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EUROPEAN COST ACTION 531: BASIC RESEARCH ON LEAD-FREE SOLDERING

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The European Union's RoHS directive - The Restriction of the use of certain Hazardous Substances in Electrical and Electronic Equipment - became European law on July 1, 2006. According to this directive, lead should be eliminated from electrical and electronic equipment (besides other materials like mercury, cadmium, chromium (VI), and polybrominated biphenyls and polybrominated diphenylether), and with that also from the traditional solder materials.

In addition to being able to conform to the RoHS directive, another reason why the industry was in need of new solders was the increased demands on modern solder materials: e.g. the electronic components are becoming ever smaller, and the solders have to sustain higher temperatures and more severe temperature fluctuations; the surface to bulk ratio changes, which leads to different microstructural behavior; new technologies like the flip chip method require solder ball sizes of 50-100 μm and smaller.

Therefore, the last 15 to 20 years saw many efforts around the world to develop new lead-free solder materials.

Various research teams throughout the world have been working on different aspects of "lead-free soldering", but at the beginning there were hardly any organized opportunities for a regular information exchange between them. In this situation, the structure of the European COST program offered a good opportunity to better coordinate basic research on this subject. Therefore, two scientists from the University of Vienna, Herbert Ipser and Adolf Mikula, initiated a research action on "Lead-free Solder Materials" within this COST program: COST Action 531. It started officially in March 2002 with the first meeting of the Management Committee in Brussels and it ends in the first half of 2007. It was clear from the beginning that such a COST-based network would provide a sound base for information exchange as well as for identification of opportunities for collaboration. It would also contribute

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significantly to a coordination of national research efforts within Europe - including research sponsored by the EU FP6 (Framework 6 Program).

What is COST ?

Founded in 1971, COST is an intergovernmental framework for European CO-operation in the field of Scientific and Technical Research, allowing the coordination of nationally funded research on a European level. The program covers basic and pre-competitive research as well as activities of public utility. The goal of COST is to ensure that Europe holds a strong position in the field of scientific and technical research by increasing European cooperation and interaction.

In the meantime, COST has developed into one of the largest frameworks for research cooperation in Europe and is a valuable mechanism coordinating national research activities in different countries. COST is based on so-called Actions. These are networks of coordinated national research projects (which must also be funded on a national basis) in fields which are of interest to a minimum number of participants from (at least five) different Member States. The Actions are defined by a Memorandum of Understanding (MoU) signed by the Governments of the COST states wishing to participate. The duration of an Action is generally four to five years.

Currently more than 200 Actions are active, and nearly 30,000 scientists from its 35 Member States are involved, as well as about 175 participating institutions from 26 different non-COST Member States and Non Governmental Organizations.

The advantages of the European COST program are that it

- Creates lasting networks of scientists and researchers
- Fosters Scientific &Technical co-operation across Europe
- Promotes cooperation between countries inside and outside the EU
- Allows the exploration of new areas of cooperative research endeavor

Currently COST represents an estimated volume of national funding of more than □2,000 million per year. An average of □80,000 per Action is available for coordination depending on size and activity of the Action. This expenditure represents less than 1% of the overall national funding which shows that COST gives excellent value for money. This funding is basically used to cover coordination costs such as contributions to workshops/conferences, travel costs for meetings, contributions to publications and short term scientific missions of researchers to visit other laboratories.

How is COST 531 ("Lead-free Solder Materials") organized?

According to the corresponding Memorandum of Understanding, the main objective of COST Action 531 has been "... 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." Thus it was proposed to establish a European database of knowledge on such materials keeping in mind the various soldering processes; this database should contain all necessary information on physical, chemical, electrical, mechanical properties of possible solder materials and the corresponding joints.

It was decided at the beginning to concentrate research on the following alloy systems as possible solder candidates: Sn-Ag, Sn-Cu, Sn-In, Sn-Bi, and Sn-Zn based systems, but possible alternative alloys should also be kept in mind.

Since the Action started at the beginning of 2002, altogether 22 European countries signed the corresponding Memorandum of Understanding with the intention to cooperate in this Action: Austria, Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Serbia and Montenegro, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. In addition, research organizations in Canada, Taiwan, and Ukraine have been accepted as participants from non-COST countries. Although a few countries never actively contributed to the Action, there are at the end still about 50 research institutions from 18 countries involved in basic research on lead-free soldering within COST 531.

