COST 531 • Lead Free Solders
Volume 1

Atlas of Phase Diagrams for Lead-Free Soldering

compiled by
A. T. Dinsdale[a], A. Watson[b], A. Kroupa[c], J. Vřešťál[d], A. Zemanová[c] and J. Vízdal[e]

[a]National Physical Laboratory, Teddington, UK

[b]University of Leeds, UK

[c]The Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Brno, Czech Republic

[d]Masaryk University, Brno, Czech Republic

[e]Brno University of Technology, Czech Republic

The Legal notice by the COST office

Neither the COST Office nor any person acting on its behalf is responsible for the use which might be made of the information contained in this publication. The COST Office is not responsible for the external websites referred to in this publication

ESF provides the COST Office through an EC contract

COST is supported by the EU RTD Framework programme

Volume 1: ISBN 978-80-86292-28-1
Volumes 1-2: ISBN 978 -80-86292-27-4

Printed in the Czech Republic

COST – the acronym for European **CO**operation in the field of **S**cientific and **T**echnical Research- is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November l971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST – less than 1% of the total value of the projects – support the COST cooperation networks (COST Actions) through which, with € 30 million per year, more than 30,000 European scientists are involved in research having a total value which exceeds EUR 2 billion per year. This is the financial worth of the European added value which COST achieves.

A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "a la carte participation" (only countries interested in the Action participate), "equality of access" (participation is open also to the scientific communities of countries not belonging to the European Union) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains such as: Biomedicine and Molecular Biosciences; Food and Agriculture; Forests, their Products and Services; Materials, Physical and Nanosciences; Chemistry and Molecular Sciences and Technologies; Earth System Science and Environmental Management; Information and Communication Technologies; Transport and Urban Development; Individuals, Societies, Cultures and Health. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

Web: www.cost.esf.org

Foreword

COST Action 531 had the official title "Lead-free Solder Materials"; its main objective, according to the Memorandum of Understanding, was "… to increase the basic knowledge on possible alloy systems that can be used as lead-free solder materials and to provide a scientific basis for a decision which of these materials to use for different soldering purposes in order to replace the currently used lead-containing solders in the future". The Action started officially on March 10, 2002, with the first meeting of the Management Committee in Brussels, and its official end was March 10, 2007, although a Final Meeting (including a last Management Committee Meeting) was held between May 17 and 19, 2007 in Vienna.

Altogether, 22 countries signed the Memorandum of Understanding. Of these, 19 countries involving around 45 research institutions were actively engaged in research on lead-free solder materials as part of COST 531: Austria, Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Poland, Portugal, Serbia (and Montenegro), Slovakia, Slovenia, Sweden, Switzerland, and United Kingdom. In addition, several research institutions from non-COST countries participated officially in the Action: MMO (Materials and Manufacturing Ontario, Canada), CMAP (Centre for Microelectronics Assembly and Packaging, Canada), the National Cheng Kung University (Tainan, Taiwan), and the Physics of Metals Department of the Ivan Franko University (Lviv, Ukraine).

The work in COST 531 was organized into four Working Groups, each with a different main focus:

- Working Group 1 was responsible for experimental thermodynamic properties of alloy systems and experimental phase diagrams; it was coordinated by B. Legendre, Paris (F), and A. Watson, Leeds (UK)
- Working Group 2 was responsible for theoretical modelling of phase diagrams; it was coordinated by L. Zabdyr, Kraków (PL), and A. Kroupa, Brno (CZ)
- Working Group 3-4* was responsible for physical and chemical properties of various alloy systems as well as of solder joints; it was coordinated by W. J. Plumbridge, Milton Keynes (UK), and N. Sobczak, Kraków (PL)
- Working Group 5-6* was responsible for reliability issues as well as packaging and miniaturization; it was coordinated by J. Botsis, Lausanne (CH), and J. Villain, Augsburg (D), who took over from B. Michel, Berlin (D), in early 2005.

