

Contents

Part I. Quantum Dots

A Quantum Dot Single Photon Source

Peter Michler, Alper Kiraz, Christoph Becher, Winston V. Schoenfeld,
Pierre M. Petroff, Lidong Zhang, Evelyn Hu and Atac İmamoğlu3

1. Introduction	3
2. Experimental	5
3. Results	6
4. Summary	12
References	13

Control of Light in Microresonators

Manfred Bayer and Alfred Forchel15

1. Photonic Crystals	16
2. Photonic Crystals with Implemented Defects	18
3. Inhibition and Enhancement of Spontaneous Emission	21
4. Summary	25
References	26

Numerical Renormalization Group Analysis of Interacting Quantum Dots

Walter Hofstetter27

1. Introduction	27
2. Generalized Numerical Renormalization Group	28
3. Interference and Interaction in Multi-level Dots	32
4. Conclusion	36
References	37

Few-Particle Effects in Self-Organized Quantum Dots

Robert Heitz, Volker Türck and Oliver Stier	39
1. The Biexciton Binding Energy	40
2. Single-Dot Spectroscopy on Epitaxial CdSe QDs	42
2.1. Charged Excitons	44
2.2. Lateral Energy Transfer	47
3. Conclusions	48
References	49

Spectroscopy on Single Dots – Monitoring Carrier Interaction with the Environment

Gerd Bacher, Jochen Seufert, Markus K. Welsch, Herbert Schömig, Michael Obert, Vladimir D. Kulakovskii and Alfred Forchel	51
1. Introduction	51
2. Access to Single Quantum Dots	52
3. Charges in Single Quantum Dots – The Stark Effect	53
3.1. External Lateral Electrical Fields	53
3.2. Spectral Diffusion	54
4. Spins in Single Quantum Dots	56
4.1. Exchange and Zeeman Interaction in Nonmagnetic SQDs	56
4.2. Semimagnetic SQDs – Carriers in a Magnetic Environment	58
5. Summary	60
References	61

Optical Spectroscopy on Single Quantum Dots: Charged Excitons

Frank Findeis, Martin Baier, Eric Duijs, Evelin Beham, Max Bichler, Artur Zrenner, Ulrich Hohenester and Elisa Molinari	63
1. Introduction	63
2. Bias Controlled Single Electron Charging	64
3. Spectroscopic Results	65
3.1. Charged Exciton States in Quantum Dots	65
3.2. Comparison with Theoretical Model Calculations	67
3.3. Influence of Magnetic Fields	69
3.4. Charge Equilibrium and Non-equilibrium States	70
4. Summary	72
References	73

Long-Wavelength Buried-Tunnel-Junction Vertical-Cavity Surface-Emitting Lasers

Markus-Christian Amann,, Markus Ortsiefer, Robert Shau, Jürgen Roßkopf, F. Köhler and G. Böhm	75
1. Introduction	75
2. Basic Structure of BTJ-VCSEL	77
3. Laser Characteristics and Discussion	81
4. Conclusion	84
References	84

Part II. Optics**Photon Echo Experiments on Electron-Plasmon Quantum Kinetics in GaAs**

Martin Wegener and Werner Hügel	89
1. Introduction	89
2. Photon Echo Experiments	90
2.1. A Phenomenological Model	93
3. Coherent Control Photon Echo Experiments	94
4. Conclusion	98
References	99

Phonon and Coulomb Quantum Kinetics for Femtosecond Spectroscopy

Hartmut Haug	101
1. Semiclassical Kinetics versus Quantum Kinetics	101
1.1. Non-equilibrium Many-Body Theory and Quantum Kinetics	102
2. Time-Dependent Screening of the Phonon and Coulomb Interactions	104
3. Calculations for Resonant Femtosecond FWM	106
4. Two-Time Calculations for Low-Density DTS with Intermediate Coupling	107
5. Quantum Kinetics of the Bose-Einstein Condensation of Excitons	108
References	112

Quantum Kinetic Effects in Semiconductors Studied via Femtosecond Transmission Measurements