The scientific work in COST Action 531 is divided into four Working Groups (WG):

WG 1: Experimental thermodynamic properties of alloy systems and experimental phase diagrams

WG 2: Theoretical modeling of phase diagrams

WG 3/4: Physical and chemical properties of alloy systems as well as of the resulting solder joints (wettability, surface tension, viscosity; ductility, strength, fatigue, ...; toxicity, ...)

WG 5/6: Reliability issues, packaging and miniaturization (thermal fatigue, mechanical fatigue, modeling of reliability, ...)

Results of Research in COST 531

At the end of its activity, and after minor problems with funding of the proposed research projects in some of the countries, COST Action 531 has achieved not all of its goals but a large part of them. This will be discussed at the Final Meeting of all the Working Groups in May 2007 in Vienna. The results that have been achieved can be grouped in two parts, i.e. those of Working Groups 1 and 2 which have been cooperating very closely, as well as of Working Groups 3/4 and 5/6 which have also been interdependent in their research work.

a. Working Groups 1 and 2

The aim of these two Working Groups has been the development of a Thermodynamic Database: optimized thermochemical data of the various elements, as well as of binary, ternary, and higher-order alloy systems are stored in parametric form, and with the corresponding software packages (which are available commercially) it is possible to calculate the various phase diagrams of the solder alloys, but also of the alloy systems consisting of solders and substrates. This allows, for example, the prediction of the possible intermetallic compounds that will be formed when different solders react with various types of substrates.

At the beginning of the Action it was decided to include the following elements in this COST 531 Thermodynamic Database: Ag, Au, Bi, Cu, In, Ni(P), Pb, Pd, Sb, Sn, and Zn (however, not the elements Al, Si, and Ge although they might also play some role in lead-free soldering). With this a number of combinations between lead-free solder and substrate could be covered, as for example:

- Sn-Ag-Cu + Au, Ni, or Pd
- Sn-Ag-Bi + Ni
- Sn-Bi-Zn + Pd
- Sn-Ag-In + Au, Cu, PdSn-In-Zn + Pd

Based on extensive experimental and theoretical work, the first version of this Thermodynamic Database had been made available in 2004 to the participants of COST 531, and it contained all binary systems out of the elements listed above. An improved version (version 2) had been released early in 2006 which included a number of key ternary systems. The final results will be presented as an "Atlas of Phase Diagrams for Lead-free Solders", and it is expected to be published at the end of 2007.

b. Working Groups 3/4 and 5/6

Research in Working Group 3/4 has concentrated on experiments to determine wetting properties, microstructures, different mechanical properties, and thermo-mechanical properties of various lead-free solder alloys in contact with different substrate materials. In particular, research has also been directed to the question of the so-called size effect, i.e. the influence of the size of the solder joint on its mechanical properties. As it turned out, there are indications that solder joints become stronger, but also more brittle, with decreasing size of the joint.

At the same time, participants in Working Group 5/6 have been trying to determine experimentally failure mechanisms and characteristic lifetimes of electronic packages depending on parameters like atmosphere (moisture), mechanical load (vibrations), and electrical load (power cycling). Based on such experiments, the corresponding simulations were adjusted to arrive at sound predictions of the life time and the general reliability of solder joints without the necessity of extended and time consuming tests.

Together, these two Working Groups are preparing a corresponding Handbook that contains a collection of mechanical properties of Sn-Ag and Sn-Ag-Cu based lead-free solder alloys and solder joints. This is being done in close cooperation with ELFNET, a European Coordination Action within the Framework 6 Program of the European Union, and its publication is also expected for the end of 2007.

New Action COST MP0602 on "High-Temperature Solders"

Although COST Action 531 will end in 2007, basic research on important topics of lead-free soldering will continue in a coordinated way throughout Europe. In November 2006, a new Action (MP0602) was approved with the full title "Advanced Solder Materials for High-Temperature Application - Their Nature, Design, Process and Control in a Multi-scale Domain". It will start in the first half of 2007. According to the Memorandum of Understanding, its main objective will be "… through investigations on the meso-, macro- and micro-scale, to increase the fundamental knowledge of the crucial properties of alloys that can be used as environmentally friendly lead-free alternatives to existing high-temperature solders." Although the detailed research program will, as always in COST Actions, depend on the funding for the national projects it is planned to investigate solder systems based on Bi-Ag, Al-Zn, Sb-Sn, Au-Sn, and Au-Sb-Sn. However, other possible alloys should also be considered if they turn out to be interesting and useful.