Contents

Foreword *V*
Preface *XVII*
List of Contributors *XIX*

Part I Basic Concepts in Crystal Growth Technology *1*

1 Thermodynamic Modeling of Crystal-Growth Processes *3*
Eberhard Buhrig, Manfred Jurisch, Jürgen Korb, and Olf Pätzold
1.1 Introduction *3*
1.2 General Approach of Thermodynamic Modeling *4*
1.2.1 Basics *4*
1.2.1.1 State Variables for the Description of Equilibrium Conditions *4*
1.2.1.2 The *ChemSage* Software Package *5*
1.3 Crystal Growth in the System Si–C–O–Ar (Example 1) *6*
1.3.1 Selection of Species *7*
1.3.2 Test Calculation, Check of Consistency *7*
1.3.3 Calculation of Gibbs Free Energy for Selected Reactions *8*
1.3.4 Minimization of Gibbs Free Energy of Complex Systems *9*
1.3.5 The Thermodynamic-Technological Model of the Edge-Defined Film-Fed Growth of Silicon *10*
1.4 Crystal Growth of Carbon-Doped GaAs (Example 2) *15*
1.4.1 Components and Species in the System *16*
1.4.2 Results *17*
1.4.3 Extended Model *19*
1.5 Summary and Conclusions *22*
Acknowledgments *23*
References *23*

2 Modeling of Vapor-Phase Growth of SiC and AlN Bulk Crystals *25*
Roman A. Talalaev, Alexander S. Segal, Eugene V. Yakovlev, and Andrey N. Vorob'ev
2.1 Introduction *25*

Bibliografische Informationen
http://d-nb.info/994011156

digitalisiert durch DEUTSCHE NATIONAL BIBLIOTHEK

2.2 Model Description 28
2.2.1 Quasi-Thermodynamic Model of AlN and AlGaN HVPE 29
2.2.2 Modeling of Gas-Phase Nucleation in SiC CVD and HTCVD 30
2.3 Results and Discussions 31
2.3.1 GaN, AlN, and AlGaN HVPE 31
2.3.2 SiC HTCVD 35
2.4 Conclusions 38
References 39

3 Advanced Technologies of Crystal Growth from Melt Using Vibrational Influence 41
Evgeny V. Zharikov
3.1 Introduction 41
3.2 Axial Vibrational Control in Crystal Growth 42
3.3 AVC-Assisted Czochralski Method 49
3.4 AVC-Assisted Bridgman Method 54
3.5 AVC-Assisted Floating Zone Method 58
3.6 Conclusions 59
Acknowledgments 60
References 60

Part II Semiconductors 65

4 Numerical Analysis of Selected Processes in Directional Solidification of Silicon for Photovoltaics 67
Koichi Kakimoto
4.1 Introduction 67
4.2 Directional Solidification Method 67
4.3 Crystallization Process 68
4.4 Impurity Incorporation in Crystals 71
4.5 Summary 74
Acknowledgment 74
References 74

5 Characterization and Control of Defects in VCz GaAs Crystals Grown without B_2O_3 Encapsulant 75
Frank M. Kiessling
5.1 Introduction 75
5.2 Retrospection 76
5.3 Crystal Growth without B_2O_3 Encapsulant 77
5.4 Inclusions, Precipitates and Dislocations 80
5.5 Residual Impurities and Special Defect Studies 83
5.6 Electrical and Optical Properties in SI GaAs 84
5.7 Boron in SC GaAs 89

5.8 Outlook on TMF-VCz *91*
5.9 Conclusions *94*
Acknowledgments *95*
References *95*

6 The Growth of Semiconductor Crystals (Ge, GaAs) by the Combined Heater Magnet Technology *101*
Peter Rudolph, Matthias Czupalla, Christiane Frank-Rotsch, Frank-Michael Kiessling and Bernd Lux
6.1 Introduction *101*
6.2 Selected Fundamentals *102*
6.2.1 Convection-Driven Forces *102*
6.2.2 The Features of Traveling Magnetic Fields *104*
6.3 TMF Generation in Heater-Magnet Modules *106*
6.4 The HMM Design *107*
6.5 Numerical Modeling *109*
6.6 Dummy Measurements *111*
6.7 Growth Results under TMF *112*
6.7.1 LEC of GaAs *112*
6.7.2 VGF of Ge *114*
6.8 Conclusions and Outlook *118*
Acknowledgment *118*
References *119*

