Pb- Free Memory Module with Sn-Bi Lead Finish and Sn-Ag-Cu Solder Paste

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A Pb-free package and module were developed using Sn-Bi lead finish and Sn-Ag-Cu solder paste. But the main problem associated with Sn-Bi was bending crack. As this crack becomes more severe, it can lead to corrosion at the lead shoulder during the pressure cooker testing. To minimize the bending cracks at the stress concentration points of the package lead, and lead shoulder and foot, the current density of the plating process should be lower than about 5% of the limiting current density, and the plating temperature should be above 40℃. When the Sn-Ag-Cu solder paste is applied to the Sn-Bi lead finish in the module, the peak reflow process temperature will reach between 240~260℃ because of its high melting temperature. To evaluate the reliability of the solder joint in this memory module in this temperature range, the lead pull test was analyzed, and reliability tests such as the thermal cycling test(-25~125℃) and temperature humidity bias test(85%,85℃,5.0V) were performed. In this paper, the validity of the Sn-Bi lead finish, Sn-Ag-Cu solder paste and module are presented.

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Introduction

In response to the worldwide effort to remove and replace Pb from electronic products, promising new material and processes are proposed. The candidates for this new lead finishing process are the Pb-free plating process using Sn-Bi[1][2], Sn-Ag[3], Sn-Cu, Pure Sn[4][5], and Sn-Zn plating. For the surface mount process, Pb- free solder paste material such as Sn-Ag, Sn-Ag-Cu[6-8], Sn-Ag-Bi, Sn-Bi and Sn-Ag-Cu-Bi are considered[9]. A few companies have already produced some Pb-free products[10-12], and have been on the move to increase the number of Pb-free products, ever since. However, in the Sn-Bi lead finish, cracks are a major concern and should be reduced, especially those located in the lead shoulder of the package after the forming process. These cracks occur because of the brittle nature of the Bi. As for the Sn-Ag lead finish, there are two major problems. One is the large melting temperature variation with respect to the Ag content, and the other is the electroplating solution stability. In a Sn-Zn lead finish, Zn oxidation during thermal exposure, such as reflow process, is a problem. In a Sn-Cu lead finish, it is difficult to analyze the contents of the Cu in the electrodeposit because of the interference caused by the Cu based leadframe used. In a pure Sn lead finish, the whisker formation becomes an issue .

In the surface mount process, the solder paste must be carefully selected. The Sn-Bi solder paste has two major problems; one is the melting temperature that is much lower than that of the Sn-Pb solder paste, and the other is its brittle nature and lift phenomenon. Because the Sn-Ag solder paste has a high melting temperature, the Sn-Ag solder paste with Cu and Bi was considered.

In this paper, the Sn-Bi lead finish and the crack at the lead shoulder of the package with respect to bath temperature and current density were investigated. The proper current density and temperature to minimize the bending crack at the shoulder was found. With the results from our investigation and subsequent elimination of bending cracks, a reliable lead-free memory module can be obtained.

Experimental Procedure

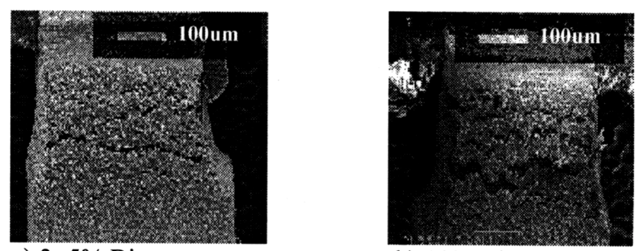
The TSOP with 0.4mm pitch was used to characterize the Pb-free electrodeposit. The leadframe material of this package is a Cu based alloy. This LOC type package uses an adhesive tape and epoxy molding compound.

A 10 liter volume bath with one filter, one motor and heater was prepared to electroplate the package lead with Sn-Bi. This bath was controlled with an external heating controller and supplied with an external power line through one rectifier. This bath was similar to a high speed reel-to-reel plating machine. Except for the methane sulfonic bismuth, the composition of the chemical solution used in this process is similar to that used in the Sn-Pb plating process. It is composed of four chemicals, methane sulfonic acid, methane sulfonic tin, methane sulfonic bismuth and an additive. The thickness of the electrodeposit ranged between 7.0~15.0um (280~600u-in.) and the Bi content in the Bi metal ranged between 3.0~5.0%. After plating the Sn-Bi on the leadframe, the hardness and the grain size were observed. Then, after performing the lead forming process, the relationship between the grain size and crack density was analyzed. In the surface mount process, Sn-Ag-Cu solder paste with 95.8%Sn-3.5%Ag-0.7%Cu was used.

