

# Contents

<b>1</b>	<b>Self-Assembly of Quantum Dots and Rings on Semiconductor Surfaces</b> .....	<b>1</b>
	Christian Heyn, Andrea Stemmann, and Wolfgang Hansen	
1.1	Introduction .....	1
1.1.1	Molecular Beam Epitaxy .....	3
1.1.2	Kinetics of Crystal Growth .....	4
1.2	Strain-Driven InAs QDs in Stranski–Krastanov Mode .....	6
1.3	Droplet Epitaxy in Volmer–Weber Mode .....	11
1.4	Local Droplet Etching .....	14
1.4.1	Structural Properties of LDE Nanoholes and Rings .....	15
1.4.2	Fabrication of QDs by Filling of LDE Nanoholes .....	19
1.5	Conclusions .....	21
	References .....	22
<b>2</b>	<b>Curved Two-Dimensional Electron Systems in Semiconductor Nanoscrolls</b> .....	<b>25</b>
	Karen Peters, Stefan Mendach, and Wolfgang Hansen	
2.1	Introduction .....	25
2.2	The Basic Principle Behind “Rolled-Up Nanotech” .....	28
2.3	First Evidence of Rolled-up 2DES in Freestanding Curved Lamellae .....	33
2.4	2DES in Rolled-Up Hall Bars: Static Skin Effect, Magnetic Barriers, and Reflected Edge Channels .....	39
2.4.1	Low Magnetic Field Regime: Static Skin Effect and Magnetic Barriers .....	40
2.4.2	High Magnetic Field Regime: Reflected Edge Channels ...	42
2.5	Conclusions .....	46
	References .....	47

<b>3</b>	<b>Capacitance Spectroscopy on Self-Assembled Quantum Dots</b> .....	51
	Andreas Schramm, Christiane Konetzni, and Wolfgang Hansen	
3.1	Introduction .....	51
3.2	Experimental Techniques .....	52
3.2.1	Deep Level Transient Spectroscopy .....	52
3.2.2	Capacitance Voltage Spectroscopy on Schottky Diodes .....	56
3.3	Experimental Results .....	57
3.3.1	Capacitance Spectroscopy on Quantum-Dot Schottky Diodes .....	57
3.3.2	Deep Level Transient Spectroscopy on Quantum-Dot Schottky Diodes .....	59
3.3.3	Evaluation of Quantum-Dot Shell Energies in the Thermally Assisted Tunneling Model .....	62
3.3.4	DLTS Experiments in Magnetic Fields .....	67
3.3.5	Advanced Time-Resolved Capacitance Spectroscopy Methods: Tunneling-DLTS, Constant-Capacitance DLTS and Reverse-DLTS .....	69
3.3.6	Alternative Capacitance Spectroscopy Methods .....	72
3.4	Conclusion and Outlook .....	73
	References .....	75
<b>4</b>	<b>The Different Faces of Coulomb Interaction in Transport Through Quantum Dot Systems</b> .....	79
	Benjamin Baxevanis, Daniel Becker, Johann Gutjahr, Peter Moraczewski, and Daniela Pfannkuche	
4.1	Introduction .....	79
4.2	Transport Through Quantum Dot Systems .....	80
4.3	Electronic Structure of Quantum Dots .....	83
4.3.1	Circular Quantum Dots .....	83
4.3.2	Elliptical Quantum Dots .....	85
4.3.3	Quantum Rings .....	87
4.3.4	Magnetically Doped Quantum Dots .....	89
4.3.5	Correlations Beyond Hund's Rule .....	93
4.4	Transport Beyond Spectroscopy .....	95
4.5	Outlook .....	97
	References .....	99
<b>5</b>	<b>Far-Infrared Spectroscopy of Low-Dimensional Electron Systems</b> .....	103
	Detlef Heitmann and Can-Ming Hu	
5.1	Introduction .....	103
5.2	Experimental FIR Spectroscopic Techniques .....	104

