Assembly Technology Using Pb-free Solders: the State of the Art and Issues

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FUJITSU LABORATORIES LTD.

Outline

- Background
- Candidates for Pb-free solders
- Application of Pb-free solders
- Problems and solutions in assembly using Pb-free solders
- Sn-Zn-Al solders
- Thermal analysis for uniform heating during assembly

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RoHS[*1] Directive

- Restriction on the use of certain hazardous substances in EEE[*2]

Substance	lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE)
Categories of EEE	Household appliances, IT and telecommunications equipment, consumer equipment, et al.
Effective date	July 1, 2006
Exemption	mercury in compact fluorescent lamps (<5 mg), lead in high melting temperature type solder, lead in glass of cathode ray tubes, et al.
Under examination	mercury in straight fluorescent lamps, lead in solders for servers, storage, et al., light bulbs, Deca BDE

[*1] RoHS: Restriction on Hazardous Substances
[*2] EEE: Electrical and Electronic Equipment

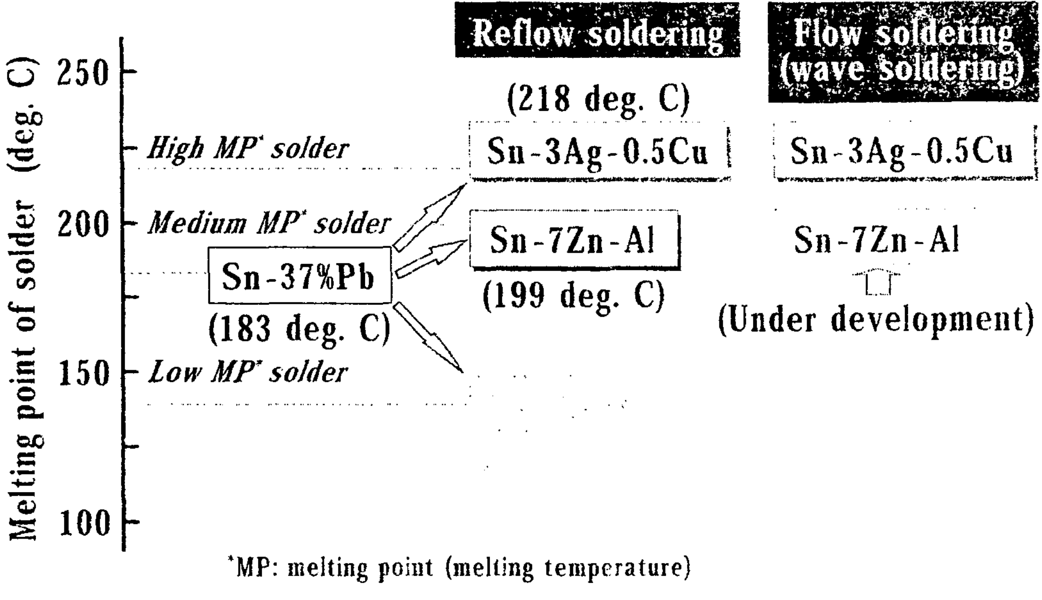
Candidates for Pb-free Solder

Solder	Feature	Issue
High MP* Sn-Ag Sn-Ag-Cu	• High reliability of solder joint • Excellent mechanical properties • High soldering temperature	• Uniformity of soldering temp. • Lift-off with Bi and Pb • Improvement of heat-resistant property of component • Easy to repair
Sn-Cu	• Inexpensive • High soldering temperature	• Lift-off with Pb
Medium MP Sn-Zn	• Approximately the same soldering temperature as the eutectic Sn-Pb • Low cost (low material cost) • Severe oxidation • Unknown compatibility with surface finishes of lead and pad	• Inhibition of oxidation • Possibility of reflowing in air • Reliability of solder joint
Low MP Sn-Bi	• Low soldering temperature (able to simultaneous reflow of low and high heat-resistant components) • Low reliability of solder joint with Pb-containing component	• Pb-free surface finish of package and component

*MP: melting point (melting temperature)

Pb-free Solder – Materials and Process

The present situation in Fujitsu

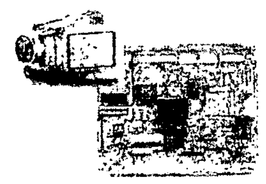


Practical Use of Pb-free Solder (1)

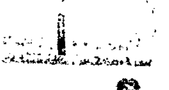
Company	Product	Year	Comment
Matsushita	Compact mini-disk (MD) Video tape recorder Cassette tape recorder	1998 1999 2000	Sn-Ag-Bi-In, reflow soldering Sn-Cu (-Ni), flow soldering Sn-Ag-Bi-In, reflow soldering
NEC	Pager Notebook personal computer	1998 1999	Sn-Ag-Cu, reflow soldering Sn-8Zn-3Bi, reflow soldering in N_2 Flux modification Board: Au/Ni
Hitachi	Video camcorder, Refrigerator Cleaner, Washing machine, Air conditioner Notebook personal computer	1999 2000 2000	Sn-Ag-Cu, flow soldering Sn-Ag-Cu, flow soldering Sn-Ag-Cu, flow soldering
Sony	Video camcorder, TV, Notebook personal computer	2000	Sn-2.5Ag-1Bi-0.5Cu reflow soldering
Toshiba	TV, Refrigerator, Washing machine Home laundry, Cleaner	2000	Flow soldering (insertion mount)
Fujitsu	Hand-held terminal Large scale computer (server)	2000 2000	Sn-Ag-Cu Sn-Bi-Ag and Sn-Ag
Nissan	Keyless entry system	2000	Sn-Ag-Cu
Philips	Light valve	2000	Sn-1Ag-5Bi, flow soldering
Ford (Visteon)	Transceiver module for burglar alarm	2000	Solder composition is not announced.

