**MULTICHIP MODULE
TECHNOLOGIES AND ALTERNATIVES:
THE BASICS**

Cover Photo

Courtesy of Unisys photographer, Paul Robinson. The top MCM is a hermetic processor module utilizing the *latest* MCM-D technology with fine pitch, high lead count, flip TAB connections. The bottom three packages are MCM-C modules with conventional wire bond connections. These modules are described in Chapter 14.

MULTICHIP MODULE
TECHNOLOGIES AND ALTERNATIVES:
THE BASICS

Edited by:
Daryl Ann Doane
Paul D. Franzon

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DEDICATION

This book is dedicated with sincere gratitude
to the 42 authors who contributed their knowledge,
suggestions and many hours of writing
to form the chapters we requested.
Without their diligence, timeliness of response and
patience with our requests
for additional or alternative information,
there would be no book.

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FOREWORD

Far from being the passive containers for semiconductor devices of the past, the packages in today's high performance computers pose numerous challenges in interconnecting, powering, cooling and protecting devices. While semiconductor circuit performance measured in picoseconds continues to improve, computer performance is expected to be in nanoseconds for the rest of this century - a factor of 1000 difference between on-chip and off-chip performance which is attributable to losses associated with the package. Thus the package, which interconnects all the chips to form a particular function such as a central processor, is likely to set the limits on how far computers can evolve.

Multichip packaging, which can relax these limits and also improve the reliability and cost at the systems level, is expected to be the basis of all advanced computers in the future. In addition, since this technology allows chips to be spaced more closely, in less space and with less weight, it has the added advantage of being useful in portable consumer electronics as well as in medical, aerospace, automotive and telecommunications products. The multichip technologies with which these applications can be addressed are many. They range from ceramics to polymer-metal thin films to printed wiring boards for interconnections; flip chip, TAB or wire bond for chip-to-substrate connections; and air or water cooling for the removal of heat.

While there are several books now on packaging, these books deal with the subject of multichip modules as part of packaging in general, or they treat a particular multichip module technology or they are at an advanced level. What is needed, therefore, is a *comprehensive book at the basic level*, structured so that anyone entering the field can quickly learn about the technologies, understand the tradeoffs, review the product examples, and make systems level decisions.

Such a book has been provided by Daryl Ann Doane and Paul D. Franzon. They have worked with an outstanding team of packaging experts from industry and universities. Together they have produced **Multichip Module Technologies and Alternatives: The Basics**, an outstanding book for both industry and university use. It is equally appropriate as an introduction to the multichip module technologies for those just entering the field, and as an up-to-date basic technical book for those currently practicing in it.

The book deals with the subject of multichip modules along three parts: systems level perspectives including packaging technology options and costs, the basics of ceramic, thin film and printed wiring board technologies as well as chip and module level connections; thermal and electrical design considerations including electrical testing; and finally product examples illustrating how multichip modules have been useful.

The basic and integrated nature of the book clearly reflects the dedication and the hard work of the editors and the authors.

Rao R. Tummala
IBM Fellow

PREFACE

Welcome!

Welcome to our book. We feel it is a unique book in the field of packaging and we hope you find it both useful and enjoyable. We (editors and authors) have certainly enjoyed bringing it to you!

Uniqueness of the Book

This is a very unique book! Its uniqueness comes about in two ways: first in the approach to the subject, and second, in the approach to the writing of the book.

First, we feel that this book helps define a turning point in the discipline of packaging. The “bottleneck” to increased systems performance is now more often the package than the chip. One effect of this is that suddenly a whole “breed” of engineers need to gain an understanding of how package design affects their systems performance and cost goals. Another effect is the widespread recognition that multichip module packaging technologies are possible solutions to this performance limitation. The attendant explosive growth in the MCM technology alternatives available is a testimony to this recognition.