Results and Discussion

Crack characterization as a function of temperature

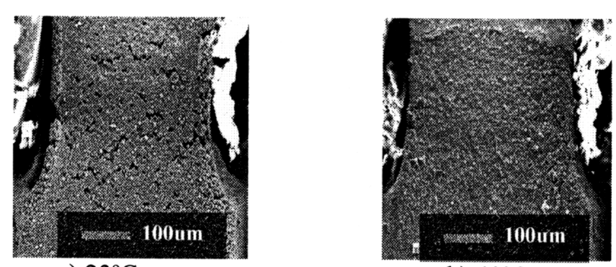
In general, the crack increased but the wetting behavior improved with increasing Bi contents in the Sn-Bi electrodeposit. But, the whisker formation may have occurred at low Bi contents in the Sn-Bi electodeposit. Several experiments were performed to investigate the effect of Bi contents on the crack formation at the lead shoulder of the package. Based on other experimental results, 3~5% Bi contents was chosen to elucidate the effects of plating bath temperature and current density. As shown Figure 1, the crack density level of the lead shoulder of the package with 3~5% Bi contents was acceptable.



a) 3~5% Bi content   b) 10% Bi content

Figure 1. The crack density of Sn-Bi elecrodeposit at the lead shoulder of the package

By increasing the bath temperature from room temperature(23°C) to 40°C, the crack density was drastically decreased at the lead shoulder(Fig. 2.). Cu was not exposed (i.e., lead frame) at every point on the lead. The hardness and grain size, revealed through the hardness tester and SEM, were observed and analyzed to determine the cause of the decrease in crack density with increasing temperature in the Sn-Bi lead finish.



a) 23°C   b) 40°C

Figure 2. The SEM micrograph of the crack as a function of temperature

The decrease in the crack density at the lead shoulder of the package may have been due to the change in the mechanical properties of the electrodeposit. The hardness of the electrodeposit was measured as a function of the electroplating bath temperature. Figure 4. shows the hardness variation. The fundamental cause for the crack decrease were drawn from these experimental results.

Figure 4. depicts the grain size variation at each temperature. As seen, the grain size increases with temperature increase which may be caused by the difference between the growth rate and nuclei formation rate during the electroplating process. This increase in grain size decreases the hardness and increases the ductility of electrodeposit.

Therefore, it is conceivable that the more ductile the electrodeposit, the more stress is absorbed at the lead shoulder of the package during the forming process. Furthermore, based on the results, the hardness of the electrodeposit plated at 40°C is less than that plated at 23°C.

Table 1. The hardness of Sn-Bi electrodeposit as a function of temperature

Temp	The hardness of the Sn-Bi electrodeposit		
	Avg.	Max.	Min.
23°C	58.1	58.6	56.6
40°C	55.9	57.0	54.7
50°C	51.9	54.2	50.7

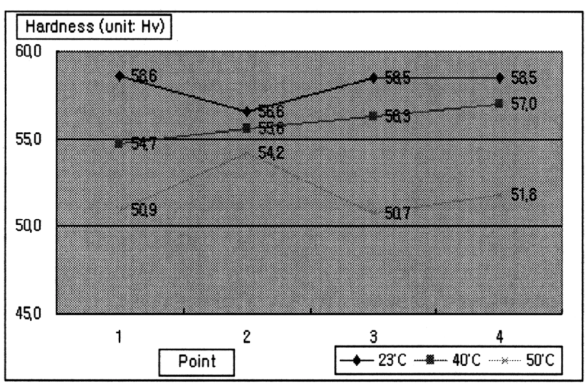
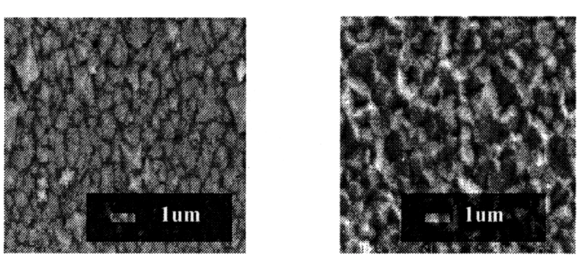


Figure 3. The hardness variation as a function of temperature at each point of the lead frame



a) 23°C b) 40°C

Figure 4. The SEM micrographs of the Sn-Bi electrodeposit as a function of temperature

Crack characterization as a function of current density

In much the same way that temperature affects the grain size, the current density can also control the mechanical properties of the electrodeposit. To investigate this effect, experiments were performed as a function of the current density at 40°C, at which condition the crack resistance is greater than that with current density at 23°C. The ratio of the applied current density to the limiting current density, determined by diffusion coefficient of the metal ion in the solution and the double layer thickness, is a particularly important factor in determining the mechanical properties of the electrodeposit. Potentiodynamic experiments were performed with Sn-Bi electroplating solution to determine the limiting current density at various temperatures. But, as shown in Figure 5, the limiting current densities are nearly the same at each temperature. The leadframes were plated at 20% and 5% current density of the limiting current density to assess the effect of current density on crack density. As shown in Figure 6, the grain size also increases as current density decreases , resulting in low hardness (Figure 7.).