Practical Use of Pb-free Solder (2)

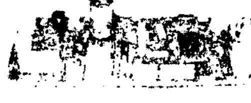
Light valve [Philips]
Sn-Ag-Bi solder
Reflow soldering

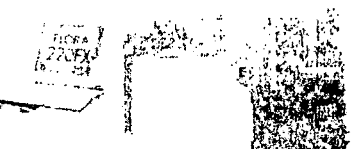


Video camcorder [Sony]
Sn-Ag-Bi-Cu solder



Air conditioner
[Hitachi]
Sn-Ag-Cu solder

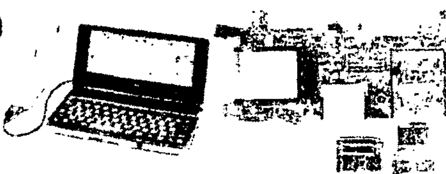




Personal Computer [Hitachi]
Sn-Ag-Cu Solder

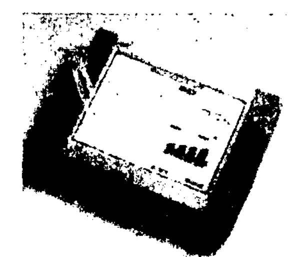
Personal computer [NEC]
Sn-Zn solder

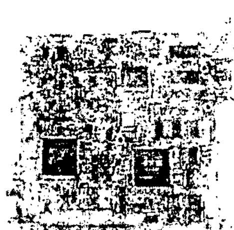
Compact mini-disk (MD)
[Matsushita]
Sn-Ag-Bi-In solder
Reflow soldering



"Mobile Gear" [NEC]
Sn-Ag solder
Reflow soldering

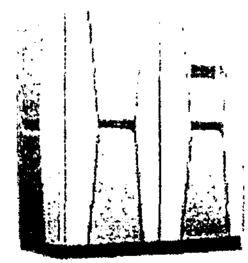
Practical Use of Pb-free Solder (3)





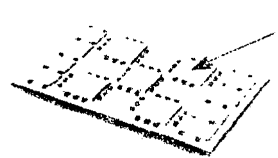
Hand-held terminal
[Fujitsu]
Sn-Ag-Cu solder

Large scale computer (high-end server) [Fujitsu]



[GS 8900]

Sn-Bi-Ag solder
(MCM - mother board)

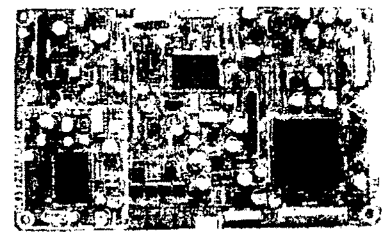


Sn-Ag solder (chip - MCM)

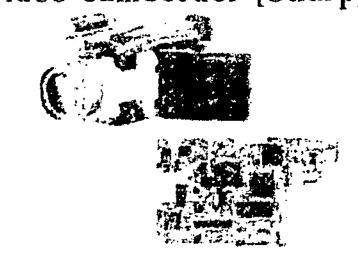
Practical Use of Pb-free Solder (4)

Sn-Ag-Cu solder (reflow soldering)

LCD (liquid crystal display) TV [Sharp]

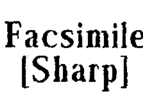


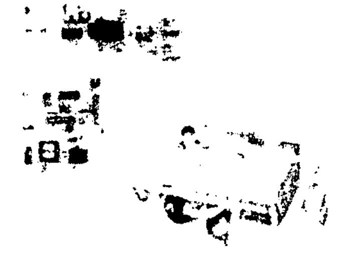
Video camcorder [Sharp]

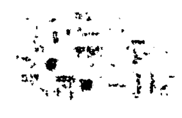


Sn-Ag-Cu solder (flow soldering)

Facsimile [Sharp]





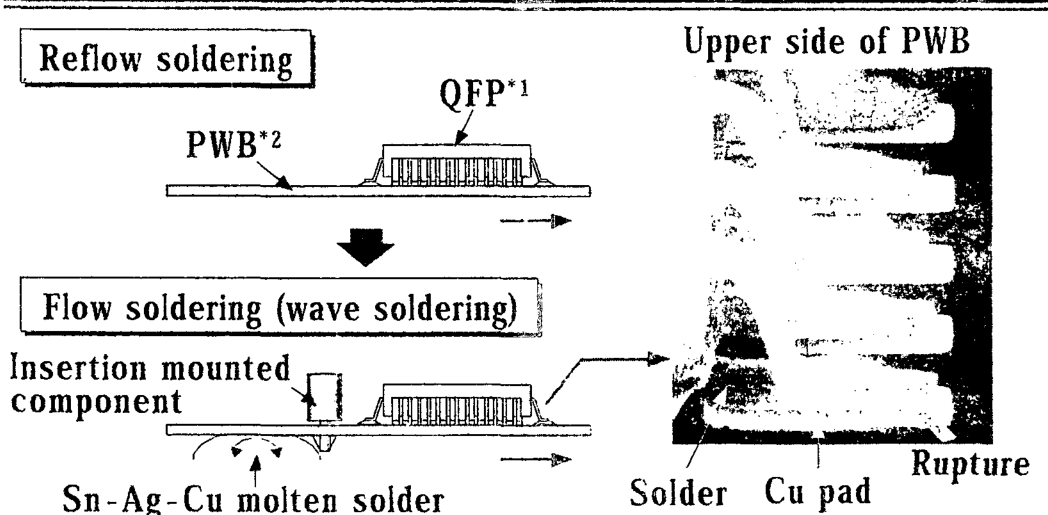


Refrigerator [Sharp]