5.3	Preparation of Arrays of Quantum Materials .....	106
5.4	Theoretical Models .....	108
5.5	Far-infrared Transmission Experiments .....	112
5.6	FIR Photoconductivity Spectroscopy .....	119
5.7	Summary .....	135
	References .....	136
<b>6</b>	<b>Electronic Raman Spectroscopy of Quantum Dots</b> .....	<b>139</b>
	Tobias Kipp, Christian Schüller, and Detlef Heitmann	
6.1	Introduction .....	139
6.2	Fabrication of Charged Quantum Dots .....	141
6.3	Electronic States in Quantum Dots .....	142
6.4	Raman Experiments on Etched GaAs–AlGaAs QDs .....	145
6.4.1	QDs with Many Electrons .....	145
6.4.2	QDs with Only Few Electrons .....	149
6.5	Raman Experiments on Self-Assembled In(Ga)As QDs .....	150
6.5.1	QDs with a Fixed Number of Electrons, $N_e \approx 6-7$ .....	150
6.5.2	QDs with a Tunable Number of Electrons, $N_e = 2 \dots 6$ .....	151
6.5.3	Comparison to Calculated Resonant Raman Spectra for $N_e = 2 \dots 6$ .....	154
6.5.4	QDs with $N_e = 2$ Electrons: Artificial He Atoms .....	156
6.6	Summary .....	160
	References .....	162
<b>7</b>	<b>Light Confinement in Microtubes</b> .....	<b>165</b>
	Tobias Kipp, Christian Strelow, and Detlef Heitmann	
7.1	Introduction .....	165
7.2	Fabrication .....	167
7.3	Experimental Setup .....	168
7.4	Microtubes with Unstructured Rolling Edges .....	168
7.5	Influence of the Rolling Edges on the Emission Properties .....	171
7.6	Controlled Three-Dimensional Confinement by Structured Rolling Edges .....	173
7.7	Conclusion and Outlook .....	180
	References .....	181
<b>8</b>	<b>Scanning Tunneling Spectroscopy of Semiconductor Quantum Dots and Nanocrystals</b> .....	<b>183</b>
	Giuseppe Maruccio and Roland Wiesendanger	
8.1	Introduction .....	183
8.2	Electronic Structure and Single-Particle Wavefunctions .....	184
8.3	Electron Transport Through Quantum Dots and Nanocrystals .....	187
8.3.1	Tunneling Spectroscopy .....	187
8.3.2	Coulomb Blockade .....	190
8.3.3	Shell-Tunneling and Shell-Filling Spectroscopy .....	191

8.4	MBE-Grown Quantum Dots .....	194
8.4.1	Scanning Tunneling Microscopy and Cross-Sectional STM .....	194
8.4.2	Wavefunction Mapping of MBE-Grown InAs Quantum Dots .....	197
8.4.3	Coulomb Interactions and Correlation Effects .....	201
8.5	Colloidal Nanocrystals .....	205
8.5.1	Electronic Properties, Atomic-Like States, and Charging Multiplets .....	205
8.5.2	Electronic Wavefunctions in Immobilized Semiconductor Nanocrystals .....	208
8.6	Conclusions .....	211
	References .....	212
<b>9</b>	<b>Scanning Tunneling Spectroscopy on III–V Materials: Effects of Dimensionality, Magnetic Field, and Magnetic Impurities .....</b>	<b>217</b>
	Markus Morgenstern, Jens Wiebe, Felix Marcinowski, and Roland Wiesendanger	
9.1	Introduction .....	217
9.2	Interpreting STM and STS Data .....	218
9.2.1	Assumptions .....	221
9.2.2	Tip-Induced Band Bending .....	221
9.2.3	Experimental Procedures .....	224
9.3	Electrons in Different Dimensions .....	224
9.3.1	Overview .....	224
9.3.2	Three-Dimensional Electron System (3DES) .....	225
9.3.3	Comparison of 2DES and 3DES .....	228
9.3.4	2DES in a Magnetic Field .....	230
9.4	Magnetic Acceptors .....	234
9.4.1	Overview .....	234
9.4.2	Determining the Depth Below the (110) Surface .....	235
9.4.3	Acceptor Charge Switching by Tip-Induced Band Bending .....	236
9.4.4	Properties of the Hole Bound to the Mn Acceptor .....	238
9.5	Conclusions and Outlook .....	239
	References .....	240
<b>10</b>	<b>Magnetization of Interacting Electrons in Low-Dimensional Systems .....</b>	<b>245</b>
	Marc A. Wilde, Dirk Grundler, and Detlef Heitmann	
10.1	Introduction .....	245
10.2	Highly Sensitive Magnetometry .....	246
10.2.1	Figures-of-Merit .....	246
10.2.2	SQUID Magnetometer .....	248

10.2.3	Concepts of Torque Magnetometry .....	249
10.2.4	Torsion-Balance Magnetometers .....	250
10.2.5	Cantilever Magnetometers .....	251
10.3	Theory of Magnetic Quantum Oscillations .....	255
10.3.1	Thermodynamics Definition of Magnetization .....	256
10.3.2	DHvA Effect in 2DESSs .....	256
10.4	Experimental Results on 2DESSs .....	257
10.4.1	DOS and Energy Gaps at Even Integer $\nu$ .....	258
10.4.2	Energy Gaps at Odd Integer $\nu$ .....	261
10.4.3	Fractional QHE Gaps .....	262
10.5	Magnetization of Nanostructures .....	263
10.5.1	Magnetization of AlGaAs/GaAs Quantum Wires .....	263
10.5.2	Magnetization of AlGaAs/GaAs Quantum Dots .....	267
10.6	Conclusions .....	272
	References .....	273
<b>11</b>	<b>Spin Polarized Transport and Spin Relaxation in Quantum Wires .....</b>	<b>277</b>
	Paul Wenk, Masayuki Yamamoto, Jun-ichiro Ohe, Tomi Ohtsuki, Bernhard Kramer, and Stefan Kettemann	
11.1	Introduction .....	277
11.2	Spin-Dynamics in Semiconductor Quantum Wires .....	278
11.2.1	Spin-Orbit Interaction in Semiconductors .....	278
11.2.2	Spin Diffusion .....	282
11.2.3	Spin Relaxation Mechanisms .....	284
11.2.4	Spin Dynamics in Quantum Wires .....	286
11.3	Spin Polarized Currents in Quantum Wires .....	292
11.3.1	Self-Duality and Spin Polarization .....	292
11.3.2	Spin Filtering Effect by Nonuniform Rashba SOC .....	293
11.3.3	Generation of the Spin-Polarized Current in a T-Shape Conductor .....	295
11.4	Critical Discussion and Future Perspective .....	299
	References .....	300
<b>12</b>	<b>InAs Spin Filters Based on the Spin-Hall Effect .....</b>	<b>303</b>
	Jan Jacob, Toru Matsuyama, Guido Meier, and Ulrich Merkt	
12.1	Introduction .....	303
12.2	Spin-Orbit Coupling .....	304
12.2.1	Spin-Orbit Coupling in Vacuum .....	304
12.2.2	Spin-Orbit Coupling in III-V Semiconductors .....	305
12.3	Spin Hall Effect .....	307
12.3.1	Extrinsic Spin Hall Effect .....	308
12.3.2	Intrinsic Spin Hall Effect .....	309
12.3.3	Experimental Detection of the Spin Hall Effect .....	309
12.4	Spin Filters .....	310

