Journal of the Microelectronics & Packaging Society
Vol. 12, No. 1, p. 65-71. 2005

Practical Application of Sn-3.0Ag-0.5Cu Lead Free Solder in Electronic Production

Kyu-Sang Chae, Jae-Sang Min, Ik-Joo Kim and Il-Je Cho
LG Electronics, 19-1 Cheongho-ri, Jinwuy-myun, Pyungtaek-si, kyunggi-do, Korea

Abstract: At present, Electronic industries push ahead to eliminate the Pb(Lead) -a hazardous material- from all products. Especially, we have performed to select the optimum standard composition of lead free alloy for the application to products for about 3 years from 2000. These days, we have the chance for applying to the mass-production. This project constructed the system for applying the lead free solders on consumer electronic products, which is one of the major products of the LG Electronics. To select the lead free solders with corresponding to the product features, we have passed through the test and applied with Sn-3.0Ag-0.5Cu alloy system to our products, and for the application to the high melting temperature composition, we secured the thermal resistance of the many parts and substrate and optimized the processing conditions. We have operated the temperature cycling test and the high temperature storage test under the standards to confirm the reliability of the products. On these samples, we considered the consequence of our decision by the operating test. For the long life time of the product, we have operated the temperature cycling test at -45°C - +125°C, 1 cycle/hour, 1000 cycles. Also we have tested the tin whisker growth about lead free plating on lead finish. We have analyzed with the SEM, EDS and any other equipment for confirming the failure mode at the joint and the tin whisker growth on lead free finish.

Key words: lead free, solder joint, tin whisker

1. Introduction

The application of lead free solder to consumer electronic products will become reality in a few years. The original impetus of lead free packaging were driven by legislation, but recently other forces such as commercial advantages related to environment-friendly electronics have raised more interest in industry and speeded the process. Although lead-containing electronic products could be effectively recycled, 'green electronics' is gaining greater appreciation by consumers[1,2].

In many countries and companies, new measures are being considered that would require recycling of consumer electronics. The national electronics manufacturing initiative (NEMI) developed a program, called NEMI lead free assembly project, tin whisker accelerated test, modeling, to propose the solution of lead free electronics manufacturing.

Europe has also taken an aggressive portion towards lead free legislation. The waste electrical and electronic equipment (WEEE) directive by EU has claimed that use of lead in consumer electronics will be banned after July 2006.[2,3] There are impending producers responsibility laws for electronic and electrical equipment in a number of European countries. Such laws passed in the Netherlands and Switzerland before 1999. In some cases, producer responsibility may require the manufacturer, importer or reseller to take back products for proper end of life treatment[4].

2. Experiments

2.1 Evaluation of solder joint reliability by the Temperature Cycling

*Corresponding author
E-mail: choilje@lge.com

We have studied about the shrinkage growth behavior and the thermal fatigue failure at the joint of lead free solder (Sn-3.0Ag-0.5Cu solder paste) products by the environmental condition which is more severe than practical operating condition. We have chosen the 4 factors-PCB land hole size, cooling rate, Flux, Preheating temperature-which effected to the shrinkage, and understood the main effect factor by using the Taguchi experiment design method with these 4 factors.

We did experiment on the basis of the JESD22-A104 (temperature cycling standard) and evaluated the solder joint reliability on the basis of the LG Electronics reliability standard (Table 2).

2.2 Evaluation of solder joint reliability by the high temperature storage

We have studied the microstructure of solder joint and measured the bonding strength of solder joint which was effected from the thermal diffusion on solder joint, and analyzed the failure mode to evaluate the reliability of solder joint on the basis of the LG Electronics reliability standard.

2.3 Tin whisker growth test

To verify the Tin whisker growth problem on lead free plating components-The test packages used for the experiments were QFP, SOP type IC and connector of proto-type electronic products. All packages are from the different lot and random sampling[5,6].

Inspection has at first been done with an optical microscope at a magnification of 50X-100X. Next, the samples described under were subjected to different environment condition for whisker growth test.

Test conditions

- <u>Ambient storage</u>:
  20-25°C, ~30-80% RH, 500 hours
- <u>Temperature/Humidity storage</u>:
  60±5°C, 93±2, 3% RH, 500 hours
- <u>Temperature Cycling</u>:
  -55+0, -10°C to 85+10, -0°C air to temperature cycle per JEDEC Temperature Cycling Standard No. 22-A104, Test condition A, soak mode 3(10 minute), 2 cycles/hour

After storage test for each time, all samples were examined via optical microscope at various magnifications to verify the tin whisker growth. Next there were investigated in SEM and analyzed with EDS. Test and Analysis procedure is on the basis of the NEMI (National Electronic Manufacturing Initiatives, Inc.) proposed method and JEDEC standard.