Problems and Solutions in Pb-free Solders

- Viscosity increase in solder paste
- Displacement of components
- Inspection criteria for solder joint
- Mixed use of flow and reflow soldering
- Compatibility to Pb containing metallization

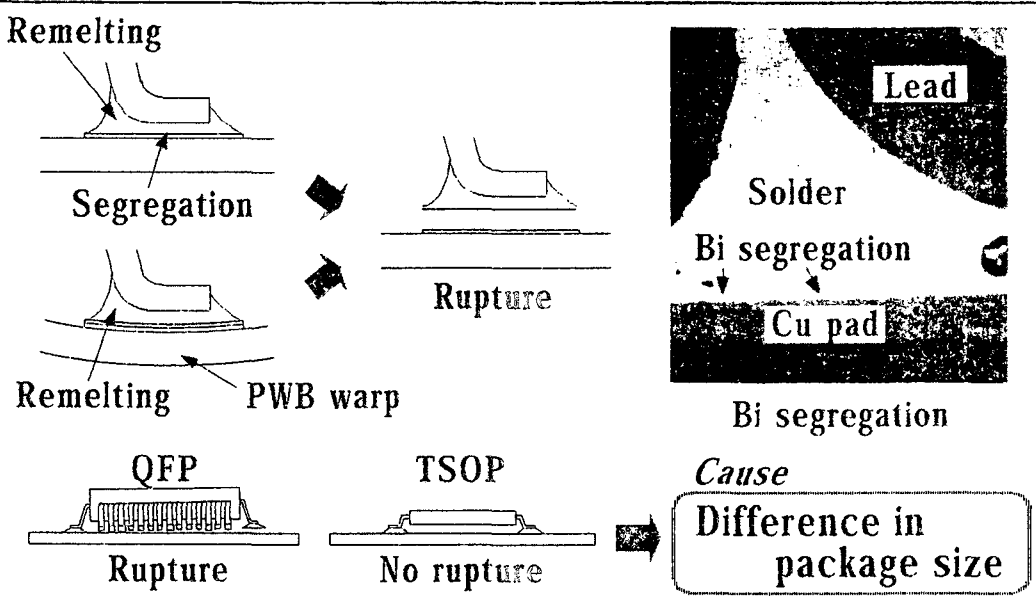
Interface Rupture Occurred in Mixed Use of Flow and Reflow Soldering



*1QFP: Quad flat package *2PWB: printed wiring board

Source: *S. Sugahara, Denshi Zairyo (Electronic Parts and Materials) Special Ed. (June 2004) pp. 92-97.*

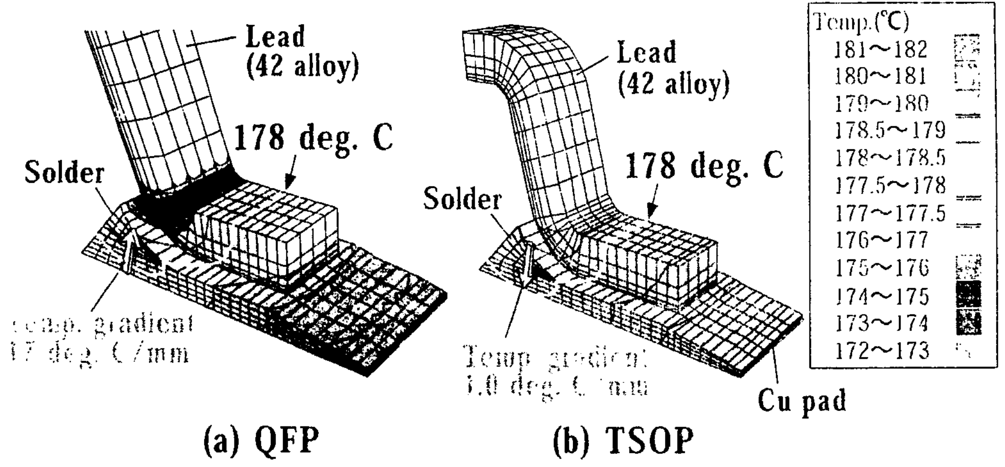
Mechanism of Interface Rupture



QFP: quad flat package TSOP: thin small outline package

Source: *S. Sugahara, Denshi Zairyo (Electronic Parts and Materials) Special Ed. (June 2004) pp. 92-97.*

Temperature Distribution at Solder Joint



(a) QFP (b) TSOP

Segregation does not occur in small package with small heat capacity like TSOP because of small temperature gradient.

