
8.2	Spin Meissner Effect	235
8.3	Spin Switching	237
8.4	Spin Superfluidity	239
8.5	Conclusions	242
	References	243
9	Disorder Effects on Exciton–Polariton Condensates	245
	G. Malpuech and D. Solnyshkov	
9.1	Introduction	246
9.2	Historical Overview	248
9.3	Static Condensate in a Disorder Potential	250
9.4	Localization and Superfluidity of a Moving Condensate	254
9.4.1	Anderson Localization	254
9.4.2	Superfluidity	257
9.4.3	Phase Diagram	260
9.5	Conclusion and Perspectives	263
	References	264
10	Truncated Wigner Approximation for Nonequilibrium Polariton Quantum Fluids	267
	Michiel Wouters and Vincenzo Savona	
10.1	Introduction	267
10.2	Derivation of the Stochastic Equations of Motion	272

10.3	Truncated Wigner Approximation	276
10.4	Numerical Results	278
10.5	Conclusions	282
	References.....	285
11	Exciton–Polariton Coupling with Acoustic Phonons	289
	Edgar Cerda-Méndez, Dmitry Krizhanovskii, Michiel Wouters, Klaus Biermann, Rudolf Hey, Maurice S. Skolnick, and Paulo V. Santos	
11.1	Introduction.....	290
11.2	Polariton Microcavities for Acoustic Modulation	292
11.3	Acoustic Modulation of Polaritons	295
11.3.1	Linear Regime	295
11.3.2	Resonantly Pumped Condensate	298
11.3.3	Transport of Polariton Lattice Potential	303
11.3.4	Conclusions	304
	References.....	304
12	Polariton Condensation and Lasing	307
	David Snoke	
12.1	The State of Matter in Excitonic Condensation and Lasing	308
12.2	Condensation and Classical Waves	311
12.3	Differences Between Polariton Condensation and Lasing	315
12.4	Experimental Differences Between Condensation and Lasing.....	319
12.5	Josephson Junctions, Phase Locking, Solitons, and Vortices	322
12.6	Photon Condensation.....	324
12.7	Conclusions.....	326
	References.....	326
13	The Future Prospects of Room-Temperature Polariton Lasers	329
	Gabriel Christmann and Jeremy J. Baumberg	
13.1	Introduction.....	329
13.2	Strong Coupling Regime at Room Temperature	330
13.2.1	Generalities on the Strong Coupling Regime	330
13.2.2	Designs for Room Temperature.....	332
13.2.3	Experimental Realizations	334
13.3	Room-Temperature Polariton Lasing.....	337
13.3.1	Bulk Microcavities	337
13.3.2	Multiple Quantum Well Microcavities	341
13.4	Future Prospects	342
13.4.1	Novel Sample Designs	342
13.4.2	Electrical Injection.....	344
	References.....	346

14 Exciton–Polaritons in Organic Semiconductor Optical Microcavities	349
Stéphane Kéna-Cohen and Stephen R. Forrest	
14.1 Introduction	349
14.2 Strong Exciton–Photon Coupling in Organic Semiconductor Microcavities	351
14.3 Single Crystalline Organic Microcavities	355
14.4 Polariton Lasing in Single Crystalline Organic Microcavities	363
14.5 Hybrid Organic–Inorganic Microcavities	371
14.6 Conclusions	373
References	374
15 Electrically Driven Polariton Light Emitting Devices	377
Simeon I. Tsintzos, Nikolaos T. Pelekanos, and Pavlos G. Savvidis	
15.1 Introduction	377
15.2 Electrically Injected Polariton LEDs	378
15.3 Polariton LED Design Considerations	379
15.3.1 Resistivity of DBRs	379
15.4 Doping-Related Losses	380
15.5 Room Temperature GaAs Polariton LED	381
15.6 Toward Polariton Laser Diodes	389
15.7 Bias Controlled Polariton Parametric Amplification	390
15.8 Conclusions	394
References	394
Index	397