

Open access • Book • DOI:10.1007/978-3-540-74761-1

Springer handbook of crystal growth — Source link

Govindhan Dhanaraj, Kullaiah Byrappa, Vishwanath Prasad, Michael Dudley

Published on: 01 Jan 2010

Topics: Solid-state physics

Related papers:

- [Crystal growth technology](#)
- [The Growth of Crystals and the Equilibrium Structure of their Surfaces](#)
- [Handbook of Microscopy. Applications in Materials Science, Solid State Physics and Chemistry](#)
- [α activity of natural tungsten isotopes](#)
- [Scintillation properties and radioactive contamination of CaWO₄ crystal scintillators](#)

Share this paper:    

View more about this paper here: <https://typeset.io/papers/springer-handbook-of-crystal-growth-1tks6heju4>

Contents

List of Abbreviations	XXXI
-----------------------------	------

Part A Fundamentals of Crystal Growth and Defect Formation

1 Crystal Growth Techniques and Characterization: An Overview

<i>Govindhan Dhanaraj, Kullaiah Byrappa, Vishwanath (Vish) Prasad, Michael Dudley</i>	3
1.1 Historical Developments	3
1.2 Theories of Crystal Growth	4
1.3 Crystal Growth Techniques	6
1.4 Crystal Defects and Characterization	11
References	15

2 Nucleation at Surfaces

<i>Ivan V. Markov</i>	17
2.1 Equilibrium Crystal–Ambient Phase	18
2.2 Work for Nucleus Formation	24
2.3 Rate of Nucleation	28
2.4 Saturation Nucleus Density	35
2.5 Second-Layer Nucleation in Homoepitaxy	38
2.6 Mechanism of Clustering in Heteroepitaxy	43
2.7 Effect of Surfactants on Nucleation	45
2.8 Conclusions and Outlook	48
References	48

3 Morphology of Crystals Grown from Solutions

<i>Francesco Abbona, Dino Aquilano</i>	53
3.1 Equilibrium Shape	55
3.2 The Theoretical Growth Shape	64
3.3 Factors Influencing the Crystal Habit	71
3.4 Surface Structure	72
3.5 Crystal Defects	73
3.6 Supersaturation – Growth Kinetics	73
3.7 Solvent	75
3.8 Impurities	78
3.9 Other Factors	84
3.10 Evolution of Crystal Habit	85
3.11 A Short Conclusion	86
3.A Appendix	86
References	87

4 Generation and Propagation of Defects During Crystal Growth	
<i>Helmut Klapper</i>	93
4.1 Overview	94
4.2 Inclusions	95
4.3 Striations and Growth Sectors	101
4.4 Dislocations	107
4.5 Twinning	120
4.6 Perfection of Crystals Grown Rapidly from Solution	125
References	127
5 Single Crystals Grown Under Unconstrained Conditions	
<i>Ichiro Sunagawa</i>	133
5.1 Background	134
5.2 Smooth and Rough Interfaces: Growth Mechanism and Morphology	136
5.3 Surface Microtopography	139
5.4 Growth Forms of Polyhedral Crystals	143
5.5 Internal Morphology	146
5.6 Perfection of Single Crystals	152
References	156
6 Defect Formation During Crystal Growth from the Melt	
<i>Peter Rudolph</i>	159
6.1 Overview	159
6.2 Point Defects	163
6.3 Dislocations	176
6.4 Second-Phase Particles	188
6.5 Faceting	191
6.6 Twinning	193
6.7 Summary	194
References	195

Part B Crystal Growth from Melt Techniques

7 Indium Phosphide: Crystal Growth and Defect Control by Applying Steady Magnetic Fields	
<i>David F. Bliss</i>	205
7.1 Historical Overview	205
7.2 Magnetic Liquid-Encapsulated Growth	206
7.3 Magnetic Field Interactions with the Melt	209
7.4 Dislocation Density	216
7.5 Magnetic Field Effects on Impurity Segregation	220
7.6 Optical Characterization of InP:Fe	224
7.7 Summary	226
References	227

