Presented at IPC Printed Circuits Expo®
SMEMA Council APEX®
Designers Summit 04

Reliability Testing and Failure Analysis of Lead-Free Solder Joints under Thermo-Mechanical Stress

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Abstract
The commercial use of lead-free solder has been making significant gains worldwide in recent years. To identify the effects of thermo-mechanical stress on Sn-Ag-Cu and Sn-Zn-Bi solder with different lead finishes (Sn-10Pb, Ni/Pd/Au plating), we performed the following reliability tests: high temperature tests, thermal cycle tests, and combined thermal-vibration tests. Following the tests, we investigated the causes of degradation by checking solder joint strength and observing solder joint cross-sections.

Our investigations indicate that the same level of reliability can be obtained with Sn-Ag-Cu solder as with conventional Sn-Pb eutectic solder. On the other hand, in response to thermo-mechanical stress, Sn-Zn-Bi solder forms voids and intermetallic compounds at the joint interface between the solder and the printed circuit board (PCB), resulting in a loss of joint strength. We then used Sn-Ag-Cu solder in mass production prototype PCBs. We subjected these PCBs to a variety of reliability tests and carried out three years of field reliability testing. These PCBs with Sn-Ag-Cu solder held up successfully under a minimum of 3,000 cycles in thermal cycle tests and a minimum of 20,000 hours in field reliability testing.

Introduction
Environmental problems with Pb have spurred research into the application of lead-free solder throughout the world. With the use of lead-free solder comes the necessity of evaluating its reliability with regard to the affects on the function and quality of the electronic parts by thermo-mechanical stress from the environments in which they are used and transported.

Sn-Ag-Cu lead-free solder has been widely adopted.[1-3] However, Sn-Ag-Cu solder has a higher melting point than conventional Sn-Pb eutectic solder (melting point: 219C *vs.* 183C) and the requirement for higher temperature in the assembly process is hindering acceptance of this solder. The temperature requirement has stimulated interest in the use of Sn-Zn, which has a lower melting point.[4] However, it has been pointed out that the Zn component of Sn-Zn solder readily oxidizes, resulting in decreased wettability in the assembly process.[5] Sn-Zn-Bi is now under consideration, with the Bi added to improve wettability, but there seems to be a risk of the Bi causing a loss of joint strength. It has also been reported that when Sn-Zn solder is used in high-temperature environments, a Cu-Zn intermetallic layer forms, causing a loss of joint strength.[6,7]

During the migration phase of lead-free solder, some mixing of the Pb from parts seems possible when using conventional surface finish (Sn-Pb plating). Combination evaluations were required to investigate the effects of the different combinations of lead-free solder and parts lead finishes.[8]

For this report, we performed high temperature tests, thermal cycle tests, and combined thermal-vibration tests on Sn-Ag-Cu and Sn-Zn-Bi solder combined with different lead finishes (Sn-10Pb, Ni/Pd/Au plating), and we confirmed the effects of thermo-mechanical stress. Following the tests, we investigated the causes of degradation by checking solder joint strength and observing solder joint cross-sections. Finally, we prepared mass production prototype Printed Circuit Boards (PCBs) using Sn-Ag-Cu solder. These mass production prototype PCBs were subjected to a variety of environmental tests and to three years of field reliability testing to compare their durability to that of products using conventional Sn-Pb eutectic solder. This report presents the overall results of our investigation.

Experimentation
Solder Materials and Lead Finish
Table 1 presents the solders used in the experiments and the surface finishes for the parts. Commercial paste preparations of Sn -3Ag -0.5Cu and Sn -8Zn -3Bi were used for the lead-free solder. A paste form of Sn-Pb eutectic solder was also used for comparison. Assembly parts consisted of Quad Flat Packages (QFP: 0.5 mm pitch, 100 pin) with the internal wiring daisy chained. The QFP copper leads used were either plated with conventional Sn-10Pb plating or with Ni/Pd/Au plating used for lead-free solder. Evaluation PCBs was glass epoxy (FR-4, 100 x 100 x 1.6mm) with Organic Solderability Preservative (OSP) coating covering the Cu pattern.

Table 1 - Experiment Solder Materials and Lead Finish

Solder materials	Sn - 3 Ag - 0.5Cu Sn - 8 Zn - 3 Bi Sn - 37 Pb
QFP copper lead finish (0.5mm pitch)	Sn - 10 Pb (10μm) Ni / Pd / Au (0.3/0.08/0.01μm)
PWB	Surface finish : Cu + OSP Substrate : Glass Epoxy (FR-4)

Assembly Process

Table 2 shows the reflow conditions during the assembly process, and Figure 1 shows an evaluation PCB. The assembly process was performed entirely in open air. The temperature profile settings in the assembly process in descending order of temperature were: Sn-Ag-Cu, Sn-Zn-Bi, and Sn-Pb. Mounted on each PCB were one Sn-10Pb-plated QFP, and one Ni/Pd/Au-plated QFP.

Figure 2 shows Backscattered Electron (BE) image of the cross section of the solder joint after assembly. The combination of lead-free solder with Ni/Pd/Au plating exhibits poor solder distribution, with the solder not completely covering the entire fillet. The Sn-Zn-Bi solder suffered large voids inside the solder. The Sn-Pb solder also exhibited voids, but not as large as those seen in the Sn-Zn-Bi solder.

Table 2 - Reflow Conditions for Assembly Process

Parameter	Sn-Ag-Cu	Sn-Zn-Bi	Sn-Pb
Pre-heat temperature (℃)	155~170	155~163	150~155
Dwell time (sec)	90	90	90
Peak temperature (℃)	238~242	223~228	220~225
Time under melting point (sec)	40~45	35~40	45~50
Atmosphere	Air		

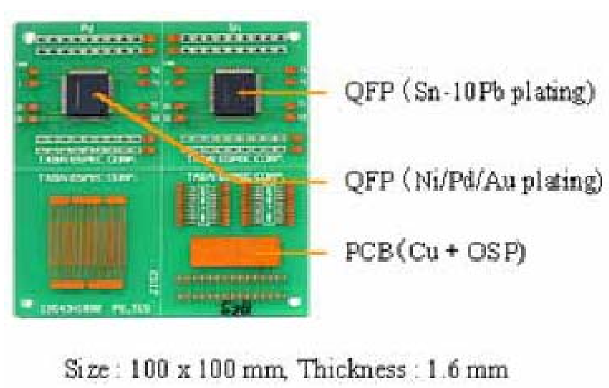


Figure 1 - Evaluation PCB

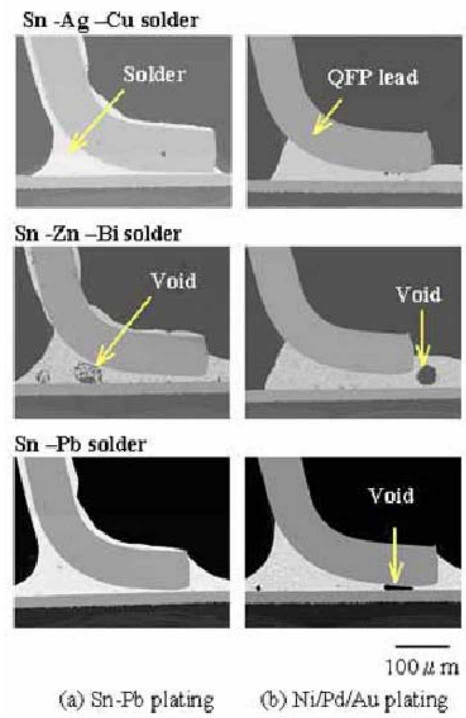


Figure 2 - Cross - sectional BE Image of QFP Solder Joints after Assembly Process

Reliability Test Condition

Table 3 shows the reliability test conditions. Reliability tests investigating the effects of the thermal stress from the usage environment on the joint sections consisted of high temperature tests and temperature cycle tests (air to air). Considering the glass transition point of the PCBs (FR-4), the upper temperature limit for the reliability tests was set at 125 °C, and considering the material changes of Sn, the lower temperature limit was set at -40 °C. To evaluate the specimens for thermo-mechanical stress, combined thermal -vibration tests (similar to the IEC-68-2-51 or JIS-C-0037 standards) were run to simulate the commercial environment in product heat generation and the transportation environment.

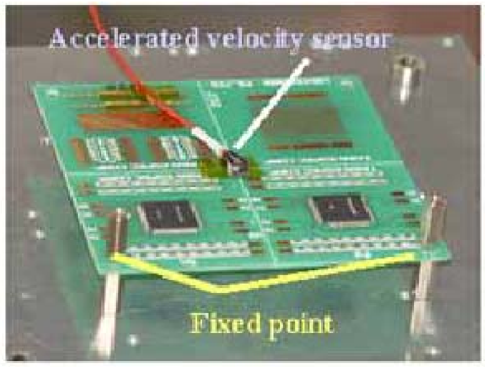
Figure 3 shows the method of resonance frequency detection for the combined thermal-vibration tests. Because of the possibility of creating severe distortion to the solder joint when fastening the evaluation PCB to the vibration stand, the PCBs were fastened at 2 points on each side (Figure 3-a). The force of vibration was set at 9.8 m/s2 (=1 G) as the acceleration during transportation by truck. The direction of vibration was up and down (on the z axis) for the PCB. The upper temperature limit was set at 125 °C for the tests. Figure 3-b shows the output during the sweep of the vibration frequency (10 to 100 Hz) for the input acceleration (9.8 m/s2). The evaluation PCBs showed a maximum acceleration of approximately 54 Hz. Based on this, the tests were performed at 54 Hz +/- 5 Hz.

Figure 4 shows the method of measuring solder joint strength. As the diagram shows, the pull test for the QFP leads was performed at 20 mm/min and at a 45-degree angle. The pull test was performed during and after each reliability test, measuring the strength of at least one lead for each vicinity and calculating the averages. Figure 5 shows the method of measuring the electrical conductivity of the solder joints during thermal cycle tests. The daisy-chained QFPs were measured by the four terminal measurement methods using a scanner and a milli-ohmmeter. This method is capable of measuring the degradation time of the solder joints.

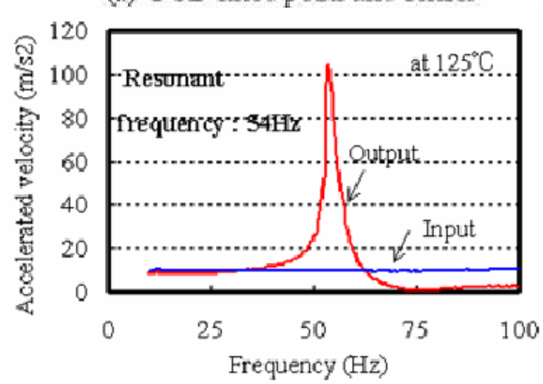
After each test, an Electron Probe Micro Analyzer (EPMA) was used to perform cross-sectional observation and elemental analysis.

