
Contents

1 From Smart Materials to Piezo-composites	1
1.1 Piezo-composites as an Important Group of Smart Materials.....	1
1.1.1 Smart Materials	1
1.1.2 Composites	1
1.1.3 Piezo-active Composites	2
1.2 Classification of Composite Materials	4
1.2.1 Connectivity	4
1.2.2 Sizes and Shape	4
1.2.3 Arrangement	4
1.2.4 Classification, Connectivity Patterns and Specific Examples	5
References.....	9
2 Effective Electromechanical Properties in Piezo-composites	11
2.1 Piezoelectric Medium and Its Properties	11
2.2 Sum, Combination and Product Properties	22
2.2.1 Sum Properties.....	22
2.2.2 Combination Properties	22
2.2.3 Product Properties	24
2.3 Methods for Evaluation of Effective Parameters	25
2.4 Evolution of α - β Connectivity Patterns	30
2.5 Modelling of Effective Properties in Piezo-composites with Planar Interfaces	32
2.6 Connectivity – Links – Properties.....	35
References.....	35
3 Non-monotonic Volume-fraction Dependences of Effective Properties in α-β Ceramic / Polymer Piezo-composites	43
3.1 Composites with 2–2 Connectivity, Manufacturing and Applications....	43
3.1.1 Effective Electromechanical Constants of 2–2 Composites.....	46
3.1.2 Examples of Volume-fraction Dependences Predicted for 2–2 Composites.....	48
3.2 Composites with 1–3 Connectivity, Manufacturing and Applications	52

3.2.1	Examples of Volume-fraction Dependences Predicted for 1–3 Composites.....	54
3.2.2	Diagrams of Changes in Piezoelectric Properties Predicted for 1–3 Composites.....	57
3.2.3	Maxima of Squared Figures of Merit of 1–3 Composites.....	61
3.3	Composites with 0–3 Connectivity, Manufacturing and Applications....	62
3.3.1	Modelling of the Effective Properties in 0–3 Composites with Spheroidal Inclusions.....	63
3.3.2	Piezoelectric Properties in 0–3 Composites Based on PbTiO ₃ -type Ceramics.....	65
3.3.3	0–3 Composites with a Hierarchy of Inclusions.....	75
3.3.4	0–3 Composites with Planar Microgeometry.....	82
3.4	Composites with 3–3 Connectivity, Increasing the Piezoelectric Sensitivity and Applications.....	85
3.5	Connectivity – Non-monotonic Behaviour – Manufacturing.....	92
	References.....	93
4	Piezoelectric Response of Porous Ceramic and Composite Materials Based on (Pb, Zr)TiO₃	101
4.1	Porous Materials, General Characteristic and Manufacturing	101
4.2	Volume-fraction Dependences of Parameters of Porous Piezo-active Materials	103
4.3	Model of the Modified Layered Composite: Application to Porous Materials	110
4.4	Comparison of Calculated and Experimental Results.....	111
4.5	From 3–3 Connectivity to Porous Materials.....	116
	References	118
5	Effective Properties in Novel Piezo-composites Based on Relaxor-ferroelectric Single Crystals	123
5.1	Relaxor-ferroelectric Solid Solutions and Engineering	123
5.2	0–3 Single Crystal / Ceramic Composites.....	125
5.3	0–1–3 Single Crystal / Ceramic / Polymer Composites.....	132
5.4	1–3 Single Crystal / Ceramic Composites.....	142
5.5	1–0–3 Single Crystal / Polymer Composites	150
5.6	High Performance in Wide Ranges.....	154
	References	155
6	Comparison of Results on Two-component Piezo-composites	159
6.1	The Pros and Cons of Different Methods	159
6.2	0–3 Versus 2–2 or 1–3.....	160
6.3	Data on 1–3 Composites.....	165
6.3.1	Composites with Cylindrical Ceramic Rods.....	165
6.3.2	Composites with Parallelepiped-shaped Ceramic Rods.....	168
6.3.3	Variational Bounds for Effective Properties in 1–3 Composites with Cylindrical Ceramic Rods.....	171

6.3.4 Variational Bounds for Effective Properties in 1–3 Composites with Parallelepiped-shaped Ceramic Rods.....	173
6.4 Data on 0–3 Composites	175
References	182
7 Conclusions.....	185
7.1 From Components to Effective Electromechanical Properties	185
References	186
Appendix Formulae for Effective Electromechanical Constants of 2–2 and 1–3 Piezo-composites	187
References	189
List of Abbreviations.....	191
About the Authors	193
Index.....	195