

Impact of Drop-In Lead Free Solders on Microelectronics Packaging

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Abstract

Lead-free solders and soldering technology will be a revisited concern in microelectronics packaging challenges to meet the demands of wafers-level packaging and 3D packaging operations where greater demands will be made on soldering smaller and smaller pads sizes and the high expectations of solder joint strength and long-term reliability. This paper reports on the drop-in lead-free solder approach and will provide characterization research results on Sn-Ag-Cu-In drop-in solder material composition, wetting, assembly characteristics and mechanical properties for stress-strain and creep performance compared to Sn-3.8Ag-0.7Cu solder.

1. Introduction

The global electronic industry is making a paradigm shift to lead-free or Pb-free solders and soldering technology. Pb-free solder technology involves multi-disciplinary knowledge in Pb-free solder alloys, material properties, compatibility with IC components and PCB materials, soldering and surface mount technology, quality and long-term solder joint reliability. Although the current attention is on Sn-Ag-Cu solder, continual development of drop-in replacement for eutectic 63Sn-37Pb solder alloys which have nominal melting point temperature of 183°C and typical solder reflow peak temperatures of 220 to 230°C. In this study, two drop-in, Pb-free Sn-Ag-Cu-In solder alloys were investigated. These two drop-in alloys (ie: Sn-4.1Ag-0.5Cu-4.0In and Sn-4.1Ag-0.5Cu-7.0In) have slightly higher melting point temperatures but compatible solder process peak temperatures [1]. The added advantage of compatible process peak temperatures to 63Sn-37Pb enable existing plastic and polymeric materials to be used without the added reliability concern of the higher process peak temperatures fo 245 – 260°C for Sn-Ag-Cu solder. The Pb-free drop-in alloys also meet compatible standards oin solderbility and quality and better fatigue and creep resistance to Sn-Ag-Cu and 63Sn-37Pb solder alloys.

2. Why Indium (In) Containing Alloy?

Compositional studies especially on the In percentage have been extensively studied to enhance the SAC alloys in both the SMT and wavesoldering applications without changing the current tin/lead infrastructure. In order to justify a drop in replacement alloy, it has been confirmed that solder melting temperature should not exceed more than 210°C. Sn-4.1Ag-0.5Cu-4In with a melting temperature of 210°C is used as drop-in replacement for wavesoldering application due to its excellent fluidity in pot temperature of

245°C. On the other hand in SMT application, Sn -4.1Ag-0.5Cu-7In which has a melting point of 207°C is the closest alloy to work as a drop-in replacement with a reflow temperature of 225°C without jeopardizing the joint reliability aspect such as mechanical properties, fatigue resistance..

Wetting ability of solder is normally measured by the wetting time and force on a certain substrate. In this experiment, copper laminates had been utilized to study the wetting time and also force of the alloy towards the substrate. A comparison is made using the In containing Sn-Ag-Cu-In solder alloys and compared to conventional tin-lead alloy, Sn63Sn-37Pb, and several Pb-free solders. The wetting time results is shown in Table 1.

Table 1: Comparison on Wetting Time against temperature between lead free alloys and tin/lead alloys

Solder Alloy	Wetting Time (Sec) at Solder Temp (°C)		
	235	245	255
63Sn37Pb	0.767	0.606	0.546
Sn3.5Ag	2.189	1.352	1.05
Sn/0.7Cu	1.411	1.034	0.682
Sn4.0Ag0.5Cu	3.368	1.946	1.284
Sn2.5Ag1.0Bi0.5Cu	1.86	1.235	0.824
Sn4.1Ag0.5Cu4.0In	1.156	0.716	0.544
Sn4.1Ag0.5Cu7.0In	1.171	0.573	0.464

Under the JIS Standard on the wetting ability of solder alloy, for an alloy to achieve good wetting, the wetting time for any alloys should be less than 2 secs for all applications but under wavesoldering process, it has been established that for a good wetting, wetting time of the alloy should not exceed more than 1 sec. With different alloys being studied, it was found that both Sn-Ag-Cu-In alloys have wetting ability closest to 63Sn-37Pb solder. These two drop-in solder alloys have the wetting time well within the JIS Standard.

