A Review of Sn-Zn-Al Lead-Free Solder Alloys for Electronic Devices and Circuits

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Abstract— Conventional Sn-37Pb solder has been as the most frequently used material to interconnect and pack modern electronic components and devices. Sn-Pb solder has been used because it is cheap and has good material properties. However, lead and lead containing compounds are considered to be very toxic. Due to health and environmental concerns, efforts to replace conventional Sn-Pb eutectic solder with lead-free alternatives have begun. Considering performance, reliability, cost and resources Sn-Zn, Sn-cu and Sn-Ag alloys are supposed to be the best alternatives. Hence lead free solders are becoming substitute of Sn-Pb solder. This paper present review of reported work on lead-free solders.

Key words: Lead-free solders, Mechanical properties, Corrosion resistance

I. INTRODUCTION

In recent past years the development of lead free solders has emerged as one of the key issues in the electronic industries. Sn – Pb alloys have had wide use due to their low melting temperature and good wettability. In electronics industry Tin-Lead (Sn-Pb) solder has been very important material. The main constituent of solder alloysis lead and also Sn-Pb solder alloys have been found to be most popular materials because they have a low melting point, low material cost, good wettability and easily available.

Sn-pb based solders have adverse effect environment and health. Due to this the current waste management and particular concerns about the growth the hazardous content of electrical and electronic equipment (EEE), the European Commission adopted two directives in June 2000 on Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) stated that the member states shall ensure that the use of lead in electronics industry is banned by 2006. So the investigation on lead free solders has become the most important project in the present situation. Several alternate alloys are being investigated and their various properties are being studied. This articles present reported work by various researchers Sn-Cu, Sn-Ag, Sn-Cu-Ag and Sn-Zn

II. REPORTED WORK

A detailed Literatures on lead free solders revealed that, numerous researches have attempted to investigate the effect of various process variables on the output characteristics by various techniques. Some of the reported works are as under:

[1] Liu et al studied The effect of indium (In) addition on thermal property, microstructure, wettability and interfacial reactions of Sn–8Zn–3Bi lead-free solder alloys has been investigated. Results showed that addition of In could lower both solidus and liquidus temperatures of the solder alloys with wettabilty improvement of 34% compared to that of Sn–8Zn–3Bi.

[2] studied The effect of aluminum concentration on the microstructure, wettability, interfacial IMC and mechanical properties of Sn–0.7Cu lead-free solder alloy is investigated. The results show that the microstructure of Sn–Cu–Al solder alloy consists of b-Sn, eutectic and IMC, and the microstructure of Sn–0.7Cu alloy is refined by adding aluminium. The wettability of Sn–Cu–Al solder alloy is improved by aluminium, the spreading coefficient of Sn–0.7Cu–0.075Al reaches about 70%. The tensile strength and the creep resistance of Sn–0.7Cu–(0.05–0.075) Al are superior to Sn–0.7Cu–(0.01–0.025) Al due to the hindering dislocation slipping by the disperse Al2Cu. Sn–0.7Cu–(0.05–0.075) Al is an applicable lead-free solder alloy for the Cu substrate.

[3] Investigated the effects of effects of diamond nanoparticles amounts (0.5, 1.5, and 2.5 wt.%) reinforcement on lead-free SAC 305 solder paste after the reflow soldering process. Te characteristics studied were melting point, morphology and thickness of the intermetallic compound (IMC), agglomeration of diamond nanoparticles, and hardness. Results showed that diamond nanoparticles slightly decreases the melting point but significantly reduces the IMC thickness. The morphologies of the nano-reinforced solder paste showed the agglomeration of nanoparticles on the surface of the solder paste with increasing diamond nanoparticles percentage. The addition of 0.5 wt.% diamond nanoparticles was well embedded in the solder matrix The addition of 0.5 wt.% diamond nanoparticles improved the hardness of SAC 305 by 77.5%. Increasing the nanoparticles amount by 1.5 and 2.5 wt.% in SAC 305 enhanced the hardness of SAC 305–0.5 wt.% by 6.3% and 17.8%, respectively.

[4] investigate the effects of Ni (i.e. 0.05, 0.1, 0.5 and 1.0 wt.%) on the physical properties of Sn58Bi–xNi lead-free solder, and to examine its interfacial reaction with the copper substrate on their respective microstructure tensile strength, elongation, melting temperature, wet ability and electrical resistivity of Sn58Bi–xNi The results indicated that Ni refined the microstructure of the solder matrix and induced the formation of Ni3Sn4 intermetallic phase, and that the size and volume fraction of Ni3Sn4 were positively correlated to the Ni content with optimal concentration of 0.1wt%. addition of Ni enhance the melting temperature, wetting behavior and thickness of the intermetallic layer with no change in electrical resistivity.

[5] investigated The microstructure and impression creep behavior of the high-temperature Zn–4Al–3Mg–xSn (x=0, 7, and 13 wt. %) alloys in the range of 50-800MPa and in the range of 345-473K. They concluded that addition of Sn in base alloy results in higher creep rates, and lower creep resistances. The deteriorating effects of Sn, the creep

resistance of the quaternary alloys was still higher than those of the Zn–Sn and Pb–Sn high temperature solders. The stress exponents of 4.0–7.9 and activation energy values of 51.6–92.6 kJ mol−1, are indicative of a dislocation climb controlled creep mechanism.

[6] investigated the solder joint reliability for the plastic quad flat package (PQFP) which was mounted on the printed circuit board (PCB) using 95.5Sn–3.8Ag–0.7Cu lead-free solder using random vibration test. Fatigue life prediction for the copper (Cu) lead and PQFP solder joint was carried out using three different cycle counting methods and the Miner's law. It was shown that solder fatigue failure is more critical than Cu lead failure for the PQFP assembly under the random vibration test.