Alfred Leitenstorfer, Markus Betz, Cornelius Fürst and Gernot Göger	113
1. Introduction	113
2. Two-Color Femtosecond Transmission Spectroscopy	115
3. The Fröhlich Interaction in GaAs and CdTe	115

4. LO Phonon Emission of Electrons in GaAs: Energy-Time Uncertainty and Memory Effects	116
5. Sub-threshold Heavy Holes in CdTe: Polaronic Quantum Dynamics ..	120
6. Conclusion	123
References	123

Phonon Quantum Kinetics in Spatially Inhomogeneous Systems

Tilmann Kuhn	125
1. Density Matrix Theory	126
2. Spatially Resolved Quantum Kinetics	130
3. Coherent Phonon Dynamics	132
4. Carrier Trapping	133
5. Conclusions	136
References	136

Propagating Anisotropic Solitons in Active Semiconductor Media

Ortwin Hess and Edeltraud Gehrig	137
1. Introduction	137
2. Solitons in Partially Coherent Active Semiconductor Media?	138
2.1. Maxwell-Bloch Langevin Equations	139
2.2. Spatio-Temporal Refractive Index and Gain Dynamics	141
2.3. Dynamic Spatio-Spectral Dispersion Compensation	144
3. Conclusions	146

Photorefractive Spatial Solitons

Detlef Kip	149
1. Introduction	149
2. Spatial Solitons	151
2.1. Kerr-Type Nonlinearity	151
2.2. Saturable Nonlinearity	152
3. Soliton Interactions	154
3.1. Coherent Interactions	155
3.2. Incoherent Interactions	155
4. Incoherent Solitons	156
4.1. Modulation Instability and Pattern Formation	156
References	158

X-Ray Magneto-Optics

K. Starke, F. Heigl, J. E. Prieto, O. Krupin, A. Vollmer, G. Reichardt, F. Senf, R. Follath, N. B. Brookes and G. Kaindl	161
1. Introduction	161
2. GaAs as Model Example for Magneto-Optical Effects	162
3. Experimental	165
4. 4d-4f XMOKE Spectra of Gd and Tb	165
5. Element Specificity	166
6. Atomic Scattering Factors at Tb $M_{4,5}$	168
7. Conclusions and Outlook	168
References	169

Part III. Electron and Spin Transport

Spintronics: Spin Electronics and Optoelectronics in Semiconductors

Michael Oestreich, Jens Hübner, Daniel Hägele, Markus Bender, Nils Gerhardt, Martin Hofmann, Wolfgang W. Rühle, Heinz Kalt, Thorsten Hartmann, Peter Klar, Wolfram Heimbrodt and Wolfgang Stolz	173
1. Spin Optoelectronics	174
1.1. Spin Dephasing in Semiconductors	177
2. Spin Injection	180
2.1. GaMnAs	182
3. Spin transport	184
4. Conclusion	185
References	186

Transport in Quasi One-Dimensional Systems

Achim Rosch	187
1. Transport in an Anisotropic Fermi Liquid	188
1.1. Pseudo Momentum Conservation Close to Half Filling	188
1.2. Pseudo Momentum and Conductivity	190
1.3. Rigorous Results	191
1.4. Low-Frequency Weight in Fermi Liquid Theory	192
2. Luttinger Liquids	193
2.1. Pseudo Momenta	193
2.2. Competition of Scattering Processes and Role of Integrability ...	196
3. Conclusions	197
References	197

Transport in Nanostructures:**A Comparison between Nonequilibrium Green Functions and Density Matrices**

Andreas Wacker	199
1. Introduction	199
2. General Aspects of Quantum Transport	199
3. Method of Nonequilibrium Green Functions	200
4. A Simple Example	202
5. Treatment by Density Matrices	204
6. Results for Quantum Cascade Laser Structures	207
7. Conclusion	209
References	210