In addition to having good wetting ability, the creep and fatigue reliability of solder joints is another aspect which needs further characterization. The fatigue life of solder industries is generally measured by a low cycle isothermal fatigue mode and/or by thermomechanical mode. Isothermal fatigue results for different solders are shown in Table 2. Generally, Pb-free solder alloys have better fatigue resistance than conventional 63Sn-37Pb solder alloy.

Table 2: Isothermal fatigue resistance of lead free alloys

Alloy	Melting T	Nf
88.5sn/3.0Ag/0.5Cu/8In	195-201	>19,000
88.4Sn/4.1Ag/0.5Cu/7.0In	202-207	
91.5Sn/3.5Ag/1.0Bi/4.0In	208-213	
92.8Sn/0.7Cu/0.5Ga/6.0In	210-215	10,000-12,000
85.2Sn/4.1Ag/2.2Bi/0.5Cu/8.0In	193-199	
91.4Sn/4.1Ag/0.5Cu/4.0In	205-210	9812
93.3Sn/3.1Ag/3.1Bi/0.5Cu	209-212	6,000-9,000
96.2sn/2.5ag/0.8Cu/0.5Sb	216-217	
95.4Sn/3.1Ag/1.5Cu	216-217	
88.0Sn/4.0Ag/4.0Bi/4In	199-209	
96.5Sn/3.5Ag	221	4,186
63Sn/37Pb	183	3,650
99.3Sn/0.7Cu	227	1,125

3. Compatibility of Sn-Ag-Cu-In solder with substrates

For effective lead free implementation, the understanding and verification of compatibility are critically important. Compatibility between lead free joint and the components coating or lead free solder joint with the pcb finishes needed to be studied carefully to determine the formation of the fillet and intermetallic during bonding process or after ageing.

Figure 1 shows the joints formation of Sn-4.1Ag-0.5Cu-4In (V349) by wave soldering at 245°C on boards with Cu/OSP and Ni/Au substrate. Full fillet was observed on both the substrates of the PTH boards. The fluidity of the solder at 245°C was excellent and thus exhibited a good capillary effect for the solder to flow to the top side of the boards, a feat that is quite difficult to attain by most lead free alloys. Formation of a strong intermetallic bond between the solder and substrate is noted. Figure 2 shows the microstructure and intermetallic layer.

Viromet 349 on PTH boards

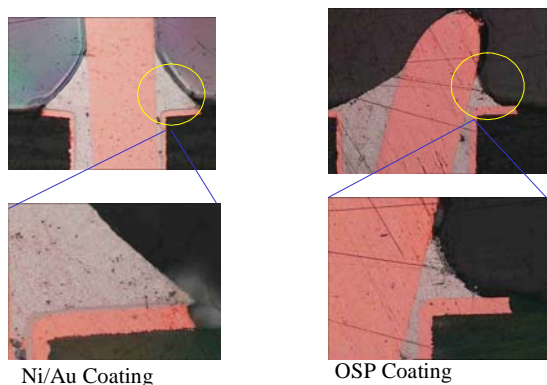


Figure 1: Fillet Structure of Viromet 349 alloy with Cu/OSP and Ni/Au coating surface.

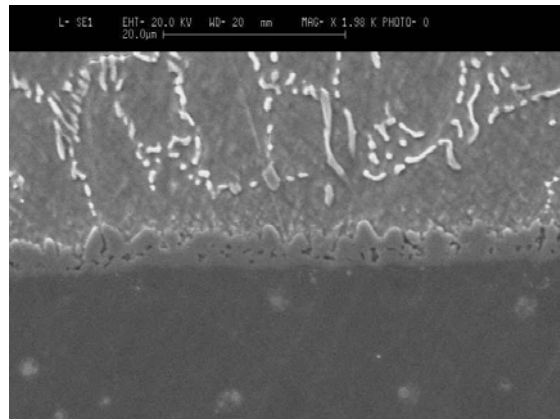


Figure 2: Microstructure of Sn-Ag-Cu-In solder joint and intermetallic layer.

The test samples have different surface finish and soldering processes. BGA1/SOT1: Sn substrate with Vapor Phase, BGA2/SOT2: Ag substrate with Vapor Phase, BGA3/SOT3: Cu/OSP substrate with Vapor Phase, BGA4/SOT4: Ni/Au substrate with Vapor Phase, BGA5/SOT5: Cu/OSP substrate with convection process, BGA6/SOT6: Sn substrate with convection.

