

Contents

1	Surface Studies by Low-Energy Electron Diffraction and Reflection High-Energy-Electron Diffraction	1
	P. Laukkanen, J. Sadowski, and M. Guina	
1.1	Basics of RHEED and LEED	1
1.2	Analysis of LEED and RHEED Patterns	4
1.3	Using LEED to Study III–V Surfaces	8
1.3.1	The $c(8 \times 2)$ Surfaces of InAs(100) and InSb(100)	8
1.3.2	The GaAs(100) Reconstructions	9
1.3.3	The Bi-Induced Reconstructions on III–V(100)	11
1.4	Using RHEED to Study III–Vs	12
1.4.1	Optimizing the Growth Conditions of GaAs/AlAs Heterostructures	12
1.4.2	The GaAs(100) Reconstructions	13
1.4.3	The GaAs(111) Reconstructions	14
1.4.4	Probing Surface Reconstructions in GaInAsN(100)	15
1.4.5	In-Situ Calibrations of Growth Rate and Composition of Multinary Compounds	15
1.5	Concluding Remarks	18
	References	19
2	High-Resolution Electron Microscopy of Semiconductor Heterostructures and Nanostructures	23
	David L. Sales, Ana M. Beltrán, Juan G. Lozano, José M. Manuel, M. Paz Guerrero-Lebrero, Teresa Ben, Miriam Herrera, Francisco M. Morales, Joaquín Pizarro, Ana M. Sánchez, Pedro L. Galindo, David González, Rafael García, and Sergio I. Molina	
2.1	Introduction	23

2.1.1	Transmission Electron Microscopy, a Powerful Tool for Semiconductor Research	24
2.2	Compositional Quantification Column-To-Column in III-V Semiconductors	27
2.2.1	Reference Samples Study	28
2.2.2	Image Analysis and Comparative Index	29
2.2.3	Simulation of Integrated Intensities.....	31
2.3	Strain Measurements from High-Resolution Electron Microscopy Images	32
2.3.1	Techniques	32
2.3.2	Methodology.....	33
2.3.3	Applications.....	36
2.4	Results on III-Sb Hetero- and Nanostructures	36
2.5	Results on InAs Quantum Wires	40
2.5.1	Nucleation and Initial Growth Stages of InAs/InP(001) QWRs	40
2.5.2	Simulated and Experimental Determination of Strain Map and Prediction of Nucleation Sites for the Growth of the Stacked Structures.....	42
2.6	Analysis of the N Distribution in GaAsN	44
2.7	Review on InN Nanostructures	48
2.8	Crystalline, Compositional, and Strain TEM Assessments of High-Quality Epilayers of Ternary and Quaternary III-N Alloys.....	51
2.8.1	Previous Considerations.....	52
2.8.2	Briefly, a Complete (S)TEM Study	53
2.8.3	Analyses of Lateral Strains.....	56
	References.....	58
3	Hot Electron Energy and Momentum Relaxation	63
	Naci Balkan	
3.1	Introduction.....	63
3.2	Hot Electron Photoluminescence in the Steady State.....	65
3.3	Mobility Mapping	69
3.4	Nonequilibrium Phonons (Hot Phonons)	70
3.5	Cooling of Hot Electron Hole Plasma by LO Phonon Emission Using the CW and Transient Photoluminescence Spectroscopy	73
3.5.1	Optical Heating in the Steady State Using CW Photoluminescence	74
3.5.2	Time-Resolved PL Measurements	75
3.6	Hot Electron Momentum Relaxation	78
3.6.1	Experimental Techniques	79
3.6.2	Theoretical Modeling of Experimental Results	81