Table 3 - Reliability Test Conditions

High temperature test	125°C, 1000 hours
Thermal cycle test (air to air flow)	- 40 / 125 °C, 1000 cycles Dwell time : 30 minutes each
Combined thermal - vibration test	Temperature : 125 °C Vibration : 54±5 Hz, 9.8 m/s^2 Time : 1 min/single sweep 100 hours

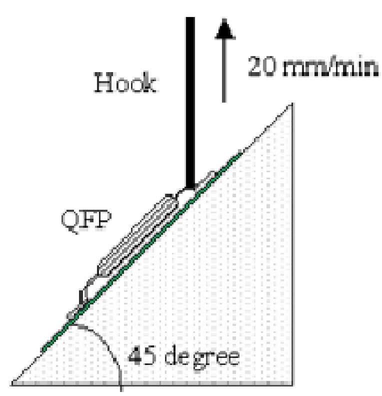


(a) PCB fixed point and sensor



(b) Resonant Frequency under test

Figure 3 - Method of Resonant Frequency Detection for Combined Thermal-Vibration Test



QFP 45 degree pull test

Figure 4 – Method of Measuring Solder Joint Strength

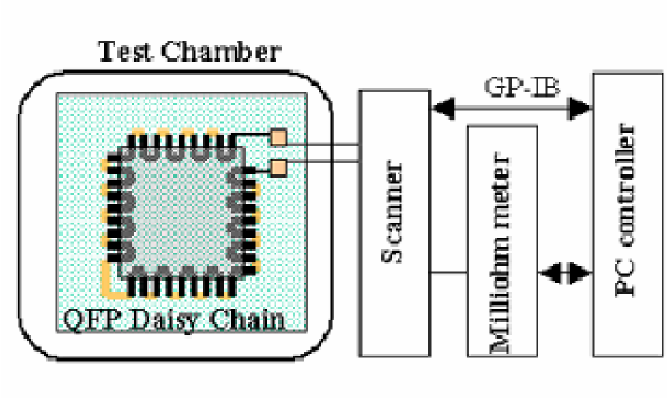


Figure 5 - Method of Measuring Electrical Conductivity of Solder Joint

Test Results

High Temperature test

Figure 6 shows the variation over time of the joint strength during high temperature test. The Sn-Zn-Bi solder exhibits a loss of joint strength at 250 hours after the beginning of the test. However, we were able to confirm that Sn-Ag-Cu solder did not exhibit this significant loss of joint strength that was seen in Sn-Zn-Bi.

Figure 7 shows sites of solder joint fracture during the 45-degree pull test after 1,000 hours in the high temperature test. The fracture was observed in the Sn-Ag-Cu solder from the back solder fillet toward the top fillet. Peeling was observed in the Sn-Zn-Bi solder in the entire interface between the solder joints and the PCB. It is possible that the fracture direction and fracture site could affect joint strength.

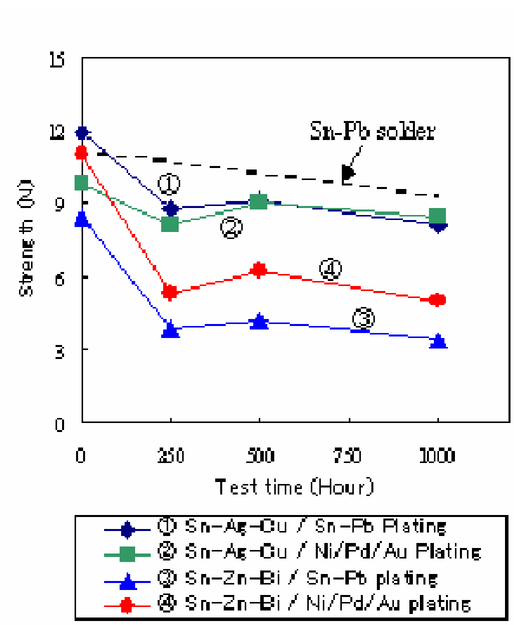


Figure 6 - Results of 45-degree Pull Test for QFP Lead-free Solder Joints after High Temperature Test

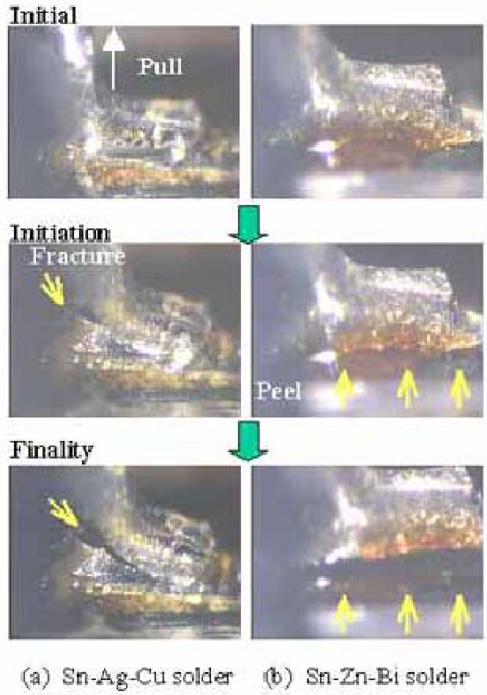


Figure 7 - QFP Solder Joints with Sn-10Pb-plated Lead during 45-degree Pull Test after High Temperature Test

Thermal Cycle tests and Combined Thermal –Vibration test
Figure 8 shows changes in resistance during the thermal cycle test. The combination of Sn-Zn-Bi solder with Sn-10Pb-plated leads exhibited a gradual rise in resistance at approximately 500 cycles. However, with other combinations of solder materials and lead finishes, this type of change was not seen before 1,000 cycles. A cross-sectional analysis was performed to determine the factors causing the temperature rise for the combination of Sn-Zn-Bi solder with Sn-10Pb-plated leads.

Figure 9 shows the results of cross-sectional observation following the thermal cycle tests. The Sn-Ag-Cu solder exhibited small cracking in top solder fillet. The Sn-Zn-Bi solder exhibited peeling between the solder joint and the PCB, similar to the peeling seen after the pull tests done during the high temperature test. This indicates that the rise in resistance in Sn-Zn-Bi solder results from incomplete conductor contact due to solder joint cracking caused by thermal stress during the thermal cycle test.

In these experiments, the evaluations were performed on specimens mounted in open air, but it has been reported that in thermal cycle tests using parts mounted in a nitrogen atmosphere, the combination of Sn-Zn-Bi solder with Sn-10Pb-plated leads was able to maintain reliability for a minimum of 1,000 cycles.[9] These results suggest that solder joint conditions differ for different assembly conditions, resulting in major differences in time to failure.

Figure 10 shows cross-sectional observation after the combined thermal-vibration test. The Sn-Zn-Bi solder exhibited peeling from the solder joints just as in the results following the thermal cycle tests. However, during a similar vibration test at room temperature, joint degradation did not occur even after more than 500 hours. These results suggest that thermal stress has a major impact on the degradation of solder joints, and that the addition of mechanical stress causes failure to occur within a short time.

Figure 11 shows a comparison of solder joint strength following each type of reliability test. Overall, Sn-Zn-Bi solder is the material in these experiments most affected by thermo-mechanical stress. On the other hand, Sn-Ag-Cu solder exhibited a slight drop in joint strength caused by thermo-mechanical stress. The amount of joint strength lost is approximately the same as with conventional Sn-Pb eutectic solder.

In considering the effects of lead finish on Sn-Zn-Bi solder, Sn-10Pb-plated leads exhibited a much greater loss of joint strength than Ni/Pd/Au-plated leads. These results indicate that to obtain solder joint reliability, lead finishes containing Pb must not be used with lead-free solder.

Next, we will consider the effects of lead-free solder materials and lead finish in terms of solder joint reliability.

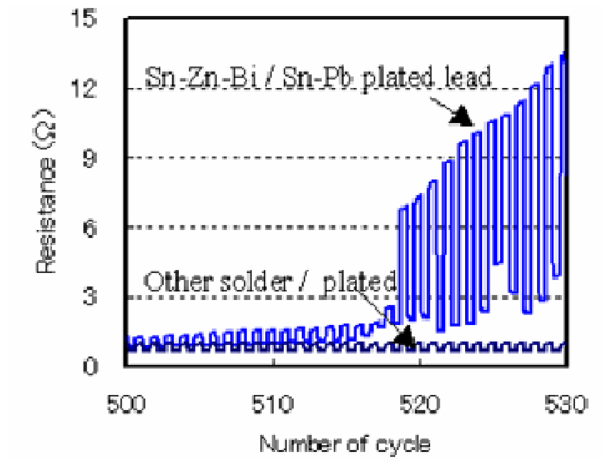


Figure 8 - Change in Resistance of QFP Solder Joints during Thermal Cycle Test

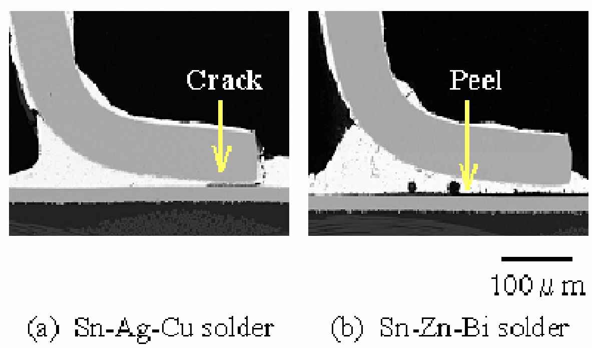


Figure 9 Cross-sectional BE Image of QFP Solder Joints with Sn-10Pb-plated Lead after Thermal Cycle Test

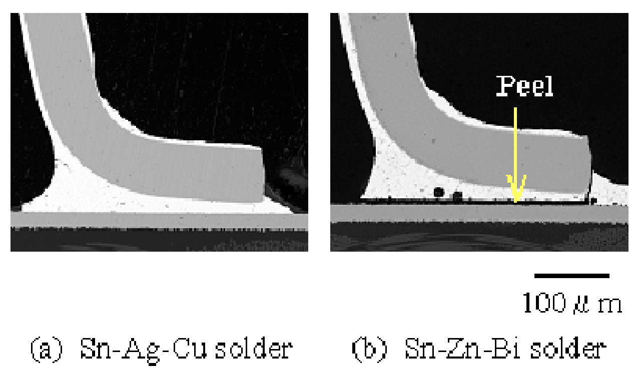


Figure 10 - Cross-sectional BE Image of QFP Solder Joints with Sn-10Pb-plated Lead after Thermal -Vibration Test

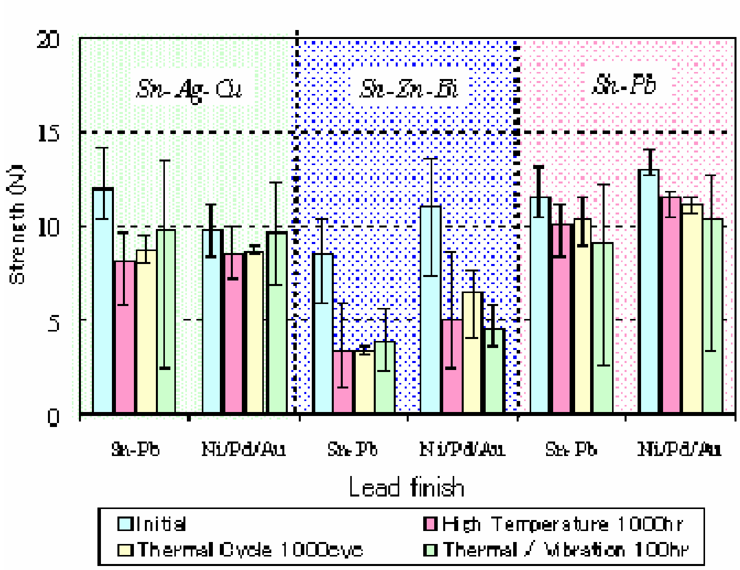


Figure 11 - Comparison of QFP Solder Joints Strength following Each Type Reliability Test

Discussion

Effect of Solder Materials

Figure 12 shows pre- and post-test cross sectional images of intermetallic compounds at the interfaces between lead-free solder and QFP leads/PCBs. After assembly with Sn-Ag-Cu solder, a thin Cu-Sn intermetallic layer forms between the QFP leads and the PCB. This Cu-Sn layer becomes thicker as the heat causes the Cu to disperse. The thicker Cu-Sn layer becomes, the greater the loss of joint strength.[10] This suggests that Sn-Ag-Cu solder joint reliability is directly related to the increase in the thickness of the Cu-Sn intermetallic layer.

