

Index

a

abnormal grain growth (AGG) 40
 aliovalent doping 54
 alkaline carbonate 37, 39
 anti-resonance frequencies 8
 anti-resonating frequency 8
 antiferroelectric 1, 19, 23, 24, 26, 33,
 86–90, 100, 107
 antiferroelectric PNRs 89
 antiferroelectric relaxor 89
 antiferroelectricity 1, 23
 antiferromagnetism 158, 159–161, 162,
 183
 atomic force microscopy (AFM) 108,
 143, 159, 172
 average cubic symmetry 99

b

ball-milled powder 37
 BaTiO₃ system
 ceramics 125–128
 history 123–125
 single crystal 128–130
 BaTiO₃-based solid solution ceramics
 129–135
 (Ba,Ca)(Ti,Hf)O₃ 134–135
 (Ba,Ca)(Ti,Sn)O₃ 132–134
 (Ba,Ca)(Ti,Zr)O₃ 130–132
 piezoelectricity enhancement
 domain engineering 137–138
 phase engineering 135–137
 texturing 139
 sintering processes 139–140

glass compositions 141–142
 Li-containing sintering additives
 140–141
 mechanical property 142–144
 Berlincourt method 10–12
 BiFeO₃-based ceramics 28
 BiFeO₃ system
 dielectric permittivity 169–170
 domain wall conductivity 172–174
 electrical conductivity and defects
 170–172
 ion substitutions 174–175
 ferroelectricity 175–177
 on magnetic properties 177–178
 on phase transformation 177, 178
 magnetoelectric coupling
 antiferromagnetic switching
 161–162
 ferroelectricity, on magnetic field
 162–163
 multiferroic materials 157–158
 multiferroicity 159
 antiferromagnetism 159–161
 ferroelectricity 159
 phase diagram
 high curie temperature and
 processing issues 163–165
 influence of pressure 165–166
 thin film and strain effect 166–169
 BiFeO₃-based solid solutions
 applications 180–184
 ferroelectricity and electronics
 181–182

- BiFeO₃-based solid solutions (*contd.*)
- magnetolectric coupling and spintronics 182–184
 - BiFeO₃-BaTiO₃ 178–180
 - solid solutions 180
- (Bi_{1/2}Na_{1/2})TiO₃ system
- BNT system 85–86
 - high converse piezoelectricity 93, 94
 - depolarization temperature, modulation 103–106
 - electric-field-induced phase transition 95–98
 - ergodic and non-ergodic relaxor 98–102
 - high-power application 110–112
 - phase diagram
 - complex phase structure 90–93
 - MPB 90–93
 - relaxor or antiferroelectric 86–90
 - single crystals 109
 - thin films 106–108
- bipolar loading 60
- bismuth ferrite (BiFeO₃) 27
- bismuth layer-structured ferroelectric ceramics (BLSFs) 28
- bonding fraction 54, 55
- broad bandwidth (BW) 202, 208, 210
- bulk BiFeO₃ 158, 159, 170, 171, 177
- bulk single crystals 124
- Burns temperature (T_B) 98
- C**
- camera focusing system 85
 - cation displacements 89, 93
 - chamber shrinkage 202
 - chemical heterogeneity 53
 - “complex domain” structure 89
 - compositional modification approach 103–104
 - conductive electrodes 202
 - conductive ferroelectric domain walls 158
 - constant electrical displacement 3
 - constant electrical field 3, 7
 - constant strain 3
 - constant stress 3, 7
 - convergent beam electron diffraction (CBED) 48, 137, 138
 - corner-linked oxygen octahedra 123
 - coupling factor 8, 9, 19, 67, 131
 - crystalline quartz 5
 - crystalline substances 4
 - cycloid spin configuration 163
- d**
- depolarization temperature (T_d) 87, 103, 107
 - depolarization temperature, modulation 103
 - composite approach 104–105
 - compositional modification approach 103–104
 - stress approach 105–106
 - Device Under Test (DUT) 10
 - dielectric constant 7, 19, 22, 26, 35, 41, 48, 67, 136, 138, 164, 169, 170, 177, 179, 180
 - dielectric relaxation behavior 87
 - differential scanning calorimetry (DSC) 179
 - diffraction patterns 26, 58, 96, 98
 - diffusionless process 129
 - domain backswitching 129
 - domain wall based electronics 184
 - domain wall conductivity 157, 158, 169–174, 184, 185
 - dopants, effects of 37, 41, 46, 47, 48, 49, 53, 54, 56, 60, 103, 128, 176, 177
 - double-loop P - E hysteresis 85
 - dynamic fluctuation 89
- e**
- E-field 5
 - ejecting ink 202
 - electric displacement 3, 10, 14, 199
 - electric field component 3
 - electric-field-induced strain (S_E) 93–94
 - electrical poling 6, 96, 158