QFP: quad flat package TSOP: thin small outline package

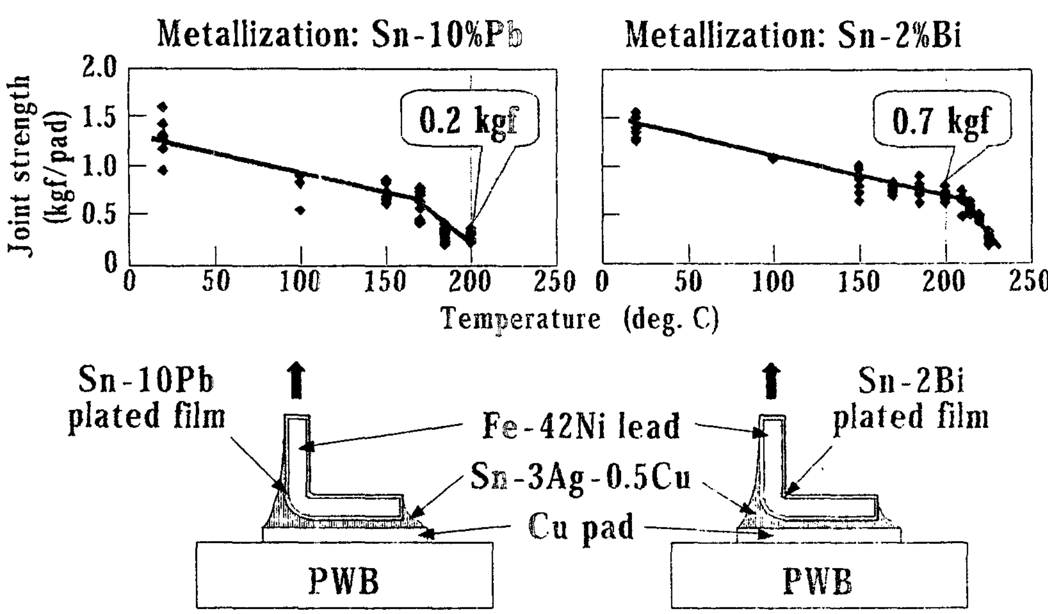
Source: *S. Sugahara, Denshi Zairyo (Electronic Parts and Materials) Special Ed. (June 2004) pp. 92-97.*

Mechanism of Interface Rupture

1. Formation of low melting point phase
2. Segregation of solder alloy element at the interface between solder and metallization (Segregation is probably induced by the temperature gradient at the solder joint)
3. Stress induced at the solder joint due to board warp during flow soldering

Source: *S. Sugahara, Denshi Zairyo (Electronic Parts and Materials) Special Ed. (June 2004) pp. 92-97.*

Joint Strength at High Temperature



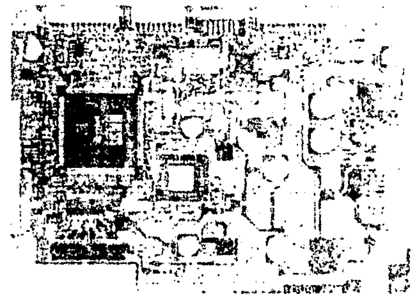
Source: *S. Sugahara, Denshi Zairyo (Electronic Parts and Materials) Special Ed. (June 2004) pp. 92-97.*

Practical Use of Sn-Zn-Al Solder (1)

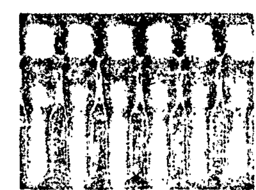
Sn-7Zn-Al solder [Fujitsu]

15 inches LCD

Printed circuit board (FR-4)



155 x 110 mm
241 components

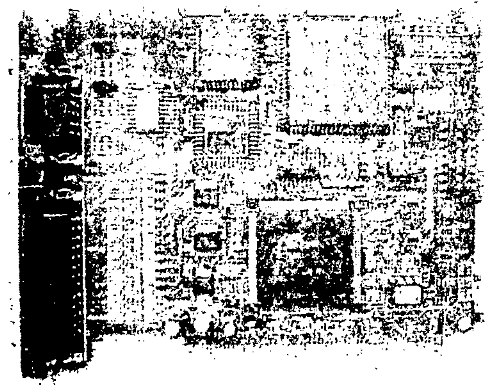


Soldered QFP leads
(pitch: 0.5 mm)

Practical Use of Sn-Zn-Al Solder (2)

Sn-7Zn-Al solder [Fujitsu]

Serial parallel card (FMV-103)



Board (FR-4) Size: 150 x 100 mm
Number of components: 130
LSI package lead pitch : 0.4 mm