Spin-Orbit Coupling in Two-Dimensional Electron and Hole Systems

R. Winkler, S. J. Papadakis, E. P. De Poortere and M. Shayegan	211
1. Spin-Orbit Coupling Effects in Bulk Semiconductors	212
2. $B = 0$ Spin Splitting and Anomalous Shubnikov- de Haas Oscillations in Quasi 2D Systems ...	214
3. Anisotropic Zeeman Splitting in Quasi 2D Systems	218
References	221

Part IV. Nanostructures

Lanthanide-Silicide Films on Silicon Surfaces

M. Dähne, S. Vandr�, C. Preinesberger, S. K. Becker, W. Busse and T. Kalka	227
1. Introduction	227
2. Experimental Details	228
3. Structure and Electronic Properties of Ln-Silicide Layers on Si(111) .	228
3.1. Two-Dimensional Growth	228
3.2. Photoemission Results	229
3.3. Flat-Band Conditions at the Monolayer	231
3.4. Passivation of the Monolayer	231
4. Growth of Silicide Nanostructures on Si(001)	233
4.1. Closed-Packed Thin Nanowires	233
4.2. Free-Standing Broad Nanowires	234
4.3. Rectangular Islands	236
5. Summary and Outlook	237
References	237

Development of Texture and Microstructure in MgO Buffer Layers**Using Ion-Beam Assisted Pulsed Laser Deposition**

Ruben Hühne, Christoph Beyer, Bernhard Holzapfel, Carl-Georg Oertel, Ludwig Schultz and Werner Skrotzki	239
1. Introduction	239
2. Experimental Details	240
3. Results	241
3.1. Pulsed Laser Deposition	241
3.2. Ion-Beam Assisted Pulsed Laser Deposition	242
3.3. Sputter Experiments on MgO Single Crystals	244
3.4. Homoepitaxial Growth of MgO Using PLD	245
4. Discussion	245
References	247

Modelling of Structure Formation and Mechanical Stresses during Growth of Vapor Deposited Amorphous Thin Films

S. G. Mayr	251
1. Introduction	251
2. Experimental Details	252
3. Experimental Results	253
4. Modelling with Continuum Equations	256
5. Modelling of Intrinsic Stress Formation	260
6. Conclusion	260
References	261

Some Materials Science Aspects of PVD Hard Coatings

Christian Mitterer and Paul H. Mayrhofer	263
1. Introduction	263
2. Coating Deposition	264
3. Interrelationships between Microstructure and Mechanical Properties	266
4. Interrelationships between Microstructure and Thermal Stability	268
5. Conclusions	271
References	272

X-Ray Diffraction and X-Ray Reflectivity Applied to Investigation of Thin Films

David Rafaja	275
1. Introduction	275
2. Overview of Experimental Techniques	277

3. Polycrystalline Thin Films	281
4. Structure of Periodic Multilayers	283
References	286

**Three-Dimensional Electric Field Probing
of Ferroelectrics on the Nanometer Scale
Using Scanning Force Microscopy**

L. M. Eng, S. Grafström, Ch. Loppacher, F. Schlaphof, S. Trogisch, A. Roelofs and R. Waser	287
1. Introduction	287
2. Internal Electric Field Measurements with Piezoresponse Force Microscopy (PFM)	289
3. 3-D Hysteresis Probing on the Nanometer Scale Using PFM	292
4. Access to Surface Chemistry with Kelvin Probe Force Microscopy (KPFM)	293
5. Future Aspects in Nanoscale Investigations of Ferroelectrics	296
6. Conclusions	296
References	297

Part V. Superconducting Systems

Terahertz Hilbert Spectroscopy by High- T_c Josephson Junctions

Yuri Divin, Oleg Volkov, Valery Pavlovskii, Vadim Shirovov, Pavel Shadrin, Ulrich Poppe and Knut Urban	301
1. Introduction	301
2. Theory	302
3. Josephson Junctions	304
4. Hilbert Spectrometers	306
5. Spectral Range	306
6. Instrumental Function	307
7. Power Dynamic Range	308
8. Spectra of Transition Radiation from Electron Bunches	309
9. Polychromatic Emission Spectra from Coherent Oscillators	310
10. Conclusions	311
References	312