With Sn-Zn-Bi solder as well, a thin intermetallic layer of Cu-Zn forms at the interface between the QFP leads and the PCB after assembly. The intermetallic compound layer exhibited a relatively quick increase in the thickness of the Cu-Zn layer in response to heat. At the same time, a number of voids form in the interface. When the voids form, peeling tends to occur on the solder joint surface.[11, 12] This suggests that the reliability of the Sn-Zn-Bi solder joint reliability is directly related to the increase in thickness of the Cu-Zn intermetallic layer and to the generation of voids in the joint interface.

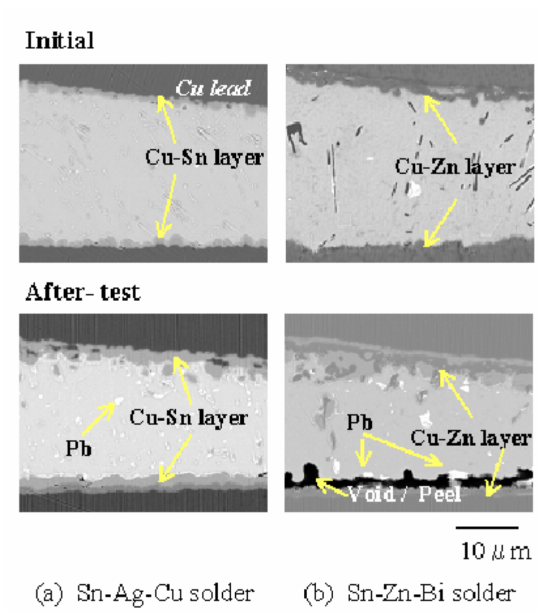


Figure 12 - Cross-sectional BE Image of Joint Interfaces between Solder and Sn-10Pb-plated Lead/PCB after High Temperature Test for 1,000hr

Effects of Lead Finish

Figure13 shows a PCB solder pad following 45-degree pull test of Sn-Zn-Bi solder after the high-temperature test. Table 4 shows the results of quantitative analysis of the solder pad. The PCB solder pad of the Sn-10Pb-plated lead is completely covered by a fine granular substance. Quantitative analysis detected an increase in Bi and Pb compared to the initial solder pad. On the other hand, observation of the PCB solder pad of the Ni/Pd/Au-plated leads indicated that the solder material had elongated. From these results, we can conclude that the Ni/Pd/Au-plated leads maintain a certain amount of joint strength even after testing. In pre- and post-test quantitative analysis, no major changes were seen in solder composition.

Elemental analysis was performed with EPMA to investigate the granular substance observed on the PCB solder pad of the Sn-10Pb-plated leads. Figure 14 shows an elemental mapping image. The granular substance was primarily composed of Pb and Bi. The presence of Pb and Bi cause a lower solder melting point and the formation of a three-component eutectic alloy (Sn-Pb-Bi: melting point, 99.5 °C).[11]

Solder joints form an intermetallic compound at the PCB Cu / solder interface, maintaining joint strength. However, the mixing of Pb into Sn-Zn-Bi solder forms a three-component eutectic alloy, causing a loss of joint strength. Solder joints that have lost strength exhibit cracking from the temperature changes in thermal cycle test and from the mechanical stress in the combined environment test, and this is linked to a rise in electrical resistance and disconnections.

The Ni/Pd/Au-plated leads have no Pb, and the Ni serves as a barrier to the growth of intermetallic compounds.[13] As a result, the Sn-10Pb-plated leads exhibit a tendency to maintain high joint strength even in the presence of thermo-mechanical stress.

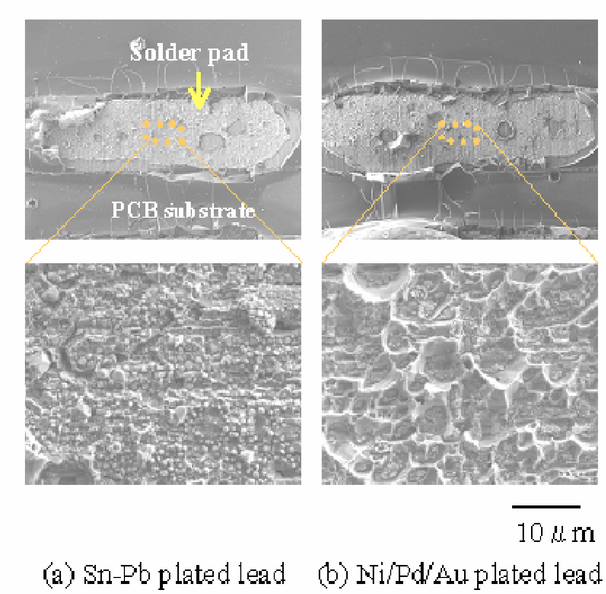


Figure 13 - Sn-Zn-Bi Solder Pad following 45-degree Pull Test after High Temperature Test for 1,000 hr

Table 4 - Quantitative Analysis of Sn-Zn-Bi Solder Pad after 45-degree Pull Test

Lead finish	Test	Detection elements (mass%)				
		Sn	Zn	Bi	Pb	Cu
Sn-10Pb	Initial	29.3	42.4	**2.7**	**1.5**	25.1
	After test	14.8	35.5	**4.8**	**18.2**	26.8
Ni/Pd/Au	Initial	62	22.3	3.2	---	12.5
	After test	68.2	19	3.6	---	9.3

* Test = high tempareture test for 1000hr

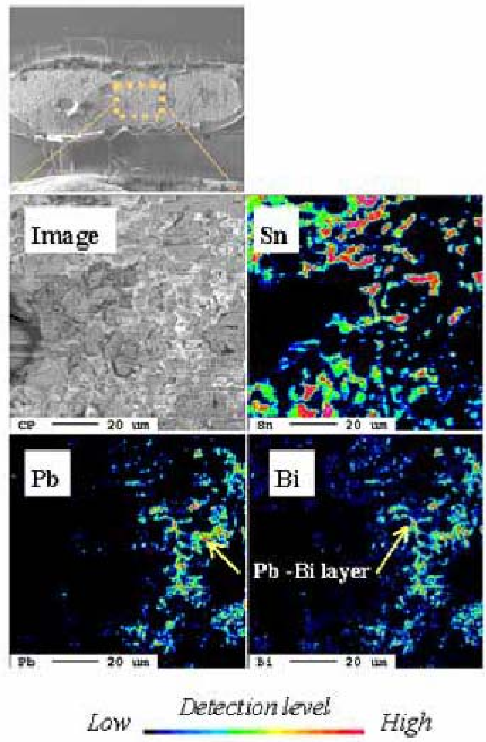


Figure 14 - EPMA Elemental Mapping of Sn-Zn-Bi Solder Pad after 45-degree Pull Test (High Temperature Test for 1,000 hr)

Reliability tests of mass production prototype PCBs

Reliability tests

In addition to the above reliability evaluations, we selected Sn-Ag-Cu solder for the following reasons:

1. Capability of maintaining equal or superior reliability to conventional Sn-Pb solder,
2. Compatibility with existing equipment in open air,
3. Equivalence to conventional assembly work,
4. Possibility of Pb mixing from parts.

Figure 15 shows one section of a mass production prototype PCB (150 x 120 x 1.6mm). The substrate is glass epoxy with parts mounted on the surface. For purposes of comparison, this evaluation also considered PCBs mounted with conventional Sn-Pb eutectic solder.

The reliability test temperature conditions for the mass production prototype PCBs were set at a maximum of 80C above and 25C below the specification temperatures of the mounted parts.

Test items included the high temperature test, thermal cycle test, and high-temperature, high-humidity test. The thermal cycle test (-25C/80C, 60 min/cycle) was continued until solder joint disconnections occurred. The results were as follows. PCBs with Sn-Pb eutectic solder began to exhibit disconnections at 2,000 cycles, and after 3,000 cycles, all had experienced disconnections. The resulting functional problems consisted mainly of digital circuit system failures.

On the other hand, PCBs with Sn-Ag-Cu solder did not exhibit failure even after 3,000 cycles 14.

Figure 16 shows cross-sectional photographs of solder joints on parts experiencing failure. Cross-sectional observation confirmed the presence of clack inside the solder. The clack generation was caused by susceptibility to thermal stress coming from the heat generated by the part itself. As a result, Sn-Pb eutectic solder exhibits structural changes in the solder caused by thermal stress, and these changes lead to the generation of micro-clack. On the other hand, Sn-Ag-Cu solder was confirmed to exhibit no disconnections at solder joints even after 3,000 cycles in the thermal cycle test. Based on these results, we believe that lead-free solder offers higher reliability in the presence of thermal stress than does conventional Sn-Pb eutectic solder.

Figure 15 - Mass Production Prototype PCB.

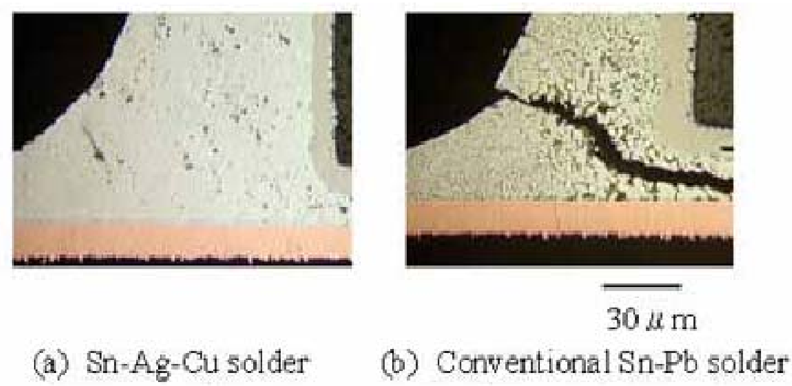


Figure 16 - Cross-sectional Photographs of Chip Components Solder Joints after Thermal Cycle Test for 3,000 cycles 14

Field Reliability testing

At the same time we were running reliability tests, we also carried out field reliability testing on PCBs used in actual products. The field reliability testing consisted of actual operations performed and evaluated at our Utsunomiya and Fukuchiyama plants. Currently, as of July 2003, the field reliability test period has been approximately three years with an operating time approaching 20,000 hours. The results of this field reliability testing show no product failures. We intend to continue the field reliability testing, and to investigate the time of deterioration for Sn-Ag-Cu solder in actual use.

