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Lead-Free Solder Interconnect Reliability (#05101G)
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Lead-Free Solder

INTERCONNECT RELIABILITY

Edited by
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Electronic Device Failure Analysis Society
An Affiliate Society of ASM International®

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The Materials Information Society

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First printing, August 2005

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Prepared under the direction of the ASM International Technical Book Committee (2004–2005), Yip-Wah Chung, FASM, Chair.

ASM International staff who worked on this project include Scott Henry, Senior Manger of Product and Service Development; Bonnie Sanders, Manager of Production; Madrid Tramble, Senior Production Coordinator, and Kathryn Muldoon, Production Assistant

Library of Congress Cataloging-in-Publication Data
Lead-free solder interconnect reliability / edited by Dongkai Shangguan.
p. cm.
Includes bibliographical references and index.
ISBN: 0-87170-816-7
1. Microelectronic packaging—Reliability. 2. Solder and soldering. 3. Lead-free electronics manufacturing processes. I. Shangguan, Dongkai, 1963–

TK7870.15.L425 2005
621.381′046—cd22 2005050106
SAN: 204-7586

ASM International®
Materials Park, OH 44073-0002
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Printed in the United States of America

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Foreword

By Gary F. Shade and Thomas S. Passek

The worldwide drive to remove lead from electronic assemblies adds challenges to an already complex and difficult technology. Well beyond simple structures, solder interconnects provide at least as many challenges as the components they connect. Constant new demands of size, speed, power, and new materials continually direct the developer onto the frontiers of science to provide reliable interconnects.

Despite these challenges for materials, mechanical and thermal practitioners, most universities have largely overlooked solder interconnects as a prime area for teaching and research. To fill this void, Dongkai Shangguan has assembled a team of leading experts representing international government research facilities, universities, and industrial companies. Together they provide a wealth of up-to-date knowledge and data on the reliability of lead-free solder interconnects.

Solder interconnects have been a constant challenge in the past and remain that way today. Industry is putting tremendous resources into action to provide reliable lead-free interconnects, and this will undoubtedly continue for the foreseeable future as packages, boards, and materials continue to evolve to meet the needs for improved reliability, performance, and cost.

The Electronic Device Failure Analysis Society (EDFAS), an affiliate society of ASM International, is pleased to see this fine work made available for practitioners in reliability and failure analysis of lead-free interconnects. EDFAS and ASM, along with the editors, the authors, and the reviewers have collaborated to produce a book that meets high technical standards. To all who contributed toward the completion of this task, we extend our sincere thanks.

Gary F. Shade
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Foreword

By Nicholas Brathwaite

It's only recently that inhabitants of planet Earth have begun attempting to conscientiously, proactively, and responsibly manage the environment in which we live. A truly global, environmentally conscious culture has emerged across all tiers of society.

The fact is, we have little choice.

Take the electronics industry, for example, upon which our society increasingly depends for safety, security, comfort, and convenience. As a result of our ever-growing appetite for electronic products, we now generate millions of tons of electronic waste annually.

In addition to challenging the capacity of landfills, this trend continues to deplete our resources and increase environmental pollution. The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) and Waste Electrical and Electronic Equipment (WEEE) directives, introduced by the European Union, are intended to protect human health and the environment.

By demanding reuse, recycling, and separate collection, the primary purpose of the WEEE directive is reduction in the amount of electrical and electronic equipment entering landfills. The RoHS directive is intended to eliminate or reduce harmful substances at the source, ensuring that these hazardous substances are not a threat to human life.

Similar legislation is emerging in other parts of the world (most notably, China). While there are still differing opinions regarding the merits of these directives, their global impact on the electronics industry is undeniably clear. It is probably no exaggeration to say that these are leading to revolutionary changes in the electronics industry.

Of the six substances restricted by RoHS, lead is arguable the one that has the greatest impact on the electronics packaging and assembly industry. Approximately 100 million pounds of solder (mostly with tin-lead alloys) are consumed annually to generate 10 trillion solder joints, which is the primary interconnect between the integrated circuit and the printed circuit board. The implementation of lead-free solder assembly processes, therefore, is a critical element in the global effort towards RoHS compliance.

Significant volumes of research and development work on manufacturing issues associated with lead-free assembly have been conducted and published in the past decade by the industry, national laboratories, consortia, and academia worldwide. Reliability studies of lead-free solder interconnects, however, are still emerging.

