

Contents

1 What Do We Want With Fiber Crystals? An Introductory Overview.....	1
Peter Rudolph.....	1
1.1 Introduction.....	1
1.2 Methods.....	3
1.2.1 Micro Floating Zone Methods.....	5
1.2.2 Pulling Techniques from a Die.....	7
1.3 Selected Fundamentals.....	11
1.3.1 Conservation of Mass.....	12
1.3.2 Balance of Heat Transfer.....	12
1.3.3 Capillary Stability.....	13
1.3.4 Segregation and Axial Component Distribution.....	15
1.4 Fiber Materials and their Applications.....	16
1.4.1 Oxides.....	16
1.4.2 Eutectics.....	33
1.4.3 Semiconductors.....	36
1.4.4 Metals.....	38
1.5 Conclusions and Outlooks.....	38
References.....	40
2 Fundamentals of Growth Dynamics of the μ-Pulling Down Method	47
Satoshi Uda.....	47
2.1 Conservation of Mass and Heat and Meniscus Stability of the Molten Zone.....	47
2.2 Solute Transport in Melt and Solid during Growth via the μ -Pulling Down Method.....	50
2.2.1 Analytical Approach.....	50
2.2.2 Example of Fiber Crystal Growth.....	58
2.2.3 Effect of Flow in the Molten Zone.....	61
2.3 Influence of the Interface Electric Field on Solute Partitioning.....	63
2.3.1 Interface Electric Field.....	63
2.3.2 Experimental Setup.....	65
2.3.3 Experimental Results.....	66
2.3.4 Analytical.....	68
2.4 Solute Redistribution by an Interface Electric Field during Fiber Crystal Growth.....	75
2.4.1 Interface Electric Field along the Radial Direction.....	75
2.4.2 Experimental Procedure.....	75
2.4.3 Analytical Investigation.....	79
2.4.4 Influence of the Inverted Temperature Gradient on the Radial Electric Field.....	83
Appendix.....	85
Solution for the partial differential equation, (2.37).....	85
References.....	87

3 Theoretical Analysis of the Micro-Pulling-Down Process	89
C.W. Lan.....	89
3.1 Introduction.....	89
3.2 Model and Solution Scheme.....	90
3.3 Results and Discussion	94
3.3.1 Meniscus Shape and Grown Fiber Size	94
3.3.2 Effect of Convection.....	96
3.3.3 Effect of Pulling Rate	97
3.3.4 Effect of Die Temperature	98
3.3.5 Effect of Melt Height.....	99
3.4 Conclusion	100
References	100
4 Practice of Micro Pulling Down Growth	103
Boris M. Epelbaum.....	103
4.1 Growth of Homogeneous Fibers.....	103
4.1.1 Experimental Observations	104
4.1.2 Conditions for Growth of Axially Homogeneous Fibers	104
4.2 Faceting of μ -PD Fibers and Improvement of Surface Quality.....	108
4.2.1 Experimental Observations	109
4.2.2 Discussion on Fiber Faceting	109
4.3 Crystal Growth Studies with the Micro Pulling Down Method.....	114
4.3.1 Terbium Aluminum Garnet – Phase Diagram and Crystal Growth	114
4.3.2 Lead Tungstate – Problem of Incongruent Melt Vaporization During Growth.....	118
4.3.3 Lead Tungstate – Search for Preferential Growth Direction.....	123
References	126
5 Crystal-Chemistry and Fiber Crystal Growth of Optical Oxide Materials	129
Valery I. Chani	129
5.1 Introduction.....	129
5.2 Apparatus and Procedures.....	130
5.2.1 μ -PD Systems with Resistive Heating	131
5.2.2 μ -PD Systems with RF Heating.....	133
5.2.3 Wetting Properties of the Melt	135
5.2.4 Seeding and Separation of the Grown Crystal.....	136
5.3 $Y_3Al_5O_{12}$ (YAG) Garnet.....	137
5.3.1 Growth of YAG:Nd Crystals.....	137
5.3.2 Properties of YAG:Nd Crystals.....	138
5.3.3 Spatial Distribution of Nd^{3+} in YAG:Nd Crystals.....	139
5.3.4 Growth of YAG:Yb Crystals.....	141
5.4 $Tb_3Ga_5O_{12}$ (TGG) Garnets	144
5.4.1 $Tb_3Ga_5O_{12}$ Fiber Crystal Growth.....	144
5.4.2 $Tb_3Ga_5O_{12}$ Fiber Characterization	146
5.4.3 $Tb_3Ga_5O_{12}$ Bulk Crystal Growth.....	148