Discrete Breathers in Condensed Matter

S. Flach and Y. Zolotaryuk	315
1. Introduction	315
2. Spatial Decay Properties of Discrete Breathers	317

2.1. Algebraically Decaying Interactions	318
2.2. Presence of Goldstone Modes – Acoustic Breathers	318
3. Energy Thresholds for Discrete Breathers	319
4. Quantization and Applications	319
5. Breathers in Classical Spin Lattices	320
5.1. Easy Axis Anisotropy	321
5.2. Easy Plane Anisotropy	322
5.3. The Model and Equations of Motion	323
5.4. Rotobreather Solutions and Their Current-Voltage Dependencies	324
6. Conclusion	325
References	326

**Quantum Phase Transitions and Collective Modes
in d -Wave Superconductors**

Matthias Vojta and Subir Sachdev	329
1. Introduction	329
2. Damping of Nodal Quasiparticles	332
3. Damping of Antinodal Quasiparticles	334
4. Collective Modes Associated with $d_x^2 - y^2 + id_{xy}$ Pairing	336
5. Conclusion	339
References	340

Part VI. Complex Systems

Physics in Cell Biology:

Actin as a Model System for Polymer Physics

Erwin Frey	345
1. Introduction	345
2. The Wormlike Chain Model	347
2.1. Force-Extension Relation	347
2.2. Radial Distribution Function	348
3. Collective Properties	349
3.1. Typical Length and Time Scales; the Tube Picture	350
3.2. Plateau Modulus for Entangled Solutions	351
3.3. Viscoelasticity and High Frequency Behaviour	352
3.4. Effect of Cross Linking	353
4. Summary and Outlook	355
References	356

The Wonderful World of Active Many-Particle Systems

Dirk Helbing	357
1. Introduction	357
2. Beyond Newton	358
3. Vehicle Traffic on Freeways	359
3.1. "Phantom Traffic Jams"	359
3.2. The Rich Variety of Congested Traffic States	360
4. Collective Pedestrian Dynamics	362
4.1. Lane Formation and "Freezing by Heating"	363
4.2. Collective Phenomena at Bottlenecks	365
4.3. "Faster-Is-Slower Effect" Due to Impatience	365
4.4. "Phantom Panics"	366
5. Summary and Outlook	367
References	368

**Pattern Formation in Dissipative Systems:
A Particle Approach**

Mathias Bode	369
1. Introduction	369
2. Stationary Particles	372
2.1. One Component Systems	372
2.2. Two-Component Systems	375
3. Spot-Spot Interactions: The Formation of Molecules	377
References	377

**Structure Formation by Aggregation:
Models and Applications**

Max Kolb	381
1. Models	382
1.1. Diffusion-Limited Cluster Aggregation	382
1.2. Reaction-Limited Aggregation	383
1.3. Other Models: Trajectory, Reversibility, Interaction Range	383
2. Experiments	383
2.1. Aerosols	383
2.2. Colloids	384
2.3. Microgravity	384
3. Gelation	385
3.1. Basic Gel Models	385
3.2. Percolation Like Behaviour	386
References	387

**Amorphous Thin Film Growth:
Modeling and Pattern Formation**

Stefan J. Linz, Martin Raible and Peter Hänggi	391
1. Basics	392
2. Model Equation for Amorphous Thin Film Growth	393
3. The Physics behind the Growth Equation	395
4. Comparison with Experiments	398
5. Some Predictions Based on the Growth Equation	400
6. Conclusion	402
References	402

Dynamic Processes at the Glass Transition

P. Lunkenheimer and A. Loidl	405
1. Introduction	405
2. Dynamic Processes in Glass-Forming Materials	406
3. Experimental Details	408
4. Broadband Dielectric Spectra	409
4.1. The α -Process	411
4.2. The Excess Wing	412
4.3. The Fast β -Process	413
4.4. The Boson Peak	415
5. Summary and Conclusion	416
References	416

