ELECTRONIC PACKAGING SCIENCE AND TECHNOLOGY

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Electronic Packaging Science and Technology

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Preface

As we enter the big data era, mobile devices are ubiquitous. Internet of things (IoT) is everywhere, and we have man-to-man, man-to-machine, and machine-to-machine communications. Furthermore, in the Covid-19 virus pandemic period, the trend of distance teaching, distance medicine, home office, and on-line meeting has increased greatly the need of advanced consumer electronic products, demanding smaller form factor, larger memory, more functions, faster and larger data collection and transmission, cheaper cost, and superb reliability. At the same time, 5G advanced communication technology and 3D IC devices have begun their impact to our society, and many new artificial intelligence (AI) applications have been invented.

With the perceived slowing down of Moore’s law of miniaturization of Si chip technology, microelectronic industry is searching for alternative ways to sustain Moore’s law. 3D IC is most promising in achieving more-than-Moore, wherein the up-scale of packaging technology is critical. Indeed, new advanced packaging factories are being built worldwide. We ask what will be the technical innovations in electronic packaging for 3D IC devices in order to enhance performance and reliability? Or, what are the challenging issues in electronic packaging technology that are essential in the near future development of semiconductor technology?

The goal of this book to present the science and engineering of advanced electronic packaging technology for a deeper understanding of the essence in development and manufacturing of the more-than-Moore technology. Especially, what is new in this book are the subjects of Cu-to-Cu direct bonding by using the (111) uni-directionally oriented nanotwin Cu, innovative 3D IC systems in packaging integration for high performance of wide bandwidth and low power devices, and the analysis of mean-time-to-failure equations based on entropy production.

After the introduction chapter, the following chapters will be divided into three parts. In Part I, the history of bonding technology will be covered in Chapter 2, starting from wire-bonding, tab-automated bonding, flip chip C-4 solder joint bonding, micro-bump bonding, Cu-to-Cu direct bonding, and hybrid bonding. The microstructure, properties, and applications of randomly oriented and (111) uni-directionally oriented nano-twin Cu will be covered in Chapter 3. Then, Chapter 4 and Chapter 5 will be dedicated to chemical reactions and kinetic processes in Cu-Sn reactions for solder joint formation. Chapter 4 will review solid-liquid interfacial diffusion (SLID) reactions between liquid solder and Cu. Chapter 5 will review solid-solid reactions between solid solder and Cu. The kinetics of growth of intermetallic compound (IMC), which is a stoichiometric compound and has no composition gradient, has been an outstanding problem in solid-solid reactions. We introduce Wagner’s diffusivity to overcome it.

Part II consists of chapters on electric circuit integration in packaging technology. The emphasis is on the design of low power devices and intelligent integration. The technical issues related to the need for faster rates and increased amounts of data transport in 2.5D/3D IC are discussed. It is explained how to increase the I/O density and the bandwidth in packaging technology.

Part III is a collection of chapters on reliability science. It begins with a chapter on irreversible processes of atomic flow, heat flow, and charge flow in open systems. The most important issue of Joule heating will be analyzed. The topics of electromigration, thermomigration, stress migration, and failure analysis will be covered. Equations of mean-time-to-failure (MTTF) will be reanalyzed on the basis of entropy production.

Finally, in Chapter 14, a brief discussion on how to use artificial intelligence to accelerate reliability testing will be presented. We propose an x-ray based graphic processing unit (X-GPU) to analyze early reliability failure before it occurs in any newly developed 3D IC device for mass production. The goal of AI here is to change the time-dependent and time-consuming reliability tests to time-independent tests. The basic idea of mean microstructure-change to failure (MMTF) will be introduced, so that we can link MTTF to MMTF.

We appreciate the capable help of Mrs. Jody Lee and Mr. John Wu at NCTU in preparing the book.

Hsinchu, December 2020

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1

Introduction

1.1 Introduction

As we enter the big data era, mobile devices are ubiquitous. On hardware, nearly everyone has a cell phone. On software, internet of things (IOT) reaches everywhere. We have man-to-man, man-to-machine, and machine-to-machine communications. Furthermore, during the Covid-19 virus pandemic, the trend of distance teaching, distance medicine, home office, and online meeting has increased greatly the need of advanced consumer electronic products, demanding smaller form factor, larger memory, more function, cheaper cost, faster and greater rate of data transmission, and superb reliability. Actually, the advanced 5G communication technology and 3-dimensional integration of circuits (3D IC) have already begun their impact to our society. No doubt the world around us is changing rapidly. In human history, this is the second time of a fundamental revolution.

In eighteenth century, we had industrial revolution when steam engine was invented. It developed machine power to replace human power and animal power. The activities in civilization were changing from agriculture to industry. We had railroad trains, ocean liners, automobiles, airplanes, and electricity. While industrial production has transformed human society from feudal to democratic, it was accompanied by capitalism, then communism, and then socialism. Indeed, the impact to human society was huge in the last two to three hundred years.

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