Conclusions

We have run a variety of reliability tests to evaluate the effects of thermo-mechanical stress on lead-free solder. We have also performed reliability tests and field reliability testing on a mass production prototype PCB using Sn-Ag-Cu solder. The results of this testing has led us to the following conclusions.

1. Sn-Ag-Cu solder exhibited a slight drop in joint strength caused by thermo-mechanical stress. The amount of joint strength lost is approximately the same as with conventional Sn-Pb eutectic solder.
2. On the other hand, Sn-Zn-Bi solder is more susceptible to thermo-mechanical stress than Sn-Ag-Cu solder. When using Sn-Zn-Bi solder, lead plating and assembly conditions must be precisely controlled.
3. The joint reliability of Sn-Ag-Cu solder is directly related to the amount of increase in thickness of the Cu-Sn intermetallic layer. The joint reliability of Sn-Zn-Bi solder is directly related to the amount of increase in thickness of the Cu-Zn intermetallic layer and to the amount of voids generated in the joint interface.
4. Mixing Pb into Sn-Zn-Bi solder introduces a high risk of joint degradation. On the other hand, plating such as Ni/Pd/Au used with lead-free solder contains no Pb. In these, Ni acts as an effective barrier to the growth of intermetallic compounds, and so these combinations exhibit high joint reliability.
5. Mass production prototype PCBs using Sn-Ag-Cu solder have assured endurance of a minimum of 3,000 cycles in temperature cycle tests and a minimum of 20,000 hours in field reliability testing.

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Reliability Testing and Failure Analysis of Lead-Free Solder Joints under Thermo-Mechanical Stress

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February 2004 Anaheim CA

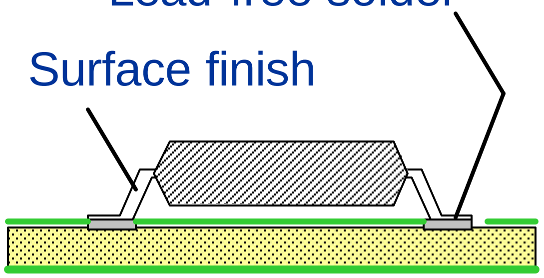
Table of Contents

Background

1. Practical application of lead-free solder:

Sn-Ag-Cu solder is widely adopted

2. Problem:



- Sn-Ag-Cu : High melting point (216C -220C)
- Sn-Zn-Bi : Low melting point (=193C)
- Mixing Pb from components

3. What's new in the present work:

- Effects of lead-free solder (Sn-Ag-Cu and Sn-Zn-Bi) joint under thermo-mechanical stress
- Investigate of mass production PCBs using Sn-Ag-Cu

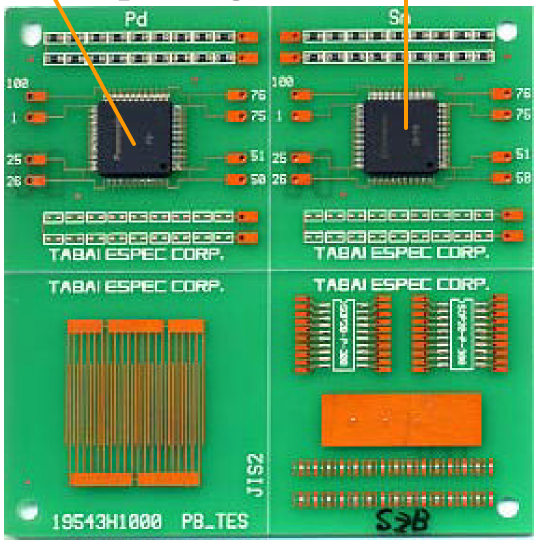
Experimentation

Solder materials	Sn - 3 Ag - 0.5Cu Sn - 8 Zn - 3 Bi Sn - 37 Pb
QFP copper lead finish (0.5mm pitch)	Sn - 10 Pb (10μm) Ni / Pd / Au (0.3/0.08/0.01μm)
PWB	Substrate : FR-4 Thickness : 1.6mm Surface finish : Cu

Solder Materials and Lead Finish

QFP (Ni/Pd/Au plating)

QFP (Sn-10Pb plating)



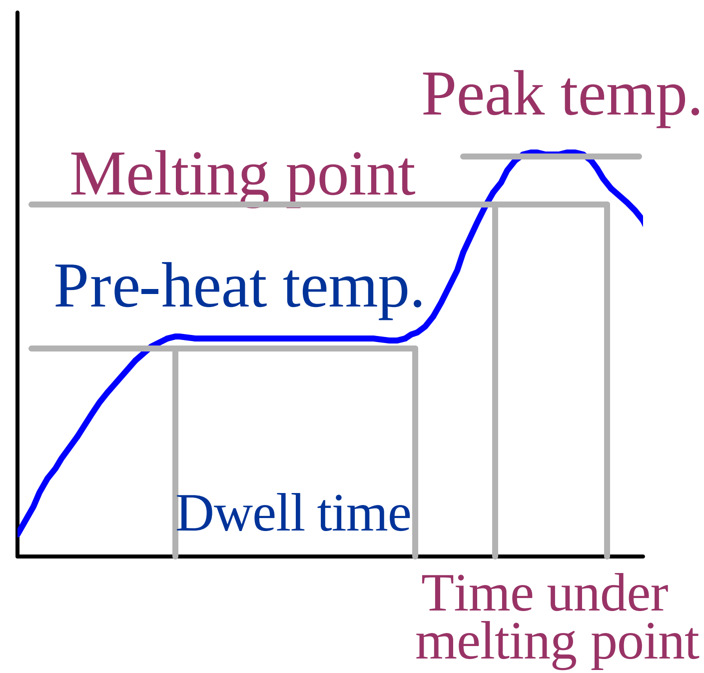
Size : 100 x 100 mm

Evaluation PCB

Assembly Process Conditions

Parameter	Sn -Ag -Cu	Sn -Zn -Bi	Sn - Pb
Pre-heat temperature (?)	155~ 170	155~ 163	150~ 155
Dwell time (sec)	90	90	90
Peak temperature (?)	238~ 242	223~ 228	220~ 225
Time under melting point (sec)	40~ 45	35~ 40	45~ 50
Atmosphere	Air		

Reflow conditions for assembly process

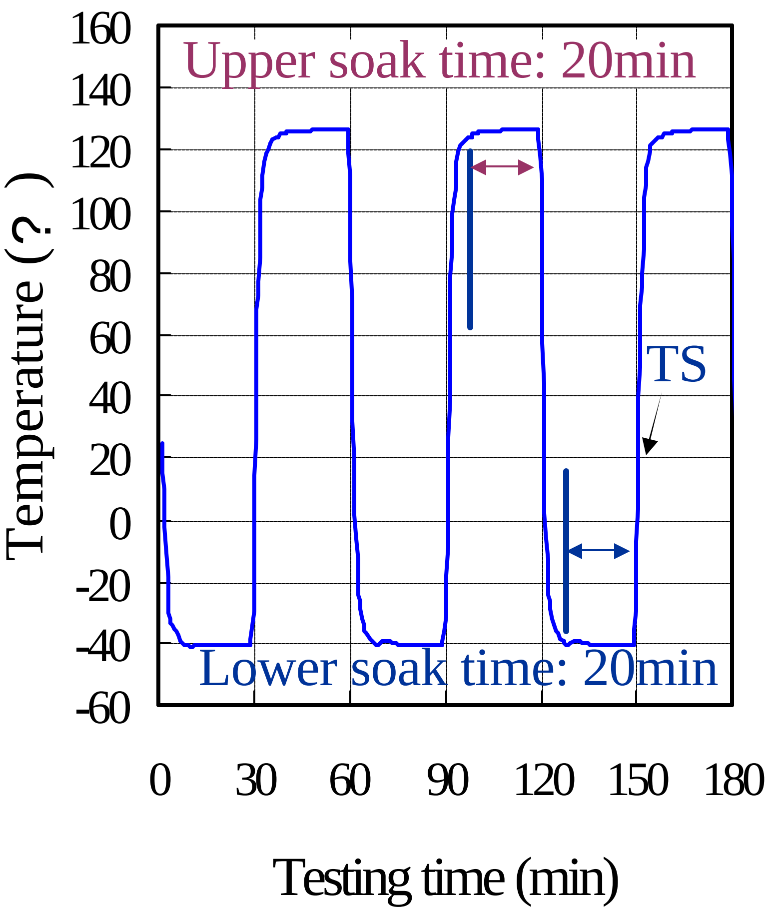


Profile for assembly process

Reliability Test Conditions

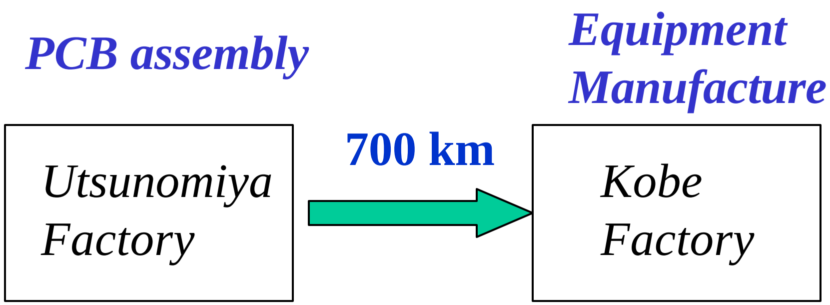
High temperature test	125? , 1000 hours
Thermal cycle test (air to air flow)	- 40 / 125 ? , 1000 cycles 30 minutes each
Combined thermal-vibration test	Temperature : 125 ? Vibration : 54±5 Hz 9.8 m/s^2(=1G) Time : 1 min/single sweep 100 hours

