

Handbook of Advanced Electronic and Photonic Materials and Devices

4

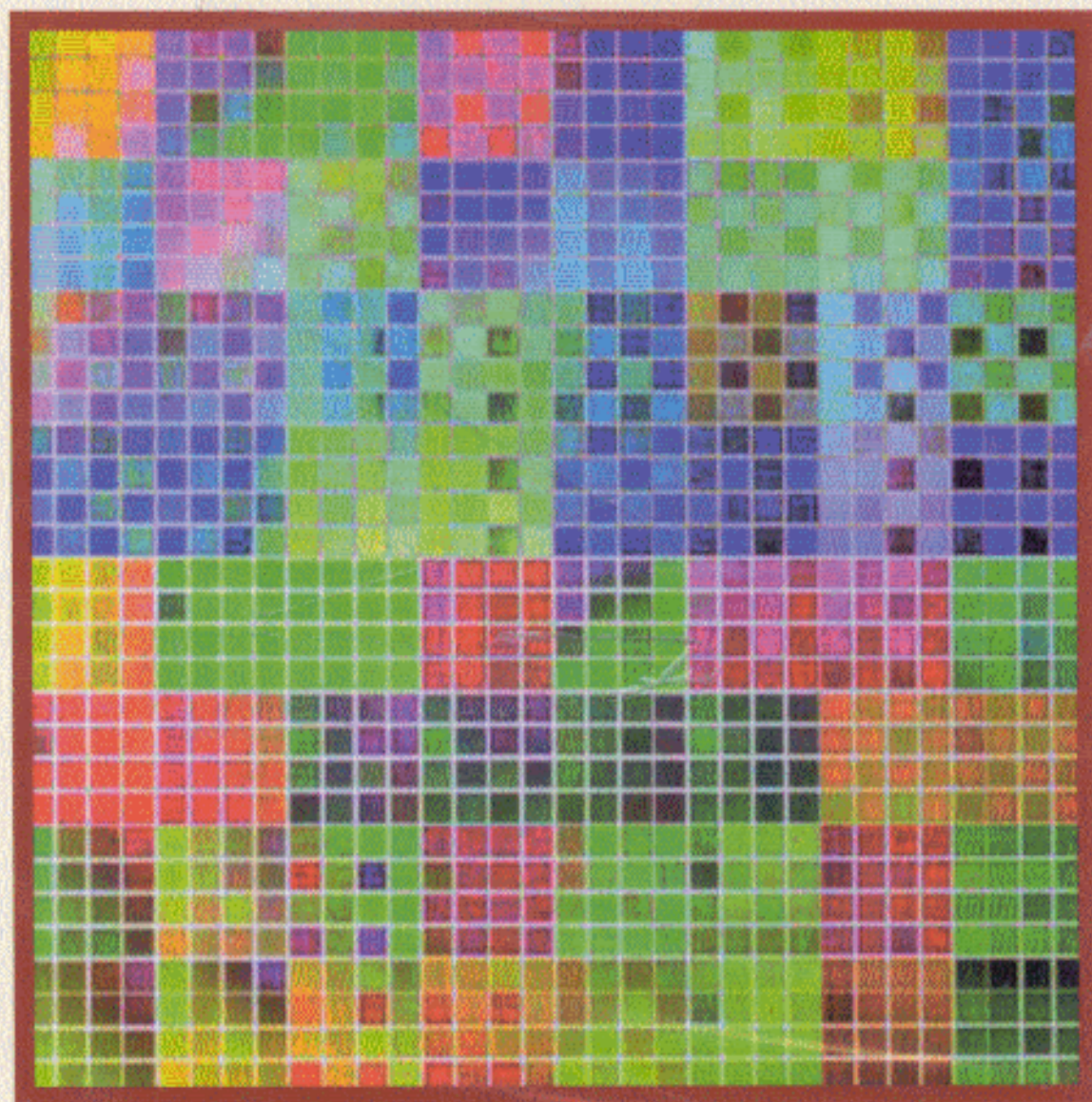
Edited by

Hari Singh Nalwa

Foreword by

Nicolaas Bloembergen, Nobel Laureate

**Ferroelectrics and
Dielectrics**



ACADEMIC
PRESS

Contents

About the Editor	xvii
List of Contributors	xix
Volume Listing	xxi

Chapter 1. PYROELECTRICITY: FUNDAMENTALS AND APPLICATIONS

Sidney B. Lang, Dilip K. Das-Gupta

1. Introduction	1
2. History of Pyroelectricity	2
2.1. Greek and Roman Periods, Dark and Middle Ages	2
2.2. 18th Century	2
2.3. 19th Century	3
2.4. 20th Century	3
3. Theory	4
3.1. Definition of Pyroelectricity	4
3.2. Thermodynamic Relationship of Physical Coefficients	4
3.3. Effect of Domains	7
3.4. Pyroelectricity in Polymers	8
3.5. Ferroelectric Ceramic-Polymer Composites	11
3.6. Models of 0-3 and Mixed Connectivity Composites	14
3.7. Methods of Measurements of Pyroelectric Coefficient	16
4. Pyroelectric Devices and Applications	17
4.1. Single-Element Infrared Detectors	18
4.2. Arrays and Imaging	28
4.3. Photopyroelectric Spectroscopy (PPES)	37
4.4. Determination of Polarization and Space Charge Distributions	41
4.5. Other Applications	46
5. Conclusions	50
Acknowledgments	50
References	50

