Development and Application of Lead-Free Solder Bonding Technology

Kenichiro Suetsugu
Circuits manufacturing Technology Laboratory
Matsushita Electric industrial Co.. Ltd.

1. INTRODUCTION

Because of global environmental problems, concern for the environment is growing worldwide1-3). Attention is also focusing on discarded electronic equipment and, in particular, on the lead found in solder which solves outs under acid rain and infiltrates underground water Systems 4.). Japan enacted the Recycle Law in 1998 which obligates manufacturers to recover used home appliances that fall within four general categories as of 2001. In Europe, it will be prohibited to use special substances such as lead as of the year 2004, because of the EU Directive on the Disposal of Electric and Electronic Equipment.

As can be understood by this, the legal system is getting tougher on lead, making it an urgent issue for manufacturers to develop and apply lead-free bonding technology 5).

For what regards the introduction and application of lead-free solder, development has progressed on the pretext that Sn-Ag-Bi solder - a potential alternative to eutectic solder because of its characteristics - could be used with existing production equipment and under current production conditions. This paper reports on the tests and future development plans to introduce an Sn-Ag-Bi solder into reflow soldering on a mass-production line 5).6).

2. TEST METHOD

The first thing that comes to mind in regards to applying a lead-free solder to mass-production is that, whatever solder is used, it must have a melting point below that of eutectic solder in order not to thermally damage electronic components.

In a Sn-Ag-Bi system, the overall melting point can be brought down with the addition of Bi, but; it has been noted that the bonding process as weIl as solder characteristics are affected by the amount of additive. Therefore, in order to examine what effects the amount of Bi additive might have, bonding characteristics were evaluated in lead-free Sn-Ag-Bi solders with 3 and 15 wt% additions of Bi and a conventional Sn-Pb eutectic solder. These solders are shown in Table 1.

Table 1 Solder Alloy

Solder alloys	Melting point
Sn-Ag-3Bi type	210
Sn-Ag-6Bi type	220
Sn-Ag-10Bi type	205
Sn-Ag-15Bi type	209
Sn-Pb type	185

Table 2 Plating of main components

Components	Plating
Chip Capacitor (1005,1608,2012)	Sn-10pb
Chip Resister (1005,1608,2012)	Sn-10pb
QFP (P o.5,P 0.65)	Sn-10pb,pd
SOP	Sn-10pb,Sn-Bi
Mini Tr	Sn-10pb,Sn-Bi
Mini Di	Sn-10pb,Sn-Bi

Mounting tests were run on existing production equipment using a glass epoxy test board 0.8 mm in thickness. To examine the compatibility between lead-free solder and electroplated parts, mounting performance and reliability were tested and evaluated using the electronic components listed in Fig. 2. Some were Sn-10Pb electroplated, while others used a lead-free plating. Also, reflow peak temperature was set to a maximum 230°C in consideration of the temperature of the test board itself.

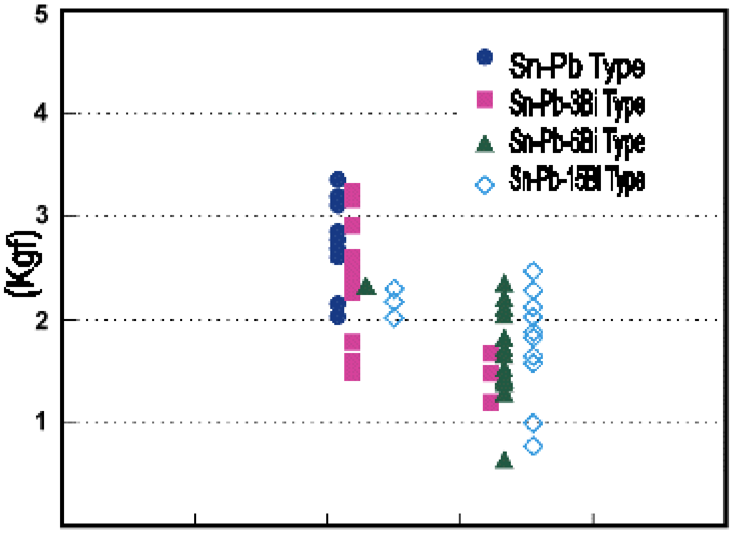
2-1 EVALUATION METHOD

2-1-1 Mounting Performance

Mounting performance was evaluated as in current mounting processes, in terms of printing (rolling, transferability, etc.) and solder-ability (wettability, sol-der ball formation, etc.).