Reliability test conditions

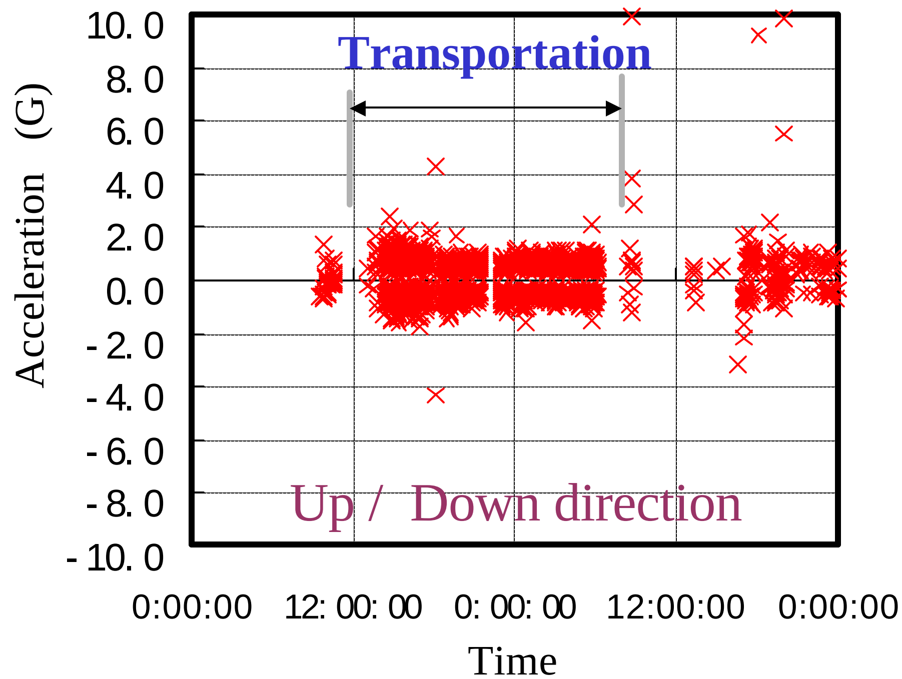


Profile during Thermal cycle
(TS = Sample Temperature)