Table 1. Temperature cycling test condition.

Temperature range	-40°C - 125°C (Condition G)
Time	1 cycle / hour
Cycles	1000 cycles

(Ref. JESD22-A104)

Table 2. Evaluation standard of joint reliability after temperature cycling test.

Bonding strength specification	More than 50% of the initial joint strength
Internal/External characteristic specification	Delamination : None Crack: -Length : ≤(fillet length)/2 -Depth : ≤ (fillet height)/2

Table 3. Four effective factors for shrinkage formation

Factor	Level 1	Level 2
Size rate (Hole size/Component size)	1.5 (0.9 mm/ 0.6 mm)	1.3 (0.8 mm/ 0.6 mm)
Cooling rate (250°C→180°C)	8°C/sec	15°C/sec
Flux	Supplier A	Supplier B
Preheat temperature	100°C	120°C

Table 4. Evaluation standard of joint reliability after high temperature storage.

Bonding strength specification	More than 50% of the initial joint strength
Internal/External characteristic specification	Delamination : None Crack : None

Table 5. The components used for the experiments.

No.	Component type	Base metal	Surface finish	Plating thickness (unit : um)	Remark
1	QFP	42 Alloy	Sn/Sn-2.5Bi	8/2	
2	QFP	Cu	Sn-2.5Bi	6	
3	QFP	Cu	Matte Sn	7	
4	Connector	Cu	Ni/Matte Sn	1/3	
5	SOP	Cu	SnCu	5	
6	SOP	Cu	SnPb	5	Ref.

3. Results

3.1 Evaluation of solder joint reliability by the Temperature Cycling

Fig. 1 shows a solder joint surface of the prototype electronic product applying lead free solder(Sn-3.0Ag-0.5Cu). The shrinkage is similar with the solder joint crack externally. So we have studied the characteristic and growth behavior of the shrinkage by the temperature cycling test and optimized the manufacturing process to remove the shrinkage.

We observed the growth of the shrinkage by SEM at 500, 750, 1000 cycles in temperature cycling test. At 500 and 750 cycles, shrinkage length was increased with temperature cycling test, but at 1000 cycles, we could observe decreasing shrinkage length. We supposed that the shrinkage is increased for the thermal fatigue, and upper end of joint would be pushed to the lower end (like a landslide). At final 1000 cycles, we observed a fatigue failure of the other solder joint area by the thermal shock, not the shrinkage growth. In conclusion, It will be expected the shrinkage had a little growth on environmental test, and it was little effective to the solder joint reliability.

Next, the growth of shrinkages was investigated in SEM at 500, 750, 1000 cycles in temperature cycling test. At first, shrinkage length was increased with temperature cycling test, but at 1000 cycles, we could observe decreasing shrinkage length. We supposed that the shrinkage is increased for the thermal fatigue, and upper end of joint would be pushed to the lower end (like a landslide). At final 1000 cycles, we could not observe a growth of the shrinkage and transition to the solder joint crack. In conclusion, the shrinkage had a small growth behavior on environmental test, and it was little effective to the solder joint reliability.

To validate the effective factor of the shrinkage formation, we made an experiment on basis of the Taguchi D.O.E. We have analyzed about the main effect and interaction with four factors (PCB land

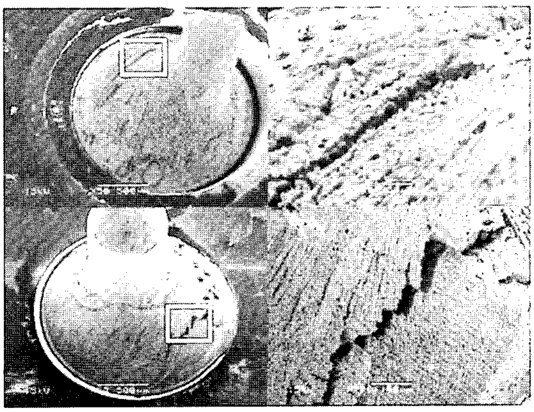

Fig. 1. The shrinkages of overview on joint surface.

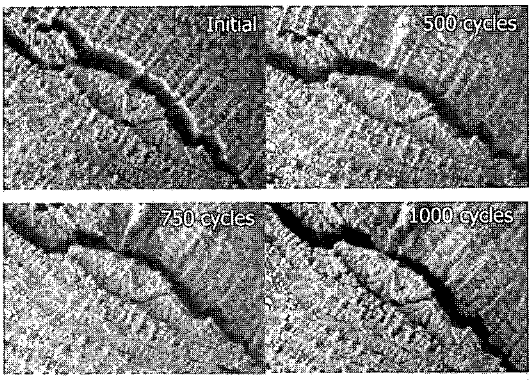

Fig. 2. The shrinkages on solder joint surface before optimizing process.