7 Manufacturing of Bulk AlN Substrates *121*
Oleg V. Avdeev, Tatiana Yu. Chemekova, Heikki Helava, Yuri N. Makarov, Evgenii N. Mokhov, Sergei S. Nagalyuk, M.G. Ramm, Alexander S. Segal, and Alexander I. Zhmakin
7.1 Introduction *121*
7.1.1 Substrates for Group III Nitride Devices *121*
7.1.2 Growth of Bulk Group III Nitride Crystals *123*
7.1.3 Sublimation Growth of AlN Crystals *125*
7.2 Modeling *126*
7.3 Experiment *129*
7.3.1 Pregrowth Processing *129*
7.3.2 Seeding and Initial Growth *131*
7.3.3 Growth of Bulk AlN Crystals *131*
7.4 Results and Discussion *131*
7.5 Conclusions *133*
Acknowledgments *133*
References *133*

8 Interactions of Dislocations During Epitaxial Growth of SiC and GaN *137*
Jochen Friedrich, Birgit Kallinger, Patrick Berwian, Elke Meissner
8.1 Introduction *137*

8.2 Classification, Nomenclature and Characterization of Dislocations in SiC and GaN *138*
8.3 Conversion of Basal Plane Dislocations During SiC Epitaxy *141*
8.3.1 Experimental Strategies for Obtaining High Conversion Rates *141*
8.3.2 Driving Force for BPD Conversion *143*
8.4 Reduction of Dislocations During Homoepitaxy of GaN *144*
8.4.1 Objectives and Techniques *144*
8.4.2 Driving Force for Dislocation Reduction *145*
8.5 Conclusions *148*
Acknowledgment *148*
References *148*

9 Low-Temperature Growth of Ternary III-V Semiconductor Crystals from Antimonide-Based Quaternary Melts *151*
Partha.S. Dutta
9.1 Introduction *151*
9.2 Crystal Growth from Quaternary Melts *152*
9.3 Advantages of Quaternary Melts *152*
9.4 Synthesis and Bulk Crystal Growth *154*
9.4.1 Growth from $Ga_{1-x}In_xAs_{1-y}Sb_y$ Melt *158*
9.4.1.1 Growth of $Ga_{1-x}In_xAs$ *158*
9.4.1.2 Growth of $GaAs_{1-y}Sb_y$ *161*
9.4.2 Growth from $Ga_{1-x}In_xP_{1-y}Sb_y$ Melt *161*
9.4.2.1 Growth of $Ga_{1-x}In_xP$ *161*
9.4.3 Growth from $Al_{1-x}Ga_xAs_{1-y}Sb_y$ Melt *163*
9.4.3.1 Growth of $Al_{1-x}Ga_xAs$ *163*
9.4.3.2 Growth of $AlAs_{1-y}Sb_y$ *164*
9.4.4 Growth from $Al_{1-x}In_xAs_{1-y}Sb_y$ Melt *164*
9.4.4.1 Growth of $Al_{1-x}In_xAs$ *165*
9.4.4.2 Growth of $AlAs_{1-y}Sb_y$ *165*
9.4.5 Growth from $Al_{1-x}In_xP_{1-y}Sb_y$ Melt *165*
9.4.5.1 Growth of $Al_{1-x}In_xP$ *166*
9.4.6 Growth from $Al_{1-x}Ga_xP_{1-y}Sb_y$ Melt *166*
9.4.6.1 Growth of $Al_{1-x}Ga_xP$ *166*
9.4.7 Growth from $Al_{1-x-y}Ga_xIn_ySb$ Melt *167*
9.4.7.1 Growth of $Al_{1-x}Ga_xSb$ *168*
9.4.8 Growth from $InP_{1-x-y}As_xSb_y$ Melt *168*
9.4.8.1 Growth of $InP_{1-y}As_y$ *168*
9.4.9 Growth from $GaP_{1-x-y}As_xSb_y$ Melt *169*
9.4.9.1 Growth of $GaP_{1-y}As_y$ *169*
9.4.10 Growth from $AlP_{1-x-y}As_xSb_y$ Melt *170*
9.4.10.1 Growth of $AlP_{1-y}As_y$ *170*
9.5 Conclusion *171*
References *172*

