Practical Application of Lead-free Solder in Electronic Products

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Abstract

At present, LG Electronics pushes 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℃ - +125℃, 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.

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.

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[1,2]. 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[3].

LG Electronics (LGE) has provided a strong driving force for lead free manufacturing because LGE supplies a large portion of the world's consumer electronics. In late 2003, LGE announced accelerated schedules for lead free products and electronic products developed in 2004 are being applied to the lead free solder.

2 Experiments

2.1 Evaluation of solder joint reliability by the Temperature Cycling

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).

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

Table 1: Temperature cycling test condition (Ref. JESD22-A104)

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 2: Evaluation standard of joint reliability after temperature cycling test

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

Table 3: 4 effective factors for shrinkage formation

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.

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

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

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[4,5].

No	Component type	Lead finish plating	Description	Remark
1	QFP	Sn/ Sn-2.5Bi	176pin, 0.4pitch	
2	SOP	Sn/ Sn-2.5Bi	36pin, 0.5pitch	
3	SOP	Matte Sn	48pin, 0.5pitch	
4	Connector	Ni/ Matte Sn	36pin, 0.5pitch	
5	SOP	Sn/Pb	32pin, 0.5pitch	Reference for comparison

Table 5: The components used for the experiments

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

- Ambient storage:

  20-25℃, ~30-80% RH, 500 hours
- Temperature/Humidity storage:

  60±5℃, 93±2, 3% RH, 500 hours
- Temperature Cycling:

  -55+0, -10℃ to 85+10, -0℃ 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.

3 Results

3.1 Evaluation of solder joint reliability by the Temperature Cycling

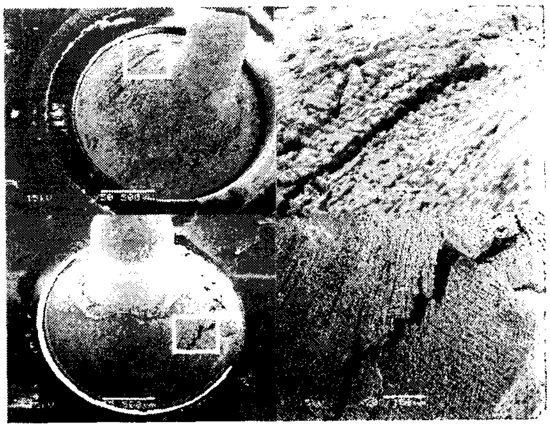

Figure 1: The shrinkages of overview on joint surface

Figure 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.

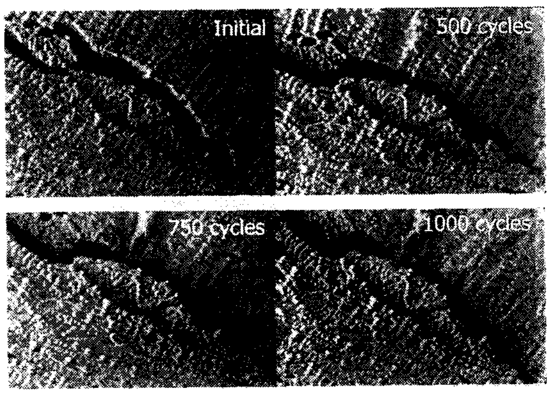

Figure 2: The shrinkages on solder joint surface before optimizing process

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.

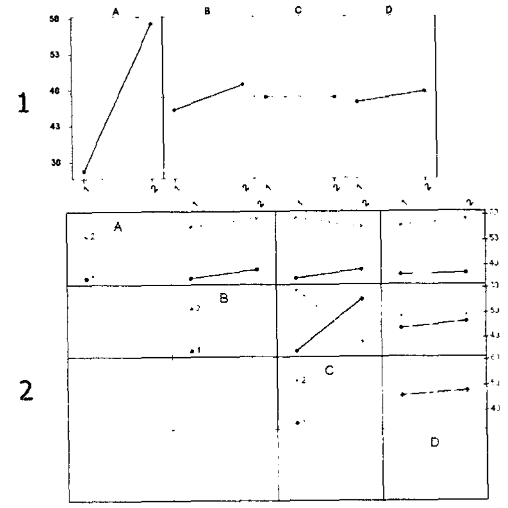

Figure 3: 1-Main effect plot, 2-Interaction plot. A: PCB land hole size, B: Cooling rate, C: Flux, D: Preheat temperature

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 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℃/sec to 15℃/sec, PCB land hole size rate 1.5 to 1.3. Figure 4 is a solder joint surface with amended product manufacturing process.

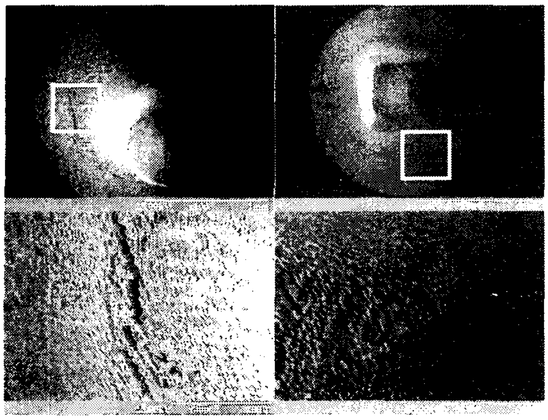

Figure 4: The shrinkages on solder joint surface after optimizing process

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

	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 6: Initial Bonding strength, 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

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

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.