[7] investigated the effects of n indium addition into Sn–0.7Cu–0.2Ni lead-free solder on melting temperature, coefficient of thermal expansion (CTE), wettability, corrosion resistance and hardness of the solder alloys. They concluded that enhancement of CTE and spreading area of Sn–0.7Cu–0.2Ni–xIn solders with optimal CTE was 17.5 106 /C by adding 0.3 wt.% indium. Spreading area increased about 15.6%, corrosion resistance increased about 32.8% with decrease in hardness of about 11.7%

[8] Investigated the low Ag-content Sn–1.5Ag–0.7Cu (SAC157) lead-free solder was modified with addition of Bi in terms of microstructure, melt properties and tensile behaviour after and before compositional modifications. From microstructures evaluation, 1 wt% Bi addition to SAC157 significantly enhanced the solid solution effect of Bi and refined needle-like Ag3Sn and plate-like Cu6Sn5 particles as well as extended the eutectic area, which raised the mechanical strength and Young’s modulus to about 1.5 times of SAC157 solder. With increasing Bi addition to 3 wt% the cubic-shaped Bi precipitates and enlarged eutectic area cause a dramatic increase of ultimate tensile strength, yield strength and Young’s modulus to about 2.2–2.6 times of the SAC157 alloy, although the elongation was maintained at the SAC157 level. , the addition of Bi not only reduced the solidus temperature (Tonset) and eutectic temperature (Tm), but also decreased the undercooling even though the pasty rang is slightly increased.

[9] investigated low-cycle fatigue test was conducted for a lead-free solder joint at two test temperatures (348 K, 398 K) and three strain amplitudes (3%, 4%, and 8%). The results show that the maximum load gradually drops with increasing the number of loading cycles. When the strain range or temperature is low, the maximum load drop curve can be divided into three stages. Then, it degrades into a linear stage with increasing the strain range or temperature. Both the softening of solder and the reduction of effective load-bearing area are responsible for the maximum load drop depending on the test condition. The fatigue ductility is dependent on temperature, whereas other parameters in these two models keep stable under different temperature.

[10] studied the ability of crystal plasticity finite element (CPFE) modeling to account for elastic and plastic anisotropy in tin based solder joints was examined using shear deformation applied on a simplified representation of a real microstructure of four specific SAC305 solder balls. Microstructure observed were single crystals or a particular microstructure with solidification twin relationship with about 55–65 rotations about a common [1 0 0] axis (known as beach-ball microstructure. Simulation results show the ability of CPFE to predict the heterogeneous deformation due to the anisotropic elastic and plastic properties of tin in lead free solder joints.

[11] Studied the effects of temperature fluctuations on a number of various solder materials namely SAC105, SAC305, SAC405 and Sn–36Pb–2Ag. For these three different classic joint assemblies (a ball joint, a test specimen joint and finger lead joint) were modeled which provided the foundation for the creep and fatigue behaviors’ simulation. Anand’s viscoplasticity as a constitutive equation was employed to characterize the behaviour of solders numerically under the influence of thermal power cycles (80–150 C) and thermal shock cycles (40 to 125 C). T

[12] studied the latest metallurgical alloys, tin zinc (Sn–Zn) and tin bismuth (Sn–Bi), for lower temperature processed electronic interconnections. The fundamentals of solder paste production and flux development for these highly surface active metallic powders are introduced. Intermetallic compounds that underpin low temperature solder joint production and reliability are discussed. The influence of alloying on these alloys is described in terms of critical microstructural changes, mechanical properties and reliability. The review concludes with an outlook for next generation electronic interconnects materials.

[13] investigated that the levels of natural radionuclides (238U, 232Th, and 40K) and their daughter products contained in Sn–6.5Zn solders have been estimated via gamma-ray spectrometry using a 100% Hyper-Pure Germanium (HPGe) detector.n–Zn solders are candidate alternatives to Sn–Pb-based solder alloys. With the increasing requirement for lead-free solders, the reliability of successor solders in microelectronics assemblies is in high demand. The elimination of radionuclides, heavy metals, and other poisonous elements in lead-free Sn–6.5Zn solders in the microelectronics industry is a worldwide goal. As a result, it is useful to identify the natural concentrations of radioactive nuclides, heavy metals and other poisonous trace elements (both macro- and micro-element contents), such as Au-196, Th-227, Ag-110M, Fe-59, Zn-65, Rb-89, Rh-106M, Bi-207, Cs-137, Eu-154, Sb-126, Eu-152, Co-56, Co-58, Co-60 and K-40. If this lead-free solder contains high concentrations of natural radioactive nuclides, then workers handling it might be exposed to significant levels of radiation. Therefore, it is important to determine the levels of radioactive nuclides in this solder to protect workers; these levels provide background for the safety rules and precautions that should be applied for those working in this field.

III. CONCLUSIONS

Following conclusions can be made from the report works by various authors, which may help for research in future.

Properties of Sn-Zn-Al alloys can be optimized and made similar to that of presently used lead joints.

1) The pasty range of three solders lies in the range of 1 - 4 °C which is lower than 11.5 °C for Sn-Pb eutectic solder and the pasty range increase in the order Sn-9Zn < Sn-7.5Zn < Sn-6.5Zn.

2) Sn-6.5Zn shows the highest spread area among the other two solder alloys developed. Hence, have the best wettability.
3) The above reported results showed that Sn-6.5Zn is the best choice to be used as a solder among the binary Sn-Zn system.
4) The addition of indium, aluminum and Ni enhanced wet ability and intermetallic compounds.
5) The addition of bismuth in lead free soldier modifies microstructure, melting properties and tensile behavior.

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