3.7	Hot Electron Energy Relaxation via Acoustic Phonon Emission	83
3.7.1	Experimental Procedures	85
3.7.2	Theoretical Modeling of Experimental Results	89
3.8	Conclusions	91
	References	92
4	Optical Modulation Spectroscopy	95
	Robert Kudrawiec and Jan Misiewicz	
4.1	Principles of Optical Modulation Spectroscopy	95
4.1.1	Built-in Electric Field in Semiconductor Structures and Its Modulation	97
4.1.2	Experimental Setup for Photo- and Contactless Electro-Reflectance	98
4.1.3	Analysis of Photo- and Electro-Reflectance Spectra	104
4.2	Applications of Photo- and Contactless Electro-Reflectance	109
4.2.1	Bulk-Like Epilayers	110
4.2.2	Quantum Wells	115
4.2.3	Quantum Dots	117
4.2.4	Device Structures	120
	References	123
5	Photoluminescence: A Tool for Investigating Optical, Electronic, and Structural Properties of Semiconductors	125
	G. Pettinari, A. Polimeni, and M. Capizzi	
5.1	Introduction	125
5.2	Generalities	126
5.2.1	Experimental Apparatus	126
5.2.2	Absorption Spectroscopy	128
5.2.3	Photoluminescence Spectroscopy	130
5.2.4	Photoluminescence Excitation Spectroscopy	133
5.3	Photoluminescence Spectroscopy: A Tool for Crystalline Disorder Investigation	136
5.3.1	Probing Quantum Well Imperfections	136
5.3.2	Localized States in an Alloy	138
5.3.3	Localized States and Carrier Thermalization	140
5.3.4	Degenerate Semiconductors	142
5.4	Magneto-Photoluminescence	146
5.4.1	Excitons in a Magnetic Field	147
5.4.2	High Magnetic Field Limit	149
5.4.3	Low Magnetic Field Limit	159
5.4.4	Intermediate Magnetic Field Limit	162
5.5	Conclusions	166
	References	167

6	Pressure Studies	171
	Andrew Prins, Alf Adams and Stephen Sweeney	
6.1	Introduction	171
6.2	The Effect of Pressure on Electronic Band Structure	172
6.2.1	The Gunn Effect	173
6.2.2	Anvil Cells and Optical Work	175
6.2.3	Transport Properties	177
6.2.4	Defects Under Pressure	179
6.2.5	Band Anticrossing	180
6.3	Phase Transitions in Bulk, Superlattices and Nanoparticles	180
6.4	Optoelectronic Device Measurements Under Pressure	183
6.4.1	Semiconductor Lasers	185
6.4.2	Quantum Cascade Lasers	188
6.4.3	Avalanche Photodiodes	190
6.5	Commercial Equipment and Applications	191
	References	192
7	Spatially Resolved Luminescence Spectroscopy	197
	Gintautas Tamulaitis	
7.1	Introduction	197
7.2	Micro-photoluminescence (μ -PL)	199
7.3	Scanning Confocal Microscopy (SCM)	200
7.4	Scanning Near-Field Optical Microscopy	204
7.5	Cathodoluminescence	212
7.6	Excitation of Luminescence in Semiconductors	215
7.7	Comparison of Techniques for Spatially Resolved Spectroscopy of Semiconductors	218
7.7.1	Micro-photoluminescence (μ -PL)	218
7.7.2	Scanning Confocal Microscopy	218
7.7.3	Scanning Near-Field Optical Microscopy	219
7.7.4	Cathodoluminescence	219
	References	219
8	Time-Resolved Optical Spectroscopy	223
	Andrea Balocchi, Thierry Amand, and Xavier Marie	
8.1	Introduction	223
8.2	Streak Cameras for Time-Resolved Photoluminescence Spectroscopy	225
8.2.1	Working Principle	225
8.2.2	Synchronization and Sweep Methods	226
8.2.3	Measurement Methods	228
8.2.4	Photocathode Type and Sensitivity	229
8.2.5	Time Resolution	229
8.2.6	Application Examples	230

