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Book Reviews

Environment-Friendly Electronics: Lead-Free Technology, edited by Jennie H. Hwang. Electrochemical Publications Ltd., Isle of Man, British Isles, 2001, 879 pp, $238.00 (USA unit price), ISBN 0 901150 40 1

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Dr. Jennie Hwang's book, *Environment-Friendly Electronics: Lead-Free Technology*, is a welcome reference to today's engineers working in the electronics industry. Green technology continues to spread throughout the industry and now is the time for some accurate references to make their presence known. Dr. Hwang has not disappointed us in this respect. The book consists of 31 chapters, each thoroughly addressing the important aspects of lead-free technology. An applications approach was used in presenting this book review, i.e., it was used as one of several references for developing a syllabus for an in-house course on alternatives to lead solder. Therefore, this review will not address each and every chapter but, rather, highlight significant contributions of several chapters in Dr. Hwang's book.

Chapters 1 and 2 discuss global driving forces, market trends, technological demands, and new developments of semiconductors and IC packages. Chapter 3 focuses on the legislative activities, both domestically and abroad. With ever-increasing markets in the international arena, manufacturers and suppliers are addressing the foreign interest in environmentally attractive solders and, thus, one sees a dramatic increase of lead-free materials and subsequent adaptation of the industry to this technology. Subsequently, Chap. 3 does a very nice job of summarizing world-wide legislation.

The topic of Chap. 4 is "Fundamental Technology and Methodology." It begins with a very concise overview of conventional lead solder technology discussing physical, metallurgical, mechanical, and performance properties. Next, common failure modes, for lead solders, are presented. This next leads into a discussion of lead-free technology and, as with lead-free solders, various strengthening approaches are presented along with the fundamentals of lead-free technology. There is a sufficient amount of theory and graphics to explain all key points. The chapter proves valuable as an aid to the designer since today's literature is flooded with data on advantages and disadvantages of lead-free materials, i.e., this chapter provides tools for the engineer to make an informed decision on selection of lead-free solder.

Chapter 5 provides information on 50 patents for some lead-free alloys. The chapter is nicely organized according to the constituents of an alloy system, which in turn are listed in alphabetical order based on primary elements. Data include alloy compositions and material properties. Another attractive feature is that references are provided for each composition.

Chapter 6 covers binary systems (Sn–Ag, Sn–Bi, Sn–Cu, Sn–In, Sn–Sb, and Sn–Zn) while Chaps. 7–9 address three tertiary systems (SnAgBi, SnAgCu, and SnAgSb). No information is lacking as Dr. Hwang has provided exhaustive yet comprehensive data on microstructure, strengthening mechanisms, fatigue, creep, and applications for the binaries while providing similar information on tertiaries, focusing on phase transition temperature, stress/strain, and low-cycle fatigue (among other aspects of these materials).

Chapters 10–14 discuss quaternary systems (SnAgBiCu, SnAgBiIn, SnAgCuIn, SnAgCuSb, and SnCuGaIn). Chapters 15–17 focus on other ternary, quaternary, and higher-element systems. As in the previous chapters, Dr. Hwang addresses key properties and concerns, i.e., phase transition temperature, stress/strain, and low-cycle fatigue, and adds some specific information dependent upon the alloy. For example, in Chap. 14, talking about Sn/Cu/Ga/In systems, the author discusses effects of In, Cu, and Ga on the strength and fatigue life of the overall alloy.

In Chap. 18, we now see a categorization of solder into two groups: high temperature verses low temperature (with respect to the melting point of eutectic tin-lead). The distinction between the two is made and the chapter presents aspects of both groups discussing stress/strain and low cycle fatigue. As in previous chapters, there is an abundant amount of data to support design.

Chapter 19 discusses the materials and processes of coating systems for component lead coatings and PCB surface finishes. The chapter begins with a very good discourse on the wetting phenomenon and solderability factors. These subsections set the stage for a very informative and useful chapter. Various component lead plating technologies are discussed including tin-lead and palladium. Other systems are briefly addressed. Printed wiring board surface finishes are also presented.

In the next several chapters, Dr. Hwang has utilized the talents of several noteworthy researchers. In Chap. 20, Dr. Paul Vianco (of Sandia National Labs), along with several other researchers, presents information on intermetallics of lead-free solders. In this chapter, an experimental study is presented which looks at interface effects which can degrade solder joint performance. Along with the 63-37 Sn–Pb baseline, eight solder systems discussed focusing on aging parameters, interface reaction product compositions, and interface reaction product growth kinetics. Chapter 21 addresses compatibility of lead-free solders with reflow processes. Dr. Benlih Huang and Dr. Ning-Cheng Lee of Indium Corporation of America are the chapter authors. The chapter includes a comprehensive table showing compatibility between fluxes and solder alloys. In Chap. 22, Dr. Srinivas and Dr. Dongkai Shangguan present data on the microstructural evolution of SnAg solders and subsequent relationships with mechanical properties. As SnAg solders continue to gain popularity as potential "drop in" candidates for eutectic tin-lead, this chapter serves a keen purpose in presenting microstructural data, highlighting effects of various cooling rates during the reflow process.