electrically-induced antiferromagnetic switching 161
 electromechanical coupling coefficient 7, 8, 15, 110, 128, 134, 202, 208
 electromechanical coupling factors 67
 electronegativity 23, 54, 55
 energy harvesting devices 67, 197
 ergodicrelaxor (ER) 94, 98
 ethanolamine 107

f

fatigue-free behavior 58
 ferroelectric crystal 6
 ferroelectric domain walls 158, 159, 184
 ferroelectric field-effect transistors 181
 ferroelectric materials 3, 4, 5, 6, 20, 45, 56, 124, 142, 174, 183
 ferroelectric polarization 5, 158, 162, 163, 170, 181, 182
 ferroelectric state controls 184
 ferroelectric-to-relaxor phase transition temperature (T_{F-R}) 103
 ferroelectricity 1, 3, 22, 23, 27, 33, 123–125, 138, 157–159, 162–163, 175–177, 180, 181–182, 183, 185
 first order transition 164, 170
 flexible energy harvesters 206
 flux method 109
 frequency dispersion 85, 87, 89, 101, 106, 170
 fuel injector 201

g

Gibbs free energy 165

h

high electric-field-induced strain 26, 85, 112
 high-performance lead-free piezoelectrics
 BaTiO₃ 21–23
 BiFeO₃ 27–28
 (Bi_{1/2}Na_{1/2})TiO₃ 25–27
 (K,Na)NbO₃ 23–25
 high-power piezoelectric materials 110

higher-order magnetoelectric coupling 161, 162

homogeneous composition 67
 hot-pressing 39, 41
 hot-press sintering 125
 hybridization of covalency 23
 hydrothermal process 67

i

inhomogeneous microstructure 41
 inkjet printheads 201
 intrinsic dielectric permittivity 169
 ionic conduction mechanism 172
 irreversible electric-field-induced phase transition 88, 99
 irreversible relaxor-ferroelectric phase transition 99
 irreversible thermodynamic process 38

k

(K,Na)NbO₃ system
 crystal structure and phase diagram 33–36
 development of, KNN-based materials 36–37
 fatigue 57–60
 history of 33
 KNN thin films 62–67
 physical methods 65–67
 sol-gel-processed films 63–65
 mechanical properties 60–62
 piezoelectricity enhancement 44–45
 multiscale heterogeneity 53–57
 phase engineering 45–49
 poling techniques 57
 thermal stability 49–53
 single crystals 67–68
 synthesis 37
 calcination 37–38
 sintering 38–43
 tecturing 43–44
 KNN ceramics mechanism 39
 KNN-based materials 33
 KNN-based piezoceramics 200

l

- lamellar domains 98
- lanthanum-doped lead zirconatetitanate 87
- laser-heated pedestal growth (LHPG) technique 128
- lattice parameters 44, 46, 92, 106, 168
- lead magnesium niobate 87
- lead titanate (PbTiO_3) 19
- lead zirconate (PbZrO_3) 1, 19, 20, 24, 33, 86, 125, 185, 197
- lead-free perovskite ferroelectrics 139
- lead-free piezoelectric ceramics
 - KNN-based actuation structure in inkjet printhead 201–202
 - KNN-based knocking sensors 205–206
- piezoelectric multilayer actuators 199–201
- potential applications
 - energy harvesting 206–208
 - high-frequency medical imaging transducers 208–210
 - high-temperature piezoelectrics and applications 210
 - ultrasonic transducers 202–205
- lead-free piezoelectric materials 20
- lead-free prototype devices 197
- linear electromechanical interaction 3
- linear magnetoelectric effect 163
- lithium doping 47
- Lyddane–Sachs–Teller effect 170

m

- macroscopic polarization 7
- magneto-crystalline anisotropy energy 160
- magnetoelectric coupling
 - ferroelectricity, on magnetic field 162–163
- maximum electric-field-induced strain 94
- Maxwell–Wagner mechanism 170

