

US Microelectronics Packaging Ecosystem: Challenges and Opportunities

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Abstract—The semiconductor industry is experiencing a significant shift from traditional methods of shrinking devices and reducing costs. Chip designers actively seek new technological solutions to enhance cost-effectiveness while incorporating more features into the silicon footprint. One promising approach is Heterogeneous Integration (HI), which involves advanced packaging techniques to integrate independently designed and manufactured components using the most suitable process technology. However, adopting HI introduces design and security challenges. To enable HI, research and development of advanced packaging is crucial. The existing research raises the possible security threats in the advanced packaging supply chain, as most of the Outsourced Semiconductor Assembly and Test (OSAT) facilities/vendors are offshore. To deal with the increasing demand for semiconductors and to ensure a secure semiconductor supply chain, there are sizable efforts from the United States (US) government to bring semiconductor fabrication facilities onshore. However, the US-based advanced packaging capabilities must also be ramped up to fully realize the vision of establishing a secure, efficient, resilient semiconductor supply chain. Our effort was motivated to identify the possible bottlenecks and weak links in the advanced packaging supply chain based in the US.

Index Terms—Advanced Packaging, Semiconductor Supply Chain, Advanced Packaging Supply Chain, Hardware Security and Assurance, Secure Heterogeneous Integration.

I. INTRODUCTION

The pervasive presence of electronic devices is profoundly transforming our way of life and work, becoming deeply embedded in our daily routines. In today's digital-driven economy, the widespread use of high-speed devices and seamless connectivity generates an immense volume of data. Various critical systems, including autonomous cars, data centers, and Artificial Intelligence (AI) systems, rely on capturing, storing, and analyzing this big data to enable data-driven transactions. Integrated Circuits (ICs) play a pivotal role in supporting the evolution of data processing, high-performance computing, and wireless communication. Today's cutting-edge ICs provide high-bandwidth memory, multiple processing cores, and high-speed input/output (I/O) ports. The presence of these cutting-edge ICs can be primarily credited to Moore's Law, which has driven the semiconductor sector to consistently produce ICs that are faster, smaller, and more cost-effective. However, this long-standing law faces limitations due to rising fabrication

costs, power dissipation challenges, and yield issues associated with advanced technology nodes.

In response to the hurdles encountered in the traditional scaling of CMOS technology, the International Technology Roadmap for Semiconductors (ITRS) 2015 introduced a forward-looking strategy to sustain the historical advancement of CMOS technology[1]. This vision centers around adopting HI as a viable solution. HI involves integrating individually designed and fabricated components on a substrate layer known as an interposer, allowing them to function like a System on Chip (SoC) collectively.

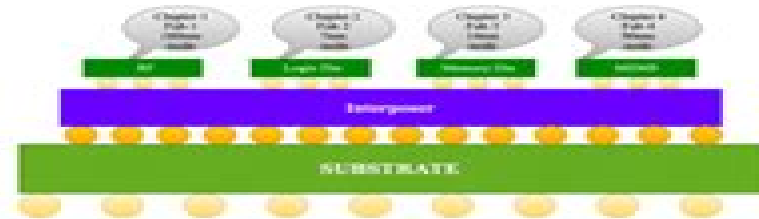


Fig. 1: System-in-Package (SiP) for HI

HI amalgamates separately manufactured components with varying technology nodes and functionalities, resulting in a more advanced assembly known as a Multi-Chip Module (MCM) or System in Package (SiP) (Fig. 1). SiPs offer expanded functionality and improved operational characteristics that are difficult to accomplish with a single-die SoC approach. Diverse components, such as chiplets, active/passive parts, and MEMS devices, can be integrated as a unified package into the SiP. Chiplets, for example, are individually fabricated silicon dies [2] designed explicitly for targeted functions like memory, analog-mixed signal processing, radio frequency (RF), or processors. The SiP can be integrated through adjacent placement (2.5D) or vertical stacking (3D) of chiplets on the interposer.

While HI offers numerous advantages, further research and development are needed to enhance its effectiveness. To realize the vision of HI and continue Moore's Law, packaging technology needs to be improved to standardize intercon-

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Modeling and Simulation for Microelectronic Packaging Assembly Shen Liu, Yong Liu, 2011-08-24 Although there is increasing need for modeling and simulation in the IC package design phase most assembly processes and various reliability tests are still based on the time consuming test and try out method to obtain the best solution Modeling and simulation can easily ensure virtual Design of Experiments DoE to achieve the optimal solution This has greatly reduced the cost and production time especially for new product development Using modeling and simulation will become increasingly necessary for future advances in 3D package development In this book Liu and Liu allow people in the area to learn the basic and advanced modeling and simulation skills to help solve problems they encounter Models and simulates numerous processes in manufacturing reliability and testing for the first time Provides the skills necessary for virtual prototyping and virtual reliability qualification and testing Demonstrates concurrent engineering and co design approaches for advanced engineering design of microelectronic products Covers packaging and assembly for typical ICs optoelectronics MEMS 2D 3D SiP and nano interconnects Appendix and color images available for download from the book s companion website Liu and Liu have optimized the book for practicing engineers researchers and post graduates in microelectronic packaging and interconnection design assembly manufacturing electronic reliability quality and semiconductor materials Product managers application engineers sales and marketing staff who need to explain to customers how the assembly manufacturing reliability and testing will impact their products will also find this book a critical resource Appendix and color version of selected figures can be found at www.wiley.com/go/liu_packaging

Functional Materials Deborah D. L. Chung, 2010 The book features hundreds of illustrations to help explain concepts and provide quantitative information The style is general towards tutorial Most chapters include sections on example problems review questions and supplementary reading