2-I-2 Bonding Reliability

The aforementioned samples were subjected to 500 thermal shock cycles (-40 to 85°C, 30 minutes each) after reflow. Bonding was evaluated in soldered spots.
Bonding strength was measured as tensile strength in leads and shear strength in chips. Furthermore cross-sections of the bond were observed by SEM and XMA for all samples.

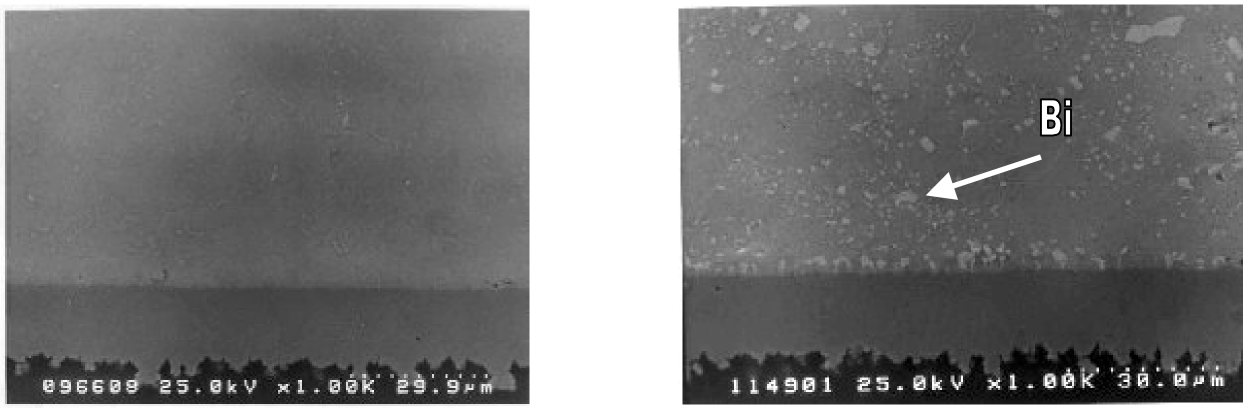


Component Solder and Land/PCB Fracture Mode

Fig.1 Shear strength and fracture mode (0603R)