8 Czochralski Silicon Single Crystals for Semiconductor and Solar Cell Applications	
<i>Koichi Kakimoto</i>	231
8.1 Silicon Single Crystals for LSIs and Solar Applications	232
8.2 Control of Crystal Defects in Czochralski Silicon.....	237
8.3 Growth and Characterization of Silicon Multicrystal for Solar Cell Applications	239
8.4 Summary	240
References	241
9 Czochralski Growth of Oxide Photorefractive Crystals	
<i>Ernesto Diéguez, Jose Luis Plaza, Mohan D. Aggarwal, Ashok K. Batra</i>	245
9.1 Background	246
9.2 Crystal Growth.....	246
9.3 Design and Development of Czochralski Growth System	247
9.4 Growth of Lithium Niobate Crystals and Its Characteristics	252
9.5 Other Oxide Photorefractive Crystals	262
9.6 Growth of Sillenite Crystals and Its Characteristics	264
9.7 Conclusions	273
References	273
10 Bulk Crystal Growth of Ternary III–V Semiconductors	
<i>Partha S. Dutta</i>	281
10.1 III–V Ternary Semiconductors	282
10.2 Need for Ternary Substrates	283
10.3 Criteria for Device–Grade Ternary Substrates	284
10.4 Introduction to Bridgman Crystal Growth Techniques	286
10.5 Overview of III–V Binary Crystal Growth Technologies	292
10.6 Phase Equilibria for Ternary Compounds.....	300
10.7 Alloy Segregation in Ternary Semiconductors	302
10.8 Crack Formation in Ternary Crystals	304
10.9 Single-Crystalline Ternary Seed Generation Processes.....	308
10.10 Solute Feeding Processes for Homogeneous Alloy Growth	311
10.11 Role of Melt–Solid Interface Shapes	318
10.12 Conclusion	321
References	321
11 Growth and Characterization of Antimony-Based Narrow-Bandgap III–V Semiconductor Crystals for Infrared Detector Applications	
<i>Vijay K. Dixit, Handady L. Bhat</i>	327
11.1 Importance of Antimony-Based Semiconductors.....	329
11.2 Phase Diagrams.....	330
11.3 Crystal Structure and Bonding.....	331
11.4 Material Synthesis and Purification	333

11.5	Bulk Growth of InSb	334
11.6	Structural Properties of InSb, InAs _x Sb _{1-x} , and InBi _x Sb _{1-x}	340
11.7	Physical Properties of InSb, InAs _x Sb _{1-x} , and InBi _x Sb _{1-x}	346
11.8	Applications	357
11.9	Concluding Remarks and Future Outlook	359
	References	360

12 Crystal Growth of Oxides by Optical Floating Zone Technique

	<i>Hanna A. Dabkowska, Antoni B. Dabkowski.....</i>	367
12.1	Historical Notes	367
12.2	Optical Floating Zone Technique – Application for Oxides	368
12.3	Optical Floating Zone and Traveling Solvent Crystal Growth Techniques	369
12.4	Advantages and Limitations of the Floating Zone Techniques	370
12.5	Optical Floating Zone Furnaces	371
12.6	Experimental Details of Ceramics and Rod Preparation for OFZT	372
12.7	Stable Growth of Congruently and Incongruently Melting Oxides	373
12.8	Constitutional Supercooling and Crystallization Front Stability	375
12.9	Crystal Growth Termination and Cooling	377
12.10	Characterization of Crystals Grown by the OFZ Technique	377
12.11	Determination of Defects in Crystals – The Experimental Approach ..	380
12.12	Details of Conditions for Growth of Selected Oxide Single Crystals by OFZ and TSFZ Methods	383
12.13	Conclusions	386
	References	386

13 Laser-Heated Pedestal Growth of Oxide Fibers

	<i>Marcello R.B. Andreetta, Antonio Carlos Hernandes</i>	393
13.1	Fiber-Pulling Research	394
13.2	The Laser-Heated Pedestal Growth Technique	399
13.3	Fundamentals	402
13.4	Fiber Growth Aspects	409
13.5	Conclusions	418
	References	419