- mechanical quality factor (Q_m) 9, 20, 52, 86, 110, 111, 112, 132, 133, 134, 202, 203, 210
- mechanical stress 1, 2, 3, 6, 7, 8, 106
- 2-methoxyethanol 108
- Michelson interferometer 12, 13
- microelectromechanical systems (MEMS) 62, 106, 206, 207
- microprobe methods 172
- microwave sintering (MWS) 39, 41–43, 125, 126, 131, 132, 139
- Mn-doped compositions 112
- monoclinic (M) 92
- monoclinic symmetry 34
- morphotropic phase boundary (MPB) 1, 2, 19, 20, 25–27, 49, 51, 68, 85, 86, 87, 90–93, 98, 103, 107, 110–112, 130, 135, 137, 138, 177, 179
- multiferroic materials 157–158
- multiferroicity 157, 159, 182
- multilayer grain growth (MLGG) 43
- multiscale heterogeneity 53–57

n

- Néel temperature 157, 158, 160, 178
- nano-electromechanical system (NEMS) 67
- nanodomain structures 137
- nickel iodine boracite, ($\text{Ni}_3\text{B}_2\text{O}_{13}\text{I}$) 158
- niobate-based materials 33
- niobium oxide 37
- non-centrosymmetric crystal structure 4
- non-polar paraelectric (P_E) 98–99
- “non-polar” phase 88
- non-textured polycrystalline materials 139
- nonergodicrelaxor (NR) 99
- normal remnant polarization 175, 177
- normal sintering 39–41, 62, 68, 126, 131
- n-type conductance 172

o

- orthorhombic perovskite structure 43
- orthorhombic phase (O) 25, 123
- orthorhombic structure 33, 34, 35, 124

p

parallel resonant frequency 16
 Pb-containing piezoceramics 23
P4bm symmetry 89, 90, 92
P-E loop 5, 7, 86, 95, 99, 103
 permittivity 8, 35, 87, 92, 107, 123, 130, 131, 136, 144, 157, 169–174
 perovskite ferroelectrics 92, 139, 159, 178
 perovskite piezoelectric material 85
 perovskite structure 19, 25, 26, 27, 34, 43, 64, 123
 phase engineering
 O–T phase boundary 45–47
 R–T phase boundary 47–49, 51
 piezoelectric actuators 27, 28, 85, 199–201
 piezoelectric cantilevers 206
 piezoelectric charge 3, 7–8, 10, 13, 16, 68, 85, 131, 205
 piezoelectric charge (strain) constant 7–8
 piezoelectric coefficient 3, 10, 12–14, 19, 21, 27, 28, 33, 36, 45, 52, 57, 64, 67, 107, 108, 109, 128, 130, 134, 137
 piezoelectric constant 1, 3, 4, 7–8, 15, 24, 25, 43, 67, 94, 125
 piezoelectric coupling coefficient 8–9
 piezoelectric displacement 14, 199
 piezoelectric effect 1, 2–3, 180
 piezoelectric energy harvesting 206
 piezoelectric materials 1, 2, 3, 4, 6, 7, 12, 20, 21, 33, 35, 57, 60, 110, 123, 125, 139, 144, 157, 180, 197, 198, 203, 206, 211
 piezoelectric parameters
 piezoelectric constants
 piezoelectric charge (strain) constant 7–8
 piezoelectric voltage coefficient (g-constant) 8
 piezoelectric properties
 laser interferometer 12–14

 resonance and anti-resonance method 14–16
 piezoelectric voltage coefficient (g-constant) 8
 piezoelectricity, fundamentals of
 ferroelectric properties 3–7
 piezoelectric effects 2, 3
 piezoelectric parameters
 mechanical quality factor 9
 piezoelectric constants 7–8
 piezoelectric coupling coefficient 8–9
 piezoresponse force microscopy (PFM) 65, 66, 100, 101, 102, 108
 polar nanoregions (PNRs) 56, 86–90, 92, 96, 98–99, 106
 polarization magnitude 4
 polarization rotation 35, 49, 137
 polarization-electric field loop 5
 poling process 6, 7, 27, 36, 57, 124
 poling techniques 36, 45, 57
 polycrystalline 1, 6, 38, 47, 57, 64, 68, 93, 107, 124, 137, 139, 142, 163, 174, 175, 177, 181
 polycrystalline ceramics 38, 68, 124, 142
 polycrystalline piezoceramics 57
 polycrystalline piezoelectric ceramics 1
 polycrystalline rhombohedral BiFe₃ 163–164
 polymorphic phase transition (PPT) effect 25, 45, 49, 51, 52, 60
 potassium dihydrogen phosphate (KDP) 21, 123
 “pseudo-cubic” phase 88
 pseudo-cubic structure 27, 96
 pulsed laser deposition (PLD) 65, 67, 107
 pyroelectric crystal 4
 pyroelectrics 4

q
 quartz. BaTiO₃ 21
 quasi-static method 12, 14
 quasi-static piezo d_{33} -meter 10

