

Contents

1	Introduction	1
1.1	History of Scintillator Developments	1
1.2	Introduction of Conventional Scintillators and Crystal Growth Methods	2
1.2.1	Conventional Scintillator Single Crystals	2
1.2.2	Feature of Single Crystal	3
1.2.2.1	Characteristics of Single Crystal	3
1.2.2.2	Growth Methods of Single Crystal	4
1.2.2.3	Segregation	5
1.2.2.4	Crystal Structure	9
1.2.2.5	Crystallinity and Defects	10
1.2.3	Crystal Growth Methods for Scintillator Single Crystals	14
1.2.3.1	Czochralski Method	14
1.2.3.2	Bridgman Method	21
1.2.3.3	Floating Zone Method	24
1.2.3.4	Micro-Pulling-Down Method	29
1.2.3.5	Edge-Defined Film-Fed Growth Method	40
1.2.3.6	Verneuil Method	41
1.2.3.7	Laser-Heated Pedestal Growth Method	41
1.2.3.8	Skull Melting Method	43
1.2.3.9	Top-Seeded Solution Growth Method	44
1.2.3.10	Arc Melting	45
1.2.3.11	Heat-Exchange Method	47
	References	48
2	Gamma-Ray Scintillators and Crystal Growth Methods	53
	References	53
2.1	Garnet-Type Scintillators and Crystal Growth Methods	55
2.1.1	Gd ₃ (Ga,Al) ₅ O ₁₂ Doped with Ce Scintillators	55
2.1.2	Gd ₃ Ga ₃ Al ₂ O ₁₂ :Ce Scintillators Grown at Various Ga/Al ratios and Their Scintillation Properties	58

2.1.3	Effects of Divalent Cation Co-doping to $\text{Gd}_3\text{Ga}_3\text{Al}_2\text{O}_{12}:\text{Ce}$ on Optical and Scintillation Properties	59
2.1.4	Effects of Monovalent Cation Co-doping to Ce-doped Oxide Scintillators on Optical and Scintillation Properties	64
2.1.4.1	$\text{Lu}_2\text{SiO}_5:\text{Ce},\text{Li}$	64
2.1.4.2	$\text{Lu}_3\text{Al}_5\text{O}_{12}:\text{Ce}$, $\text{Li}/\text{Y}_3\text{Al}_5\text{O}_{12}:\text{Ce}$, Li	67
2.1.4.3	$\text{Gd}_3\text{Ga}_3\text{Al}_2\text{O}_{12}:\text{Ce},\text{Li}$	71
2.1.5	$(\text{Gd},\text{Y})_3(\text{Ga},\text{Al})_5\text{O}_{12}$ Quaternary Garnet Scintillator Crystals	75
2.1.6	Study on the Effect of Co-doping of Ce and Tb ions in Garnet-Type Oxide Single Crystals	76
2.1.7	Shape-Controlled Crystal Growth of Garnet-Type Single Crystals	77
2.1.8	Growth of Garnet-Type Single Crystals Using a Crucible-Free Crystal Growth Method	83
	References	87
2.2	Pyrosilicate-Type Scintillators and Crystal Growth Methods	91
2.2.1	Single-Crystal Growth and Characterization of $\text{Lu}_2\text{Si}_2\text{O}_7$	93
2.2.2	Single-Crystal Growth and Characterization of $\text{Sc}_2\text{Si}_2\text{O}_7$, $\text{Yb}_2\text{Si}_2\text{O}_7$, $\text{Tm}_2\text{Si}_2\text{O}_7$	95
2.2.3	Single-Crystal Growth and Characterization of $\text{Er}_2\text{Si}_2\text{O}_7$, $\text{Y}_2\text{Si}_2\text{O}_7$, $\text{Ho}_2\text{Si}_2\text{O}_7$	99
2.2.4	Single-Crystal Growth and Characterization of $\text{Dy}_2\text{Si}_2\text{O}_7$, $\text{Tb}_2\text{Si}_2\text{O}_7$, $\text{Gd}_2\text{Si}_2\text{O}_7$	101
2.2.5	Single-Crystal Growth and Characterization of $\text{Pr}_2\text{Si}_2\text{O}_7$, $\text{Ce}_2\text{Si}_2\text{O}_7$, $\text{La}_2\text{Si}_2\text{O}_7$	104
2.2.6	Single-Crystal Growth and Characterization of Complex $\text{RE}_2\text{Si}_2\text{O}_7$	109
	References	117
2.3	Halide Scintillators and Crystal Growth Methods	121
2.3.1	Characteristics of Halide Scintillators	121
2.3.2	Development of Crystal Growth Method for Halide Scintillator	123
2.3.2.1	VB Method for Halide Scintillators	123
2.3.2.2	μ -PD Method for Halide Scintillators	124
2.3.2.3	EFG Method for Halide Scintillators	125
2.3.2.4	Cz method for Halide Scintillators	127
2.3.2.5	Evaluation Technique for Halide Scintillators	128
2.3.2.6	Processing Technique for Halide Scintillators	129
2.3.3	Halide Scintillators	129
2.3.3.1	NaI and CsI Scintillators	130
2.3.3.2	LaBr_3 and CeBr_3 Scintillators	130
2.3.3.3	Growth of CeBr_3 Single Crystal by H- μ -PD Method	131
2.3.3.4	$\text{SrI}_2:\text{Eu}$ Scintillator	134
2.3.3.5	Growth of $\text{SrI}_2:\text{Eu}$ Single Crystal by H- μ -PD and H-VB Methods	135