Vibration during Transportation

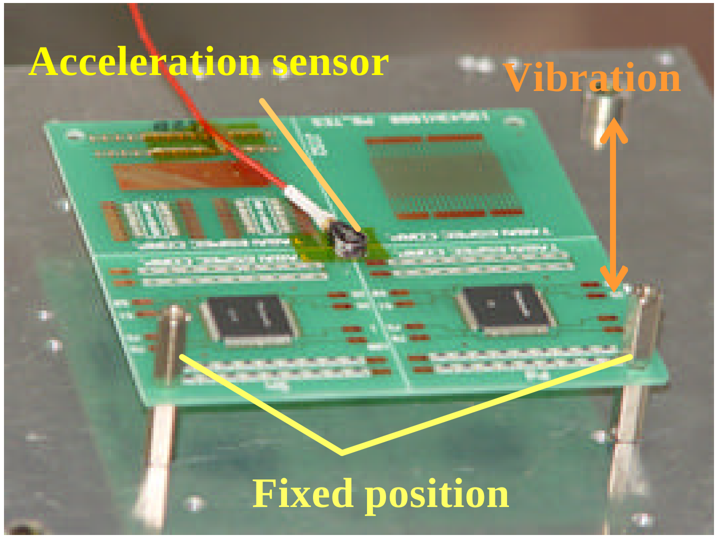


Transportation by truck

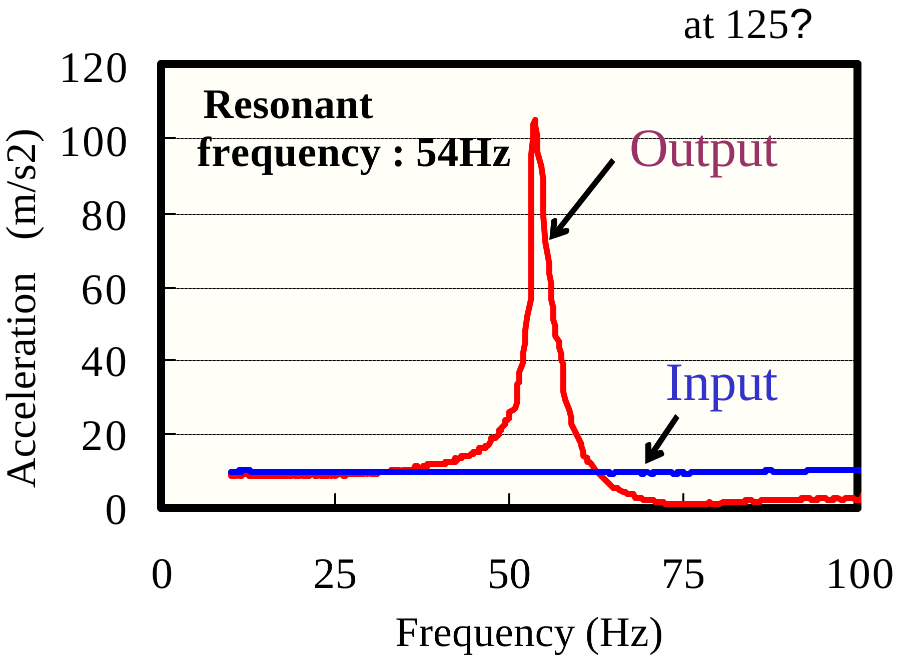


Vibration data during transportation

Combined Thermal - Vibration Test

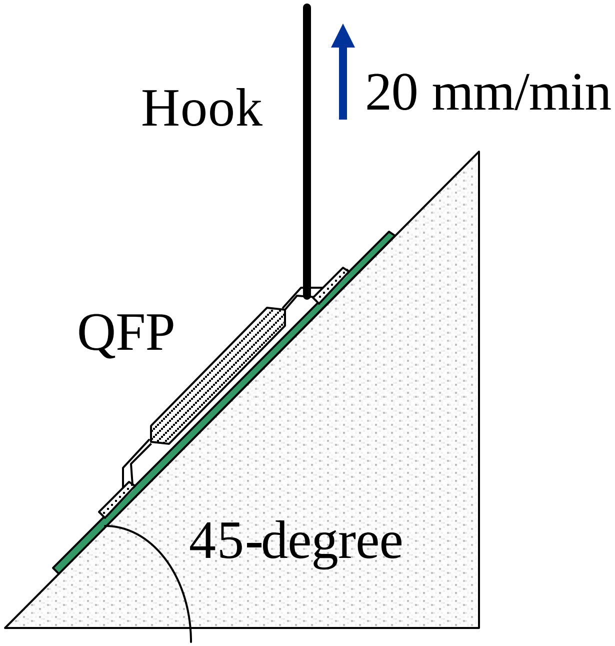


PCB fixed point and sensor

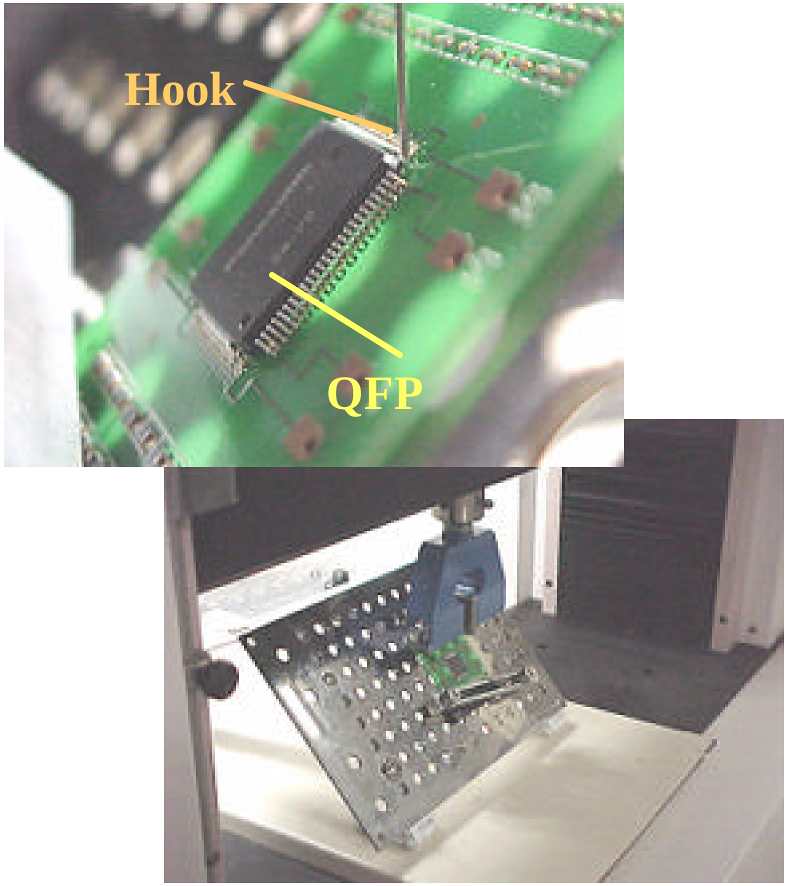


Resonant Frequency under test

Measuring Solder Joint Strength

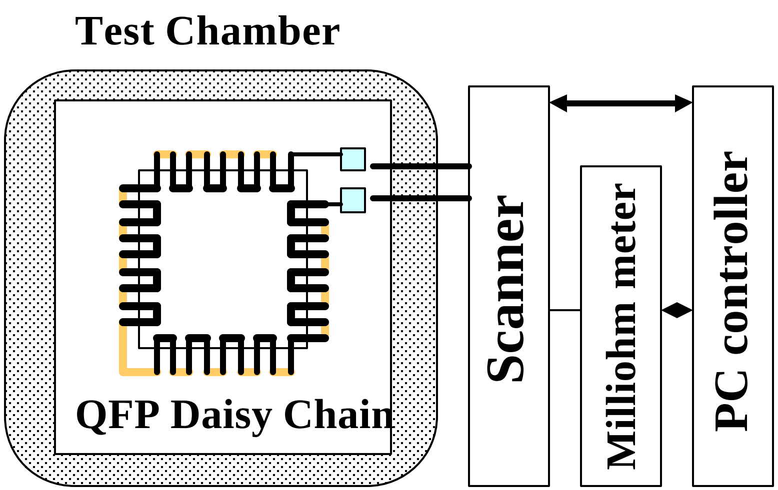


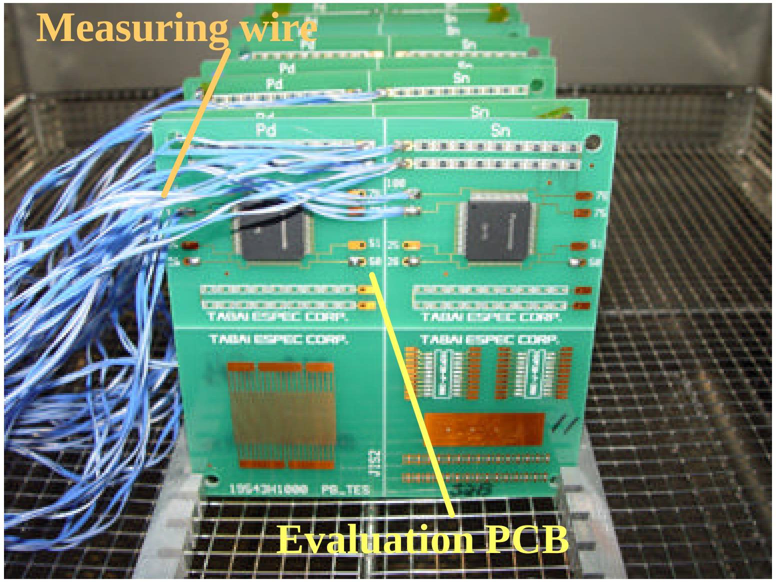
QFP 45-degree pull test



Test appearance during pull test

Measuring Solder Joint Resistance

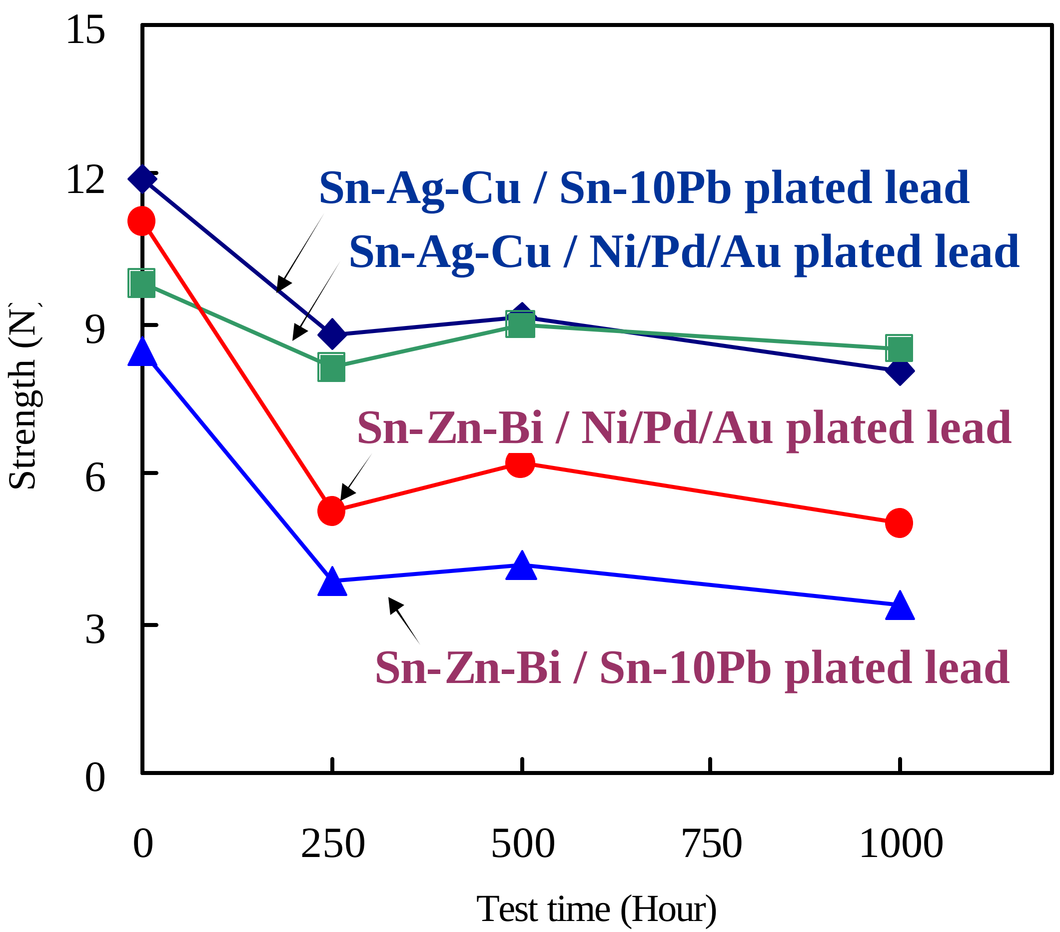




Method of monitoring the solder joint resistance

Test appearance during thermal cycle test

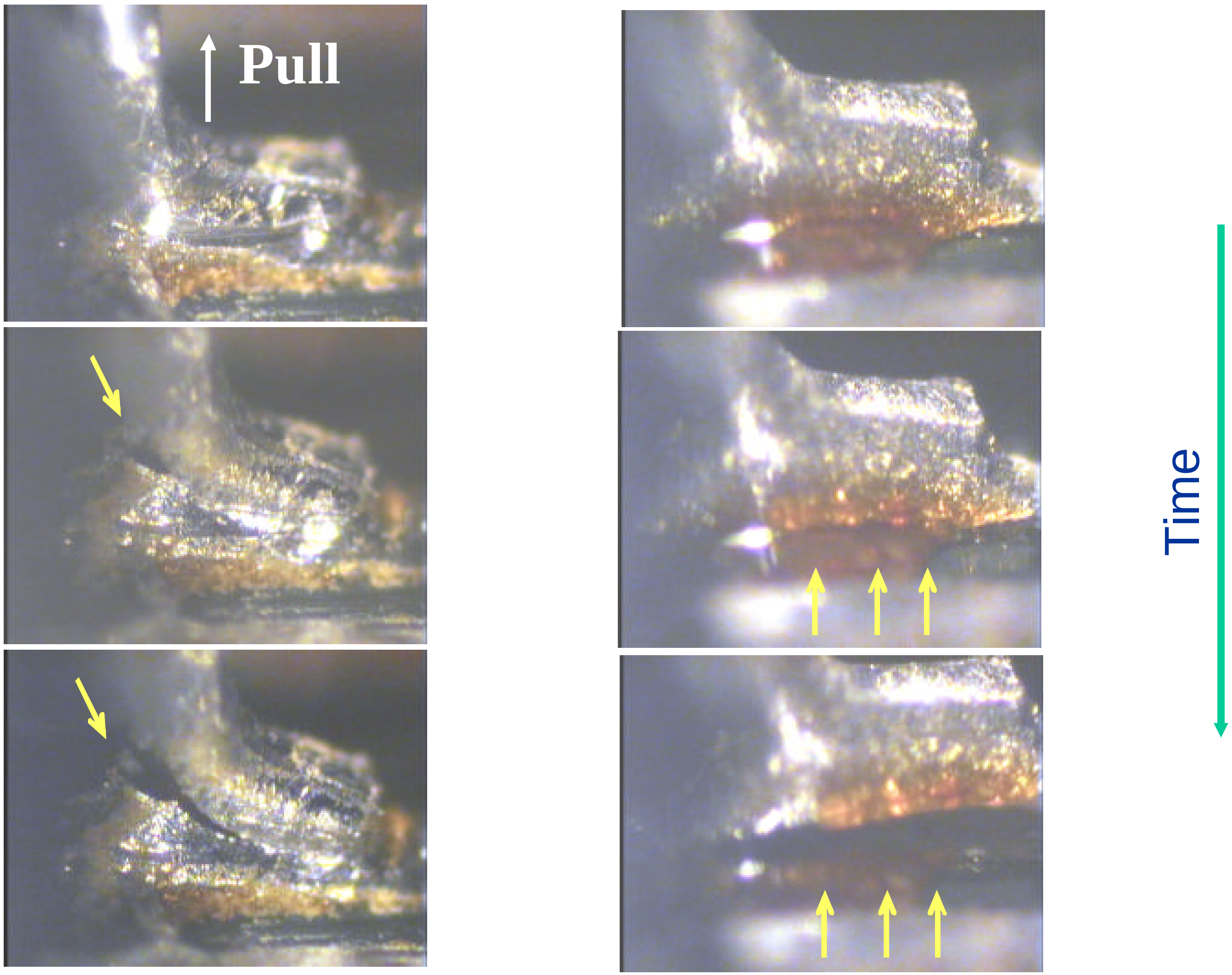
Result of High Temperature test



Pull strength of solder joints

Solder Joint Fracture after HT test

Sn-Ag-Cu / Sn-10Pb plating   Sn-Zn-Bi / Sn-10Pb plating



Result of Thermal Cycle test

- **Sn-Zn-Bi / Sn-10Pb plating:**

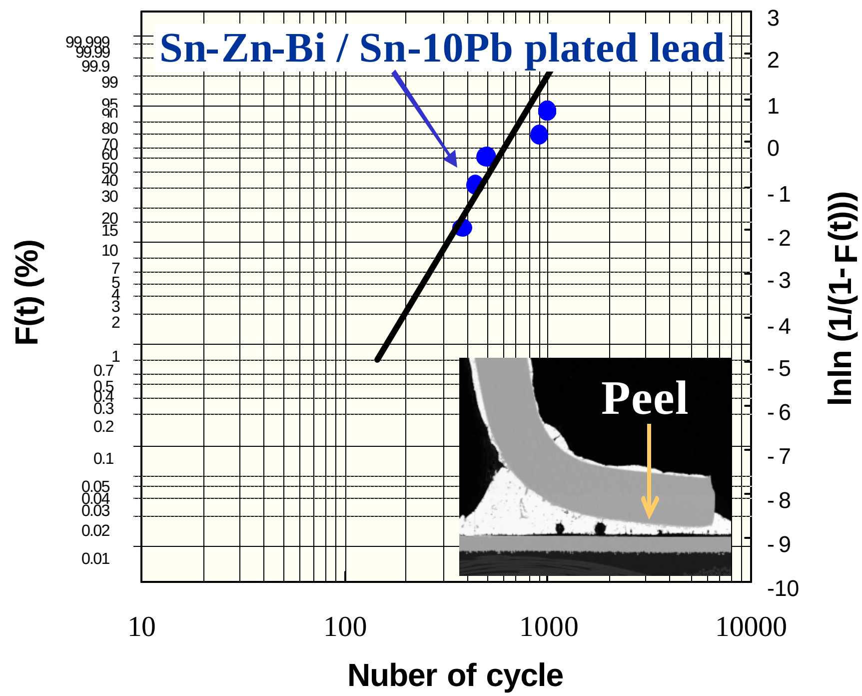
  - *Failure rate(L_{50}) : 650 cycles*

  - *Failure location:*

    Peeling between solder / PCB

- **Other combinations:**

  - *No failure (at 1,000 cycles)*



Weibull chart (median rank)

