Technical Bulletin
JOHNSON MANUFACTURING COMPANY
Princeton, Iowa 52768-0096

JOHNSON'S IA-423 TERNARY EUTECTIC SOLDER
Patent No. 5,527,628

A Technologically Viable Lead-Free Solder: Sn-Ag-Cu

I. E. Anderson, C. M. Miller, J. F. Smith and R. L Terpstra,
Ames Laboratory, Iowa State University, Ames, Iowa 50011

The global drive to replace the use of toxic lead metal and its alloys in industrial applications has focused, in part on the development of new Pb-free solder alloys. In addition to the toxicity of lead, there are other problems concerning continued widespread use of inexpensive Sn-Pb and Pb-based solders. Current leaded solders lack shear strength and resistance to creep and to thermal-mechanical fatigue. A solder which exhibits enhancements of these properties and retains solderability is crucial in avionics and automotive applications where the solder joints are subjected to many thermal cycles, severe vibrations, and sustained temperatures of up to 150°C. The consequences of solder joint failure in these critical applications or in any application where "lifetime" performance is now expected can be disastrous. Another important consideration is the extensive industrial infrastructure and manufacturing process linkage to existing leaded solders. The real need is to develop new solders that have similar processing characteristics and usage cost to Sn-Pb solders, but are lead-free and have improved mechanical properties and microstructural stability.

A Pb-free ternary eutectic solder alloy, Sn-4.7Ag-1.7Cu (wt.%) with T_e=217°C, has been discovered which can form the basis for a new family of Pb-free solders. The melting point of the ternary eutectic alloy is 4°C lower than the Sn-Ag binary eutectic melting point, 221°C, which positions the Sn-Ag-Cu ternary eutectic within the range (190 to 217°C) of several other Pb-free solder alloy candidates based on Sn-Ag. This moderately elevated melting temperature range can be accommodated within the control adjustments of many commercial solder reflow ovens and wave soldering machines that are used for Sn-Pb eutectic solder (T_e=183°C). Compared to the other Pb-free solder candidates based on Sn-Ag, however; the Sn-Ag-Cu alloy appears to have greater potential as a widespread replacement for Sn-Pb eutectic solder. In this Pb-free class, all of the other alternative solders contain alloy additions that are either directly related to the refining of Pb ore, e.g., Bi and Sb, of limited long-term availability, e.g., In, or too costly, e.g., Ga.

The new Sn-Ag-Cu eutectic solder alloy exhibits a ternary eutectic reaction at 217°C, where the liquid solidifies as a fine eutectic microstructure of Cu_6Sn_5 and Ag_3Sn dispersed in a Sn(bct) matrix when cooled under typical solder reflow conditions. Wavelength dispersive spectrometry measurements on large (30um dia.) interdendritic regions of a near-eutectic alloy from a chill cast sample established the initial estimated eutectic composition. Microstructural analysis of chill cast samples of the initial estimated eutectic composition and differential thermal analysis measurements of eutectic and numerous off-eutectic compositions helped to verify the composition and temperature of the Sn-Ag-Cu ternary eutectic reaction. This ternary eutectic had not been reported in previous experimental or calculated phase diagram studies and its discovery and use for soldering applications currently has a patent pending. Some recent phase diagram calculations performed by U. Katner at NIST involving a thermodynamic re-examination of existing binary equilibrium data have lent theoretical support to our experimental finding.

Annealing experiments on hand soldered through-hole solder joints made with Sn-Ag-Cu eutectic wire demonstrated that the presence of two intermetallic phases, Cu_6Sn_5 and Ag_3Sn, in the Sn matrix promote significant microstructural stability and retention of strength. The solder alloy microstructure retained at least 60% of its original hardness after annealing in air for up to 10^6 sec. at temperatures up to 210°C to simulate conditions more harsh than the current automotive electronics environment.

Qualitative evidence of very good solderability and compatibility with available fluxes was gathered from in-house technician tests of circuit board soldering behavior and from industrial trials at Allied Signal/Kansas City Division with solder wire , at Alpha Metals with solder paste and at Johnson Manufacturing with bath solder in an ambient atmosphere wave soldering machine. Wetting test performed by Sandia National Laboratory also ranked highly to Sn-Ag-Cu eutectic and several Sn-Ag-Cu-X alloys compared to a wide variety of alternative Pb-free solder alloys. Based on the encouraging results of our studies and on their own wave soldering trials, a license agreement has recently been executed with Johnson Manufacturing to make and sell commercial solders based on the Sn-Ag-Cu eutectic alloy. The new solder probably will find immediate use in electrical and mechanical connector applications and heat exchanger manufacturing, but should also be utilized broadly in electronic packaging applications for harsh environments, e.g., automotive and avionics. A reduction of the distribution of Pb in the global environment, an increase in the performance of critical solder joints and a minimization of the cost of replacing Sn-Pb and Pb-based solders in manufacturing processes are all achievable goals for the commercial development of this Pb-free solder.

6 July 1995, Iver E. Anderson, Ames Lab, 2-page abstract for invited talk at IMM Workshop on "Lead Free Solders, A Mechanics and Materials Approach" to be held at Northwestern University, Evanston, IL July 24-26, 1995.

This technical abstract is distributed by Johnson Manufacturing Company, under license agreeement with Ames Lab, ISU, Ames Iowa.