Until recently, packaging was mainly the domain of mechanical and materials specialists, and furthermore was rarely taught at universities. *This has changed.* Almost overnight, the pressure of high on-chip speeds and high transistor counts meant that packaging became a subject that must be understood by just about any engineer involved in designing a system. When these engineers tried to establish their understanding they found themselves in a virtual “Tower of Babel.” First, often the same terms were used for different things or, just as bad, different terms were used for the same thing. Second, as this was the domain of specialists, significant background was required in each discipline in order to understand it. This book turns the discipline of packaging into a subject accessible to the generalist rather than just one accessible to the specialist. Common terms are defined and crosslinked to the terms in current usage. Each discipline is presented in such a way that is both understandable to all and is useful. In providing this book, we help turn packaging into a discipline in which anyone can participate. We also present a book highly suited for teaching within a university.

The book also is unique in how it was created! Packaging is a multidisciplinary subject. We realized that no two people can claim mastery of all the disciplines needed and involved in the subjects we wished to cover. We also realized that rapid writing was important. Thus an edited text was called for. But edited texts are often poorly lacking in terms of understandability and flow. Usually an editor relies on selecting appropriate experts and then accepting what each expert writes with minor alterations.

This book is very different. It could be called a “closely edited” text. Each chapter has had the heavy hand of development of both editors in it. This happened in several forms. Often we spent many hours with individual authors defining what we thought was appropriate and guiding them in the actual writing. In all cases, as well as seeking outside reviewers, we wrote “anonymous” reviews ourselves. In some cases, we directly adjusted the text after it was submitted. Thus we are responsible for the final product as much as each chapter author is.

The result, we feel, is a book that has the authority that comes with a book written by a team of experts, but has the understandability, completeness and flow of a book written by a single author. At least we hope that the book comes as close to that ideal as possible!

Audience

For whom is the book intended? **This book is for everyone!** The emphasis in the book is on understanding the fundamentals and the reporting of real

experiences rather than including a huge amount of data. It is intended for those who need a broad exposure to the concepts underlying the design, fabrication, packaging, assembly, manufacturing of multichip modules and the costs associated with alternative packaging technologies. The book is intended for applications, manufacturing and design engineers as well as for technical decision makers and managers who are confused about MCM issues but who wish to understand the fundamentals and basics. Specifically, it will be useful to

- **engineers** in design, processing, fabrication, manufacturing, assembly and test who need to choose a packaging technology for specific product and application goals;
- **managers** determining technology alternatives for new systems needs;
- **marketing; sales technologists** who need a working knowledge of the alternative MCM technologies.

The book also is a suitable text for advanced undergraduate and graduate students in design, electrical, mechanical and systems engineering as well as for students in the applied sciences as discussed further on in this Preface.

Philosophy of the Book

What are the key decisions needed when considering using MCM technologies? There are four perspectives: materials, manufacturing, systems performance and cost requirements. The book presents the basics of MCM technologies from these four perspectives with an emphasis on decision-making. How do you choose a packaging technology from a systems performance, cost perspective? What are the fundamental materials and manufacturing issues that need to be considered? Is the packaging strategy appropriate to the design goal?

This book is applications-oriented in the sense that it discusses

- Examples of MCMs and the products and systems in which they have been used,
- Examples of equipment and processes used to design, build and test MCMs,
- Actual case studies and insights provided by leading companies themselves rather than a summary of reported results.

Organization of the Book

The book is divided into four parts which we call

- Part A - The Framework
(Making Decisions: The Big Picture)
- Part B - The Basics
- Part C - Case Studies
- Part D - Closing the Loop

Each Part begins with what we call a “frame” in which we summarize the purpose or goals of the Part. The frames alert the reader to what theme dominates in the Part, and what can be learned from it. The frames are set apart from the rest of the book by the border around their pages.

For example, in Part A, the goal is to present a basis for understanding multichip module technology possibilities for packaging. We call this a *framework for understanding*. The basic definitions needed for understanding are presented. Some alternative packaging approaches are discussed, and the themes of decision-making and the design process that run through the book are also introduced. The reader is alerted to look for the global picture in Part A, an overview that a breadth of knowledge is required for understanding, and that an awareness of the basic concepts introduced in Part A will enable him or her to follow the detailed technical information in Part B.

Part B provides an understanding of the technical fundamentals in the design, fabrication and testing of multichip modules. The tutorials in Part B are unique in the published literature. For example, there is detailed coverage of MCM-L, the fabrication technology based on laminate structures. Another special feature of Part B is the discussion of multichip module-to-printed wiring board (second level) connections in Chapter 10. The test chapter (Chapter 13) provides specific guidelines on how to design MCM products for testing and how to reduce test cost and effort. In each Chapter, the reader is alerted to the options associated with the technologies presented so that these options can be related to product applications.