Result of Thermal - Vibration test

- **Vibration test at room temp.:**

  - *No failure with all combinations*

  - *After more than 500 hr*

- **Combined thermal–vibration test:**

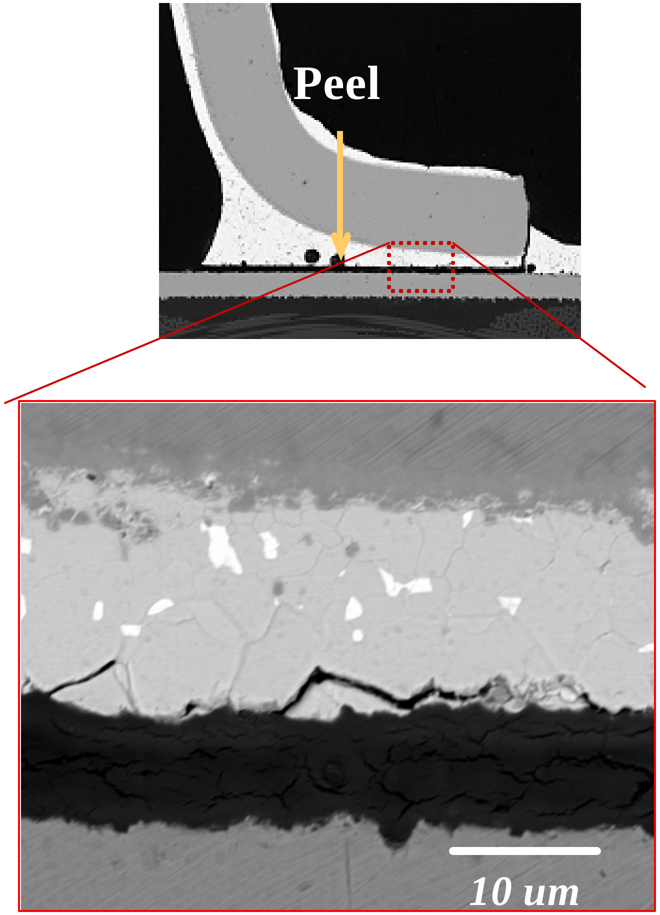
  - *All combinations failed*

  - *Within 100 hr*

- **Effect of stress:**

  - *Thermal stress: major impact*

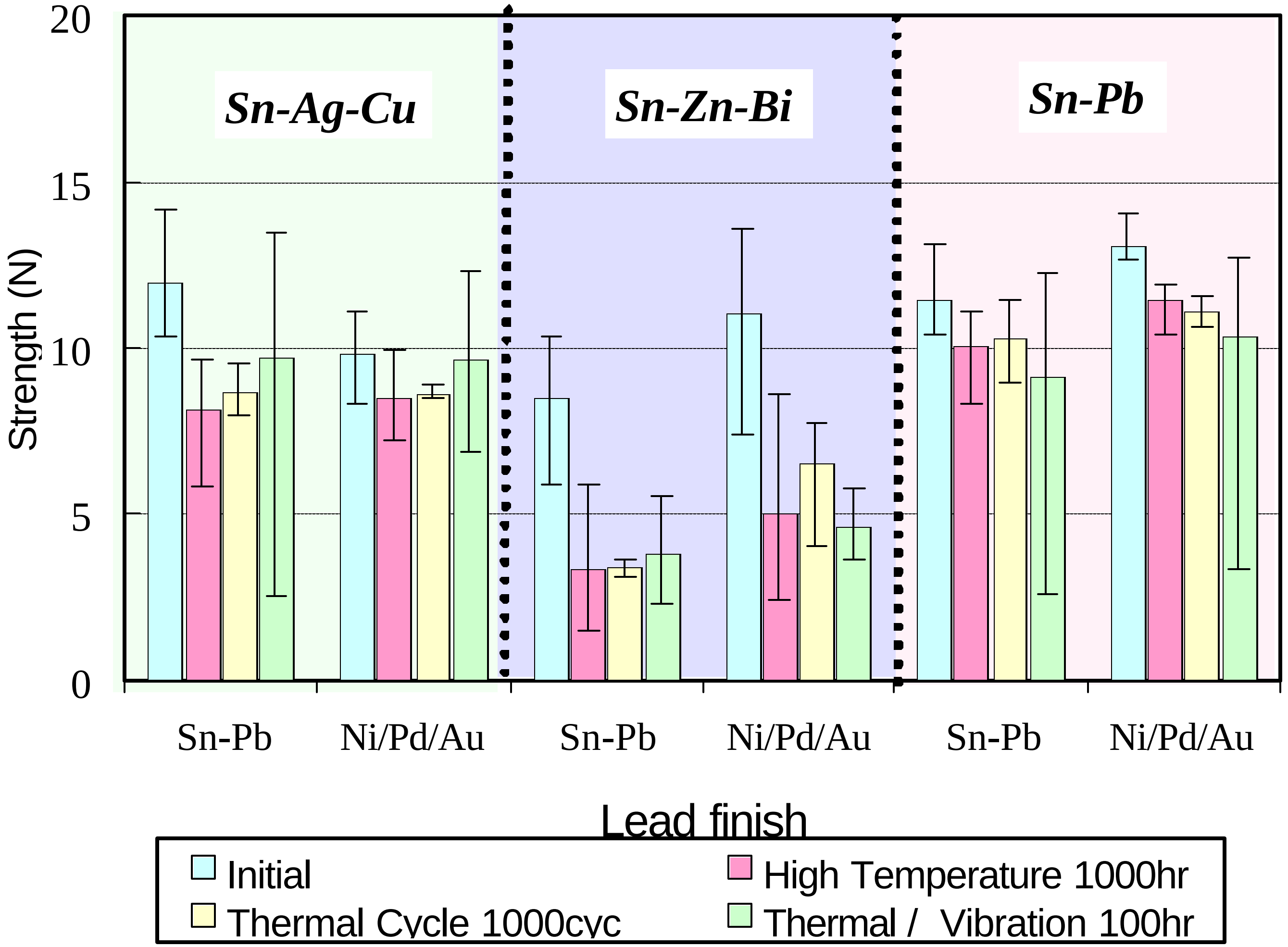
  - *Mechanical stress: leading the failure*



Cross-sectional image

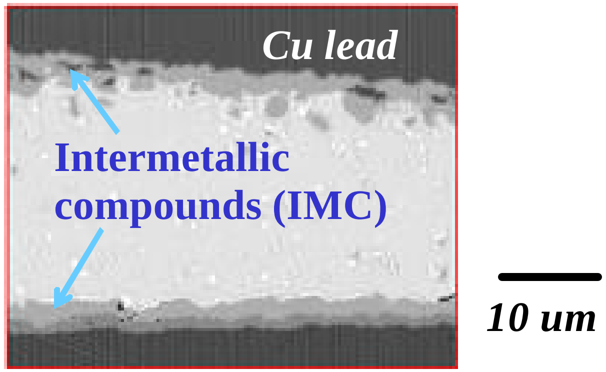
(Sn-Zn-Bi / Sn-10Pb plating)

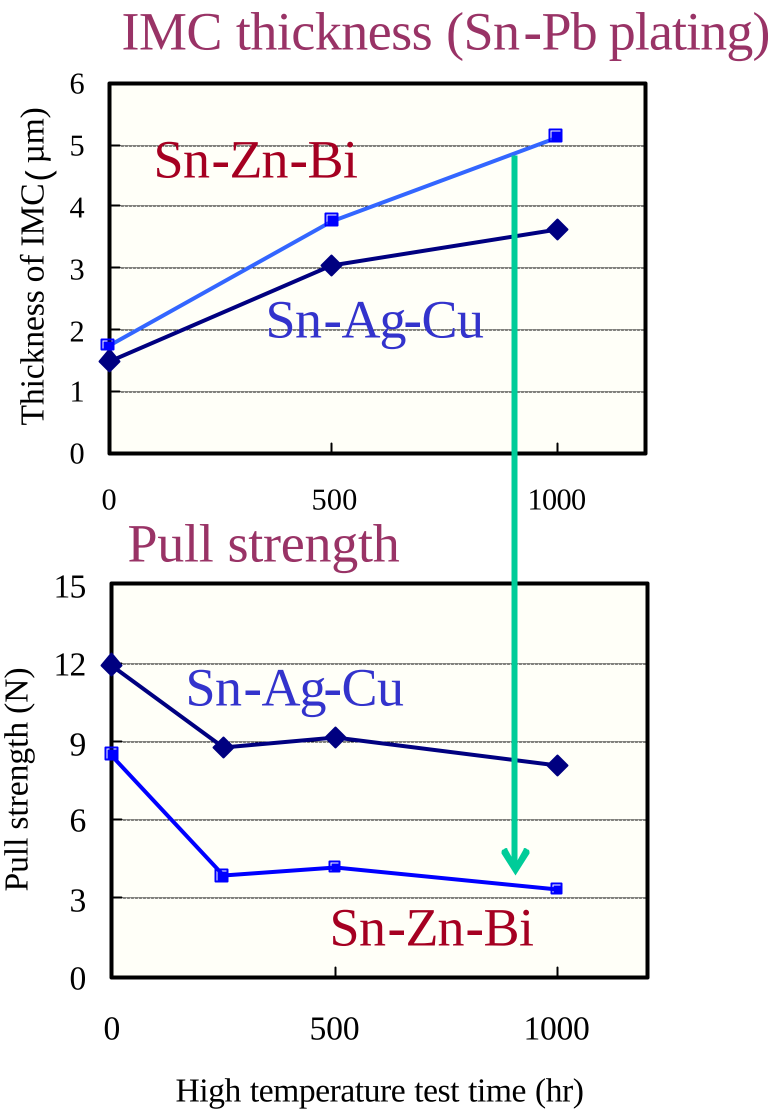
Comparison of Solder Joint Strength



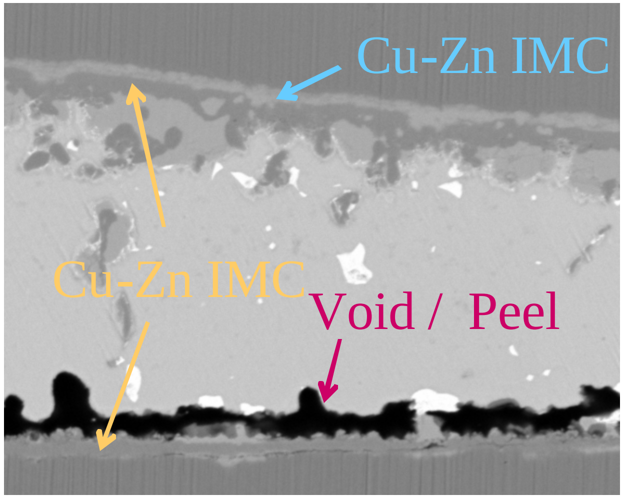
Effect of Solder Materials

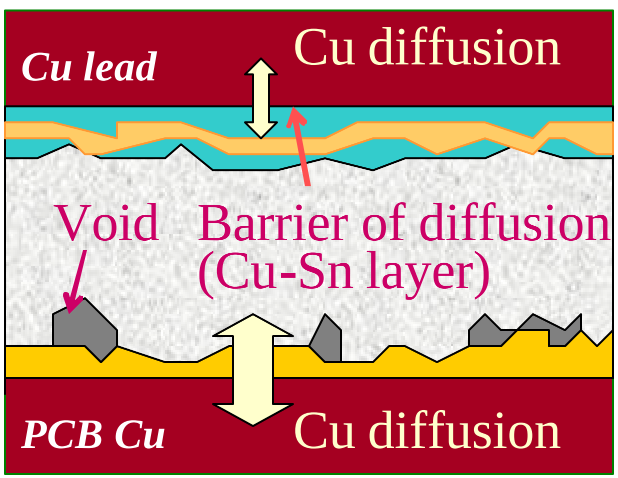
- **Composition of IMC:**
  - *Sn-Ag-Cu : Cu-Sn IMC*
  - *Sn-Zn-Bi : Cu-Zn / Cu-Sn IMC*
- **Increase of IMC thickness:**
  - *Loss of solder joint strength*
- **IMC growth rate:**
  - *Sn-Zn-Bi : Fast*





