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

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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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