10 Mercury Cadmium Telluride (MCT) Growth Technology Using ACRT and LPE *175*
Peter Capper
10.1 Introduction *175*
10.2 Bridgman/ACRT Growth of MCT *177*
10.2.1 Introduction *177*
10.2.2 Processing *178*
10.2.3 Accelerated Crucible Rotation Technique (ACRT) *178*
10.2.3.1 Introduction *178*
10.2.3.2 High-x Material *179*
10.2.4 Summary *182*
10.3 Liquid Phase Epitaxy of MCT *184*
10.3.1 Introduction *184*
10.3.2 Growth *185*
10.3.3 Summary *191*
References *192*

11 The Use of a Platinum Tube as an Ampoule Support in the Bridgman Growth of Bulk CZT Crystals *195*
Narayanasamy Vijayan, Verónica Carcelén, and Ernesto Diéguez
11.1 Introduction *195*
11.2 The Importance of the Solid/Liquid Interface *197*
11.3 Approaches for Crystal Growth Using Ampoule Support *199*
11.4 Results and Discussions *201*
11.5 Conclusions *208*
Acknowledgments *209*
References *209*

Part III Dielectrics *211*

12 Modeling and Optimization of Oxide Crystal Growth *213*
Svetlana E. Demina, Vladimir V. Kalaev, Alexander T. Kuliev, Kirill M. Mazaev, and Alexander I. Zhmakin
12.1 Introduction *213*
12.2 Radiative Heat Transfer (RHT) *214*
12.3 Numerical Model *217*
12.4 Results and Discussion *218*
12.4.1 Sapphire *219*
12.4.2 Yttrium Aluminum Garnet *219*
12.4.3 Bismuth Germanate (BGO) *222*
12.5 Conclusions *225*
Acknowledgments *225*
References *225*

13 Advanced Material Development for Inertial Fusion Energy (IFE) *229*
Kathleen Schaffers, Andrew J. Bayramian, Joseph A. Menapace, Gregory T. Rogowski, Thomas F. Soules, Christopher A. Stolz, Steve B. Sutton, John B. Tassano, Peter A. Thelin, Christopher A. Ebbers, John A. Caird, Christopher P.J. Barty, Mark A. Randles, Charles Porter, Yiting Fei, and Bruce H.T. Chai
13.1 Introduction *229*
13.2 Production of Nd:phosphate Laser Glass and KDP Frequency-Conversion Crystals *233*
13.2.1 Nd:phosphate Laser Glass *233*
13.2.2 KDP Frequency-Conversion Crystals *235*
13.3 Yb:S-FAP Crystals *235*
13.3.1 Crystal Growth *237*
13.3.2 Modeling *238*
13.3.3 Slab Fabrication *239*
13.4 YCOB Crystals *241*
13.4.1 YCOB Crystal Growth and Fabrication *242*
13.5 Advanced Material Concepts for Power-Plant Designs *243*
13.6 Summary *246*
References *246*

