

Arash Rahimi-Iman

Semiconductor Photonics of Nanomaterials and Quantum Structures

Applications in Optoelectronics and
Quantum Technologies

สำนักหอสมุด มหาวิทยาลัยเชียงใหม่

Arash Rahimi-Iman

22454925

Semiconductor Photonics of Nanomaterials and Quantum Structures

Applications in Optoelectronics and Quantum
Technologies



Contents

1	Introduction	1
1.1	A Topical Overview	1
1.2	Advances in Functional Nanomaterials Sciences	3
1.2.1	Novel Material Systems	6
1.2.2	Material Engineering and Physics	7
1.2.3	Optoelectronic Devices	11
References		13
2	Entering a Two-Dimensional Materials World	17
2.1	The Rise of the 2D Materials	17
2.2	Fundamentals of 2D Materials	21
2.3	Graphene and Related Materials	30
2.4	Layered Systems Based on Monolayer Semiconductors	32
2.4.1	Physics of Transition-Metal Dichalcogenide Heterostructures	32
2.5	Photonics and Optoelectronics of 2D Semiconductor TMDCs	37
2.5.1	Strong Light–Matter Interaction and Lasing with 2D Materials	41
References		44
3	Light–Matter Interactions for Photonic Applications	61
3.1	Where Strong Interactions with Light Matters	61
3.1.1	Basics of Light–Matter Systems	65
3.2	Matter Excitations	68
3.2.1	Excitons as Composite Bosons	69
3.2.2	Rich Exciton Physics in 2D Semiconductors	76
3.3	Strong Exciton–Photon Coupling and Polariton Bose–Einstein Condensation	80
3.3.1	Cavity–Polaritons Exposed to External Fields	83
References		86

4 In the Field of Quantum Technologies	99
4.1 Into the Quantum Realm	99
4.2 Coherent Light Sources	101
4.2.1 Semiconductor Lasers: From Efficient Nanolasers to Powerful External-Cavity Lasers	102
4.2.2 Novel Coherent Light Sources	108
4.3 Quantum Optics	109
4.3.1 Tailored Light–Matter Interactions for Quantum Light Generation	112
4.3.2 Strong Light–Matter Coupling for Polariton Research	115
References	119
5 Optical Measurement Techniques	133
5.1 Advanced Optical Tools	133
5.2 Microscopy and Spectroscopy	135
5.2.1 Monitoring and Imaging	135
5.2.2 Spatial Distribution	138
5.2.3 Time-Integrated Detection	140
5.2.4 Time-Resolved Measurements	143
5.3 Basic Material Response	151
5.3.1 Absorbance	151
5.3.2 Photoluminescence	153
5.3.3 Photocurrent Measurements	158
5.3.4 Raman Signatures	159
5.4 Nonlinearities	161
5.4.1 Z-Scans	162
5.4.2 Nonlinear Frequency Conversion	164
5.5 Fourier-Space Spectroscopy	167
5.5.1 Angle-Resolved Detection	167
5.5.2 Dispersion Measurements	168
5.6 Additional Methods	171
5.6.1 Beam Characterisation	171
5.6.2 Time-Domain Spectroscopy	173
5.6.3 Laser-Induced Plasma/Breakdown Spectroscopy	174
5.6.4 Magneto-Optical Studies	176
References	176
6 Effects of Quantisation	187
6.1 Miniaturisation Towards Quantum Structures	187
6.2 From Bulk to Zero-Dimensional Structures	188
6.2.1 Spatial Confinement	188
6.2.2 Density of States	191
6.2.3 Discrete Energies	192
6.3 Benefits and Applications	196
6.3.1 Charge–Carrier Localisation and Tailored Transitions	198
6.3.2 Impact on Optoelectronics and Nanophotonics	199
References	203

7 Structuring Possibilities	209
7.1 Epitaxy	209
7.1.1 Molecular Beam Epitaxy	211
7.1.2 Chemical Vapour Deposition	211
7.2 Patterning and Assembly	214
7.2.1 Lithography, Deposition and Etching	214
7.2.2 Synthesis of Nanoparticles	216
7.2.3 Stacking of van-der-Waals Materials	220
7.2.4 Laser Processing and Ion Beam Milling	223
References	225
8 Conclusion and Outlook	229
8.1 Summary	229
8.2 Concluding Remarks	233
8.3 Exploring the Mechanism Behind Self-Mode-Locking in VECSELs	234
8.4 Manipulating and Controlling Cavity–Polaritons with Terahertz Waves	236
8.5 Towards Optoelectronic Devices and Microcavity Experiments with 2D Materials	238
8.6 Functional Nanomaterials Sciences Cooperation Group	240
References	246
Index	255

7 Structuring Possibilities	209
7.1 Epitaxy	209
7.1.1 Molecular Beam Epitaxy	211
7.1.2 Chemical Vapour Deposition	211
7.2 Patterning and Assembly	214
7.2.1 Lithography, Deposition and Etching	214
7.2.2 Synthesis of Nanoparticles	216
7.2.3 Stacking of van-der-Waals Materials	220
7.2.4 Laser Processing and Ion Beam Milling	223
References	225
8 Conclusion and Outlook	229
8.1 Summary	229
8.2 Concluding Remarks	233
8.3 Exploring the Mechanism Behind Self-Mode-Locking in VECSELs	234
8.4 Manipulating and Controlling Cavity-Polaritons with Terahertz Waves	236
8.5 Towards Optoelectronic Devices and Microcavity Experiments with 2D Materials	238
8.6 Functional Nanomaterials Sciences Cooperation Group	240
References	246
Index	255