

Matias Acosta

# Strain Mechanisms in Lead-Free Ferroelectrics for Actuators

Doctoral Thesis accepted by  
Technical University of Darmstadt, Germany

 Springer

# Contents

<b>1 Introduction</b> .....	1
Bibliography .....	4
<b>2 Theoretical Background</b> .....	7
2.1 Dielectrics .....	7
2.2 Classification of Dielectrics .....	10
2.2.1 Ferroelectrics .....	14
2.2.2 Relaxor Ferroelectrics .....	20
2.3 Electromechanical Enhancements in Ferroelectrics .....	27
2.3.1 Composition Engineering .....	28
2.3.2 Structure Engineering .....	33
Bibliography .....	37
<b>3 Literature Review: Piezoceramics for Actuator Applications</b> .....	43
3.1 The $(1 - x)\text{Ba}(\text{Zr}_{0.2}\text{Ti}_{0.8})\text{O}_3 - x(\text{Ba}_{0.7}\text{Ca}_{0.3})\text{TiO}_3$ System .....	46
3.1.1 Processing .....	46
3.1.2 Atomic Structure .....	47
3.1.3 Microstructure .....	49
3.1.4 Electromechanical Properties .....	51
3.2 The $(1 - x)(\text{Bi}_{1/2}\text{Na}_{1/2})\text{TiO}_3 - x\text{SrTiO}_3$ System .....	53
3.2.1 Processing .....	53
3.2.2 Atomic Structure .....	55
3.2.3 Microstructure .....	57
3.2.4 Electromechanical Properties .....	57
Bibliography .....	59
<b>4 Experimental Procedure</b> .....	65
4.1 Powder and Ceramic Processing .....	65
4.2 Structural Characterization .....	67
4.2.1 Atomic Characterization .....	67
4.2.2 Microstructural Characterization .....	69

4.3	Thermal Analysis . . . . .	71
4.4	Electrical Characterization . . . . .	71
4.4.1	Temperature- and Frequency-Dependent Dielectric Properties . . . . .	71
4.4.2	Small Signal Properties . . . . .	72
4.4.3	Temperature- and Frequency-Dependent Quasi-Static Large Signal Properties . . . . .	73
	Bibliography . . . . .	75
<b>5</b>	<b>Results and Discussions . . . . .</b>	<b>77</b>
5.1	The $(1 - x)\text{Ba}(\text{Zr}_{0.2}\text{Ti}_{0.8})\text{O}_3 - x(\text{Ba}_{0.7}\text{Ca}_{0.3})\text{TiO}_3$ System . . . . .	77
5.1.1	Atomic Characterization . . . . .	77
5.1.2	Microstructure Characterization . . . . .	79
5.1.3	Electrical Characterization . . . . .	81
5.1.4	Strain Mechanisms of the $(1 - x)\text{Ba}(\text{Zr}_{0.2}\text{Ti}_{0.8})\text{O}_3 - x(\text{Ba}_{0.7}\text{Ca}_{0.3})\text{TiO}_3$ System . . . . .	102
5.2	The $(1 - x)(\text{Bi}_{1/2}\text{Na}_{1/2})\text{TiO}_3 - x\text{SrTiO}_3$ System . . . . .	111
5.2.1	Synthesis Study . . . . .	111
5.2.2	Atomic Characterization . . . . .	113
5.2.3	Microstructure Characterization . . . . .	117
5.2.4	Electrical Characterization . . . . .	122
5.2.5	Effect of Microstructure on the Quasi-Static Large Signal Properties . . . . .	134
5.2.6	Strain Mechanisms of the $(1 - x)(\text{Bi}_{1/2}\text{Na}_{1/2})\text{TiO}_3 - x\text{SrTiO}_3$ System . . . . .	135
	Bibliography . . . . .	144
<b>6</b>	<b>Conclusions . . . . .</b>	<b>151</b>
<b>7</b>	<b>Remarks and Future Work . . . . .</b>	<b>155</b>
	Bibliography . . . . .	157
	<b>Appendix I: Nomenclature for Core-Shell Microstructures . . . . .</b>	<b>159</b>
	<b>Appendix II: Electromechanical Equations . . . . .</b>	<b>163</b>
	<b>Appendix III: Dielectric Relaxation in the <math>(1 - x)\text{Ba}(\text{Zr}_{0.2}\text{Ti}_{0.8})\text{O}_3 - x(\text{Ba}_{0.7}\text{Ca}_{0.3})\text{TiO}_3</math> System . . . . .</b>	<b>165</b>
	<b>Appendix IV: Cycling Reliability of the <math>(1 - x)(\text{Bi}_{1/2}\text{Na}_{1/2})\text{TiO}_3 - x\text{SrTiO}_3</math> System . . . . .</b>	<b>167</b>
	<b>Appendix V: Application-Oriented Characterization . . . . .</b>	<b>169</b>
	<b>Summarized Curriculum Vitae . . . . .</b>	<b>173</b>