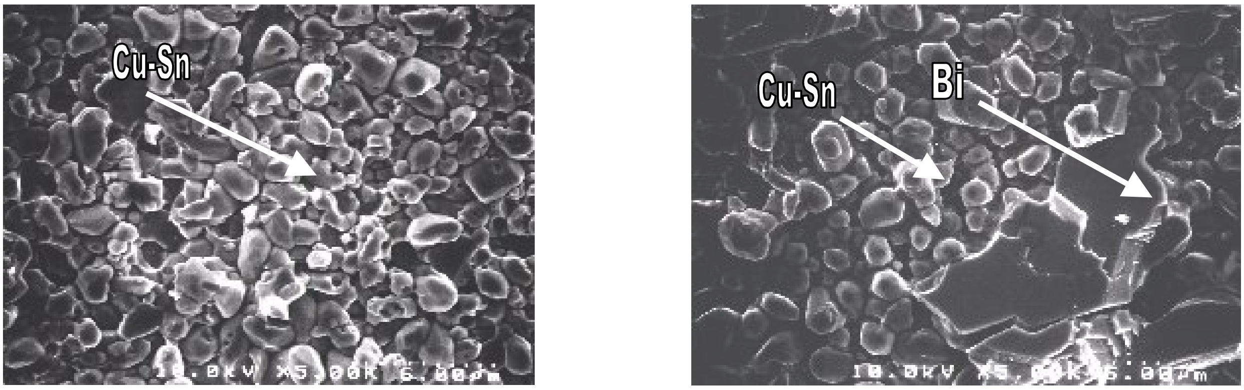
2-2 RESULTS AND OBSERVATIONS

Figure 1 shows the bonding strength of a 1608 chip resistor electroplated with Sn-Pb10. Looking closely at the fracture mode observed after strength measurements, it can be seen that the solder fractured internally when a low content of Bi was used. However, when Bi content was high, the fracture occurred at the interface between the solder and the land. In observations of the post-reflow bond structure, it was confirmed that Bi content in the solder increased with the amount of Bi additive. Because of the Bi increase. Bi segregated to the land-solder interface as well, suggesting that this Bi affected interfacial strength between the lead and land (Fig. 1).
In observations of the lands made after strength measurements (Figs. 2 and 3), a Cu-Sn intermetallic compound was found on the fractured surface. When Bi content in the Sn-Ag-Bi solder was 15 wt%, Bi deposits were observed on the interface between the land and solder, though hardly any were noted with a 3 wt% Bi content.
In all of the electroplated components that were bonded with lead-free solder, very little change in bonding strength was seen after 500 thermal shock cycles.



(a) Sn-Ag-3Bi Type (b) Sn-Ag-15Bi type

Fig 2. SEMs of land (Solder) side after measuring pull strength



(a) Bi content; 3 mass% (b) Bi content; 15 mass%

Fig. 3. Cross sectional view of solder joint

Figure 4 shows some samples of the change in bonding strength after thermal shock tests for a 0.5 mm pitch QFP with Sn-10Pb electroplated leads. The Sn-Ag-3Bi system, which had the lowest Bi content, exhibited the least amount of change, proving even better than the tested Sn-Pb eutectic solder.

What should also be pointed out is that no structural changes or crack formation were detected in any of the bonds in which lead-free solder was used this time.

Moreover, the Sn-Pb eutectic solder and lead-free solders were checked for spilling in QFPs with Pd and Sn-10Pb leads. Results for the same lead plating showed that the lead-free solder rifted slightly more than the eutectic solder though this difference was insignificant.

Also, it was seen through linear analyses (Fig. 5) of lead-solder joints after 500 thermal shock cycles that most of the Pd plating on the lead outer surface melted and dissolved in the solder at the bond interface. Pb also dispersed into the underlying Ni solder base, which taught us that the actual bond was formed between the Ni bases and solder.

The same was observed in soldering components with Sn-Bi plated leads. The Sn-Bi plating solved out of the solder and was not detected at the lead-solder interface.

Resultantly, the bond was formed between the Ni, which dispersed into the solder and the solder. This indicated that bonding with Ni was the same as with Sn-Pb eutectic solder. On the other hand, at the board land-solder interface, it was found that Cu in the board land dispersed into the solder.