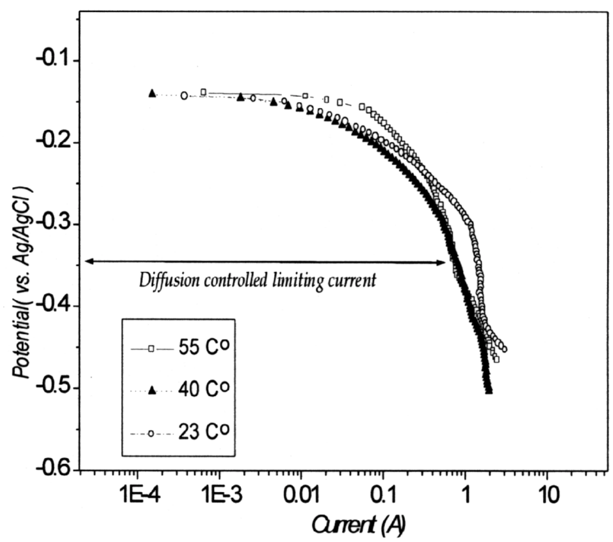
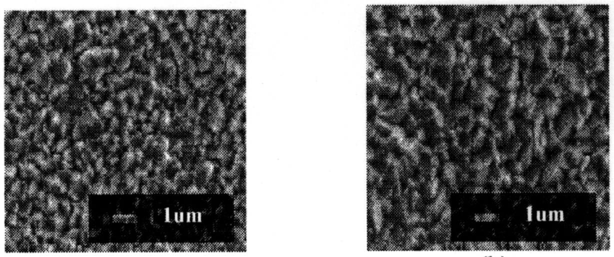


Figure 5. The limiting current density as a function of temperature

The closer the applied current density to the limiting current density, the greater role of diffusion in determining the electrodeposity growth mechanism. Therefore, the microstructure of the electrodeposit becomes more porous and the size of the grains become small as applied current density is increased to near the limiting current density. The mentioned mechanism induces faster grain growth rate and low hardness(figure 7.) but produces low crack density if the current density is decreased.



(a) (b)

Figure 6. The SEM micrograph as a function of the current density

a) 20% of limiting current density

b) 5% of limiting current density

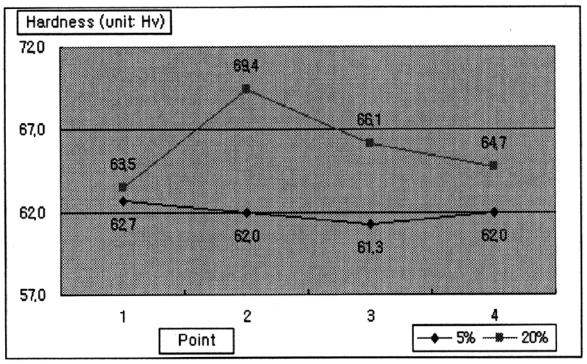
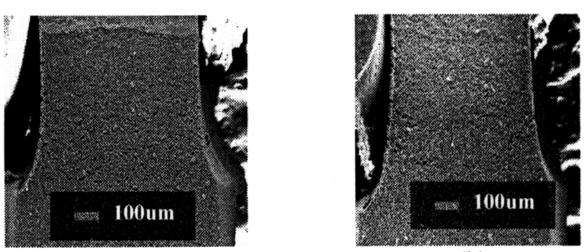


Figure 7. The hardness variation as a function of the current density

Figure 8. depicts the crack density at the lead shoulder of the package after forming process as a function of the current density during the plating process. As shown in Figure 8, the crack density is less at the low current density than at the high current density.

Consequently, the crack issue, which was a major concern among the many in the drive toward developing a Pb-free electrodeposit, can be resolved by lowering the current density and temperature. In actuality, however, the current density cannot be lowered indefinitely without offsetting productivity.



