

ELECTRONIC COMPOSITES

Electronic composites, whose properties can be controlled by thermal or electromagnetic means, play an important role in micro- and nano-electromechanical systems (MEMS/NEMS) such as sensors, actuators, filters and switches. This book describes the processing, simulation, and applications of electronic composites, beginning with a review of their mechanical, thermal, electromagnetic, and coupling behavior; their major applications are then discussed. All the key simulation models are described in detail and illustrated by reference to real examples. The book closes with a discussion of electronic-composite processing, including MEMS design and packaging. It contains a comprehensive list of references and is aimed at graduate students of electrical engineering, mechanical engineering and materials science. It will also be a useful reference for researchers and engineers in the electronic packaging and MEMS industry.

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To My Family, Makiko, Ken, Satoko and Michio

Contents

<i>Preface</i>	<i>page</i> ix
<i>Acknowledgements</i>	xi
1 Introduction	1
1.1 What is an electronic composite?	1
1.2 Early modeling of electronic composites	2
1.3 Concept of electric, magnetic, and thermal circuits	15
2 Applications of electronic composites	19
2.1 Electronic packaging	19
2.2 Micro-electromechanical systems (MEMS) and BioMEMS	23
2.3 Composites for sensors and actuators	39
2.4 Control of electromagnetic waves	51
3 Foundations of modeling	69
3.1 Introduction	69
3.2 Mechanical behavior	73
3.3 Thermal behavior	82
3.4 Electromagnetic behavior	87
3.5 Coupling behavior	119
3.6 Electrostriction	123
3.7 Magnetostriction	124
3.8 Piezomagnetism	125
4 Models for electronic composites based on effective medium theory	126
4.1 Law-of-mixtures model	126
4.2 Effective property tensor of a composite	130
4.3 Eshelby model	136
4.4 Concentration factor tensors	154
5 Resistor network model for electrical and thermal conduction problems	163
5.1 Electrical conduction	163
5.2 Thermal conduction	165
5.3 Comparison of model predictions with experimental data	169

viii	<i>Contents</i>	
6	Percolation model	173
6.1	Percolation model based on base lattices	173
6.2	Electrical conductivity by effective medium theory	180
6.3	Electrical conduction by percolation model	182
6.4	Fiber percolation model	187
6.5	Percolation model applied to piezoresistive elastomer composites	192
6.6	Percolation in a particle composite	200
7	Lamination model	208
7.1	Classical lamination theory under hygro-thermomechanical loading	208
7.2	Lamination theory applied to piezoelectric laminates	214
7.3	Accurate model for cylindrical bending of piezoelectric laminate composites	217
7.4	Design of functionally graded microstructure of piezoactuators	220
7.5	Thermal stress in coating/substrate system	232
7.6	Electromagnetic waves in laminated composites	254
8	Engineering problems	271
8.1	Processing	271
8.2	Standard measurement methods of properties	284
8.3	Electromigration	313
Appendix A	Eshelby tensors	325
A1	Eshelby tensor S_{ijkl} for elasticity	325
A2	Eshelby tensors S_{ij} for uncoupled physical behavior	330
A3	Eshelby tensors for ellipsoidal inclusions in piezoelectric matrix	331
A4	Eshelby tensors in matrix form	333
Appendix B	Physical constants and properties of materials	338
B1	Physical constants	338
B2	Thermal properties of popular packaging materials	338
B3	Dielectric constants ϵ_r of popular materials	340
B4	Magnetic properties of soft and hard magnets	341
	<i>References</i>	342
	<i>Author index</i>	352
	<i>Subject index</i>	357

Preface

The subject of “electronic composites” is both old and new. Electromagnetic properties (particularly dielectric constant and electric conductivity) of electronic composites have been studied extensively since the time of James Maxwell in the nineteenth century, while electronic composites are key materials for microelectronics that today include computer packages, actuators, sensors and micro-electromechanical systems (MEMS), nano-electromechanical systems (NEMS) and BioMEMS.

The aim of this book is to provide readers with an introductory knowledge of various models that can relate the parameters of nanostructure and/or microstructure of the constituent materials to the overall properties of the electronic composites. The readers that the author wishes to reach are graduate students and engineers who are interested in and/or involved in designing microelectronic packages, actuators, sensors, and MEMS/NEMS/BioMEMS. To determine the optimum micro- and nanostructure of electronic composites, a knowledge of the modeling of electronic composites necessarily precedes processing of the composites. This book provides a summary of such modeling. The contents of this book are introductory in early chapters (1–3) and more comprehensive in later chapters (4–8). To help readers who want in-depth knowledge, the book contains detailed appendices and a long list of references.

The author wrote a paper on “Micromechanics modeling of electronic composites” (Taya, 1995) and has been teaching “Electronic composites” as a graduate course at the University of Washington since 1998; the contents of the book originate from his lecture notes. There are no textbooks on electronic composites, presumably because electronic composites are strongly interdisciplinary, covering a wide variety of subjects. The author was motivated to edit his lecture notes into this book by including more recent subjects related to electronic composites.

Chapter 1 introduces a definition of electronic composites and their early study during the nineteenth and twentieth centuries. Chapter 2 discusses various types of electronic composites that are used in current applications: electronic packaging and MEMS, BioMEMS, sensors and actuators, and also the control of electromagnetic waves. In Chapter 3, the foundation is given of the basic equations that govern the physical behavior of electronic composites, ranging from thermomechanical to electromagnetic behavior. Chapter 4 is a key chapter of the book, discussing in detail modeling of electronic composites based on effective medium theory, which ranges from the rudimentary theory of the law of mixtures to the more rigorous Eshelby model of coupled behavior such as piezoelectricity. Chapters 5 and 6 discuss the resistor network model and the percolation model, respectively, which are effective for cases that cannot be modeled by the effective medium theory, providing a nanostructure–macro-behavior relation for electronic composites. Chapter 7 discusses the lamination model, which is simple but effective in estimating the overall behavior of electronic composites with laminated microstructure associated often with a number of modern microelectronic devices. This chapter includes design of (i) piezoelectric actuators for bending mode, (ii) thermal stress analysis in a thin film on a substrate, and (iii) electromagnetic wave propagation in laminated composites with two examples: switchable window and surface plasmon resonance. The final chapter (Chapter 8) opens with a discussion on selected engineering problems associated with the processing of electronic composites, to acquaint readers with current processing routes, ranging from lithography to deposition of organic films. This is followed by an account of standard measurements of key thermophysical properties and electromigration.

In all chapters, both index formulations with subscripts and symbolic notations are used. The former is sometimes needed for readers to grasp the exact relations in the governing equations while the latter provides readers with a simple expression, yet leading to matrix formulation, the most convenient form for numerical calculations.

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xiii

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