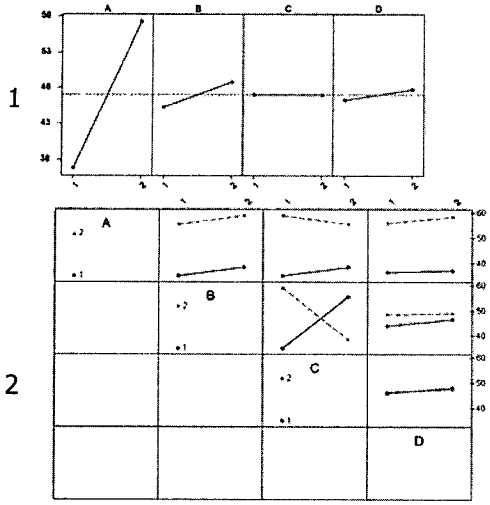

Fig. 3. 1-Main effect plot, 2-Interaction plot. A: PCB land hole size, B: Cooling rate, C: Flux, D; Preheat temperature.

hole size, cooling rate, flux, preheat temperature). From these results, we confirmed that the main effective factors were PCB land hole size and cooling rate.

We amended the cooling rate 8°C/sec to 15°C/sec, PCB land hole size rate 1.5 to 1.3. Figure 4 is a solder joint surface with amended product manufacturing process.

The shrinkages were decreased, which compared before validating process. We had a temperature

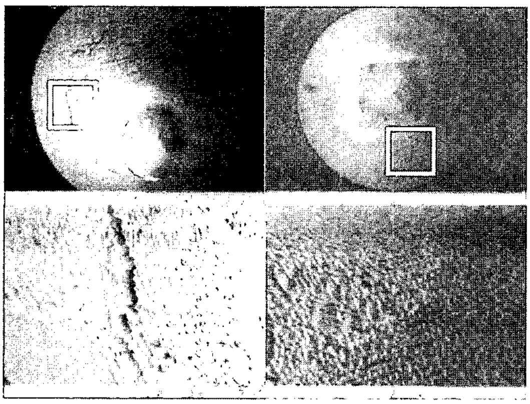

Fig. 4. The shrinkages on solder joint surface after optimizing process.

Table 6. Initial Bonding strength, measured 15 times (unit: gf)

	Initial bonding strength		
Items	2012C	2012R	SOP-0.65P
Avg.(15 times)	3013	5222	1528
Failure mode	Electrode failure	Solder joint interface failure	Solder joint interface failure

Table 7. Bonding strength after 1000 temperature cycling, measured 15 times (Unit: gf)

	Bonding strength after 1000 temp. cycled		
Items	2012C	2012R	SOP-0.65P
Avg.(15 times)	2880	4019	1431
Failure mode	Electrode failure	Solder joint interface failure	Solder joint interface failure

cycling test with these samples to confirm the shrinkage growth behavior at 1000 cycles. From these results, we could observe only the solder joint failure by the thermal fatigue and the shrinkage growth behavior was similar with the former samples.

From the result, the bonding strength after 1000 temperature cycling test was decreased about 10-20% of the initial bonding strength. But all samples had a enough bonding strength for solder joint reliability. After measuring bonding strength, we have analyzed failure mode of solder joint. 2012 capacitors were fractured at electrode area, and 2012 resistors and SOP-0.65P were at solder joint interface area.

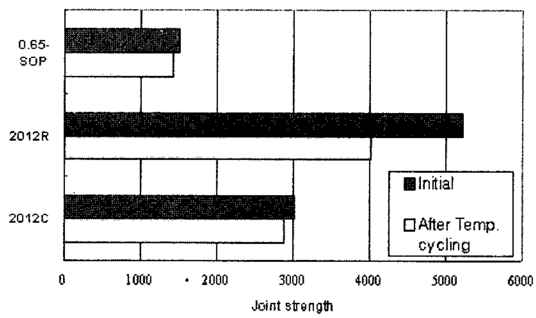

Fig. 5. The Changes of bonding strength, initial and after 1000 temperature cycled.

3.2 Evaluation of solder joint reliability by the high temperature storage

The samples were a high temperature stored on the basis of standard JESD22-A103, at 125°C and 700 hours. We observed the changed color of the flux at joint area, but could not the crack at solder joint area. Table 8. shows the bonding strength and failure mode of samples.