Part VII. Semiclassical Theory

**The Trace Formula between Classical
and Quantum Mechanics**

Martin Gutzwiller	421
1. Introduction	421
2. Classical Probability in Time and Space	423
3. The Semiclassical Propagator	424
4. Green's Function for Given Energy E	426
5. The Trace Formula (TF)	428
6. Comments on the TF and Applications	430
7. Short List of Textbooks, Monographs, and Collections	431

Tunneling in Complex Systems and Periodic Orbits

Joachim Ankerhold	433
1. Introduction	433
2. Imaginary Time Tunneling	434
2.1. Tunnel Splittings in Chaotic Potentials	434
2.2. Thermal Quantum Decay Rates	435
3. Semiclassical Real Time Tunneling	437
3.1. General Theory	438
3.2. Periodic Orbits in the Complex Coordinate Plane	439
3.3. Coherent and Incoherent Tunneling	441
3.4. Tunneling in a Scattering Potential	442
4. Conclusions	444
References	444

The Gutzwiller Trace Formula for Quantum Systems with Spin

Jens Bolte	447
1. Dirac- and Pauli-Hamiltonians	448
1.1. Weyl Representation	449
1.2. Spectra	450
1.3. Observables	451
2. Trace Formula	451
2.1. Van Vleck-Gutzwiller Propagator	452
2.2. Semiclassical Spin Transport	453
2.3. Semiclassical Trace Formula	454
3. Applications	456
References	457

Semiclassical Description of Shell Effects in Finite Fermion Systems

Matthias Brack	459
1. Introduction	459
2. Uniform Approximations for Symmetry Breaking and Bifurcations ..	460
3. Applications to Shell Structure in Finite Fermion Systems	463
3.1. Ground-State Deformations of Nuclei and Metal Clusters	463
3.2. Mass Asymmetry in Nuclear Fission	465
3.3. Mesoscopic Systems	467
References	469

Quantum Signatures of Typical Chaotic Dynamics

R. Ketzmerick, L. Hufnagel and M. Weiss	473
1. The Mixed Phase Space	474
2. Hierarchical Eigenfunctions	475
3. Conductance Fluctuations	478
References	479

The Semiclassical Tool in Complex Physical Systems: Mesoscopics and Decoherence

Rodolfo A. Jalabert and Horacio M. Pastawski	483
1. Introduction	483
2. The Semiclassical Tool in Mesoscopic Physics	485
3. Decoherence and Dissipation	488
4. Conclusion	493
References	494

Cohesion and Stability of Metal Nanowires:**A Quantum Chaos Approach**

C. A. Stafford, F. Kassubek and H. Grabert	497
1. Introduction	497
2. Free Electron Model	499
3. Weyl Expansion	501
4. Trace Formulas	501
4.1. A 2D Example	502
4.2. 3D Nanowire with Axial Symmetry	504
5. Universal Force Oscillations	506
6. Quantum Suppression of the Rayleigh Instability	507
References	510

Part VIII. Magnetism

Magnetochemistry: Compounds and Concepts

Heiko Lueken, Helmut Schilder, Thomas Eifert, Klaus Handrick and Felix Hüning	515
1. Survey of Today's Magnetochemistry	515
1.1. Systems with Unique Magnetic Centres	516
1.2. Molecular Systems with Exchange-Coupled Centres	518
1.3. Nanometer-Size Materials	519
1.4. Advances in Magnetochemical Analysis	520

2. The Local View of Magnetochemistry	520
2.1. Organo-Gadolinium Complexes	522
2.2. Ruthenium(III) Halides with Chain Structure	522
2.3. Chromium(III) Halides with Layer Structure	524
2.4. Europium(II) Magnesium Alloys	527
3. Some Perspectives	529
References	530

Lorentz Electron Microscopic Observation of Micromagnetic Configurations in Nanostructured Materials