Developing Sn-Zn-Al Solder

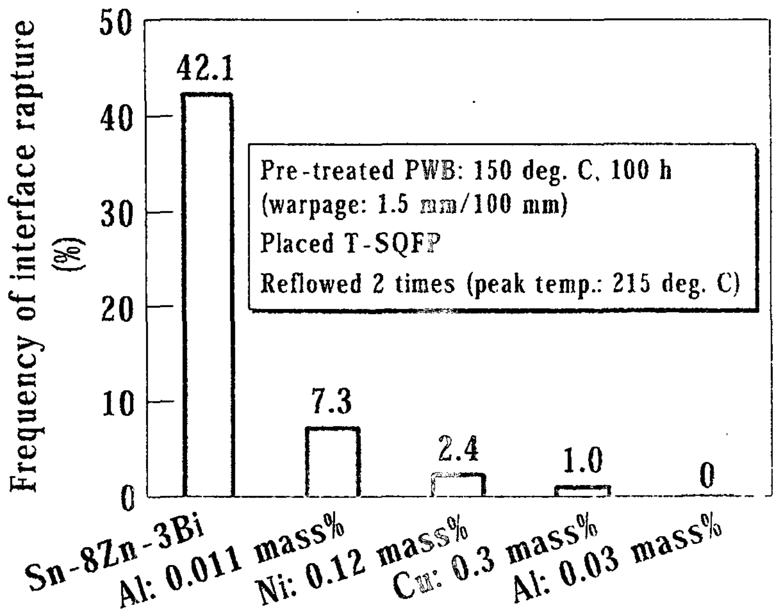
Purpose

1. To lower reflow soldering temperature
2. To increase solder joint reliability for Cu metallization
3. To enhance wettability of Sn-Zn solder by inhibiting Zn oxidation
4. To widen application field
   flow soldering (wave soldering), ball soldering (BGA)

Issues

1. New solder alloy (the third element addition to Sn-Zn)
2. New flux compatible with new solder alloy
3. Stability of solder paste using new solder alloy
   (long life for storage and continuous screen printing)
4. Easy to inspect solder joint
   (less amount of flux by enhancing wettability)

Effect of Al Alloying to Sn-Zn Solder



Effect of Al Alloying to Sn-Zn Solder

1. Inhibition of Sn-Zn solder oxidation due to predominant oxidation of Al
2. Inhibition of water penetration into solder by dense Al oxide film (to be expected corrosion resistant property in high-temperature and high-humidity environment)
3. Inhibition of intermetallic compound layer at the interface between solder and metallization

Reliability of Sn-Zn-Bi Solder Joint

Reaction between Sn-8Zn-3Bi solder and surface finish

Surface finish	Initial	100 h at 150 deg. C
Board: Cu Lead: Sn-Pb	Solder Pb-Bi Cu-Zn Cu 5μm	Solder Sn-Pb-Bi Rupture Cu-Zn 5μm
Board: Au/Ni Lead: Sn-Pb	Solder Void Ni-Zn Ni 5μm	Solder Void Ni-Zn Ni

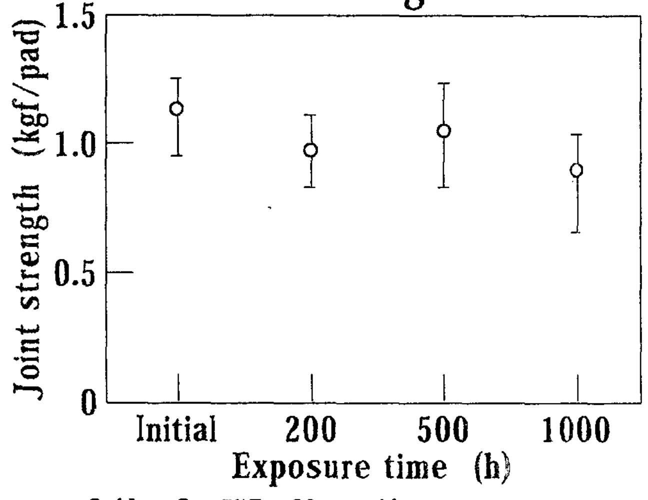
Reliability of Sn-Zn-Al Solder Joint

Reaction between Sn-Zn-Al solder and Sn-Pb/Cu

Solder	Initial	100 h at 150 deg. C
Sn-9%Zn (eutectic)	Solder Crack Cu-Zn Cu	Solder Void Cu-Zn Cu
Sn-7.3%Zn- 60 ppmAl	Solder Cu-Zn Cu	Solder Cu-Zn Cu

Reliability of Sn-Zn-Al Solder Joint

Change in joint strength after exposure to 85 deg. C and 85%R. H.



After 2000 h

200 μm

Solder: Sn-7%Zn-30 ppmAl
Soldering condition: 215 deg. C in N_2 atmosphere
Surface finish of board: Cu
Package: 208-pin TSQFP (lead pitch: 0.5 mm, surface finish of lead: Sn-Pb)

Assemble Process for Sn-Zn-Al Solder

Soldering

Solder wetting and spreading	➡ Opening ratio, shape, and position in screen printing mask
Warpage of thin PWB	➡ Suitable fixture
Repairability	➡ Optimum hand soldering condition (soldering-iron tip, temp. and time)
Soldering condition	➡ Optimum flow and reflow profiles