The samples high temperature stored were a enough bonding strength to preserve solder joint reliability.

The failure mode was similar with initial and temperature cycled samples, also these samples had a fracture on PCB land area. It would be expected the thermal fatigue for long time storage at high temperature.

3.3 Tin whisker growth test

Tin whiskers grew on the samples stored with 3 test conditions. On the three test, the temperature cycled samples, except nickel under plated matte Sn

Table 8. Bonding strength after high temperature storage 700 hours at 125°C, measured 15 times (unit: gf)

	Bonding strength after high temp. storage		
Items	2012C	2012R	0.65SOP
Avg.(15 times)	2851	4313	1391
Failure mode	Electrode & PCB land failure	Solder joint interface failure	Solder joint interface & PCB land failure

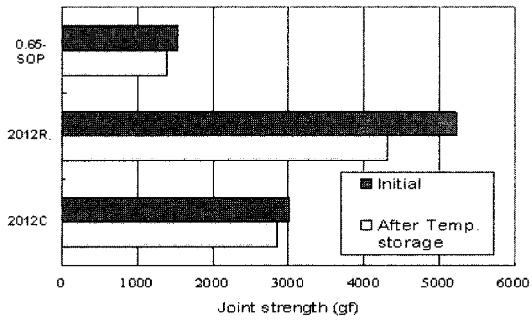

Fig. 6. The Changes of bonding strength, initial and after stored high temperature.

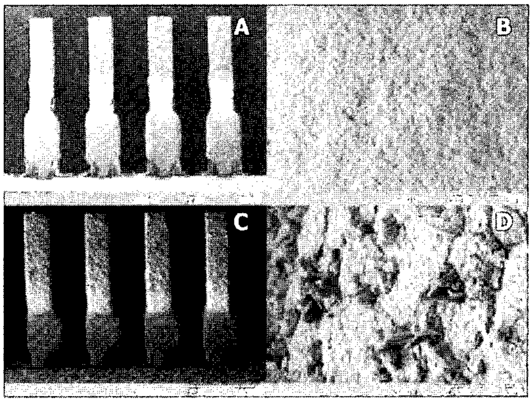

Fig. 7. QFP Sn/Sn-2.5Bi, A-initial(120X), B- lead surface (1200X), C- temp. cycled 500(120X), D-lead surface and whiskers(1500X)

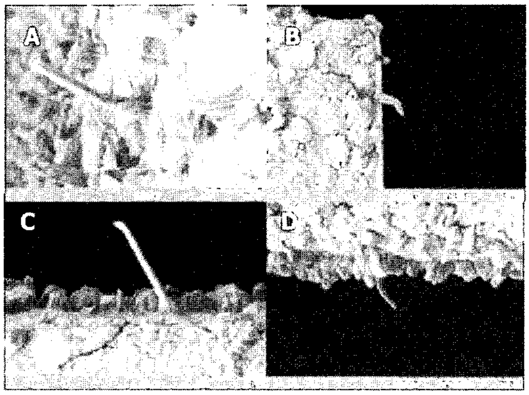

Fig. 8. Tin whiskers on QFP 176pin, 0.4pitch A-50.3 μm, B-24 μm, C-40 μm, D-22 μm.

and tin lead plated components, tin whiskers grew on lead frame, especially on bended area[7,8]. On Figure 8, it's available to verify tin whisker growth. The maximum length of tin whisker was 50.3 μm. This component has a double side plating structure that some component maker recommended this structure for mitigation of tin whisker growth. In this test, tin whisker growth is more dominant than other test components. This QFP component lead frame was a alloy 42 and 1st plating layer was Sn. From this

Table 9. Coefficient of thermal expansion Sn and Alloy 42

CTE of Sn	42 ppm / K
CTE of Alloy42	4 ppm / K

result, we could expect that the CTE (coefficient of thermal expansion) mis-match was the most effective factor in our tests.

And we could not find the tin whisker growth on nickel under plated and tin lead plated samples.

Fig. 9 shows tin whisker growth on matte Sn plated lead frame. The matte Sn is one of the effective plating materials for mitigating tin whisker growth. In this test, the length of tin whisker on the matte Sn plated lead frame was 22~41.2 μm. On the other hands, the nickel under plated matte Sn and tin lead plated components have no tin whisker growth.