Josef Zweck, Markus Schneider, Manuela Sessner, Thomas Uhlig
and Martin Heumann

1. Introduction	533
2. Experimental Setup	534
2.1. Specimen Preparation	534
2.2. Magnetising Holder	534
3. Fresnel Imaging	535
3.1. "C"-State vs. "S"-State	536
3.2. Shape Effects in Demagnetisation Cycles	536
3.3. Thickness Dependency of Magnetic Wall Structures	538
3.4. Thickness Dependency of Saturation Field	539
4. Foucault Imaging	539
5. Differential Phase Contrast Imaging (DPC)	539
6. Electron Holography	540
7. Conclusion	541
References	544

Laser-Control of Ferro- and Antiferromagnetism

M. Trzeciecki, O. Ney, G. P. Zhang and W. Hübner

References	555
------------------	-----

Spin-Polarized Photoelectron Emission Microscopy of Magnetic Nanostructures

H. A. Dürr, F. Kronast and W. Eberhardt

1. Introduction	557
2. The Spin-Polarized Photoemission Electron Microscope with Pulsed Laser Excitation	558
3. Two-Photon Photoemission from Nanoscale Dots	560
4. Laterally Resolved Spin Dynamics in Magnetic Materials	562
5. Summary	563
References	564

Study of Excitations in Structurally Incommensurately Modulated Solids by Means of Nuclear Magnetic Resonance

F. Decker, U. Häcker, K.-P. Holzer, M. Irsch, D. Michel, P. Mischo
and J. Petersson

1. Introduction	565
2. Experimental	566
3. NMR Line Shape Measurements in the Vicinity of the N-IC Transition	567
4. Nuclear Spin-Lattice Relaxation Measurements	569
5. Conclusion	574

High Resolution X-Ray Detection Using Metallic Magnetic Calorimeters

Andreas Fleischmann

1. Detection Principle	577
2. Thermodynamic Properties	579
3. Design Optimization	581
4. Prototype Detector	583
5. Fundamental Limitation	584
6. Summary	587
References	588

Magnetotransport Properties of Thin Films of Magnetic Perovskites

Gerhard Jakob, Wilhelm Westerburg, Frank Martin, Daniel Reisinger
and Nicole Auth

1. Introduction	589
2. Thin Film Preparation	590
3. 'Colossal' Magnetoresistivity	591
4. Transport in the Metallic Low Temperature Phase	592
5. Transport in the High Temperature Phase	594
6. Intergrain Transport/Spin-Polarized Tunneling	597
7. Summary	599
References	599

Dynamics of Ferroelectric Domain Walls

Volkmar Mueller

1. Introduction	601
2. Experimental Details	602
2.1. Ferroelectric Systems Examined	602

XXII Contents

2.2. Experimental Setup	604
3. Experimental Results	604
3.1. Nonlinear Domain Wall Response	604
3.2. Non-Debye Domain Wall Dispersion	607
3.3. Domain Wall Related Loss	609
3.4. Time Evolution of the Domain Wall Response	610
4. Summary and Conclusions	611
References	611

Magnetic Nanoparticles:

The Simulation of Thermodynamic Properties

U. Nowak and D. Hinzke	613
1. Introduction	613
2. Model and Simulations	614
2.1. Spin Model versus Continuum Theory	614
2.2. Landau-Lifshitz-Gilbert Equation with Langevin Dynamics	615
2.3. Monte Carlo Methods	616
3. Simulation of Co Nanoparticles	617
3.1. Precessional Reversal	617
3.2. Thermally Activated Reversal	618
4. Conclusions	621

Micromagnetic Simulation of Switching Events

Thomas Schrefl, Hermann Forster, Dieter Suess, Werner Scholz,

Vassilios Tsiantos and Josef Fidler	623
1. Introduction	623
2. Micromagnetic and Numerical Background	625
2.1. Langevin Micromagnetics	625
2.2. Space and Time Discretization	626
3. Thermally Activated Switching	626
3.1. Thermally Activated Reversal of Ellipsoidal Particles	627
3.2. Thermally Induced Nucleation in Magnetic Nanowires	628
4. Domain Wall Motion in Magnetic Nanowires	629
5. Influence of the Damping Constant	631
5.1. Columnar Grains	631
5.2. Circular Nanomagnets	632
References	634

Index	637
--------------------	-----