Chapter 2. CRYSTAL GROWTH, CHARACTERIZATION, AND DOMAIN STUDIES IN LITHIUM NIOBATE AND LITHIUM TANTALATE FERROELECTRICS

Venkatraman Gopalan, Norman A. Sanford, J. A. Aust, K. Kitamura, Y. Furukawa

1. Introduction	58
2. Crystal Growth with Controlled Lithium Stoichiometry	58
2.1. Introduction	58
2.2. Double Crucible Czochralski Method	59
2.3. Crystal Growth Procedure	60
2.4. Characterization of Grown Crystals of Stoichiometric LiTaO_3	60
2.5. Characterization of Grown Crystals of Stoichiometric LiNbO_3	61
2.6. Discussions	61
3. Crystal Uniformity Studies by Maker Fringe Analysis	63
3.1. Introduction	63
3.2. Experimental Apparatus and Data Collection	64
3.3. Modeling of Maker Fringes for x - and z -Cut LiNbO_3 Wafers	64
3.4. o -Polarized Maker Fringes and Thickness Maps of x -Cut Wafers	67

3.5.	<i>e</i> -Polarized Maker Fringes and Variations in Composition of LiNbO ₃ Wafers	69
3.6.	Photoelastic Strain Revealed by Perturbations in the Maker Fringes for <i>x</i> -Cut LiNbO ₃	72
3.7.	Concluding Remarks	75
4.	Ferroelectric Domains and Domain Walls	75
4.1.	Introduction	75
4.2.	Domain Reversal	76
4.3.	Domain Wall Structure	85
5.	The Dynamics of Domain Nucleation and Growth	93
5.1.	Introduction	93
5.2.	Congruent Lithium Tantalate	93
5.3.	Congruent Lithium Niobate	107
5.4.	Stoichiometric Lithium Niobate and Tantalate	111
6.	Concluding Remarks	112
6.1.	Summary of Reviewed Work	112
6.2.	Fundamental Scientific Issues	112
	Acknowledgments	112
	References	112

Chapter 3. BISMUTH VANADATE: A VERSATILE FERROELECTRIC MATERIAL

K. Shantha, K. B. R. Varma

1.	Introduction	116
1.1.	Structural Origin of Ferroelectricity in the Aurivillius Family of Oxides	116
1.2.	Application Potential of Bismuth Vanadate	117
2.	Crystal Structure of Bismuth Vanadate	117
2.1.	The Bi ₂ O ₃ -V ₂ O ₅ Phase Diagram	117
2.2.	The Role of Stoichiometry	117
2.3.	Room-Temperature Structure (α -Phase) of BiV	117
2.4.	Polymorphs of Bismuth Vanadate	118
3.	Bismuth Vanadate Ceramics and Single Crystals	119
3.1.	Preparation	119
3.2.	Dielectric Properties	120
3.3.	Ferroelectric and Pyroelectric Properties	122
4.	Nanocrystalline Bismuth Vanadate	123
4.1.	Mechanochemical Synthesis of Nano-BiV Powders	124
4.2.	Stabilization of the Paraelectric Tetragonal Phase at Room Temperature	124
4.3.	Optical Properties of Nano-BiV Powders	124
5.	Microstructure-Property Correlation in BiV Ceramics	124
5.1.	Grain-Size Control	125
5.2.	Grain-Boundary Modification	127
5.3.	Grain-Orientation	129
6.	Bismuth Vanadate Thin-Films	131
6.1.	Pulsed Laser Deposition (PLD)	131
6.2.	RF Sputtering	131
6.3.	Dielectric Properties	131
7.	Compositional Modification of Bismuth Vanadate	131
7.1.	Doping Mechanisms	132
7.2.	Influence of Doping on Polar Properties	132
7.3.	Influence of Doping on Ionic Conductivity	132
8.	Composites Based on Bismuth Vanadate	133
8.1.	Glass Nanocomposites (GNC)	133
8.2.	Diphase Ceramic Composites	134
9.	Nonpolar Applications	135
10.	Future Directions	136
11.	Conclusions	136
	Acknowledgments	136
	References	136