Loss of Sn-Zn-Bi Solder Joint Strength



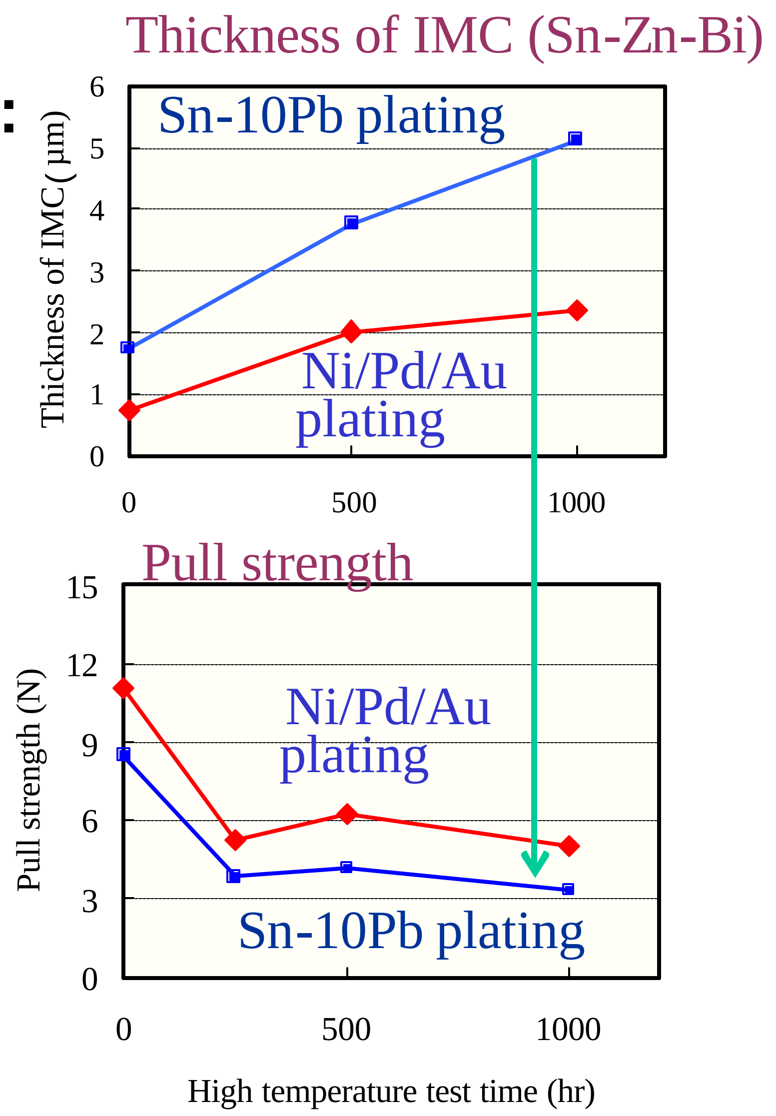


Cross-sectional image after high temperature test for 1000 hr

- **Failure location:**
  - *PCB Cu / solder interface*
- **Factor of degradation:**
  - (1) *IMC growth*
  - (2) *Void generation*
- **Void generation ?**
  - *No Cu-Sn IMC barrier on PCB?*
- **Provision:**
  - *Surface finish on PCB is required*

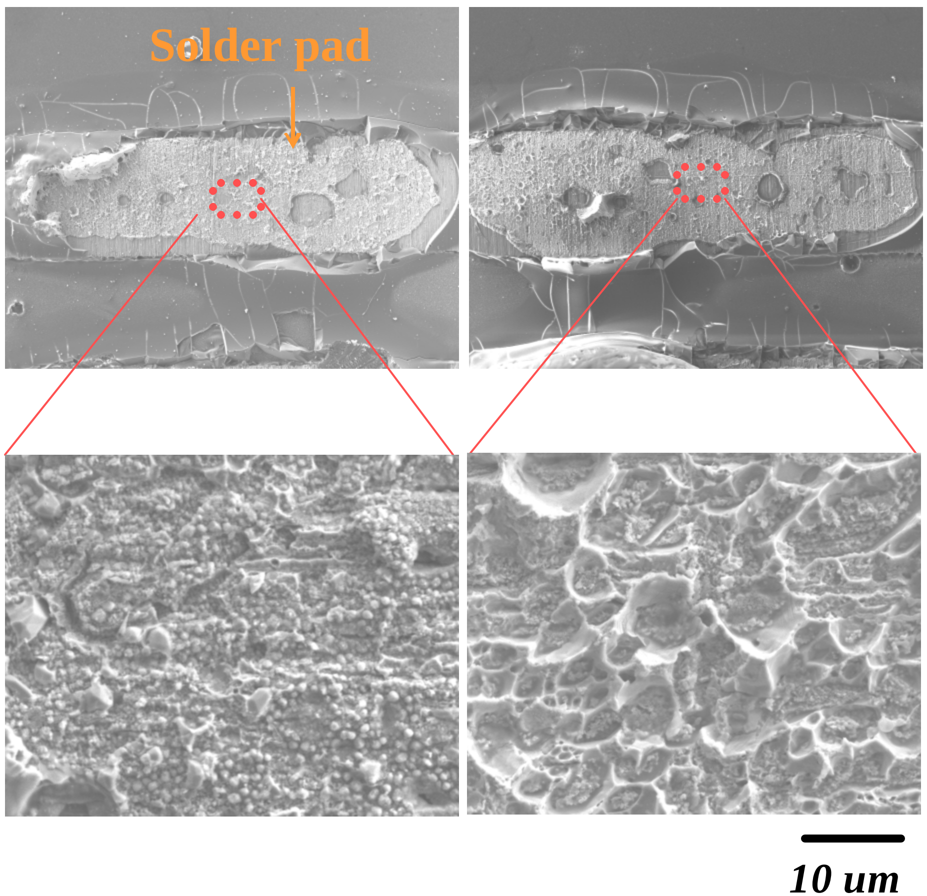
Effect of Lead Finish

- **Effect of solder and lead finish:**
  - *Sn-Ag-Cu : lightly influence*
  - *Sn-Zn-Bi : Significant impact*
- **IMC growth rate:**
  - *Sn-10Pb plating : Fast*
- **Solder joint strength:**
  - *Ni/Pd/Au plating: better*



Sn-Zn-Bi solder and Lead Finish

Sn-Pb plating Ni/Pd/Au plating



Solder pad following pull test
(high temperature test, 1000hr)

Lead finish	Test	Detection elements (mass%)				
		Sn	Zn	**Bi**	**Pb**	Cu
Sn-10Pb	Initial	29	42	**3**	**2**	25
	After	15	36	**5**	**18**	27
Ni/Pd/Au	Initial	62	22	3	---	13
	After	68	19	4	---	9

Sn-Pb-Bi: melting point = 99.5C

Quantitative analysis on solder pad

Solder selection for mass production PCBs

- *Lead-free solder selection*

(1) Possible to maintain reliability equivalent to or better than conventional Sn-Pb solder

(2) Compatibility with existing equipment in open air

(3) Equivalence to conventional assembly work

(4) Possibility of Pb mixing from parts

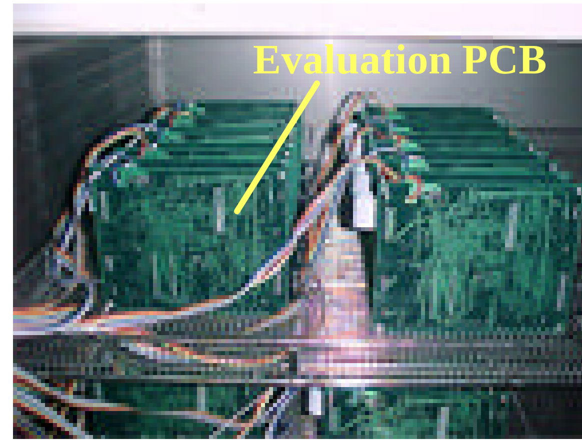
We selected Sn-Ag-Cu solder

Reliability tests of mass production PCBs

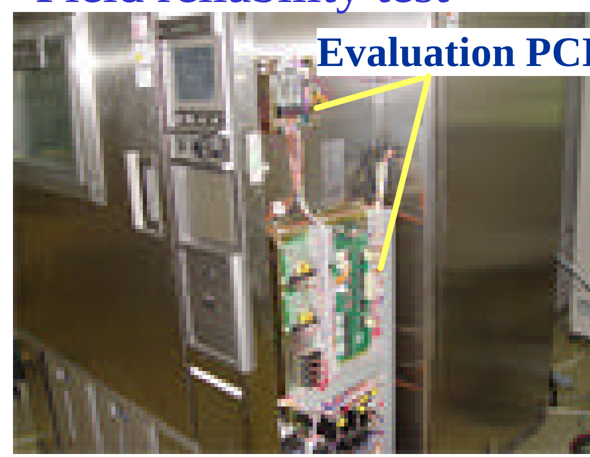
Solder materials	Sn - 3 Ag - 0.5Cu Sn - 37 Pb
High temperature test	80? , 1,000 hr
Temperature cyclic test (air to air flow)	-25 / 80 ? , 3,000 cyc 30 minutes each
High temparature high humidity test	80? / 90 %, 1,000 hr
Field test	3 years, 20,000 hr

Reliability test conditions

Thermal cycle test



Field reliability test



Test appearance

Result of Investigation

- **Temperature cycle test :**

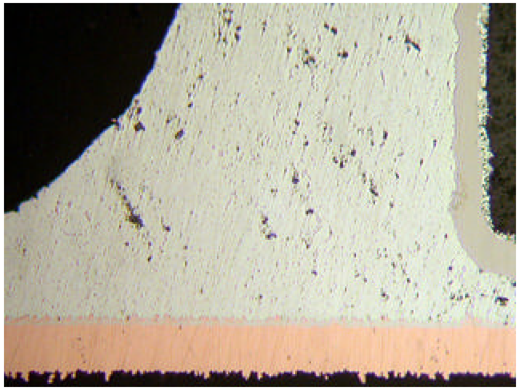
  - *Conventional Sn-Pb: All failure (at 3,000 cycles)*

  - *Sn-Ag-Cu : No failure*

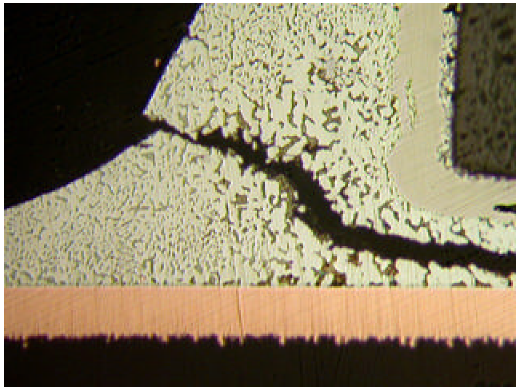
- **Field reliability test:**

  - *No failure (at 3 Years, 20,000 hr)*

Sn-Ag-Cu solder



Conventional Sn-Pb solder



30 um

Cross-sectional image after thermal cycle test for 3,000 cycles

Summary

- Effects of solder joint under thermo-mechanical stress

Factor	*Solder Materials*	
	Sn-Ag-Cu	Sn-Zn-Bi
Thermo-mechanical stress	Durable	Susceptible
Joint degradation	IMC growth	IMC growth Void generation
Mixing Pb from component	Low risk	High risk

- Investigate of mass production PCBs using Sn-Ag-Cu

  - *Endurance of 3,000 cycles in temperature cycle tests*

  - *No failure of 20,000 hours in field reliability testing*