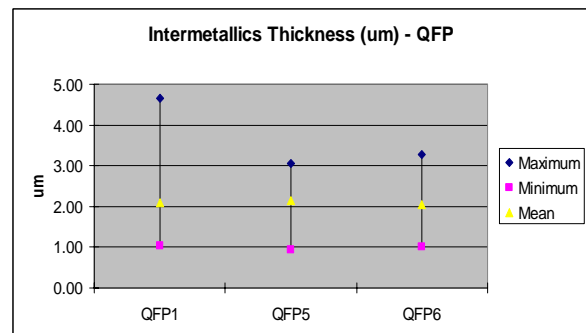
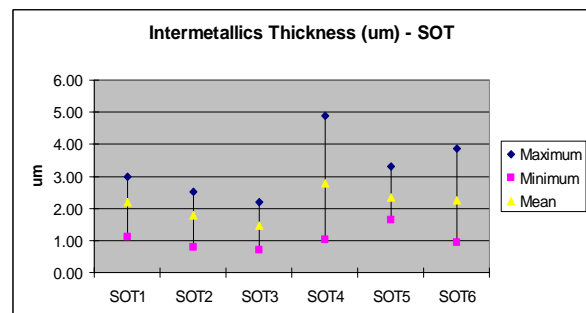
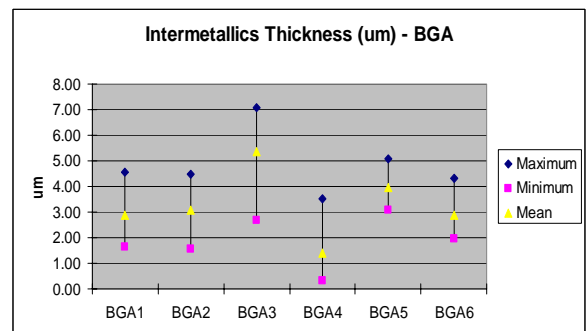


Figure 3: Intermetallic Thickness for Sn-4.1Ag-0.5Cu-7In on BGA, QFP and SOT components.

The intermetallic thickness for different test samples are shown in Figure 3 and varies with the component type. BGA solder joints have the thickest intermetallic layer. Intermetallic growth is a time-temperature dependent process, a slower cooling rate during solidification state, will result in a thicker intermetallic layer. Comparatively, the QFP, though having similar size as that of the BGA, but the heat retention of the solder joints is much less. This is because the gull wing leads are away from the housing of the QFP unlike the BGA, which has solder joints beneath the housing. It is observed that intermetallic thickness between different substrates ranges from 1.4 to 4 μm , which is within the recommended 5 μm . The intermetallic on Au substrates have the highest standard deviation, OSP/Cu have the smallest standard deviation. Intermetallic thickness of OSP/Cu substrate is consistently higher than Sn substrate for all the components tested.

4. Stability of Sn-Ag-Cu-In alloy with temperature

With increase in temperature, there will be changes in the metallurgical aspect of the alloys as we will expect changes in the phases of the material. Studies have been carried out using the XRD to determine phase changes with temperature for the Sn-Ag-Cu-In alloys. The XRD spectrum for Sn-4.1Ag-0.5Cu-7In (V347) and Sn-4.1Ag-0.5Cu-4In (V349) are shown in Figure 4 and 5 respectively. It is noted that Sn-In, and Ag_2In phase exist with different temperatures and Ag_2In phase become more prominent when temperature reaches 165°C for Sn-4.1Ag-0.5Cu-7In and 195°C for Sn-4.1Ag-0.5Cu-4In. Phase stability was observed in both the drop-in solder alloys up to 125°C.