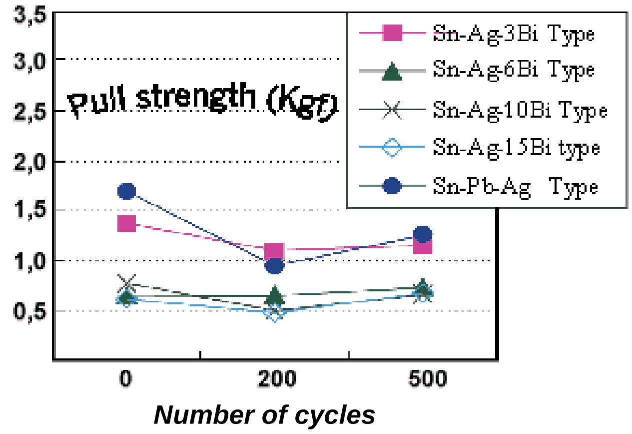


Fig.4 Pull strength of Solder joint

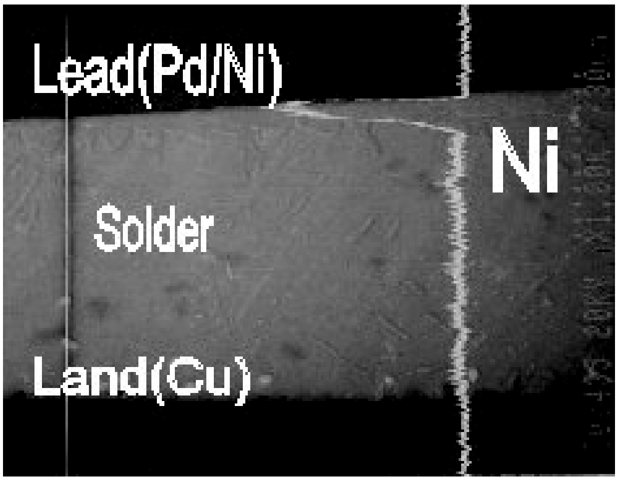


Fig 5 Cross sectional View of Solder joint

Hence, the bonding strength of lead-free solder was not a serious problem in any of tested electroplated components even after 500 thermal shock cycles. It was learned that Sn-Ag-3Bi, which had the lowest Bi content, offered the highest bonding strength, that being equivalent to eutectic solder at that. Moreover, no structural changes or crack formation were detected in the Sn-Ag-3Bi solder even after reliability testing, as were no low melting point alloys which could have formed by mixing with lead.

Based on the aforementioned results, it was concluded that the Sn-Ag-3Bi solder would present no-problems in application and was ultimately selected for test production.

3. INTRODUCTION OF LEAD-FREE SOLDER INTO REFLOW SOLDERING ON A MASS-PRODUCTION LINE

3-1 NOTES ON EVALUATION

Based on the results with the test board and in consideration of board temperature distribution, reflow peak temperature for performance tests using an actual board for a portable mini disc player was set to 220°C or higher in the point where temperature would have to be kept down the most.
Mounting was done under current production conditions using the printed circuit board shown in Fig. 6. As the final reliability criterion, it was decided that the board would have to clear actual product reliability standards.

Fig. 6 PCB (MD)

3-2 EVALUATION IN MASS-PRODUCTION

Evaluations in mass-production centred on soldering quality. Identical boards were produced and reflowed using each a conventional eutectic solder and the selected Sn-Ag-Bi lead-free solder. Even with consideration going to component heat-resistance and heat load, board temperature inconsistency was only tolerated up to 10 to 20°C with the Sn-Ag-Bi lead-free solder, whereas this reached 20 to 30°C with the eutectic solder.
Nonetheless, thanks to the Sn-Ag-Bi lead-free Solder selected this time and an optimised board layout, the guaranteed component heat resistance in reflow was obtained. As can be seen from Fig. 7. board temperature inconsistency was kept within 10°C. Hence, it was discovered possible to produce 40.000 boards/month on the existing line with the new solder (Fig. 8).

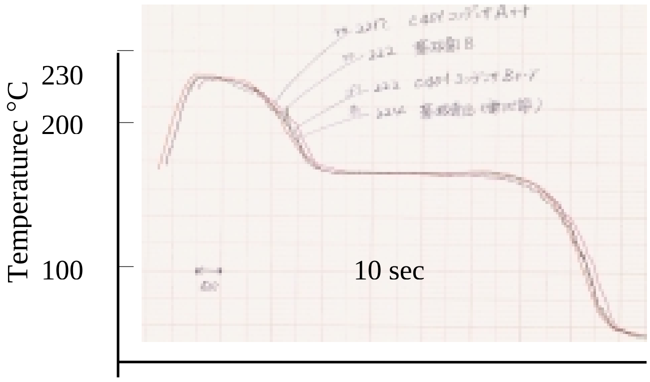


Fig. 7. Reflow temperature profile

Fig. 8. SMT Line

3-3 RELIABILITY

To evaluate reliability, the same tests run on final products (dropping, thermal shock, vibration, etc.) were conducted on the produced boards. Bonding reliability was also tested against specifications for the individual electroplated components because an actual production model is incorporated with many electrical mechanisms such as switches. Even then, the board cleared all reliability standards.