Electronic Systems Maintenance Handbook Jerry C. Whitaker, 2017-12-19 The days of troubleshooting a piece of gear armed only with a scope voltmeter and a general idea of how the hardware works are gone forever As technology continues to drive equipment design forward maintenance difficulties will continue to increase and those responsible for maintaining this equipment will continue to struggle to keep up The Electronic Systems Maintenance Handbook Second Edition establishes a foundation for servicing operating and optimizing audio video computer and RF systems Beginning with an overview of reliability principles and properties a team of top experts describes the steps essential to ensuring high reliability and minimum downtime They examine heat management issues grounding systems and all aspects of system test and measurement They even explore disaster planning and provide guidelines for keeping a facility running under extreme circumstances Today more than ever the reliability of a system can have a direct and immediate impact on the profitability of an operation Advocating a carefully planned systematic maintenance program the richly illustrated Electronic Systems Maintenance Handbook helps engineers and technicians meet the challenges inherent in modern electronic equipment and

ensure top quality performance from each piece of hardware At&t Reliability Manual David J. Klinger, Yoshinao Nakada, Maria A. Menendez, 1990 Partial Contents Reliability Concepts Device Reliability Hazard Rates Monitoring Reliability Specific Device Information and more Appendixes 60 illustrations **Microelectronic Packaging** M. Datta, Tetsuya Osaka, J. Walter Schultze, 2004-12-20 Microelectronic Packaging analyzes the massive impact of electrochemical technologies on various levels of microelectronic packaging Traditionally interconnections within a chip were considered outside the realm of packaging technologies but this book emphasizes the importance of chip wiring as a key aspect of microelectronic packaging and focuses on electrochemical processing as an enabler of advanced chip metallization Divided into five parts the book begins by outlining the basics of electrochemical processing defining the microelectronic packaging hierarchy and emphasizing the impact of electrochemical technology on packaging The second part discusses chip metallization topics including the development of robust barrier layers and alternative metallization materials Part III explores key aspects of chip package interconnect technologies followed by Part IV s analysis of packages boards and connectors which covers materials development technology trends in ceramic packages and multi chip modules and electroplated contact materials Illustrating the importance of processing tools in enabling technology development the book concludes with chapters on chemical mechanical planarization electroplating and wet etching cleaning tools Experts from industry universities and national laboratories submitted reviews on each of these subjects capturing the technological advances made in each area A detailed examination of how packaging responds to the challenges of Moore s law this book serves as a timely and valuable reference for microelectronic packaging and processing professionals and other industrial technologists *The Electronics Handbook* Jerry C. Whitaker, 2018-10-03 During the ten years since the appearance of the groundbreaking bestselling first edition of *The Electronics Handbook* the field has grown and changed tremendously With a focus on fundamental theory and practical applications the first edition guided novice and veteran engineers along the cutting edge in the design production installation operation and maintenance of electronic devices and systems Completely updated and expanded to reflect recent advances this second edition continues the tradition *The Electronics Handbook Second Edition* provides a comprehensive reference to the key concepts models and equations necessary to analyze design and predict the behavior of complex electrical devices circuits instruments and systems With 23 sections that encompass the entire electronics field from classical devices and circuits to emerging technologies and applications *The Electronics Handbook Second Edition* not only covers the engineering aspects but also includes sections on reliability safety and engineering management The book features an individual table of contents at the beginning of each chapter which enables engineers from industry government and academia to navigate easily to the vital information they need This is truly the most comprehensive easy to use reference on electronics available *3D Microelectronic Packaging* Yan Li, Deepak Goyal, 2020-11-23 This book offers a comprehensive reference guide for graduate students and professionals in both academia and industry covering the fundamentals

architecture processing details and applications of 3D microelectronic packaging It provides readers an in depth understanding of the latest research and development findings regarding this key industry trend including TSV die processing micro bumps for LMI and MMI direct bonding and advanced materials as well as quality reliability fault isolation and failure analysis for 3D microelectronic packages Images tables and didactic schematics are used to illustrate and elaborate on the concepts discussed Readers will gain a general grasp of 3D packaging quality and reliability concerns and common causes of failure and will be introduced to developing areas and remaining gaps in 3D packaging that can help inspire future research and development *Technical Abstract Bulletin* , **Moody's OTC Unlisted Manual** ,1999

Applied Engineering Analysis Tai-Ran Hsu,2018-04-30 A resource book applying mathematics to solve engineering problems Applied Engineering Analysis is a concise textbook which demonstrates how to apply mathematics to solve engineering problems It begins with an overview of engineering analysis and an introduction to mathematical modeling followed by vector calculus matrices and linear algebra and applications of first and second order differential equations Fourier series and Laplace transform are also covered along with partial differential equations numerical solutions to nonlinear and differential equations and an introduction to finite element analysis The book also covers statistics with applications to design and statistical process controls Drawing on the author's extensive industry and teaching experience spanning 40 years the book takes a pedagogical approach and includes examples case studies and end of chapter problems It is also accompanied by a website hosting a solutions manual and PowerPoint slides for instructors Key features Strong emphasis on deriving equations not just solving given equations for the solution of engineering problems Examples and problems of a practical nature with illustrations to enhance student's self learning Numerical methods and techniques including finite element analysis Includes coverage of statistical methods for probabilistic design analysis of structures and statistical process control SPC Applied Engineering Analysis is a resource book for engineering students and professionals to learn how to apply the mathematics experience and skills that they have already acquired to their engineering profession for innovation problem solving and decision making

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