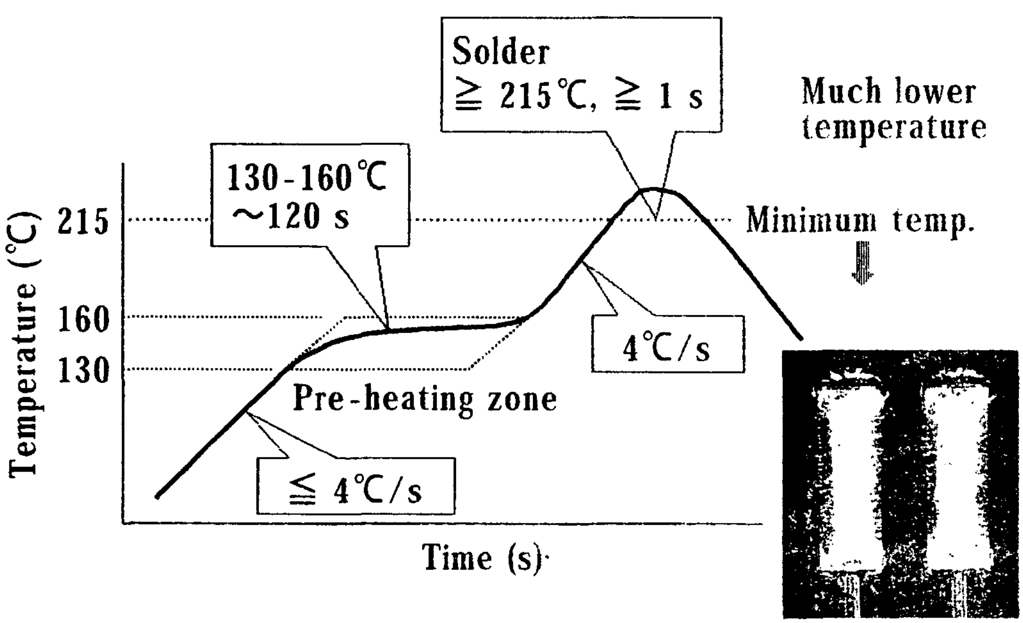
Inspection

Change in solder joint configuration	➡ Inspection criteria confirmation, instruction/training
Probe for testing	➡ Contact shape and load

Quqlity of printed circuit board assembly

Assembly	Quality of solder joint	Quality of electronic function
Pb-free	1.05	0.95
Sn-Pb	1	1

Reflow Profile for Sn-Zn-Al Solder

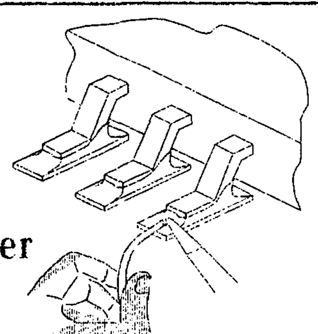


Hand Soldering for Repair

Pb-free solder wire: Sn-3Ag-0.5Cu

Wettability and workability:

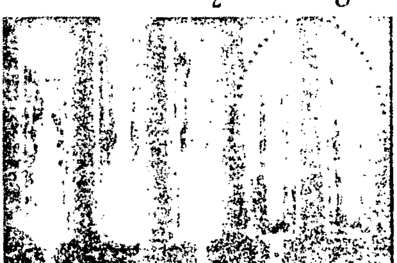
- prevention of oxidation by N_2
- post-flux suitable for Sn-Zn-Al solder



Soldered in air

Icicle

Soldered in N_2 assist gas

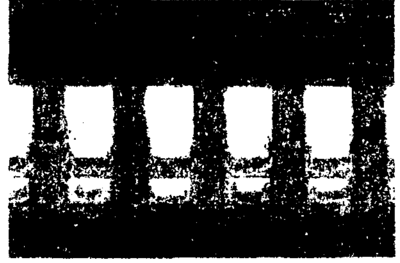


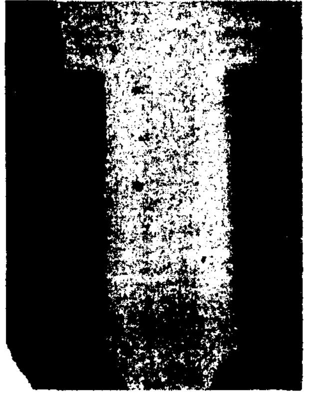
No icicle

Flow Soldering Using Sn-Zn-Al Solder

LSI Package: 24 pins
Soldering: in solder pot (50 mm dia.)
in air
Board: glass cloth/epoxy
Board thickness: 1.6 mm
Diameter of through hole: 0.8 mm

View of package side





View of solder pot side

Sn-Zn-Al Solder

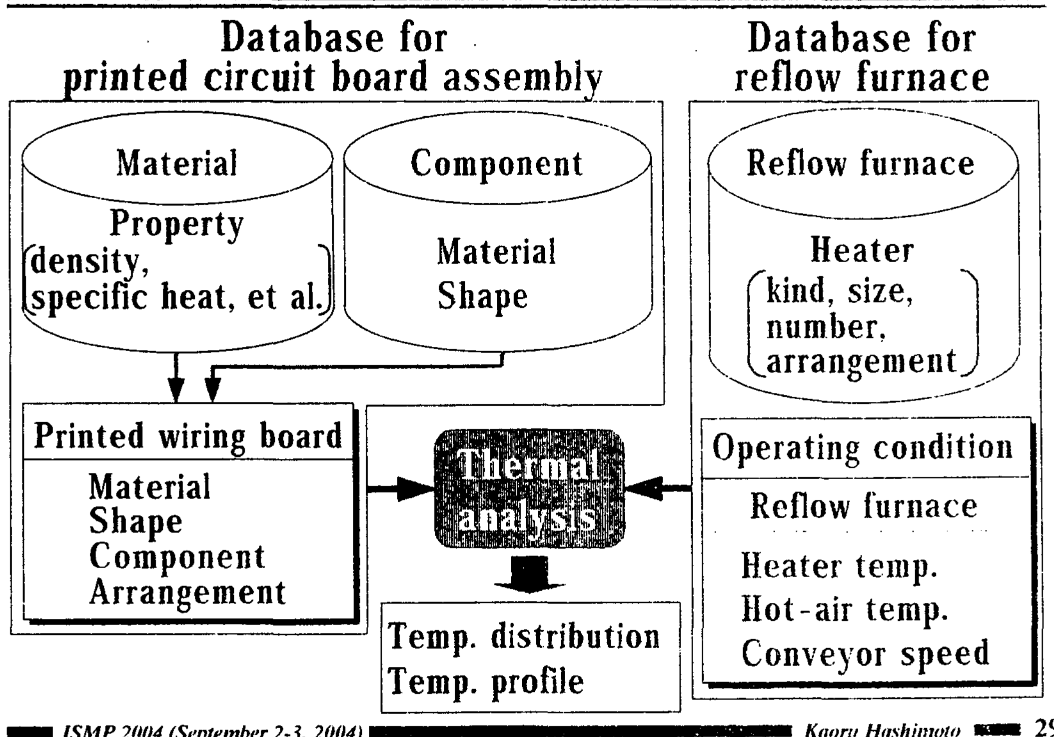
1. Alloying a small amount of Al can inhibit Sn-Zn solder oxidation by predominant oxidation of Al, and provide good wettability. This provides high reliability of solder joint with Cu metallization.