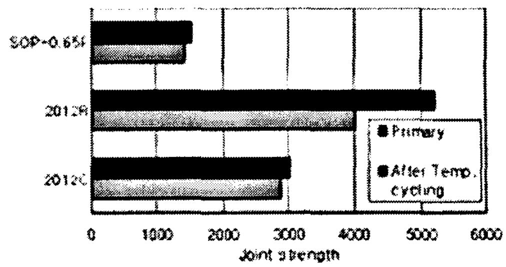

Figure 5: The Changes of bonding strength, initial and after 1000 temperature cycled

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℃ 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.

	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

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

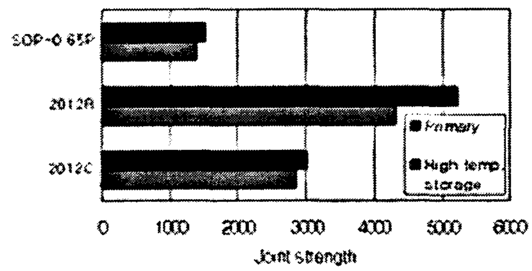

Figure 6: The Changes of bonding strength, initial and after stored high temperature

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

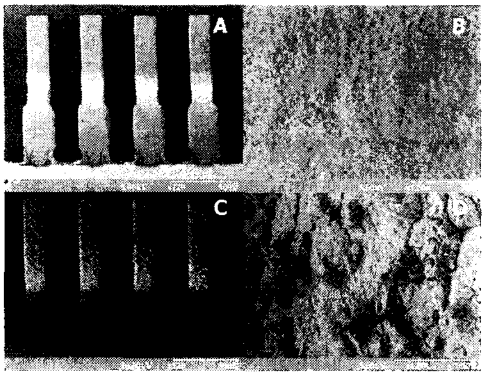

Figure 7: QFP 176pin, 0.4pitch, A- initial(120X), B- lead surface(1200X), C- temp. cycled 500(120X), D- lead surface and whiskers(1500X)

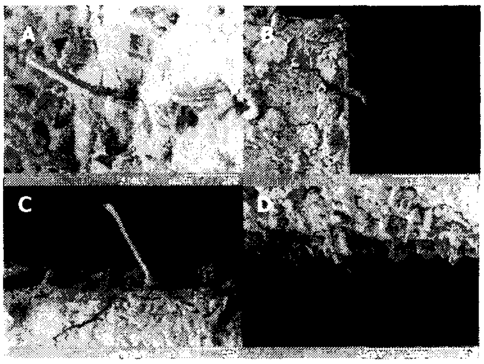

Figure 8: Tin whiskers on QFP 176pin, 0.4pitch A-50.3㎛, B-24㎛, C-40㎛, D-22㎛

Tin whiskers did not grow on the samples stored ambient and temperature/humidity condition. But on the 500 temperature cycled samples, tin whiskers grew on leadframe of QFP component(176pin, 0.4pitch, Sn/Sn-2.5Bi plating) only. Other samples-matte Sn, Ni/matte Sn plating, Sn/Pb plating samples had no whiskers on leadframe. Maximum length of whisker was 50.3 ㎛. To verify these whiskers were true whisker or not, we have analyzed elements with the EDS system and confirmed these whiskers were comprised of 100% Sn element.

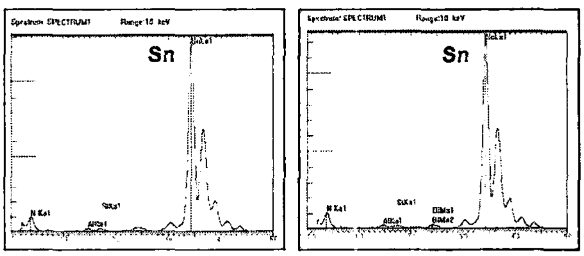

Figure 8: EDS analyzed data of the tin whiskers

In conclusion, we could find that at the Ni under plating and matte Sn plating components, tin whiskers did not grew, and the most effective test condition of tin whisker growth was a temperature cycling.

4 Future work

More testing is needed to obtain the stability of lead free solder application in electronic products. In particular, the effect of PCB land hole size and cooling rate to the shrinkage formation should be extended to smaller size, higher rate and other process factors to confirm the shrinkages can be eliminated completely. For the tin whisker growth, we are going to extended test(longer times and assembly level) to confirm the reliability of lead free electronic products from the tin whisker growth problem.

5 Reference

[1] Directive of the European Parliament on the Restriction of the Use of Certain Hazardous Substances
[2] Website: lead-free.org/legislation
[3] Website: www.nemi.org/PbFreePUBLIC
[4] NEMI Tin Whisker User Group, 2004
[5] Fisher, R.M., Acta Metallurgica, Vol. 2, 1954