The coordination of COST Action 531 was achieved through nine Management Committee Meetings and a total of 19 Working Group Meetings, three of them

* Both Working Groups 3-4 and 5-6 were combined from originally two separate ones by decision of the Management Committee on June 14, 2003, in Brno (CZ)

organized as joint Working Group Meetings (February 2005 in Lausanne, February 2006 in Genoa, and May 2007 in Vienna). The exchange of (young) scientists was supported by 59 Short Term Scientific Missions that took place over the five year period. Despite considerable difficulties at the beginning of the Action (related to the transition of the administration of COST from the European Commission to the European Science Foundation ESF) it is thought that COST 531 was able to achieve most of the goals that had been defined in the Memorandum of Understanding.

The main result of Working Groups 1 and 2 was the creation of the COST 531 Thermodynamic Database, which forms the basis for the present volume. The database was formed initially from partial databases that had been available at the beginning of the Action at the National Physical Laboratory (NPL) in the UK and at the Masaryk University and the Institute of Physics of Materials of the Czech Academy of Sciences in Brno (CZ). Over the course of the Action it was continuously expanded and developed by the authors of this volume into one large, single and self-consistent thermodynamic database. This would not have been possible without the dedication of colleagues involved in Working Groups 1 and 2, providing new experimental data and CALPHAD assessments for many of the binary and ternary alloy systems included here. Therefore, this volume is the result of real collaboration and exchange of information, on a true European level, between all those active in Working Groups 1 and 2.

The content of this volume is a collection of phase diagrams for 53 binary and 21 ternary alloys systems that are of relevance to lead-free soldering, be it possible solder alloys themselves or combinations of solder alloys with substrate materials. Owing to the very different combinations of elements in potential lead-free solders, and owing to the extended temperature ranges over which advanced electronic devices are currently used (up to 100 °C and sometimes even higher) it is of importance to know which intermetallic compounds will be formed and at which temperatures they will transform or melt. Thus, it is hoped that these phase diagrams will help users to understand the chemical reactions taking place in the solders and between solders and substrates, both occurring during the process of soldering itself and during the lifetime of the corresponding electrical or electronic equipment.

Many national funding agencies have contributed financial support to individual researchers or research groups in the various participating countries, and this support is gratefully acknowledged. Without them, the achievements of COST Action 531 would not have been possible.

Andy Watson
Vice Chairman of the Management Committee of COST 531

Herbert Ipser
Chairman of the Management Committee of COST 531

Preface

Owing to recent European legislation, lead will no longer be used in the fabrication of electrical and electronic materials within Europe. COST 531 was a scientific response to this situation through Europe wide action on the study of new lead-free materials suitable for use in the electronics industry. One of the objectives of the Action was the provision of a self-consistent thermodynamic database for lead-free solder materials and substrates. Critically assessed thermodynamic parameters for more than 50 binary systems have been collected from the literature or have been provided directly by a programme of experimental and assessment work as part of the COST Action. These data were supplemented by parameters for ternary systems to provide a self-consistent thermodynamic database. The database has been tested thoroughly using a range of available software to ensure its portability.

This volume has been created using this database in conjunction with commercial software developed for the calculation of phase equilibria from critically assessed data. Three different software packages were used – MTDATA, Thermo-Calc and PANDAT. Each package is broadly comparable in scope and can be used to exploit this database in order to explore the potential for candidate alloys to be used as lead free solders. A variety of diagrams are presented in this volume calculated with each of these packages. The aim is to demonstrate the scope and potential of the database, to provide the researchers with important and useful information about crucial systems used in lead-free soldering, to describe how the database has been developed as a result of collaboration between a large number of European partners and show how it can be used with appropriate software as an aid in the design and use of solders.

Acknowledgement

The authors of the book wish to express their thanks to the following sponsors of their work:

Ministry of Education, Youth and Sports of the Czech Republic through the research project OC 531.001 and OC 531.002

The Grant Agency of the Academy of Sciences of the CR through the research project KJB200410601

Department for Innovation, Universities and Skills of the UK with funds available through the National Measurement System.

EPSRC Platform Grant (GR/R95798) "Metallurgy at the Interface"

The authors also wish to acknowledge the assistance given by Dr. Suzana Gomes Fries, Dr. Milan Svoboda and Dr. Jiří Buršík during the preparation of the Crystallographic Table.