14 Synthesis of Refractory Materials by Skull Melting Technique

	<i>Vyacheslav V. Osiko, Mikhail A. Borik, Elena E. Lomonova</i>	433
14.1	Overview	433
14.2	Techniques for Growth of Single Crystals in a Cold Crucible	435
14.3	Growth of Single Crystals Based on Zirconium Dioxide	443
14.4	Glass Synthesis by Skull Melting in a Cold Crucible	465
14.5	Conclusion	469
	References	469

15 Crystal Growth of Laser Host Fluorides and Oxides	
<i>Hongjun Li, Jun Xu</i>	479
15.1 Crystal Growth of Laser Fluorides and Oxides from Melt.....	479
15.2 Laser Crystal Defects	487
15.3 Crystal Growth Techniques Characterization	501
References	503
16 Shaped Crystal Growth	
<i>Vitali A. Tatartchenko</i>	509
16.1 Definitions and Scope of Discussion: SCG by CST	510
16.2 DSC – Basis of SCG by CST.....	512
16.3 SA and SCG by CZT	517
16.4 SA and SCG by VT	519
16.5 SA and SCG by FZT	522
16.6 TPS Capillary Shaping.....	522
16.7 TPS Sapphire Growth	539
16.8 TPS Silicon Growth.....	546
16.9 TPS Metals Growth	551
16.10 TPS Peculiarities	552
References	552

Part C Solution Growth of Crystals

17 Bulk Single Crystals Grown from Solution on Earth and in Microgravity	
<i>Mohan D. Aggarwal, Ashok K. Batra, Ravindra B. Lal, Benjamin G. Penn, Donald O. Frazier</i>	559
17.1 Crystallization: Nucleation and Growth Kinetics	561
17.2 Low-Temperature Solution Growth	566
17.3 Solution Growth by Temperature Lowering	567
17.4 Triglycine Sulfate Crystal Growth: A Case Study	574
17.5 Solution Growth of Triglycine Sulfate Crystals in Microgravity	582
17.6 Protein Crystal Growth	592
17.7 Concluding Remarks	594
References	594
18 Hydrothermal Growth of Polyscale Crystals	
<i>Kullaiah Byrappa</i>	599
18.1 History of Hydrothermal Growth of Crystals.....	603
18.2 Thermodynamic Basis of the Hydrothermal Growth of Crystals	606
18.3 Apparatus Used in the Hydrothermal Growth of Crystals	615
18.4 Hydrothermal Growth of Some Selected Crystals.....	620
18.5 Hydrothermal Growth of Fine Crystals.....	634

18.6	Hydrothermal Growth of Nanocrystals	637
18.7	Concluding Remarks	640
18.A	Appendix	641
	References	646
 19 Hydrothermal and Ammonothermal Growth of ZnO and GaN		
	<i>Michael J. Callahan, Qi-Sheng Chen</i>	655
19.1	Overview of Hydrothermal and Ammonothermal Growth of Large Crystals	657
19.2	Requirements for Growth of Large, Low-Defect Crystals.....	661
19.3	Physical and Mathematical Models.....	666
19.4	Process Simulations	669
19.5	Hydrothermal Growth of ZnO Crystals	674
19.6	Ammonothermal GaN	681
19.7	Conclusion	685
	References	685
 20 Stoichiometry and Domain Structure of KTP-Type Nonlinear Optical Crystals		
	<i>Michael Roth</i>	691
20.1	Background	691
20.2	Stoichiometry and Ferroelectric Phase Transitions	697
20.3	Growth-Induced Ferroelectric Domains	703
20.4	Artificial Domain Structures.....	708
20.5	Nonlinear Optical Crystals	713
	References	716
 21 High-Temperature Solution Growth: Application to Laser and Nonlinear Optical Crystals		
	<i>Joan J. Carvajal, Maria Cinta Pujol, Francesc Díaz</i>	725
21.1	Basics	726
21.2	High-Temperature Solution Growth	731
21.3	Growth of Bulk Laser and NLO Single Crystals by the TSSG Method	736
21.4	Liquid-Phase Epitaxy: Growth of Epitaxial Films of Laser and NLO Materials.....	746
	References	752
 22 Growth and Characterization of KDP and Its Analogs		
	<i>Sheng-Lai Wang, Xun Sun, Xu-Tang Tao</i>	759
22.1	Background	759
22.2	Mechanism and Kinetics of Crystallization	761
22.3	Growth Techniques for Single Crystals.....	769
22.4	Effect of Growth Conditions on Defects of Crystals	776
22.5	Investigations on Crystal Quality	783
	References	789