(a) (b)

Figure 8. The SEM micrograph of the cracks as a function of current density

a) 20% of limiting current density

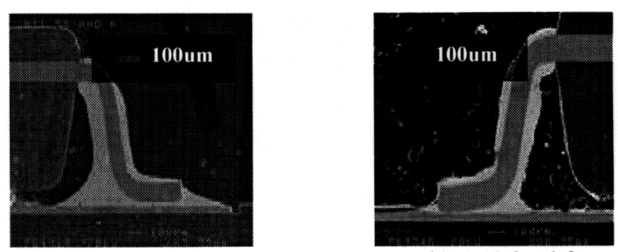
b) 5% of limiting current density

Reliability of the Pb-free memory module

The results of experiments with Sn-Bi plating done as a function of temperature and current density revealed that the lead finish process should be performed above 40°C at current density below 5% of the limiting current density. Doing this, the number of cracks at the lead shoulder, which was the major problem of the Sn-Bi lead finish, could be reduced significantly.

In addition, DIMM with the Sn-Bi lead finish and Sn-Ag-Cu solder paste were made to assess joint reliablity. The modules have the Sn-Bi lead finish and Sn-3.5Ag-0.7Cu solder paste. The melting temperature of Sn-Ag-Cu solder paste, which is higher than that of Sn-Pb solder paste, ranges between 210~220°C. The peak temperature range of the reflow process, which is must be higher than that of the sample with the Sn-Pb solder paste, is between 240~260°C. The Pb-free memory modules were characterized in terms of the following criteria to determine its solder joint reliability: the fillet shape of module, lead pull test, module T/C and THB reliability test.

Figure 9. shows the fillet shape of Pb-free memory module with the Sn-Bi lead finish and Sn-Ag-Cu solder paste using Cu and A42 lead frame. The level of the fillet shape is equal to that of memory module with the Sn-Pb lead finish and Sn-Pb solder paste. Moreover, the lead pull value is almost same or higher than that of the conventional solder joint (Figure 10.). The applied package was the TSOP with 0.4mm pitch, and the test was performed with one lead at one time after removing the package body.



a) Cu lead frame b) A42 lead frame

Figure 9. The fillet shape of the Pb-free memory module with the Sn-Bi lead finish and the Sn-Ag-Cu solder paste

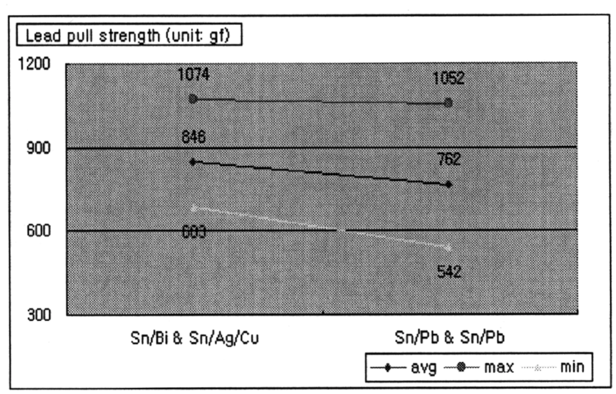


Figure 10. The comparision of the lead pull strength between the Pb-free solder joint and conventional solder joint

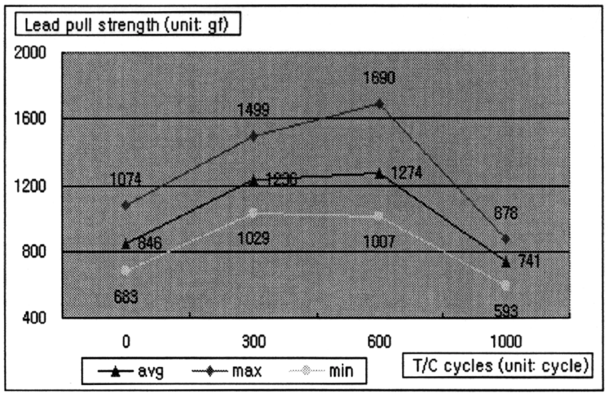


Figure 11. The lead pull strength variation as a function of T/C cycles

Figure 11. shows the variation of the lead pull strength as a function of T/C cycles of the Pb-free memory module. Initially the lead pull strength increased because of the intermetallic compound formation and then slightly decreased with increasing IMC layer thickness. The average pull strength is approximately 800gf, and the pull strength after T/C 1000cycles is almost same as the initial pull strength between -25~125°C

Table 2. The reliability test results of the Pb-free memory module with Sn-Bi lead finish and Sn-Ag-Cu solder paste