2. Optimum amount of Al is limited to a narrow range.

3. Reflow soldering process was established, and is being applied to assembly of some kinds of electronics equipment such as LCD.
   More than 300000 products are shipped since December, 2002.

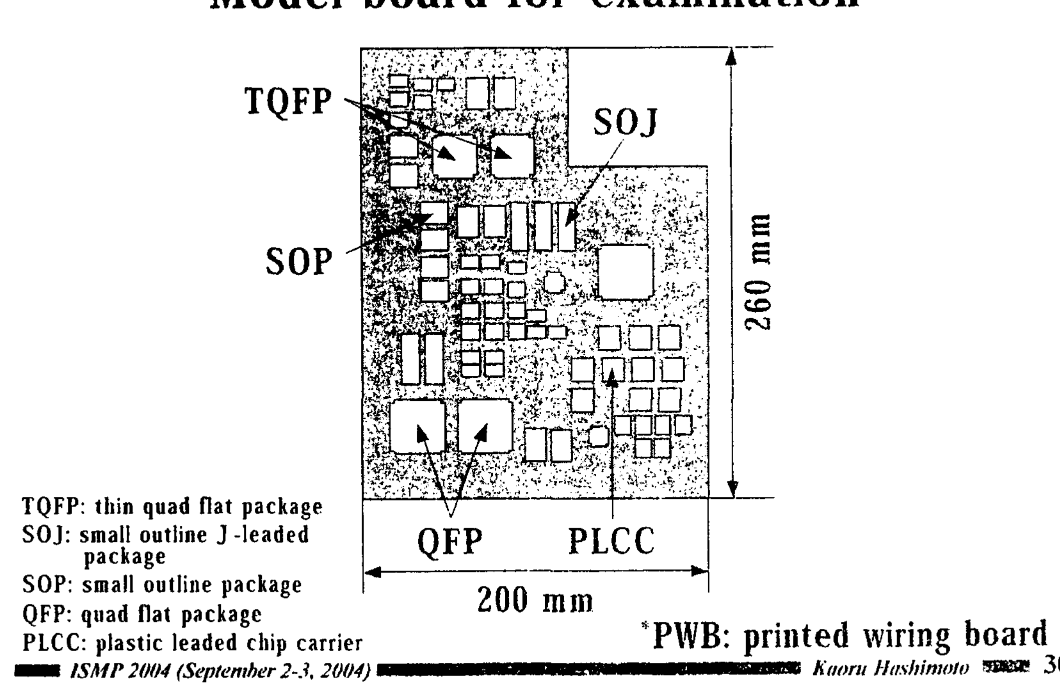
4. Possibility of flow soldering is confirmed in a preliminary study. Development using flow soldering equipment is underway, and reliability of solder joint by flow soldering is being examined.