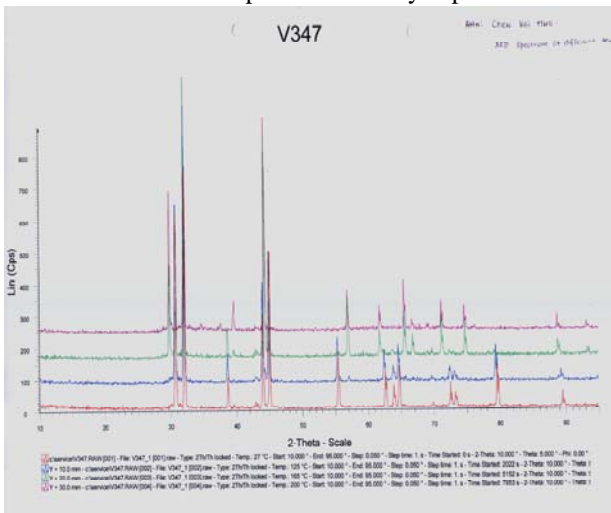


Figure 4: Viromet 347 Alloy phase studies with temperature using XRD. (From top to bottom, 195 °C, 165 °C, 125 °C and 27 °C)

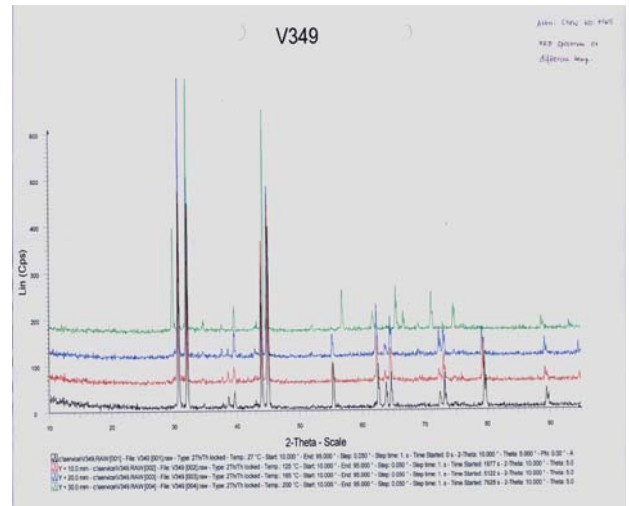


Figure 5: Viromet 349 Alloy phase studies with temperature using XRD. (From top to bottom, 195 °C, 165 °C, 125 °C and 27 °C).

5. Mechanical Properties of Sn-Ag-Cu-In solder

Mechanical strength of solders will decrease with increase in temperature [2]. Studies were carried out to understand the impact of temperature on mechanical properties. Figure 6 show the energy to break and toughness of the two Sn-Ag-Cu-In alloys compared to Sn-Ag-Cu and Sn-Cu-X alloys with increase in temperature. Sn-Ag-Cu-In alloys show a more gradual decrease rate in the energy to break and toughness compared with other lead free alloys. From room temperature to 125°C, the other alloys drop more drastically in their mechanical properties. The In-containing alloys prove to be more stable at least up to 125°C, as indicated in the XRD spectrum on the phase changes as well.

Mechanics of materials characterization of lead-free solders are needed for better understanding of solder joint reliability performance [3]. Comparative evaluation of the tensile properties (modulus, yield and UTS), steady-state creep strain rate, and solder fatigue strain-life performance is compared to Sn-3.8Ag-0.7Cu solder properties. Both the 347 (Sn-4.1Ag-0.5Cu-7In) and 349 (Sn-4.1Ag-0.5Cu-4In) drop-in solders have higher tensile properties than SAC-387 (Sn-3.8Ag-0.7Cu) as shown in Table 3

The creep performance of both 347 (Sn-4.1Ag-0.5Cu-7In) and 349 (Sn-3.5Ag-0.5Cu-4In) drop-in solders are more resistance to creep deformations with much lower steady-state creep strain rates by 1 to 2 orders of magnitudes as shown in Figure 7.