Item	Reliability Results			
Temperature Cycle	Condition	300cyc	600cyc	1000cyc
	-25℃ ~ 125℃	0/14 Modules	0/14 Modules	0/14 Modules
Temperature Humidity Bias	Condition	168hr	300hr	500hr
	85℃/85%, 5.0V	0/7 Modules	0/7 Modules	0/7 Modules

Table 2. shows the reliability of Pb-free memory module with the Sn-Bi lead finish and Sn-Ag-Cu solder paste. In this test, the modules were function tested fully at each cycles. The test condition of the temperature cycle is in the range of -25~125℃, and that of the temperature humidity bias is 85°C/ 85% humidity, 5.0V bias. Every module passed the reliability test at every temperature cycle up to 1000 cycles. Furthermore, the temperature humidity biased modules passed the test at each hour condition up to 500hours. With the Sn-Bi lead finish and Sn-Ag-Cu solder paste, the fillet shape, lead pull strength, temperature cycle and the temperature humidity biased tests were performed and the results were acceptable.

Grain size effect and intermetallic compound formation

As mentioned previously, the decrease in the crack density was due to the decrease of the hardness, which, in turn, was proposed to be caused by the larger grain size. Hardness and ductility characteristics can be changed by several mechanisms such as precipitation and deformation. However, because the factors controlling the mechanical properties of the electrodeposit were temperature and current density only in our case, the possible cause for the decrease in hardness was assumed to be grain coarsening[13-14]. Another factor to note is the stress level of the electrodeposit, but remarkable different stress level were not found.

Intermetallic compound phenomenon of Pb-free memory module with the Sn-Bi lead finish and Sn-Ag-Cu solder paste was examined to evaluate the the initial site of the joint crack. In this case, severe reliability condition was applied.(TC 1000cyc and HTS 500hr) The compositions of intermetallic compounds were Cu_6Sn_5 and Cu_3Sn, and the initial crack is produced at the interface between the Sn-Ag-Cu solder paste and the intermetallic compound[15] (figure 12.).

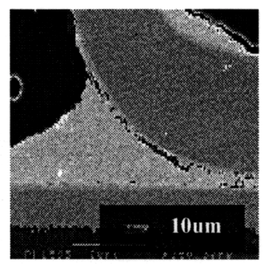


Figure 12. The joint failure with the Sn-Bi lead finish and Sn-Ag-Cu paste after TC 1000cycles and HTS 500hrs

Although the solder joint with Pb-Sn commonly failed at the cohesive site, i.e. at the inner intermetallics, the failure site of the solder joint in this case was different. Much research is being pursued to elucidate the underlying mechanism. Figure 12. shows the joint failure of the Pb-free memory module with the Sn-Bi lead finish and Sn-Ag-Cu solder paste.

Conclusions

To meet the demands of the Pb-free environment in the electronics industry, Pb-free processes and materials applicable to the lead finish of the package and surface mount of the memory module were evaluated. To make a Pb-free memory module, the Sn-Bi lead finish with 3.0~5.0% Bi content and Sn-Ag-Cu solder paste with 95.8Sn-3.5Ag-0.7Cu were applied.

However, one major flaw of the Sn-Bi lead finish is the crack phenomenon at the lead shoulder after forming process, because of the brittleness of Bi.

In an attempt to eliminate the crack, the Bi content was maintained at a level between 3.0~5.0%. But, despite small amount of Bi metal content, cracks reoccured.

The results of our experiments have revealed that the frequency of the cracks can be significantly reduced in the Sn-Bi lead finish if the temperature of Sn-Bi lead finish process was maintained over 40°C and the current density below 5% of the limiting current density. Under these conditions, the grain size of the electrodeposit increased and the hardness decreased. It is this decrease in hardness that reduces the frequency of the cracks at the lead shoulder, which occur after the forming process.

Because the melting temperature of the Sn-Ag-Cu solder paste is higher than that of the Sn-Pb solder paste in Pb-free memory module with the Sn-Bi lead finish & Sn-Ag-Cu solder paste, the peak temperature of reflow process should be maintained between 240~260°C. The fillet shape and lead pull strength were evaluated at the higher reflow peak temperature. Furthermore, both the temperature-cycle test performed between -25~125°C up to 1000 cycles and the temperature-humidity-bias test performed at 85°C temperature, 85% humidity, 5.0V bias, up to 500 hours showed no failure of the solder joint.

These experiments and results have confirmed the feasibilty of Pb free memory modules with Sn-Bi lead finish & Sn-Ag-Cu solder paste.

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