r

R-T phase transition 48, 50
 radio frequency (RF) magnetron
 sputtering 65, 107
 Raman spectroscopy 48, 136
 Rayleigh law 12
R3c symmetry 89, 93, 98
 reactive templated grain growth (RTGG)
 43, 139
 reciprocal-space map (RSM) 65, 66, 92
 relative dielectric constant 7, 22, 136
 relaxor antiferroelectric 89
 relaxor ferroelectric 26, 53, 56, 86, 87,
 90, 99, 101, 105, 106, 131
 relaxor ferroelectric material 53, 56, 131
 relaxor transforms 98
 remnant polarization 5, 6, 7, 25, 27, 41,
 57, 64, 85, 128, 158, 159, 175,
 177
 resonance frequencies 8
 resonating frequency 8
 Restriction of the use of certain
 Hazardous Substances in electrical
 and electronic equipment (RoHS)
 20, 197
 reversible domain switching mechanism
 129
 rhombohedral (R) symmetry 85
 rhombohedral (R) phase 25, 130, 131,
 178
 rhombohedral crystal structure 21
 rhombohedral distortion 92
 rhombohedral phase 20, 34, 48, 49, 68,
 88, 91, 109, 123, 124, 130, 132, 135,
 136, 164, 166
 rhombohedral regions 1
 rhombohedral Zr-rich phase 19
 rhombohedral-orthorhombic-cubic 164
 rhombohedral-orthorhombic phase
 transition temperature 47, 164
 rhombohedral-pseudocubic (R-Pc) phase
 boundary 133, 179
 rhombohedral-tetragonal phase 109
 rhombohedral-orthorhombic (R-O) 27,
 47, 48, 49, 51, 52, 135

R3m symmetry 92

root mean squared (RMS) 11

s

saturated hysteresis loops 175
 saturation polarization 5, 6
 sealed ink chamber 202
 seed-free solid-state crystal growth
 method (SFSSCG) 67
 selected area electron diffraction (SAED)
 88, 98
 sintering 38
 HP 41
 MWS 42, 43
 normal sintering 39–41
 SPS 41, 42
 sol-gel process 107
 spark plasma sintering (SPS) 41–43, 125
 ϵ -T spectra 87, 89, 101, 106
 spherical-aberration-corrected
 transmission electron microscope
 (TEM) 42, 46, 48, 65, 66, 88, 89,
 91, 92, 93, 96, 100, 101, 126, 127,
 137, 138
 spontaneous polarization 5, 21, 22, 34,
 35, 49, 57, 65, 67, 87, 129, 159
 stoichiometric starting oxides 163
 strain component 3
 strain constant 3, 7, 8, 206
 stress approach 103, 105–106
 stress component 3
 stress-induced ferroelastic domain
 switching mechanism 143
 substantial crack driving force 144
 substantial effort 21
 superlattice diffraction 89, 97
 superlattice diffraction spots 89, 97
 switchable polarization 182
 synchrotron X-ray reciprocal space
 mapping (RSM) 65, 66, 92

t

tantalite-based materials 33
 temperature-dependent dielectric
 spectrum 85

- temperature-dependent strain loops 85
 - templated grain growth (TGG) 43, 125, 126, 132, 139
 - tetragonal (T) phase 25, 130
 - tetragonal regions 1
 - tetragonal-orthorhombic polymorphic phase transition 45, 47
 - texturing technique 36, 131, 139
 - thermal stability 25, 37, 45, 49–53, 56, 58, 68, 201
 - thermodynamic instability, of BiFeO_3 164, 165
 - the temperature at maximum permittivity (T_m) 107
 - top-seeded solution growth (TSSG) technique 67, 128, 109
 - transmission electron microscopy (TEM) 42, 46, 48, 65, 66, 88, 89, 91, 92, 93, 96, 100, 101, 126, 127, 137, 138
 - triglycine sulfate (TGS) 21
 - tunneling magnetoresistance (TMR) 183, 184
 - type-I multiferroics 158
 - type-II multiferroics 158
- U**
- ultrasonic cleaner 202, 203, 204
 - ultrasonic motor 110, 197, 202, 203, 204
 - unipolar fatigue 58, 59, 144
 - “unrecoverable” strain (S_{irr}) 95
- V**
- Vickers indentation technique 143
 - virtual-ground amplifier 10
 - Voigt matrix notation 3
 - volatilization, of organic compounds 63
- W**
- Waste Electrical and Electronic Equipment (WEEE) 20
- Z**
- zero polarization state 5