4. PROBLEMS WITH REFLOW SOLDERING USING LEAD-FREE SOLDER

When the lead-free solder was introduced into mass-production, a number of problems arose because of the difference in characteristics from eutectic solder. To name Solder balls, mechanical shock, pin contact verification in the inspection stage and more. Also, for what regards using new types of components, it became evident that more studies would be needed to avoid the possible effects that electroplating specifications could have on bonding characteristics.

5. STUDIES INTO MASS-PROCTUCTION OF LARGE BOARDS WITH HIGHLY INCONSISTENT SURFACE TEMPERATURES

Section 3 talked about production of a circuit board of low heat load balance, for a portable mini disc player. But, depending on the product, boards can vary greatly in size, component size and heat load balance. With large boards of high heat balance, board surface temperature inconsistency during reflow tends to be high. Moreover, some components are weak against heat therefore production temperatures have to be kept below the guaranteed heat resistance of the electronic components. On top of all of that, it is still necessary to ensure that reflow temperature of the bond where temperature rise must be controlled the most is at least as high as the melting point of the lead-free solder. With a conventional Sn-Pb eutectic solder, board surface temperature inconsistency is allowed within a range of 40 to 50°C.. But, when using a lead-free solder on a large board with a highly inconsistent surface temperature, the allowed temperature range is less than half of that, there is no margin for setting temperature.

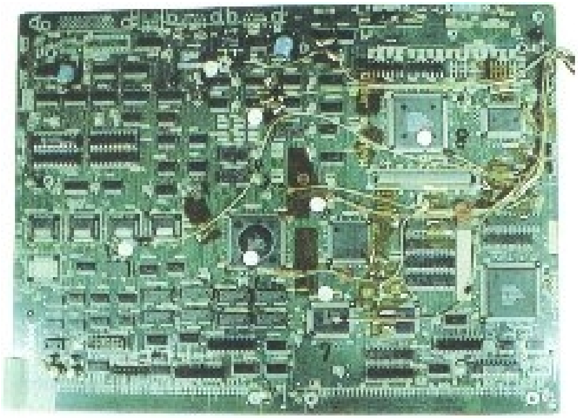


Fig. 9. PCB (Controller)
(305x230x t1.6mm)

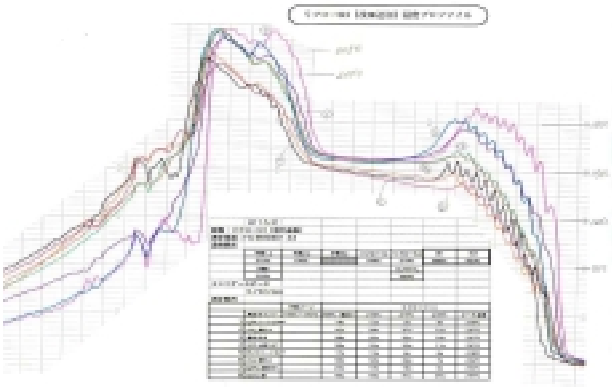


Fig. 10. Investigation of profile curves

In fact, if we take as an example the controller board shown in Fig. 9. board Surface temperature would be very inconsistent with a lead-free solder, because the board mixes large QFPs with aluminum electrolytic capacitors, which are weak against, heat. In this particular case, the inconsistency in board surface temperature can be minimised by raising the temperature of the entire board from the preheating stage, Which would make it possible to set adequate reflow conditions.