5.5 Tb ₃ Al ₅ O ₁₂ (TAG) Based Mixed Garnets	149
5.5.1 Crystal Chemistry of Mixed Garnets	150
5.5.2 (Tb,Lu) ₃ Al ₅ O ₁₂ (TLAG) Fiber Crystals	153
5.5.3 (Tb,Yb) ₃ Al ₅ O ₁₂ (TYAG) Fiber Crystals.....	157
5.6 KNbO ₃ (KN) Based Perovskite Crystals	163
5.6.1 KNbO ₃ Fiber Crystals	164
5.6.2 Flux Growth of KNbO ₃ Fiber Crystals.....	168
5.6.3 Growth of Ta- and Li-Doped KNbO ₃ Fiber Crystals	169
5.7 β-Ga ₂ O ₃ Fiber Crystals	171
5.8 Other Materials.....	173
5.8.1 Ca ₃ (Li,Nb,Ga) ₅ O ₁₂ (CLNGG) Garnet Crystals.....	174
5.8.2 Vanadium Garnet Crystals	178
5.8.3 Rare-Earth Vanadates	179
5.9 Summary	180
References.....	181
6 Oxide Eutectic Crystals for High-Temperature Structural Application... 185	
Akira Yoshikawa	185
6.1 Introduction	185
6.2 Growth Apparatus and Growth Procedures.....	188
6.2.1 Starting Materials and Compositions.....	188
6.2.2 Fiber Growth Assembly and Procedure	188
6.2.3 Evaluation Techniques.....	190
6.3 Oxide Eutectic Crystal Growth, Morphological and Structural Properties.....	191
6.3.1 YAG/Al ₂ O ₃ Eutectic	191
6.3.2 Rare Earth Para-aluminate (Garnet)/Al ₂ O ₃ Eutectic and Rare Earth Ortho-aluminate (Perovskite)/Al ₂ O ₃ Eutectic	199
6.3.3 ZrO ₂ /Al ₂ O ₃ Eutectic	204
6.3.4 Y ₂ O ₃ Stabilized ZrO ₂ /Al ₂ O ₃ Eutectic	208
References.....	216
7 Oxide Fiber Crystals Grown by μ-PD and LHPG Techniques 219	
Kheirreddine Lebbou and Georges Boulon	219
7.1 Introduction	219
7.2 Single Crystal Elaboration by Floating Zone Technique Using a Laser Source as Heater.....	220
7.2.1 The Principle of Zone Melting	220
7.2.2 Species Distribution and Pfann Relation.....	220
7.2.3 LHPG (Laser Heated Pedestal Growth) Technique.....	223
7.3 Pulling Technique from a Meniscus Using the Micropulling Down Technique (μ-PD).....	227
7.4 Illustration of the Fiber Crystal Growth Potential.....	230
7.4.1 Nonlinear Niobate Fiber Crystals LiNbO ₃	230
7.4.2 Ba ₂ NaNb ₅ O ₁₅ (BNN)	231
7.4.3 Sr _x Ba _{1-x} Nb ₂ O ₆ (SBN).....	235
7.4.4 Laser Fiber Crystals : Yb ³⁺ -doped Ca ₈ La ₂ (PO ₄) ₆ O ₂ Oxyapatite.....	238

XII Contents

7.4.5 Superconductors : Bi2212.....	238
7.4.6 Refractory Sesquioxide Fiber Crystals Grown by the LHPG Technique and Proposition of a New Combinatorial Chemistry Approach	240
7.4.7 Example of Application of the Growth of Rare Earth-doped Concentration Gradient Crystal Fibers: Analysis of Dynamical Processes of Laser Resonant Transitions in Yb ³⁺ -doped Y ₂ O ₃	243
7.4.8 Fluoride Crystal Growth (CaF ₂)	248
7.5 Conclusion	250
References	251
8 Growth of Micro and Bulk Crystals by Modified Micro-PD and their Properties	255
Tsuguo Fukuda	255
8.1 Thin Fiber Growth.....	255
8.1.1 Modification of Metal Crucibles for Oxide Growth.	255
8.1.2 Adjustment of Graphite Crucibles for Thin Silicon Fiber Growth.....	261
8.1.3 In-situ Growth of Core-Clad Fiber Structures.....	267
8.1.4 Double-die Modification of the Micro Pulling Down Method....	268
8.1.5 Self-Cladded Eutectic Fibers.....	276
8.2 Bulk Crystal Growth.....	278
References	280