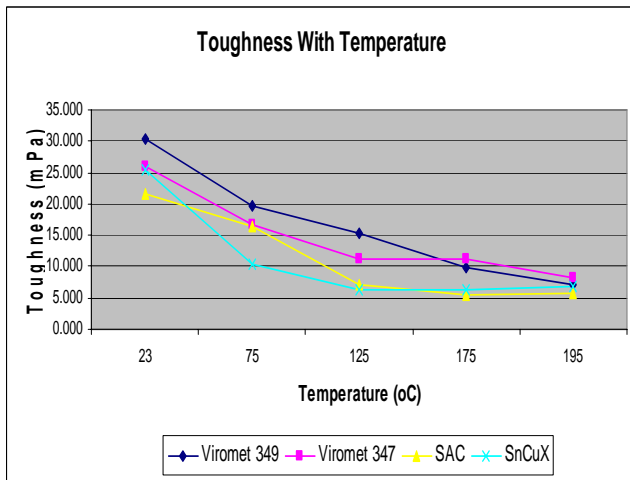
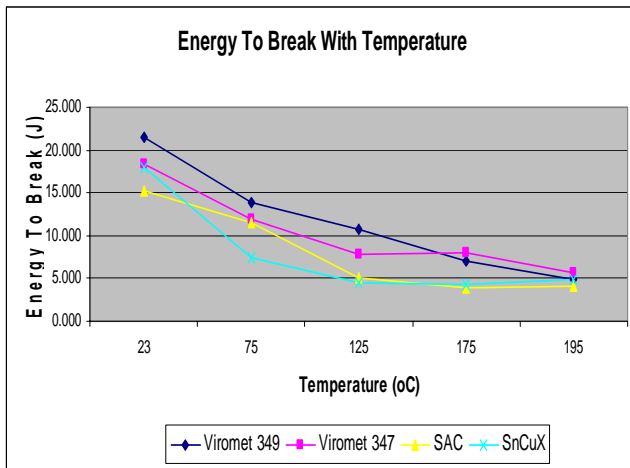


Figure 6: Mechanical properties of lead free alloys with temperature.

Table 3 Tensile Properties at strain rate of 10^{-4} (1/s) for Sn-3.5Ag-0.5Cu-4In (349) Vs Sn-3.8Ag -0.7Cu,

Temp(oC)	E (GPa)		Yield (MPa)		UTS (MPa)	
	New	SAC	New	SAC	New	SAC
25°C	43.3	41.8	43.9	35.1	54.1	40.6
75°C	32.6	30.7	36.8	25.6	22.6	29.0
125°C	20.6	18.8	20.2	16.7	22.6	19.7

Table 4 Tensile Properties at strain rate of 10^{-2} (1/s) for Sn-4.1Ag-0.5Cu-7In (347) Vs Sn-3.8Ag -0.7Cu,

Temp(oC)	E (GPa)		Yield (MPa)		UTS (MPa)	
	New	SAC	New	SAC	New	SAC
25°C	48.6	55.1	60.8	52.8	79.4	58.0
75°C	35.8	42.4	45.5	41.5	53.2	47.1
125°C	21.1	32.5	32.5	34.0	37.9	39.7

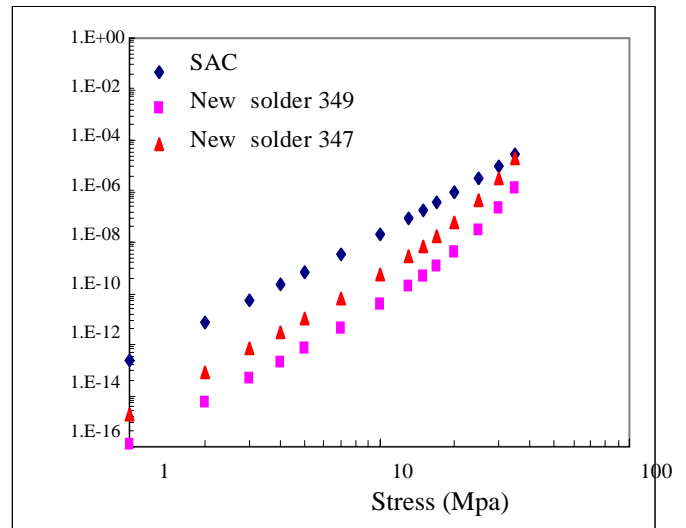


Figure 7 Comparison of Creep Properties of drop-in solders 347 and 349 with SAC at 25°C.

6. Conclusion

Characterization results for the two drop-in lead-free solder 347 (Sn-4.1Ag-0.5Cu-7In) and 349 (Sn-3.5Ag-0.5Cu-4In) indicate that the microstructure, intermetallic thickness, solder wetting, mechanical properties, tensile stress-strain and creep properties are superior to that for SAC-387) Sn-3.8Ag-0.7Cu solder. As the packaging industry is going through a paradigm shift in replacing tin-lead solder with lead-free solders, it is important to consider a drop-in approach which has both the benefits of compatible soldering process windows to eutectic tin-lead solder and yet have better solderability, mechanical, tensile and creep properties than Sn-3.8Ag-0.7Cu solder.

References

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