Fig. 10 shows tin whisker on the other plating materials, tin copper and tin bismuth alloys. On tin

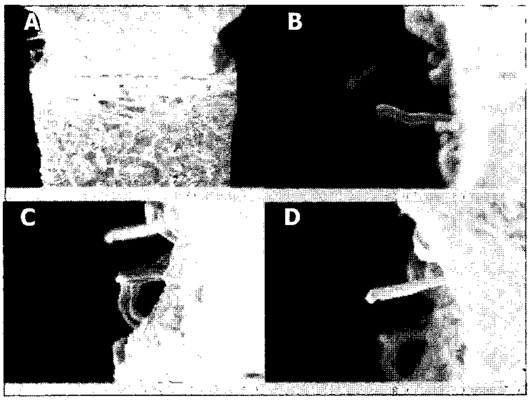

Fig. 9. QFP matte Sn after 1000 Temp. cycles A-800X, B-2000X(41.2 μm), C-3000X(27 μm), D-3000X (28 μm)

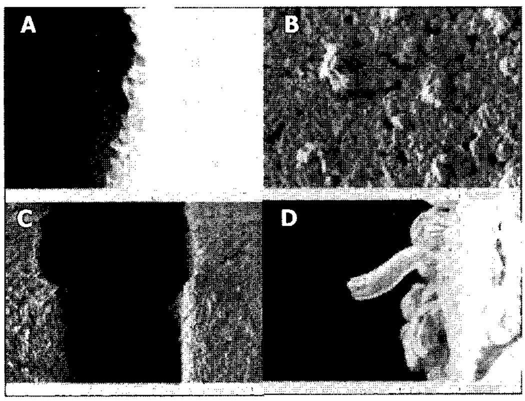

Fig. 10. QFP SnBi after 1000 Temp. cycles A, B-SnCu plated SOP; C, D-SnBi plated QFP.

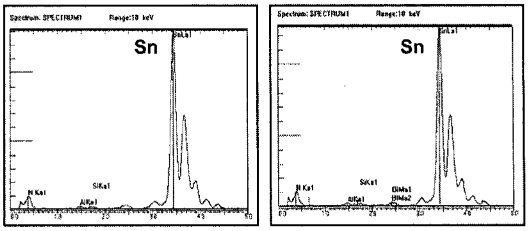

Fig. 11. EDS analyzed data of the tin whiskers.

copper alloys, the shape of tin whiskers have hillock and erupted column. It's about 4~6 μm. And there are so much polygonized structures on surface of lead frame. These days, in electronic industries, tin copper alloy plating is not accepted, because of dominant form with IMC (intermetalic compound) Cu_6Sn_5[9].

The tin bismuth alloy plated surfaces also have tin whisker growth. The maximum length of tin whisker is 28 μm. In this test, the tin whisker growth on tin bismuth alloy is less than any other plating materials, matte tin, tin copper and tin/tin bismuth plating. But It needs more research and test for long term reliability of lead free plating components.

Tin whiskers did not grow on the samples stored ambient and temperature/humidity condition. But in this test, we stored so short duration for tin whisker growth. So, we are carrying out more longer duration with ambient/temperature humidity storage test.

Fig. 11 shows EDS analysis data of tin whiskers. Some researches reported that the tin whisker comprised of pure tin. So it has only major peak of tin. In this inspection results, we could verify major peak of tin.

Next, we have a plan that tin whisker growth test with mating between lead free material plated connector and FPC (flexible printed circuit)/FFC (flat flexible cable). It concerns about mechanical stresses with mating FPC/FFC and connector. It causes tin whisker growth on connector mating area and electrode area of FPC/FFC.

4. Summary

In this test, we evaluated the solder joint reliability of Sn-3.0Ag-0.5Cu lead free solder. We could not find a crack or any other defect on solder joint with high temperature storage and temperature cycling test. Also the intermetallic compounds were formed with 1~3 μm and no serious degraded of bonding strength.

In wave soldering process, we could find so many cases of surface shrinking on solder joint. It can be misunderstanding to the surface crack. So we verified the surface shrinking behavior with temperature cycling test. After temperature cycling test, the surface shrinking showed no changes and no transform to the crack. And we could reduce surface shrinking with control the land size and cooling rate.

The tin whisker is so serious problem in electronic industries. Until now, there are no clear solutions for tin whisker problem.

In this test, we evaluated many lead free plated component for tin whisker growth. From the results, we could confirm that nickel under plated matte Sn component shows the effective mitigation the tin whisker growth. And we are going to various test with considering many other effective factors for safety from the tin whisker risk[10].

We have a plan to build up the optimized process for lead free soldering. These processes include the reflow and wave soldering, design and reliability evaluation process. And we will prepare the tin whisker acceptance test requirements and criteria.

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