Part D Crystal Growth from Vapor

23 Growth and Characterization of Silicon Carbide Crystals

<i>Govindhan Dhanaraj, Balaji Raghothamachar, Michael Dudley</i>	797
23.1 Silicon Carbide – Background and History	797
23.2 Vapor Growth.....	799
23.3 High-Temperature Solution Growth	801
23.4 Industrial Bulk Growth by Seed Sublimation	802
23.5 Structural Defects and Their Configurations.....	805
23.6 Concluding Remarks	816
References	817

24 AlN Bulk Crystal Growth by Physical Vapor Transport

<i>Rafael Dalmau, Zlatko Sitar</i>	821
24.1 PVT Crystal Growth.....	822
24.2 High-Temperature Materials Compatibility	825
24.3 Self-Seeded Growth of AlN Bulk Crystals	827
24.4 Seeded Growth of AlN Bulk Crystals	829
24.5 Characterization of High-Quality Bulk Crystals.....	832
24.6 Conclusions and Outlook.....	839
References	839

25 Growth of Single-Crystal Organic Semiconductors

<i>Christian Kloc, Theo Siegrist, Jens Pflaum</i>	845
25.1 Basics	845
25.2 Theory of Nucleation and Crystal Growth	847
25.3 Organic Materials of Interest for Semiconducting Single Crystals	848
25.4 Pregrowth Purification.....	850
25.5 Crystal Growth.....	854
25.6 Quality of Organic Semiconducting Single Crystals	862
25.7 Organic Single-Crystalline Field-Effect Transistors	863
25.8 Conclusions	864
References	865

26 Growth of III-Nitrides with Halide Vapor Phase Epitaxy (HVPE)

<i>Carl Hemmingsson, Bo Monemar, Yoshinao Kumagai, Akinori Koukitu</i>	869
26.1 Growth Chemistry and Thermodynamics	869
26.2 HVPE Growth Equipment.....	872
26.3 Substrates and Templates for Bulk GaN Growth.....	875
26.4 Substrate Removal Techniques	879
26.5 Doping Techniques for GaN in HVPE	882
26.6 Defect Densities, Dislocations, and Residual Impurities	883
26.7 Some Important Properties of HVPE-Grown Bulk GaN Material	887
26.8 Growth of AlN by HVPE: Some Preliminary Results	888
26.9 Growth of InN by HVPE: Some Preliminary Results	890
References	891

27 Growth of Semiconductor Single Crystals from Vapor Phase	
<i>Ramasamy Dhanasekaran</i>	897
27.1 Classifications of Vapor Growth	899
27.2 Chemical Vapor Transport – Transport Kinetics	901
27.3 Thermodynamic Considerations	905
27.4 Growth of II–VI Compound Semiconductors by CVT	912
27.5 Growth of Nanomaterial from Vapor Phase	916
27.6 Growth of I–III–VI ₂ Compounds	917
27.7 Growth of GaN by VPE	925
27.8 Conclusion	929
References	930

Part E Epitaxial Growth and Thin Films

28 Epitaxial Growth of Silicon Carbide by Chemical Vapor Deposition	
<i>Ishwara B. Bhat</i>	939
28.1 Polytypes of Silicon Carbide	941
28.2 Defects in SiC	942
28.3 Epitaxial Growth of Silicon Carbide	944
28.4 Epitaxial Growth on Patterned Substrates	952
28.5 Conclusions	961
References	961

29 Liquid-Phase Electroepitaxy of Semiconductors

<i>Sadik Dost</i>	967
29.1 Background	967
29.2 Early Theoretical and Modeling Studies	971
29.3 Two-Dimensional Continuum Models	977
29.4 LPEE Growth Under a Stationary Magnetic Field	978
29.5 Three-Dimensional Simulations	981
29.6 High Growth Rates in LPEE: Electromagnetic Mobility	992
References	996