12.5	Device Layout .....	311
12.6	Experiments .....	316
12.6.1	Characterization of Single Quantum Point Contacts .....	316
12.6.2	Characterization of Spin-Filter Cascades .....	317
12.6.3	Quantized Conductance .....	320
12.6.4	Correlation Between Conductance Channels and Conductance Portions .....	322
12.7	Summary .....	322
12.7.1	Conclusions .....	322
12.7.2	Outlook .....	324
	References .....	325
<b>13</b>	<b>Spin Injection and Detection in Spin Valves with Integrated Tunnel Barriers .....</b>	<b>327</b>
	Jeannette Wulforth, Andreas Vogel, Nils Kuhlmann, Ulrich Merkt, and Guido Meier	
13.1	Introduction .....	327
13.2	First Experiments .....	328
13.3	Spin Injection and Detection in Spin Valves .....	329
13.3.1	Theory .....	329
13.3.2	Permalloy Electrodes for Spin-Valve Devices .....	335
13.3.3	Spin Valves with Insulating Barriers .....	341
13.3.4	Connecting Paramagnetic Channel .....	344
13.4	Outlook .....	349
	References .....	350
<b>14</b>	<b>Growth and Characterization of Ferromagnetic Alloys for Spin Injection .....</b>	<b>353</b>
	Jan M. Scholtyssek, Hauke Lehmann, Guido Meier, and Ulrich Merkt	
14.1	Introduction .....	353
14.2	Experimental .....	358
14.2.1	Growth and Structure Investigations .....	358
14.2.2	Electrical Characterization .....	359
14.3	Results and Discussions .....	362
14.3.1	Thin Films .....	362
14.3.2	Nanopatterning .....	367
14.3.3	Heusler-Based Spin-Valves .....	368
14.4	Conclusions .....	370
	References .....	371
<b>15</b>	<b>Charge and Spin Noise in Magnetic Tunnel Junctions .....</b>	<b>373</b>
	Alexander Chudnovskiy, Jacek Swiebodzinski, Alex Kamenev, Thomas Dunn, and Daniela Pfannkuche	
15.1	Introduction .....	374
15.2	Noise and Magnetization Dynamics .....	375

15.3	Langevin-Approach .....	378
15.4	Fokker-Planck Approach to Spin-Torque Switching .....	384
15.5	Switching Time of Spin-Torque Structures .....	390
15.6	Conclusions .....	392
	References .....	393
<b>16</b>	<b>Nanostructured Ferromagnetic Systems for the Fabrication of Short-Period Magnetic Superlattices</b> .....	<b>395</b>
	Sabine Pütter, Holger Stillrich, Andreas Meyer, Norbert Franz, and Hans Peter Oepen	
16.1	Introduction .....	395
16.2	Multilayer Films with Perpendicular Anisotropy .....	397
16.3	Nanostructuring .....	402
16.3.1	Fabrication of Diblock Copolymer Micelles Filled with SiO <sub>2</sub> .....	402
16.3.2	Monomicellar Layers on Substrates .....	402
16.3.3	Fabrication of Antidot Arrays Utilizing Monomicellar Layers .....	403
16.3.4	Fabrication of Dot Arrays Utilizing Monomicellar Layers .....	405
16.4	Magnetic Behavior of Multilayers and Nanostructures .....	408
16.4.1	Multilayers .....	408
16.4.2	Dots .....	411
16.5	Summary .....	412
	References .....	413
<b>17</b>	<b>How X-Ray Methods Probe Chemically Prepared Nanoparticles from the Atomic- to the Nano-Scale</b> .....	<b>417</b>
	Edlira Suljoti, Annette Pietzsch, Wilfried Wurth, and Alexander Föhlisch	
17.1	Local Atomic Structure: Chemical State and Coordination .....	417
17.2	Crystallinity and Cluster Structure .....	421
17.3	Core-Shell Structures on the Nanoscale .....	423
17.4	Summary .....	426
	References .....	427
	<b>Index</b> .....	<b>429</b>