As we begin the process of putting more and more lead-free electronics products in the marketplace, it is vital that we have an in-depth and comprehensive understanding of lead-free solder interconnect reliability to help the industry safeguard the reliability of the electronics systems and products.

As an industry, we are facing increasingly demanding customers and mounting competitive pressures. As such, industry-wide collaboration is key to a successful journey towards environmental compliance. The industry is fortunate to have a few dedicated experts who can lead and guide us through these challenges, and we are proud to count Dongkai Shangguan among these experts.

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While our company has benefited tremendously from Dr. Shangguan's world-leading expertise in packaging and assembly technology, reliablity, and environmentally conscious design and manufacturing, it is gratifying to see that he has now assembled a global team of renowned experts, across industry and academia, to address the issue of lead-free solder interconnect reliability in great depth and breadth.

On this journey towards environmental compliance and leadership, expert advice in the form of this book is not only welcomed but is vitally necessary.

Nicholas Brathwaite
Chief Technology Officer
Flextronics

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Preface

As I sit down to put the finishing touches on this book, the year 2004 is drawing to a close. Through the window of my study, I can see green grass, blue sky, and bright sunshine, here at the heart of the Silicon Valley. This brought my memory back to 1991, when at about the same time of the year, I sat in my study in a Detroit suburb staring at the snow outside the window, trying to put together a plan for a lead-free solder project at Ford Electronics.

The electronics industry has come a long way since then. Over the past 13 years, there has been a great deal of development in the lead-free arena. The passage of the European Union "Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment" (RoHS) legislation has made the drive towards worldwide adoption of lead-free solder unstoppable for packaging, board assembly, and manufacturing of electronics products. Although there is still debate about the merits of RoHS legislation, the transition to lead-free soldering is already underway worldwide.

The global progress towards lead-free soldering includes solder alloy selection and evaluation, process development, and infrastructural development. A significant volume of R&D work has been published by industry, national labs, consortia, and academia worldwide in these areas. Nonetheless, the reliability of lead-free solder interconnects is still an emerging science. The existence of a large volume of reliability data on tin-lead solders under different use conditions has been a key prerequisite for the successful use of tin-lead solder in a multitude of applications. Correspondingly, similar data on lead-free solders are critically needed by the industry, before across-the-board conversion can take place.

The issue of reliability, however, is complicated by the wide variety of application environments and requirements, which give rise to different stress conditions (thermomechanical, dynamical, electrochemical, electrical, etc.). The physics of failure, which is directly related to reliability, is a critical topic still under intense investigation for lead-free solders. The topic is further complicated by the fact that the relative reliability comparison between the tin-lead solder and the lead-free solder alloys varies with the loading conditions. These complications create great difficulties for the development of appropriate accelerated testing profiles and for reliability prediction, both of which are critical elements of reliable product design. Due to the complexity of the subject, a great deal of confusion still exists in the industry, which hampers lead-free solder implementation and may even lead to catastrophe if reliability is not properly managed for critical products.

Researchers worldwide have undertaken serious efforts to study lead-free solder reliability under different loading conditions. While the results of these studies have been reported rather sporadically at various technical conferences, a book is critically needed which is dedicated to this topic of paramount importance to the electronics industry. Consequently, the objective of this book is to disseminate the most up-to-date knowledge and data on the reliability of lead-free solder interconnects, under various application conditions. The book attempts to cover the complex topic of lead-free solder interconnect reliability in a comprehensive manner, and both fundamental research and practical considerations are addressed. While the book will have archival reference value for academic researchers and educators alike, it is primarily targeted towards practitioners in the electronics business, who need to understand the reliability of solder interconnects, for product design, testing, and assurance.

Chapter 1 offers an overview of lead-free soldering (materials, processes and reliability), as well as a perspective of overall environmental compliance for electronics products. The intricate interplay

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among the various use conditions, physics of failure, failure modes, and testing, analysis and prediction methodology, is outlined for the interconnect system (which includes the components, the substrate, and the solder). This is followed by chapters with detailed discussions on the fundamental microstructural evolution and creep and fatigue properties of the lead-free solder alloys, and the overall comparison of reliability between tin-lead and lead-free solders. Chemical interactions and reliability, and tin whisker growth, are then presented in considerable depth to address both the fundamental understanding and the application-oriented issues. Accelerated testing methodology, reliability prediction and design for reliability, as well as characterization and failure analyses, are reviewed primarily from the practical considerations. While a number of different lead-free solder alloys exist, the data presented in this book are focused primarily on Sn-Ag-Cu and Sn-Cu alloys, as these are believed to be the primary lead-free solder alloys to be used by the worldwide electronics industry. Many of the methodologies and analyses presented in the book, however, are applicable to other lead-free solder alloy systems as well. The reliability of conductive adhesives is included towards the end of the book as another important alternative to tin-lead solders. The very last chapter of the book attempts to outline the most critical issues on lead-free solder interconnect reliability for future research.