30 Epitaxial Lateral Overgrowth of Semiconductors

<i>Zbigniew R. Ztykiewicz</i>	999
30.1 Overview	1000
30.2 Mechanism of Epitaxial Lateral Overgrowth from the Liquid Phase ...	1002
30.3 Dislocations in ELO Layers	1011
30.4 Strain in ELO Layers	1016
30.5 Recent Progress in Lateral Overgrowth of Semiconductor Structures .	1026
30.6 Concluding Remarks	1034
References	1035

31 Liquid-Phase Epitaxy of Advanced Materials

<i>Christine F. Klemenz Rivenbark</i>	1041
31.1 Historical Development of LPE	1042
31.2 Fundamentals of LPE and Solution Growth	1042
31.3 Requirements for Liquid-Phase Epitaxy	1044
31.4 Developing New Materials:	
On the Choice of the Epitaxial Deposition Method	1044
31.5 LPE of High-Temperature Superconductors	1046
31.6 LPE of Calcium Gallium Germanates.....	1055
31.7 Liquid-Phase Epitaxy of Nitrides	1059
31.8 Conclusions.....	1063
References	1064

32 Molecular-Beam Epitaxial Growth of HgCdTe

<i>James W. Garland, Sivalingam Sivananthan</i>	1069
32.1 Overview.....	1070
32.2 Theory of MBE Growth	1073
32.3 Substrate Materials.....	1076
32.4 Design of the Growth Hardware	1088
32.5 In situ Characterization Tools	
for Monitoring and Controlling the Growth	1090
32.6 Nucleation and Growth Procedure.....	1101
32.7 Dopants and Dopant Activation.....	1104
32.8 Properties of HgCdTe Epilayers Grown by MBE	1107
32.9 HgTe/CdTe Superlattices	1112
32.10 Architectures of Advanced IR Detectors	1115
32.11 IR Focal-Plane Arrays (FPAs)	1118
32.12 Conclusions.....	1119
References	1121

**33 Metalorganic Vapor-Phase Epitaxy
of Diluted Nitrides and Arsenide Quantum Dots**

<i>Udo W. Pohl</i>	1133
33.1 Principle of MOVPE.....	1133
33.2 Diluted Nitride InGaAsN Quantum Wells	1137
33.3 InAs/GaAs Quantum Dots	1142
33.4 Concluding Remarks	1148
References	1148

34 Formation of SiGe Heterostructures and Their Properties

<i>Yasuhiro Shiraki, Akira Sakai</i>	1153
34.1 Background	1153
34.2 Band Structures of Si/Ge Heterostructures.....	1154
34.3 Growth Technologies	1156
34.4 Surface Segregation	1157
34.5 Critical Thickness	1161
34.6 Mechanism of Strain Relaxation	1163

34.7	Formation of Relaxed SiGe Layers.....	1165
34.8	Formation of Quantum Wells, Superlattices, and Quantum Wires	1173
34.9	Dot Formation.....	1177
34.10	Concluding Remarks and Future Prospects	1184
	References	1184

35 Plasma Energetics in Pulsed Laser and Pulsed Electron Deposition

	<i>Mikhail D. Strikovski, Jeonggoo Kim, Solomon H. Kolagani.....</i>	1193
35.1	Energetic Condensation in Thin Film Deposition.....	1193
35.2	PLD and PED Techniques	1194
35.3	Transformations of Atomic Energy in PLD and PED	1195
35.4	Optimization of Plasma Flux for Film Growth	1204
35.5	Conclusions.....	1208
	References	1209

Part F Modeling in Crystal Growth and Defects

36 Convection and Control in Melt Growth of Bulk Crystals

	<i>Chung-Wen Lan</i>	1215
36.1	Physical Laws for Transport Processes	1217
36.2	Flow Structures in the Melt	1219
36.3	Flow Control by External Forces	1228
36.4	Outlook.....	1238
	References	1238

37 Vapor Growth of III Nitrides

	<i>Dang Cai, Lili Zheng, Hui Zhang</i>	1243
37.1	Overview of Vapor Growth of III Nitrides	1244
37.2	Mathematical Models for AlN/GaN Vapor Deposition	1248
37.3	Characteristics of AlN/GaN Vapor Deposition	1251
37.4	Modeling of GaN IVPE Growth – A Case Study	1258
37.5	Surface Evolution of GaN/AlN Film Growth from Vapor	1274
37.6	Concluding Remarks	1275
	References	1276