2.3.3.6	AM_2HfX_6 and AM_2ZrX_6 Scintillators (AM: Alkali Metal, X = Cl, Br, I)	136
2.3.3.7	$KCaI_3$ and KAE_2I_5 Scintillators (AE: Alkali-earth Metal)	137
2.3.3.8	Perovskite-Type Halide Scintillators	138
	References	139
3	Neutron Scintillators and Crystal Growth Methods	141
3.1	Development of Crystal Growth Method for Fluoride Scintillator	141
3.1.1	Advantages of Fluoride Scintillator	141
3.1.2	Crystal Growth of Fluoride Single Crystals	141
3.1.3	Generation of Oxyfluoride	146
3.1.4	Crystal Growth Under Large Supercooling Condition	148
3.1.5	Crystal Growth Using Quenching Process	149
3.1.6	Crystal Growth Using Self-flux	149
3.2	Lithium Scintillators	151
3.2.1	Characteristics of Li-Containing Scintillators	151
3.2.2	Colquiriite-Type Fluoride Single Crystals	152
3.2.3	Scheelite-Type Fluoride Single Crystals	155
3.2.4	Fluoride Scintillators with Various Dopants	159
3.2.5	Eutectic Fluoride Scintillators	159
3.2.6	Li-Containing Halide Scintillators	162
3.2.7	Li-Containing Oxide Scintillators	162
3.3	Borate Scintillators	163
3.3.1	Characteristics of B-Containing Scintillators	163
3.3.2	Advantages of Borate Scintillators	164
	References	164
4	VUV Scintillators and Crystal Growth Methods	167
4.1	Characteristics of VUV Scintillators	167
4.2	VUV Scintillators (LaF_3 , $LiCaAlF_6$, $LuLiF_4$, LuF_3 , CaF_2 , BaF_2)	167
4.3	Elpasolite-Type VUV Scintillators	167
4.4	Fluorite VUV Scintillator	168
4.5	VUV Scintillators With Two Dopants	168
	References	170
5	Perspective on Industrial Applications	173
5.1	Development of Mass Production Process for Scintillator Single Crystals	173
5.1.1	Growth of Large Bulk Single Crystal by Cz Method	173
5.1.2	Cz Method Using Double Crucibles	174
5.1.3	Automatic Diameter Control System	174
5.1.4	Continuous Crystal Growth Process of Cz Method Using Residual Melt	175
5.1.5	Shape-Controlled Single Crystals	176
5.1.6	Growth of Multiple Single Crystals by μ -PD Method	178

- 5.1.7 Growth of Single Crystal by μ -PD Method using Continuous Charging System 180
- 5.1.8 Growth of Multiple Single Crystals by VB Method 181
- 5.2 Development of Radiation Detectors 181
 - 5.2.1 Scintillator Array 182
 - 5.2.2 Packaged Halide Scintillators 182
 - 5.2.3 Flexible LiCAF Sheet 183
 - 5.2.4 CLYC:Ce Neutron Scintillator 183
 - 5.2.5 Detectors Using VUV Scintillators 183
- References 184
- Index 185