Chapter 4. ELECTRIC FIELD INFLUENCE ON ACOUSTIC WAVES

B. D. Zaitsev, I. E. Kuznetsova

1. Introduction	139
1.1. Theoretical and Experimental Investigation of Electroacoustic Interaction in Nonlinear Electrostrictive Materials	140
1.2. Theoretical and Experimental Investigation of Electroacoustic Interaction in Nonlinear Piezoelectric Materials	141
1.3. Conclusion	143
2. Theory of Electroacoustic Interaction in Dielectric Materials	143
2.1. General Equations	143
2.2. Propagation of Bulk Acoustic Waves in Nonlinear Crystals Placed in an External Electric Field	146
2.3. Propagation of Surface Acoustic Waves in Nonlinear Crystals Placed in an External Electric Field	148
2.4. Propagation of Plate Acoustic Waves in Nonlinear Crystals Placed in an External Electric Field	150
3. Influence of an External Electric Field on Characteristics of Acoustic Waves in Strontium Titanate	151
3.1. Description of Material	151
3.2. Influence of an External Electric Field on the Properties of BAW in Strontium Titanate	151
3.3. Influence of an External Electric Field on the Properties of SAW in Strontium Titanate	158
3.4. Influence of an External Electric Field on the Properties of Plate Acoustic Waves in Strontium Titanate	160
4. Influence of an External Electric Field on the Properties of Acoustic Waves in Lithium Niobate	161
4.1. Description of Material	161
4.2. Influence of an External Electric Field on the Properties of BAW in Lithium Niobate	162
4.3. Influence of an External Electric Field on the Properties of SAW in Lithium Niobate	169
4.4. Influence of an External Electric Field on the Properties of Plate Acoustic Waves in Lithium Niobate	171
5. Conclusion	173
References	173

Chapter 5. DIELECTRIC CERAMICS

Y. S. Cho, K. H. Yoon

1. Introduction	175
2. Dielectric Principles and Theory	176
2.1. Dielectric Constant and Loss	176
2.2. Polarization	177
2.3. Dielectric Strength	178
2.4. Ferroelectricity	179
3. Materials and Applications	181
3.1. Ceramic Insulators	181
3.2. Ceramic Substrates	183
3.3. Chip Capacitors	186
3.4. Microwave Dielectrics	191
3.5. Thick Film Dielectrics	193
3.6. Thin Film Dielectrics	195
References	197

Chapter 6. LOW- k MATERIALS FOR MICROELECTRONICS INTERCONNECTS

*Patrick G. Chiu, David T. Hsu, Hyung-Kun Kim, Frank G. Shi,
Hari Singh Nalwa, Bin Zhao*

1. Requirements of Low- k Dielectrics	203
1.1. Low- k Materials—Why Do We Need Them?	203
1.2. Materials Characterization of Low- k Dielectrics	204
1.3. Measuring Dielectric Film Thickness	204
1.4. Characterization of Electrical Properties of Dielectric Thin Films	205
1.5. Thermal Properties of Dielectric Films	206
1.6. Chemical and Physical Properties of Dielectric Thin Films	208
2. Processing and Integration Challenges	209
2.1. Deposition Methods of Low- k Dielectric Thin Films	209
2.2. Etching of Low- k Dielectrics	210
2.3. Planarization Issues	210
2.4. Step Coverage of Dielectric Thin Films	211
2.5. CMP Processing of Low- k Dielectrics	211
3. Oxide Films ($k > 4.0$)	211
3.1. Various Oxide Films	212
3.2. Processing of Oxide Films	212
3.3. Dielectric Properties of Oxide Films	213
4. Dielectric Films with $k = 3.0$ – 4.0	213
4.1. SiOF, Fluorosilicate Glass (FSG)	213
4.2. Hydrogen Silsesquioxane (HSQ)	215
5. Low- k Polymers with $k = 2.5$ – 2.8	216
5.1. SiLK	216
5.2. Poly(aryl ethers)	217
5.3. Poly(p -xylylenes)	218
5.4. Polynorbornene	219
5.5. Bisbenzocyclobutene	219
5.6. Fluorinated and Nonfluorinated Polyimides	220
5.7. Polyquinolines	222
5.8. Perfluorocyclobutane	223
5.9. Parylene N and F	224
5.10. Poly(phenylquinoxaline) (PPQ)	224
5.11. Diamond-like Carbon	225
6. Dielectric Films with $k < 2.0$	225
6.1. Polytetrafluoroethylene (PTFE)	225
6.2. Nanoporous Silica	227
6.3. Nanoporous Methylsilsesquioxane (MSSQ)	229
6.4. Gas and Air-Gap Structures	229
7. Future Trends and Conclusions	229
References	230