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Moisture Sensitivity of Plastic Packages of IC Devices

Foreword by C.P. Wong

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Foreword

Moisture, according to the Merriam-Webster dictionary, is defined as “liquid diffused or condensed in relatively small quantity.” It is also defined, by Longman dictionary, as “small amounts of water that are present in the air, in a substance, or on a surface.” Both definitions emphasize on the small quantity, but presumably the state of moisture is in liquid form. In fact, moisture, a small quantity of H_2O molecules, can be in vapor, liquid, or solid phase in air or in any substance.

It is interesting to note that moisture sorption is different from water sorption. Moisture sorption process refers to a process in a humid air environment, while water sorption refers to a complete immersion into water. Hydrophobic or superhydrophobic (with water contact angle >150°) materials can effectively prevent water liquid from penetrating through surface, but not for the transmission of moisture (water vapor) in a humid air environment. This interesting phenomenon is illustrated in the first chapter of the book, although the entire book is focused on “moisture” sensitivity of plastic packages of integrated circuit (IC) devices.

Most of polymeric materials in IC packaging absorb moisture from an environment. The presence of moisture in plastic materials alters thermal stress through the alteration of thermo-mechanical properties, induces hygroscopic stress through differential swelling, induces vapor pressure that is responsible for the eventual popcorn cracking, reduces interfacial adhesion strength, induces electrical-chemical migration-induced corrosion, and finally alters dielectric properties of materials. Despite the pivotal role of moisture, research activities in moisture-induced failure remain relatively low, compared to the thermally induced failure in IC packaging. This is in part due to the lack of material data and aggravated by the lack of fundamental understanding of moisture transport, material characterization techniques, and procedures. These are reflected in the limited publications and the near absence of such properties from the material vendors.

The development of three-dimensional (3D) microelectronics packaging with through-silicon via (TSV), ultrathin, and multi-die stacking technology has become essential to increase functionality with higher memory capacity in more complex and efficient architectures. Wafer thinning is required for such ultrathin die development from the original thickness of 750 μm down to as low as 30 μm. Consequently, new assembly and manufacturing processes must be invented to overcome thin wafer handling and cracking issues. Many new materials such as wafer-level coating

films have emerged. As a result, cohesive film rupture may occur due to moisture during reflow. Therefore, one of the major challenges for a practical realization of 3D microelectronics packaging concept is to design materials and meet reliability requirements without cohesive failures subjected to moisture loads.

This book provides information on the state-of-the-art technologies and methodologies related to moisture issues in plastic packages. The book covers the wide aspects including moisture diffusion and desorption, characterization and modeling, hygroscopic swelling, interfacial adhesion degradation, accelerated moisture sensitivity/reflow test, electrical-chemical migration, moisture-aging effect on long-term reliability, and several finely selected real-world case studies on various failure mechanisms due to moisture. This is the first book ever to cover the full spectrum of moisture-induced failure mechanisms in IC packages. It is a timely and important contribution to the technical literature for researchers, engineers, and practitioners both in academia and in electronics industry.

The editors of the book, Dr. Fan and Dr. Suhir, have rich experience in both theoretical development and industrial practice. They have been offering the professional development courses at various IEEE (Institute of Electrical and Electronics Engineers) CPMT (components packaging and manufacturing technologies) Society conferences, and hundreds of participants have attended their lectures. They have succeeded in bringing together well-recognized experts in this field and present a fine collection of papers covering the full spectrum of the related topics. They are to be congratulated for bringing this very important topic forth in a timely manner.

Atlanta, GA
November, 2009

C.P. Wong

Preface

Since moisture-sensitive plastic materials were introduced in integrated circuit (IC) device packaging several decades ago, moisture has been one of the major concerns for package designers and reliability engineers. With the recent development of the three-dimensional (3D) microelectronics packaging with through-silicon via (TSV) and multi-die stacking technologies, moisture-induced failures have become even more prominent due to the new materials employed and the overall reduction in package size and thickness. This book provides a comprehensive state-of-the-art and in-depth review of the fundamental knowledge and methodologies in the field of material and structural ("physical") behavior and performance of various types of moisture-sensitive plastic packages of IC devices.

The book consists of 21 chapters divided into six sections: (1) moisture diffusion, absorption and desorption, and adhesion degradation (Chapters 1, 2, 3, and 4); (2) hygroscopic swelling characterization and analysis (Chapters 5, 6, and 7); (3) integrated hydrothermal and thermal stress modeling (Chapters 8, 9, 10, 11, and 12); (4) case studies and applications (Chapters 13, 14, 15, 16, 17, 18, and 19); (5) electro-chemical migration (Chapter 20); and (6) molecular dynamics modeling and characterization (Chapter 21). Brief description of the chapter contents is set forth below.

