

## Preface

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Due to the popularity of the subject of lead-free electronic solders within the past decade, the number of researchers active in this field has increased phenomenally, and the publications resulting from their studies have exploded. These publications appear in more than 20 different scientific journals and several more technical publications. As a consequence it has become impossible to keep track of current status of understanding of a given issue. Many publications in reviewed scientific journals are written by persons active in different academic disciplines, such as material science, physics, electrical engineering, mechanical engineering, etc. Similarly, publications from industrial counterparts often times do not indicate an awareness of the academic research contributions in the area. Hence it becomes necessary to provide a comprehensive and interdisciplinary account of the current status of various issues relevant to lead-free electronic solders.

This book contains the papers that were invited for a special issue of *Journal of Materials Science: Materials in Electronics*. In this reviewed scientific journal publication there were 23 articles written by recognized authorities in the field. Because this journal may not be a regular source of scientific information for academic researchers in fields other than Materials Science and those in industry, and to provide wider awareness of the current status of lead-free electronic solders to those persons active in the area but who are

not regular readers of the *Journal of Materials Science: Materials in Electronics*, these articles are being reprinted in this book.

In the last few decades, the effect of lead contamination on human health has received significant attention. Based on such concerns elimination of lead from ceramic glaze, paint, plumbing etc. has been legislated and implemented. However, till recently, solders used in electronics, based on suitability and knowledge-base developed over a long period of time, remained lead-based. Successive rapid advances in microelectronic devices in recent decades make them obsolete within a very short period after their introduction resulting in significant quantities of electronic wastes in landfills. Leaching of toxic lead from such electronic wastes can result in contamination of the human food chain causing serious health hazards. As a consequence, several European and Pacific Rim countries have passed legislations warranting elimination of lead from electronic solders by fast approaching deadlines. Global economic pressures brought on by such legislations have resulted in a flurry of research activities to find suitable lead-free substitutes for the traditional leaded electronic solders.

In spite of the exhaustive number of studies over the past two decades, no suitable drop-in substitutes have been found for lead-based electronic solders. Among the various lead-free solder alloys considered as potential substitutes only a few, especially those based on high tin, are emerging as leading candidates. Most of these tin-based compositions are eutectics or modifications of the same. These solders are being investigated, and their performances under thermal and electrical excursions are being evaluated. In addition to such an alloying approach where the intermetallic

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compounds play significant roles, composite solders with intentionally incorporated inert, strongly bonded, compatible reinforcements are being developed. This latter approach provides a reinforcement that will not coarsen during service and lose its effectiveness.

Solder joints are multi-component systems that have several entities such as substrate, solder/substrate intermetallic layers, solder present in the joint, and intermetallics (and other reinforcements) within the solder, etc. Such a complex system with its constraints that will arise as a result of joint geometry, and severe anisotropy of tin, poses significant complications.

The worldwide multi-faceted research efforts to arrive at suitable solutions, especially as the deadline for implementation of lead-free electronic solders approaches, have resulted in an exhaustive number of research papers in several reviewed scientific journals. Similarly, there have been presentations in several national and international meetings of various technical societies. It is impossible for any researcher or student to be aware of all the materials that have been, and are being, published in this area. So it becomes essential to have most of the relevant and currently available information in a single source such as in a special edition of a reviewed scientific journal and/or a book.

With this goal in mind the important issues that are encountered in the lead-free electronic solder area were identified, and researchers recognized for their significant scientific contributions in those areas were invited to write articles on those topics. They were asked to address the importance of a given issue, the current status of understanding and available solutions, the problems that still need to be tackled and suggestions for potential approaches to do so. Virtually all of

the invitees accepted the challenge and have provided their diligently prepared papers for this special issue.

The papers that appear in this effort are arranged in the following order. Thermodynamic and phase diagram issues are presented in the first few articles. They are followed by articles addressing lead-free solder development and processing issues. Since solder joints in modern electronic applications have to possess structural integrity in addition to being electrical connections, mechanical behavior and modeling are addressed in the following articles. Since service environments impose thermal excursions, Thermomechanical Fatigue (TMF) that results from Coefficient of Thermal Expansion (CTE) mismatches of entities present in the solder joints is discussed in the following articles. Microminiaturization of electronic devices has brought out the importance of high current density with associated issues of electro-migration (EM), and whisker growth (WG) to prominence in addition to TMF. Following the papers on EM and WG, potential implications of polymorphic transformation of body-centered tetragonal tin into the diamond cubic structure at low temperatures (known as tin pest) on solder joint reliability in low temperature service is addressed. The last two papers are from researchers with extensive industrial experience and are well known for their contributions in this area. These papers deal with lead-free solder implementation in consumer electronics, and in high-end electronic components that warrant high reliability such as main-frame computers and space applications.

These papers basically cover all aspects that are relevant to lead-free electronic solder implementation and hopefully provide an overall perspective of the current status and issues to be addressed.