38 Continuum-Scale Quantitative Defect Dynamics in Growing Czochralski Silicon Crystals

	<i>Milind S. Kulkarni</i>	1281
38.1	The Discovery of Microdefects.....	1283
38.2	Defect Dynamics in the Absence of Impurities.....	1284
38.3	Czochralski Defect Dynamics in the Presence of Oxygen	1304
38.4	Czochralski Defect Dynamics in the Presence of Nitrogen	1313
38.5	The Lateral Incorporation of Vacancies in Czochralski Silicon Crystals	1321
38.6	Conclusions.....	1328
	References	1332

39 Models for Stress and Dislocation Generation in Melt Based Compound Crystal Growth	
<i>Vishwanath (Vish) Prasad, Srinivas Pendurti</i>	1335
39.1 Overview.....	1335
39.2 Crystal Growth Processes.....	1336
39.3 Dislocations in Semiconductors Materials	1337
39.4 Models for Dislocation Generation.....	1339
39.5 Diamond Structure of the Crystal	1343
39.6 Deformation Behavior of Semiconductors	1346
39.7 Application of the Haasen Model to Crystal Growth	1350
39.8 An Alternative Model	1351
39.9 Model Summary and Numerical Implementation	1360
39.10 Numerical Results.....	1362
39.11 Summary	1374
References	1375

40 Mass and Heat Transport in BS and EFG Systems	
<i>Thomas F. George, Stefan Balint, Liliana Braescu</i>	1379
40.1 Model-Based Prediction of the Impurity Distribution – Vertical BS System	1380
40.2 Model-Based Prediction of the Impurity Distribution – EFG System..	1389
References	1400

Part G Defects Characterization and Techniques

41 Crystalline Layer Structures with X-Ray Diffractometry	
<i>Paul F. Fewster</i>	1405
41.1 X-Ray Diffractometry	1406
41.2 Basic Direct X-Ray Diffraction Analysis from Layered Structures	1407
41.3 Instrumental and Theoretical Considerations	1412
41.4 Examples of Analysis from Low to High Complexity	1413
41.5 Rapid Analysis.....	1419
41.6 Wafer Micromapping	1420
41.7 The Future	1421
References	1422

42 X-Ray Topography Techniques for Defect Characterization of Crystals	
<i>Balaji Raghothamachar, Michael Dudley, Govindhan Dhanaraj</i>	1425
42.1 Basic Principles of X-Ray Topography	1426
42.2 Historical Development of the X-Ray Topography Technique.....	1428
42.3 X-Ray Topography Techniques and Geometry	1430
42.4 Theoretical Background for X-Ray Topography	1435
42.5 Mechanisms for Contrast on X-Ray Topographs	1440

42.6 Analysis of Defects on X-Ray Topographs	1445
42.7 Current Application Status and Development	1449
References	1450
43 Defect-Selective Etching of Semiconductors	
<i>Jan L. Weyher, John J. Kelly</i>	1453
43.1 Wet Etching of Semiconductors: Mechanisms	1454
43.2 Wet Etching of Semiconductors: Morphology and Defect Selectivity ..	1459
43.3 Defect-Selective Etching Methods	1461
References	1473
44 Transmission Electron Microscopy Characterization of Crystals	
<i>Jie Bai, Shixin Wang, Lu-Min Wang, Michael Dudley</i>	1477
44.1 Theoretical Basis of TEM Characterization of Defects	1477
44.2 Selected Examples of Application of TEM to Semiconductor Systems ..	1493
44.3 Concluding Remarks: Current Application Status and Development ..	1514
References	1515
45 Electron Paramagnetic Resonance Characterization of Point Defects	
<i>Mary E. Zvanut</i>	1521
45.1 Electronic Paramagnetic Resonance	1522
45.2 EPR Analysis	1524
45.3 Scope of EPR Technique	1534
45.4 Supplementary Instrumentation and Supportive Techniques	1538
45.5 Summary and Final Thoughts	1545
References	1546
46 Defect Characterization in Semiconductors with Positron Annihilation Spectroscopy	
<i>Filip Tuomisto</i>	1551
46.1 Positron Annihilation Spectroscopy	1552
46.2 Identification of Point Defects and Their Charge States	1560
46.3 Defects, Doping, and Electrical Compensation	1565
46.4 Point Defects and Growth Conditions	1569
46.5 Summary	1576
References	1576