Chapter 1 presents an overview of moisture-induced failures in plastic packages of IC devices, and illustrates the fundamental characteristics of moisture diffusion, hygroscopic swelling, and adhesion degradation. Chapter 2 describes the latest investigations of anomalous moisture diffusion and the corresponding adhesion behaviors in epoxy molding compounds. Chapter 3 provides a method and detailed analysis for real-time moisture absorption and desorption in thin films. Chapter 4 reviews the existing methodologies of moisture diffusion modeling and whole-field vapor pressure analysis. Chapters 5, 6, and 7 describe several characterization methods and techniques for hygroscopic swelling, such as photomechanics measurement techniques and point measurement method using thermo-mechanical and thermo-gravimetric analyzers. Chapters 8, 9, 10, 11, and 12 provide a collection of the most advanced analysis and methods for integrated hydrothermal stress modeling. Chapter 8 describes recent progress in modeling of moisture diffusion and moisture-induced stresses in semiconductor and MEMS packages. Chapter 9 presents a novel methodology for integrated vapor pressure, hygro-swelling, and

thermo-mechanical stress modeling of IC packages. Chapter 10 describes a failure criterion for moisture sensitivity of plastic packages based on the theory of thin flexible plates of large deflections. Chapter 11 develops a continuum theory and describes its application to moisture-induced failures in IC packages. Chapter 12 reviews recent efforts to develop micromechanics-based failure theories/models and computational tools for material and process selection in the design and fabrication of plastic IC packages and provides recommendations for the improvement of their reliability under the anticipated service conditions. Chapters 13, 14, 15, 16, 17, 18, and 19 are dedicated to several case studies on moisture-induced failures in a wide range of package types, such as QFP (quat flat package), QFN (quat flat no-lead), and D^2Pak (Chapter 14), QFN package (Chapter 15), system-in-packages and BGA (ball grid array) packages (Chapter 16), flip chip BGA packages (Chapter 17), and ultrathin 3D stacking die packages (Chapter 18). From material perspectives, epoxy molding compounds, die attach adhesives, and underfill materials are all covered in these case studies. Chapter 13 describes a new methodology for an equivalent acceleration of the IPC/JEDEC moisture sensitivity levels. Chapter 19 reviews an automated simulation system to perform moisture-related modeling for various package types. Chapter 20 describes the fundamentals of the phenomenon of the electrochemical migration (ECM), primarily manifested as bridging metallic dendrites. Chapter 21 shows how molecular dynamics simulation and the nano-scale characterization methods could be used to obtain an insight into the moisture-induced failure modes and mechanisms at the atomistic level.

The original scope of the book was based on the professional development course notes of one of the editors, Dr. Fan, on moisture-related reliability in electronic packaging, which has been presented at the IEEE (Institute of Electrical and Electronics Engineers) CPMT (components packaging and manufacturing technologies) Society-sponsored conferences. To present a complete coverage on the latest development and the most recent advances in this field, we have invited experts in this field to bring together a full spectrum of moisture-induced failure mechanisms in IC packages. We are grateful to all the authors from the industry and the academia for their in-depth contributions and their efforts to bring this book to the readers.

The first editor, Dr. Fan, would like to express his gratitude to many of his ex-colleagues at Intel, Philips Research, and the Institute of Microelectronics in Singapore. Many of the book chapters reflect the results of numerous collaborative efforts and extensive team work. Without this work our book would never be possible.

The second editor, Dr. Suhir, expresses his deep appreciation to his friends and former colleagues at Bell Laboratories, Physical Sciences and Engineering Research Division, at Murray Hill, NJ, and Allentown, PA, for introducing him about 25 years ago to the subject of, and the challenges in, the exciting field of polymeric materials in general and plastic packages of IC devices in particular. Dr. Suhir would like to take this opportunity to acknowledge, with thanks, his collaborations, for almost 20 years, during the “golden age” of Bell Labs, with Shiro Matsuoka, Phil Hubbauer, Lloyd Shepherd, Louis Manzione, Don Dahringer, Harvey Bair, C.P. Wong, Arturo

Hale, John Segelken, Alan Lyons, Bonnie Bachman, Charles Cohn, Quazi Ilyas, and many other top-notch materials scientists, physicists, chemists, and chemical engineers.

Beaumont, TX X.J. Fan
Santa Cruz, CA E. Suhir
November 2009

Series Preface

This title is the second book in the series. The series encompasses a broad area of micro-, opto-electronic, and photonic engineering, with particular emphasis on materials, physics, mechanics, design, reliability, and packaging. The titles in the series feature eminent engineers and scientists as authors and/or editors focused on addressing major issues in the above areas of engineering. Our objective is to have a comprehensive series on the materials, mechanics, physics, packaging, functional performance, and reliability as they pertain to micro- and opto-electronics.

The audience for these volumes are those who work in micro- and opto-electronics and photonics, as well as those in many related areas of applied science and engineering. The expected readers are practitioners and professionals, scientists and researchers, along with senior-level undergraduate and graduate students. These volumes can serve as expanded encyclopedias in the field of the mechanics of micro- and opto-electronic materials and structures. Selected titles could also serve as text-books, reference works, and as general guidance works for those interested in these subjects. The series contains both descriptions of the state-of-the-art developments in particular fields, as well as new results obtained by authors, editors, and their colleagues. The authors also identify and address crucial, but still unresolved, issues that come up when discussing new developments and issues within the discussed topics.

I am thankful to Dr. Fan, the editor of this title, who did the major work by bringing together an excellent team of experts and by putting together many outstanding chapters in this title. It has been a pleasure working with him.

I would also like to take this opportunity to thank the authors and editors of the books that are now in the process of being written as well as those authors who have already completed their volume for this series. Potential authors, editors, and those specialists interested in making contributions to the current state of knowledge in a particular field of engineering or applied science within the scope of this book series are invited to send their book proposals to me.

Santa Cruz, CA

E. Suhir, Ph.D.
Series Editor

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