Dr. Carol Handwerker (NIST), along with Donna Noctor of Lucent Technologies and Gordon Whitten of Delphi/Delco, have written Chap. 23 in providing important insight into the reliability of lead-free solders. The focus of the chapter is on the National Center for Manufacturing Sciences (NCMS) lead-free project which consisted of down selecting suitable lead-free alloys and

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subjecting them to a series of thermal cycle and other environmental tests. Numerical data are provided along with micrographs showing solder joint integrity.

In Chap. 24, electrically conductive adhesives are presented as another alternative material system. The chapter is authored by the renowned researcher Dr. Ken Gilleo. The chapter is well organized, perhaps taking into account that the material system being addressed is quite different from that discussed in the previous chapters. On a minor note, Dr. Gilleo does a good job in explaining the difference between thermoset and thermoplastic polymers, a key aspect that must be understood when selecting/designing interconnection schemes using these materials. Also included are discussions on manufacturability, rework, reliability and applications, and case histories for these materials.

Chapter 25 is authored by Dr. Sammy Shima of the University of Massachusetts—Lowell. An interesting point, discussed in this chapter, concerns the qualification of alternative alloy(s) which can take a considerable amount of time. Dr. Shima utilizes the design of experiments (DoE) approach for this exercise. Alloys include SnAgCu, SnCu, SnAgBi, SnZn, and SnAg. The exercise includes selection of fluxes and components as well. A section is included on "Factor Selection" emphasizing PWB finishes. Details on the experiment are provided with a current status at the end of the chapter. Final results will be published at future conferences.

Chapter 26 deals with concerns and issues that have surfaced as a result of various applications of lead-free technology. One "hot" industry issue today is the resurgence of the tin whisker phenomenon that was a prevalent concern many years ago. As more commercial suppliers direct their focus to lead-free solder, they are now implementing "compatible" technologies such as pure tin plating as a surface finish option (which is more compatible to the lead-free solders). Industry research has shown that tin whiskers can develop under typical operating conditions on any product type that uses lead-free pure tin coatings. This chapter is very useful in providing insight into the tin whisker phenomenon as well as tin pest. This chapter appears to be one of the best in the entire book with a very attractive layout in presenting some key information.

Chapter 27 addresses effects of lead contamination in lead-free solders. The information in this chapter should be considered timely and critical in the industry today. There is more emphasis on this condition regarding logistics support, i.e., situations involving spare parts, utilizing lead technology, and being compatible with lead-free technology. Eight lead-free systems are discussed which cover most of the alloys of interest. The type of information available in the chapter is very useful and applicable, i.e. melting temperatures, strength/plasticity, and low-cycle fatigue.

In Chap. 28, bismuth is discussed. Bismuth has long been a "passionate" topic of discussion in the lead-free world. It is "intriguing" (as the author states) since it presents a challenging combination of advantages and disadvantages. Dr. Hwang presents a positive position on the element but also provides a concise summary of all this element's properties.

With new technologies come concerns with process. Accordingly, Chap. 29 provides some guidance regarding various production defects that could arise as a result of lead-free solders. Mr. Bob Willis, of Electronic Presentation Services, is the chapter author. Explanations, as well as graphics, are provided on poor hole fill, solder shorts, poor solder penetration, solder flags, board bow, and incomplete fillets as well as other defects.

Chapter 30 provides an interesting approach in that several companies and industry organizations give their views on lead-free technology. The range in opinions is very interesting from supportive of the movement to expressing confusion over the rancor to a rebuttal against alleged accusations of exploiting the technology.

In fitting style, Chap. 31, the last, provides an overview on comparison, selection, and recommendations of lead-free materials. As in the previous chapter, some input is provided by industry organizations featuring recommendations from the European Union organization IDEALS and a roadmap from the Japan Electronic Industries Development Association. The chapter also includes some comparisons among previously discussed systems, i.e., Sn/Ag/Bi, Sn/Ag/Cu, Sn/Ag/Cu/Bi, Sn/Ag/Bi/In, Sn/Ag/Cu/In, and others. Optimal compositions as well as comparisons with each of the other systems are also include.

In general, Dr. Hwang has provided an extremely useful resource, which undoubtedly was a tremendous undertaking given the completeness of this book. With the ever-increasing focus on green technologies, this book is a must for anyone working in the electronic interconnection field. My congratulations to Dr. Hwang for an excellent work.