It is no exaggeration to say that we have only taken the very first step of a long journey towards reliable lead-free solder interconnect systems for electronics products worldwide. It is hoped that this book can provide help for our industry and academic colleagues worldwide in this endeavor. No doubt, many questions still remain, and much more work needs to be done and will be done. It is my personal wish that this book can play some role in stimulating further exploration in the field of lead-free reliability.

ACKNOWLEDGMENTS

Since I submitted the book proposal to ASM International 16 months ago, I have had the privilege to work with many friends and colleagues on this venture. I would like to thank the chapter authors for their contributions and cooperation over the past year and for their confidence in me. I am grateful to Keith Newman for his help with reviewing the manuscripts and for his many valuable and constructive comments.

My past and current colleagues at Ford, Visteon, and Flextronics deserve special thanks; it has been a joy and privilege to work with them. I am grateful for the opportunity to learn from them and get to know them on a personal level.

Numerous industry and academic colleagues worldwide deserve my sincere thanks, as they have been the source of stimulation and inspiration for my work in this area. Specifically, I want to mention my colleagues at the EMS Forum, and the many leaders at IPC, Soldertec, HDPUG, and other consortia as well as my friends from Shanghai University. I have also learned a great deal from the many people I met at various conferences; their comments, questions and feedback served as a constant reminder that what we know today is far from what we need to know.

Thanks are also due to Scott Henry and the editorial and production staff at ASM International for their cooperation and support.

This project would not have been possible without the support of my family. With a job that takes me to distant countries away from home for about half of the time, and long work hours wherever I may be, the “extra” time I needed for this project has necessitated sacrifice on their part. As I am writing this paragraph, my younger son just completed his pinewood derby car, but my travel schedule for the next couple of weeks will not allow me to be there when the race takes place. I am counting on his older brother to videotape the event for me. My family’s love constantly motivates me to keep marching forward on this truth-seeking journey that may in some small way benefit our society. Their support and understanding gave me the time to complete this important project, before I move on to the next one.

Dongkai Shangguan, Ph.D., MBA
San Jose, CA
December 2004

ASM International is the society for materials engineers and scientists, a worldwide network dedicated to advancing industry, technology, and applications of metals and materials.

ASM International, Materials Park, Ohio, USA
www.asminternational.org

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Publication title	**Product code**
Lead-Free Solder Interconnect Reliability	05101G

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Lead-free solders have been increasing in use due to regulatory requirements plus the health and environmental benefits of avoiding lead-based electronic components. They are almost exclusively used today in consumer electronics.[5]. Plumbers often use bars of solder, much thicker than the wire used for electrical applications. Jewelers often use solder in thin sheets, which they cut into snippets. Contents.Â Lead-free solder[edit]. Pure tin solder wire. Soldering copper pipes using a propane torch and lead-free solder. Lead free solder composition is different from composition of leaded solder. There is NO Lead (Pb) is Lead Free solder. Lead Free Solder is taking rapid momentum around the world after the EU (European Union) Directives to wipe off lead (Poison) from electronic soldering considering its health and environmental effects. Table of Contents: Terms to Know when Understanding Lead Free Solder Composition. Why Lead Free in Electronics. Video: Types of Solder Wire. Lead Free Solder and Composition. Alpha Lead-Free Solder Paste. Alpha offers a variety of solder pastes for lead-free PCB assembly that offer high reliability and high throughput applications. MENU. Find a Flux Tool. Product Documentation. Technical Bulletin ALPHAÂ® Solder Paste OM 338 Series Technical Bulletin (EN) ALPHAÂ® Solder Paste OM 535 Technical Bulletin (CN) ALPHAÂ® Solder Paste OM-550 Technical Bulletin (EN) ALPHAÂ® Solder Paste OM-550 Technical Bulletin (CN). Product Feature ALPHAÂ® Solder Paste OM 550 Flyer (EN).