However, because aluminium electrolytic capacitors are enclosed in a metallic case, heat conductance is high and this can cause temperature to shoot up rapidly. Therefore, with a board that contains mixed types of components, though temperature differential tends to be high, it is possible to utilise the way the aluminium reflects infrared rays. In other words, a second way to solder large boards is to utilise the radiated heat of far infrared rays instead of relying solely on direct heating. This would make it possible to keep temperature rise in the aluminium electrolytic capacitors down. By optimising heat efficiency using hot air and far infrared rays, it is thinkable that reflow conditions could be set for a lead-free solder (Fig. 10).

Still a third way would be to use a furnace that could uniformly heat the entire board. This should enable it to control heat in parts of the board that readily heat up in the reflow zone. It is inevitable that the aforementioned three reflow methods be used in the future because manufacturers will not be offering any bonding temperature leeway. Therefore, with lead-free solder, it will be necessary to take further steps to lower solder melting point without sacrificing bonding strength.

6. DEVELOPMENT AND APPLICATION OF FLOW-TYPE LEAD-FREE SOLDER

Tests were run on a Sn-Ag solder to verify its potential as a lead-free flow-type solder 7). Because of its different characteristics, it was found to more readily form bridges than conventional eutectic solder does. As with reflow solders, evaluation testing including bonding reliability verification continues in hope of an eventual practical application. It is already being used with CRT boards by Matsushita's TV Network systems Division 7). It has also been applied to other TV boards 8). Flow-type soldering is being pushed with other products to meet the 2001 lead-free deadline set for the four recycle categories of home appliances.

7. CONCLUSIONS

In the interest of the global environment, eutectic solders which contain lead are undergoing serious review, but as of the moment, there has yet to be found a working alternative, in terms of characteristics, to the currently used eutectic solder. However, mounting is possible using a lead-free solder because it poses no problems to actual production from the perspective of solder characteristics, mounting quality and reliability. As has been discussed in this paper, practical applications are unfolding. In other words, an Eco-friendly lead-free solder is about to rewrite the first chapter in the near 5.000 years that solder has been known to mankind. In building a recycle system for old printed circuit boards, not only will the stereo, solder and electronic component manufacturers be testing and promoting the use of lead-free solder, but the government as well. Efforts should be picking up speed in the future. In fact, the search for lead-free solder has been high paced over the past few years. Research and development has been taken to the national level as seen by the Research and Development into lead-free standardisation project of the Ministry of International Trade and Industry 9). In which private businesses and universities are also a part. Studies are also underway into labelling for products, which use lead-free solder. Industries are looking for a standard label (Fig. 11). Japan leads the world in the hunt for lead-free solder. More than ever before, people from diverse fields are now involved with lead-free solder both out of national pride and because it is an environmental technology that will carry over to the 21st century. Hopefully, it will be applied in every field so that a green-plush Earth will be here to enjoy long into the future.

Fig. 11. Label for Lead Free Solder Product

REFERENCES

1) "Lead-Free Solder", Papers for the 9th Circuit Mounting Science Conference, pg. 75 – 88, 1994.
2) "Development of Lead-Free Solder - For New Laws in the US".No.622, pg 17 – 18, 1994.
3) Japan.s Efforts to Gain ISO Certification", Environmental Management 31.No.10, pg. 7 - 16, 1995.
4) "Lead -Free Solder Technology", 3rd SMT Forum, pg. 60, 1995.
5) "Deposit-Hardened Lead-Free Sn - Ag Solder of High Thermal Shock Resistance", National Technical Report, No.1 pg 46 - 53.(1997).
6) Mike Judd and Keith Brindley, "Soldering in Electronics Assembly-Second Edition". Butterworth-Heinemann, Oxford, 1999,.
7) Matsushita's Success with Lead-Free Solder in TV Board Production at Ibaraki Plant". Nikkei Industrial Newspaper, Dec.23, 1997.
8) Matsushita Launches 21"TV Launch".Recycle No.1, Nikkei Industrial Newspaper, Aug.7.l997.
9) "Research and Development into Lead-Free Solder StandardiZation".Nihon Keizai Newspaper, May l2, 1998.