8.3	Up-Conversion Technique for Time-Resolved Photoluminescence Spectroscopy	230
8.3.1	Phase-Matching and Polarization Conditions	232
8.3.2	Two-Color Up-Conversion	234
8.3.3	Quantum Efficiency	236
8.3.4	Spectral Resolution	237
8.3.5	Time Resolution	237
8.3.6	Acceptance Angle	238
8.3.7	Calibration Procedures	238
8.3.8	Streak Camera and Up-conversion: A Comparison	238
8.3.9	Application Examples	239
8.4	Pump and Probe Time-Resolved Spectroscopies	240
8.4.1	Probe Characteristics and Detection Techniques.....	243
8.4.2	Time-Resolved Differential Absorption and Dichroism Experiments.....	245
8.4.3	Faraday and Kerr Rotation Spectroscopy.....	248
8.5	Time-Correlated Single-Photon Spectroscopy	251
8.5.1	TCSPC Setup and Electronics Components.....	252
8.5.2	TCSPC Temporal Resolution and Sensitivity	254
8.5.3	Application Examples	255
8.6	Time-Resolved Optical Spectroscopy: A Synoptic Comparison of the Different Techniques.....	256
	References.....	256
9	Raman Spectroscopy of Compound Semiconductors	259
	Jordi Ibáñez and Ramon Cuscó	
9.1	Introduction	259
9.2	Raman Scattering by Phonons	260
9.2.1	The Raman Effect	260
9.2.2	Macroscopic Theory and Selection Rules	262
9.2.3	Resonant Raman Scattering	265
9.3	Raman Instrumentation	266
9.4	Applications of Raman Spectroscopy in Semiconductor Physics.....	268
9.4.1	Crystal Quality and Strain State	269
9.4.2	Impurities and Alloys.....	271
9.4.3	Raman Scattering by LO Phonon–Plasmon Coupled Modes	275
	References.....	279
10	Cyclotron Resonance Spectroscopy	283
	Oleksiy Drachenko and Manfred Helm	
10.1	Introduction.....	283
10.2	Basic Theory.....	284
10.2.1	Classical Description	284

10.2.2	Quantum Mechanical Description	286
10.2.3	Further Considerations	288
10.3	Experimental Techniques	289
10.3.1	High Magnetic Fields.....	289
10.3.2	Cyclotron Resonance Spectroscopic Techniques	291
10.4	Cyclotron Resonance Spectroscopy	297
10.4.1	Dilute Nitride $\text{InAs}_{1-x}\text{N}_x$	297
10.4.2	Dilute Nitride $\text{GaAs}_{1-x}\text{N}_x$	301
10.4.3	Valence-Band Dispersion Probed by CR	301
10.4.4	Carrier Dynamics Probed by CR.....	303
	References.....	304
11	Using High Magnetic Fields to Study the Electronic Properties of Semiconductor Materials and Nanostructures.....	309
	A. Patanè and L. Eaves	
11.1	Introduction.....	309
11.2	Lorentz Force and Classical Hall Effect.....	310
11.3	Landau Level Quantization	312
11.4	Magnetoresistance, Shubnikov–de Haas and Quantum Hall Effects	314
11.4.1	Classical Positive Magnetoresistance.....	315
11.4.2	Shubnikov–de Haas and Quantum Hall Effects	316
11.4.3	Magnetophonon Resonance	319
11.4.4	Positive Linear Magnetoresistance	320
11.4.5	Negative Magnetoresistance	322
11.5	Magneto-Tunneling Spectroscopy	322
11.5.1	Probing Band Structures	323
11.5.2	Probing and Manipulating Low-Dimensional Systems ...	325
11.6	Conclusion.....	328
	References.....	329
12	Photoconductivity and Transient Spectroscopy	333
	Ayşe Erol and M. Çetin Arıkan	
12.1	Introduction.....	333
12.2	Photoconductivity	335
12.2.1	Photoconductivity: General Concepts	335
12.2.2	Photoconductivity: Spectral Response.....	339
12.2.3	Photoconductivity Decay.....	340
12.3	Photoconductivity Measurement Techniques	341
12.3.1	Steady-State (dc) Photoconductivity.....	341
12.3.2	Modulated (ac) Photoconductivity.....	342
12.3.3	Pulsed Photoconductivity	344
12.4	Experimental Setups for Photoconductivity Measurements.....	344
12.4.1	Spectral Photoconductivity: Experimental Setup	344
12.4.2	Transient Photoconductivity: Experimental Setup	347

12.5	Transient Spectroscopy	348
12.5.1	Generation–Recombination Rate	350
12.5.2	Photo-Induced Transient Spectroscopy	353
12.5.3	Deep-Level Transient Spectroscopy	357
12.5.4	PITS versus DLTS	363
	References	363
Index	367



<http://www.springer.com/978-3-642-23350-0>

Semiconductor Research
Experimental Techniques
Patane, A.; Balkan, N. (Eds.)
2012, XX, 372 p., Hardcover
ISBN: 978-3-642-23350-0