Part C consists of “reports” from some companies that have created and are selling successful MCM products. The development of their MCM technologies, internally from existing expertise, is described. Here the reader will benefit from the insights shared by these companies.

Finally, Part D “closes the loop.” It focuses on what aspects of all the technologies presented are likely to have the greatest impact on meeting future needs from a systems perspective. It also presents a *forward view* by describing

some open, unsolved problems, open challenges that must be met if future systems are not to be constrained in performance by limitations in packaging technologies.

Use as a Textbook

We feel that this book is highly usable as a packaging textbook. It covers this interdisciplinary topic at a level that is accessible to all while providing concrete learning material. This book emphasizes decision-making and design, and thus, relates directly to what practicing engineers do for a living. It would be useful in both graduate courses and advanced undergraduate courses. It has the tightness and continuity of a textbook in contrast to a typical edited book. In our opinion, this book is superior to any current packaging “textbook” for use as a text mainly because of the style of presentation.

Despite its title, it could be used for many courses that do not feature only MCMs. Throughout this book, single chip packaging is presented as an alternative to be considered. The design chapters apply equally well to single chip and multichip package design. The only single chip package elements that are missing are a discussion of how plastic packages are made and a specific discussion of how boards are assembled. Chapter 9 covers some of these related points. Board manufacturing is covered in Chapter 5. Single chip ceramic package manufacturing uses similar processes as those for making ceramic MCMs which are discussed in Chapter 6.

There are several types of courses that can use this book. One of us (PDF) uses the book in a semester long graduate course on packaging design for electrical engineers. That course starts with an overview of packaging alternatives (Chapters 1 and 2, with 5 to 10 as references), discusses systems level decision-making (Chapter 3 and parts of the Case Studies), and briefly discusses cost (parts of Chapter 4). Almost half of the course is concerned with electrical design of packaging (Chapter 11). A small amount of time is spent on thermal design (Chapter 12), to the level of detail needed by an electrical engineer, and on the appropriate impact of testing on design (Chapter 13).

The book also would be useful for a more technology and manufacturing oriented course. There Chapters 1 and 2 would be used to introduce the course. Establishing the reasons for the multiple packaging alternatives available and how to choose among them would be covered with the aid of Chapter 3. Chapter 4 provides a detailed look into the impact of manufacturing costs. Chapters 5 through 10 would be used to teach the bulk of the course. Brief references to Chapters 11 through 13 would provide technologists with an

understanding of how their decisions affect design. Chapter 17 would offer a detailed manufacturing viewpoint.

Finally, this book also could be useful to mechanical and chemical engineers and materials science-based courses on packaging.

Daryl Ann Doane
Paul D. Franzon

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Each chapter in the book was reviewed by at least three individuals whose areas of expertise covered the chapter topic. We also deliberately asked individuals who worked in areas peripheral to a chapter topic to review the chapters for comprehension and clarity. Although we cannot list these more than 54 individuals, we are very appreciative of their efforts, thoroughness and helpful comments. We took them all very seriously.

Still, with all the technical expertise brought to form the contents of this book, there would have been no way to complete a book of this scope, size and complexity had it not been for the unique combinations of dedication and perseverance of the staff and management at Van Nostrand Reinhold (VNR), our publisher. We are very grateful for their efforts. Especially noteworthy was the standard of inspiration set by Mr. Stephen Chapman, Electrical Engineering Editor. He shared our “vision” for the book and persevered on our behalf for the conventional as well as the nonconventional requests we made. He arranged for an accelerated publication schedule so the book could be available when requested. Without his dedication to the book it would not have appeared in such a timely manner.

Sue Alexander of Seaborn Enterprises, Chandler AZ, was responsible for producing the galleys with artwork for the entire book. She demonstrated a high level of skill and innovation in adapting busy tables and complex equations to a text already filled with an unusual amount of photos and artwork. All the while she was faced with unprecedented time constraints. We are very much in awe of the final excellence of her creation in the layout and appearance of the book.

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