Part H Special Topics in Crystal Growth

47 Protein Crystal Growth Methods	
<i>Andrea E. Gutiérrez-Quezada, Roberto Arreguín-Espinosa, Abel Moreno</i>	1583
47.1 Properties of Biomacromolecular Solutions	1584
47.2 Transport Phenomena and Crystallization	1587
47.3 Classic Methods of Crystal Growth.....	1587
47.4 Protein Crystallization by Diffusion-Controlled Methods	1588

47.5	New Trends in Crystal Growth (Crystal Quality Enhancement)	1591
47.6	2-D Characterization via Atomic Force Microscopy (Case Study).....	1595
47.7	3-D Characterization via X-Ray Diffraction and Related Methods	1598
References	1599	

48 Crystallization from Gels

<i>S. Narayana Kalkura, Subramanian Natarajan</i>	1607
48.1 Gel Growth in Crystal Deposition Diseases.....	1608
48.2 Experimental Methods.....	1609
48.3 Pattern Formation in Gel Systems.....	1610
48.4 Crystals Grown Using Gel Technique	1611
48.5 Application in Crystal Deposition Diseases	1614
48.6 Crystal-Deposition-Related Diseases	1616
48.7 Calcium Oxalate.....	1617
48.8 Calcium Phosphates	1619
48.9 Hydroxyapatite (HAP).....	1620
48.10 Dicalcium Phosphate Dihydrate (DCPD)	1620
48.11 Calcium Sulfate	1623
48.12 Uric Acid and Monosodium Urate Monohydrate.....	1623
48.13 L-Cystine	1624
48.14 L-Tyrosine, Hippuric Acid, and Ciprofloxacin	1625
48.15 Atherosclerosis and Gallstones	1625
48.16 Crystallization of Hormones: Progesterone and Testosterone	1628
48.17 Pancreatitis.....	1628
48.18 Conclusions.....	1629
References	1630

49 Crystal Growth and Ion Exchange in Titanium Silicates

<i>Aaron J. Celestian, John B. Parise, Abraham Clearfield</i>	1637
49.1 X-Ray Methods.....	1637
49.2 Equipment for Time-Resolved Experiments	1642
49.3 Detectors	1642
49.4 Software	1644
49.5 Types of In Situ Cells	1645
49.6 In-Situ Studies of Titanium Silicates (Na-TS) with Sitinakite	
Topology	1649
49.7 Discussion of In Situ Studies.....	1658
49.8 Summary	1660
References	1660

50 Single-Crystal Scintillation Materials

<i>Martin Nikl, Anna Vedula, Valentin V. Laguta</i>	1663
50.1 Background	1663
50.2 Scintillation Materials.....	1670
50.3 Future Prospects.....	1689
50.4 Conclusions.....	1691
References	1691

51 Silicon Solar Cells: Materials, Devices, and Manufacturing	
<i>Mohan Narayanan, Ted Ciszek</i>	1701
51.1 Silicon Photovoltaics.....	1701
51.2 Crystal Growth Technologies for Silicon Photovoltaics	1704
51.3 Cell Fabrication Technologies	1711
51.4 Summary and Discussion	1715
References	1716
 52 Wafer Manufacturing and Slicing Using Wiresaw	
<i>Imin Kao, Chunhui Chung, Roosevelt Moreno Rodriguez</i>	1719
52.1 From Crystal Ingots to Prime Wafers	1721
52.2 Slicing: The First Postgrowth Process in Wafer Manufacturing	1726
52.3 Modern Wiresaw in Wafer Slicing	1730
52.4 Conclusions and Further Reading	1733
References	1733
 Acknowledgements	1737
About the Authors	1741
Detailed Contents	1759
Subject Index	1791