14 Magneto-Optic Garnet Sensor Films: Preparation, Characterization, Application *249*
Peter Görnert, Andreas Lorenz, Morris Lindner, and Hendryk Richert
14.1 Introduction *249*
14.2 Bi-Substituted Garnets *249*
14.3 LPE Deposition and Topological Film Properties *251*
14.4 Magnetic and Magneto-Optic Film Properties *253*
14.4.1 Magnetic Properties *253*
14.4.2 Magneto-Optic Properties *254*
14.4.3 Reproducibility *260*
14.5 Applications *260*
14.5.1 Images of Magnetic Field Distributions *261*
14.5.2 Quantitative Determination of Magnetic Fields *264*
14.6 Conclusions *264*
Acknowledgments *265*
References *265*

15 Growth Technology and Laser Properties of Yb-Doped Sesquioxides *267*
Rigo Peters, Klaus Petermann, and Günter Huber
15.1 Introduction *267*
15.2 Structure and Physical Properties *267*
15.3 Crystal Growth *269*
15.3.1 Growth Methods with Crucibles *269*
15.3.2 Heat-Exchanger Method *270*

15.3.2.1 Crucible *270*
15.3.2.2 Atmosphere *271*
15.3.2.3 Setup *272*
15.3.2.4 Growth Procedure *273*
15.3.2.5 Results *274*
15.4 Spectroscopic Characterization *276*
15.5 Laser Experiments *279*
15.6 Summary and Outlook *280*
Acknowledgment *280*
References *281*

16 Continuous Growth of Alkali-Halides: Physics and Technology *283*
Oleg Sidletskiy
16.1 Modern Requirements to Large Alkali-Halide Crystals *283*
16.2 Conditions of Steady-State Crystallization in Conventional Melt-Growth Methods and in Their Modifications *284*
16.2.1 Conventional Methods *284*
16.2.2 Melt-Feeding Methods *285*
16.2.3 Growth-Process Control *286*
16.3 Macrodefect Formation in AHC *287*
16.4 Dynamics of Thermal Conditions during Continuous Growth *290*
16.5 Advanced Growth-Control Algorithms *292*
16.6 Summary *295*
Acknowledgements *296*
References *296*

17 Trends in Scintillation Crystals *299*
Alexander V. Gektin
17.1 Introduction *299*
17.2 Novel Scintillation Materials *300*
17.3 Scintillation Detectors for Image Visualization and Growth Techniques for Scintillation Crystals *302*
17.4 High Spatial Resolution Scintillation Detectors *305*
17.5 Conclusions *310*
References *312*

Part IV Crystal Machining *313*

18 Crystal Machining Using Atmospheric Pressure Plasma *315*
Yasuhisa Sano, Kazuya Yamamura, and Kazuto Yamauchi
18.1 Introduction *315*
18.2 Plasma Chemical Vaporization Machining (PCVM) *315*
18.2.1 General Description of PCVM *315*
18.2.2 Machining of SiC by PCVM *316*
18.2.3 Beveling of SiC Wafer *317*

18.2.3.1 Background *317*
18.2.3.2 Apparatus and Experimental Method *317*
18.2.3.3 Results and Discussion *318*
18.2.3.4 Summary of Beveling of SiC Wafer *320*
18.2.4 Thinning of SiC Wafer *320*
18.2.4.1 Background *320*
18.2.4.2 Sample Preparation and Experimental Conditions *320*
18.2.4.3 Results and Discussion *320*
18.2.4.4 Summary of Thinning of SiC Wafer *322*
18.3 Numerically Controlled Sacrificial Oxidation *322*
18.3.1 Basic Concepts *322*
18.3.2 Basic Experiments *323*
18.3.2.1 Experimental Apparatus *323*
18.3.2.2 Oxidation Mark *323*
18.3.2.3 Oxidation Rate *324*
18.3.2.4 Surface Roughness *324*
18.3.2.5 Summary of the Basic Experiments *326*
18.3.3 Improving Thickness Uniformity of SOI *326*
18.3.3.1 Background *326*
18.3.3.2 Procedure for Uniformizing *327*
18.3.3.3 Uniformizing of 300 mm SOI *327*
18.3.3.4 Summary of Improving Thickness Uniformity of SOI *328*
18.4 Conclusions *328*
References *329*

Index *331*