Construction of RS-Station



Temperature Distribution on PWB*

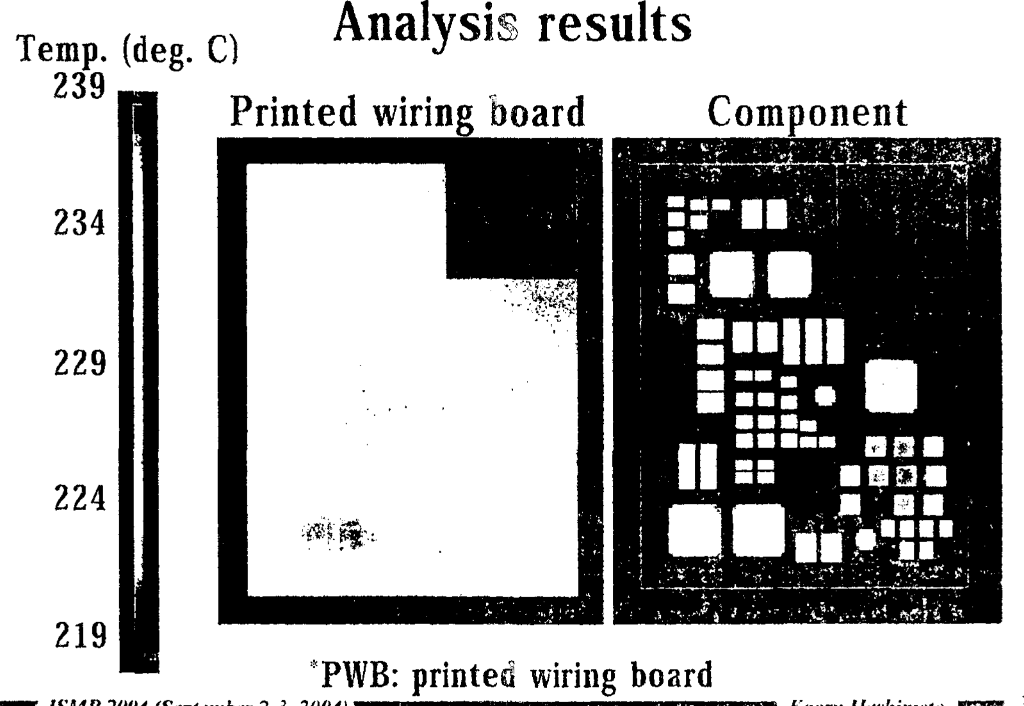
Model board for examination



TQFP: thin quad flat package
SOJ: small outline J-leaded package
SOP: small outline package
QFP: quad flat package
PLCC: plastic leaded chip carrier

*PWB: printed wiring board

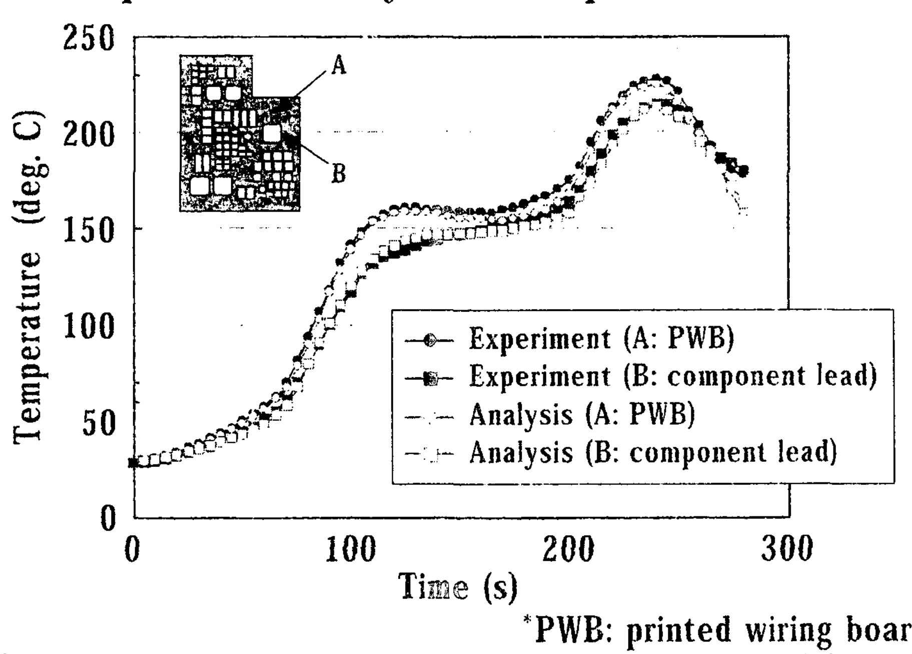
Temperature Distribution on PWB*



*PWB: printed wiring board

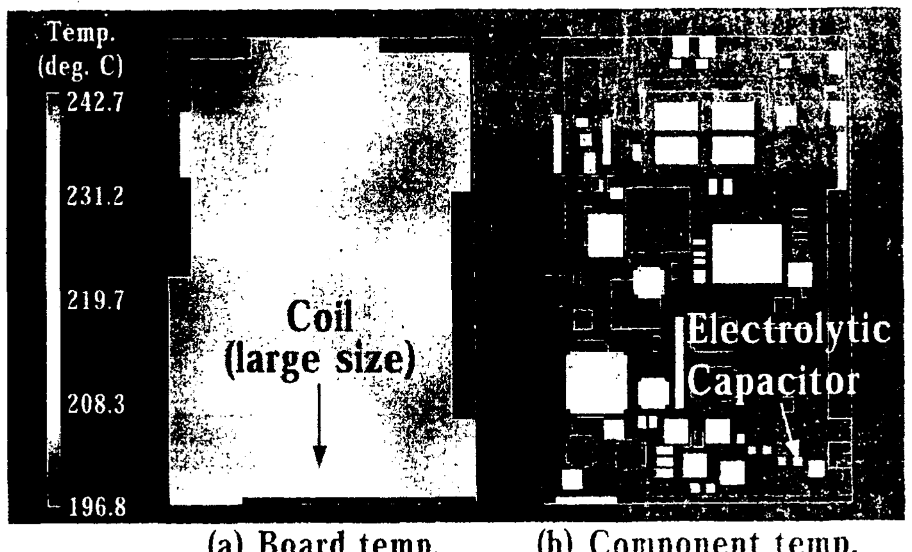
Temperature Profile on PWB*

- Comparison of analysis and experimental results



*PWB: printed wiring board

Confirmation of Critical Component

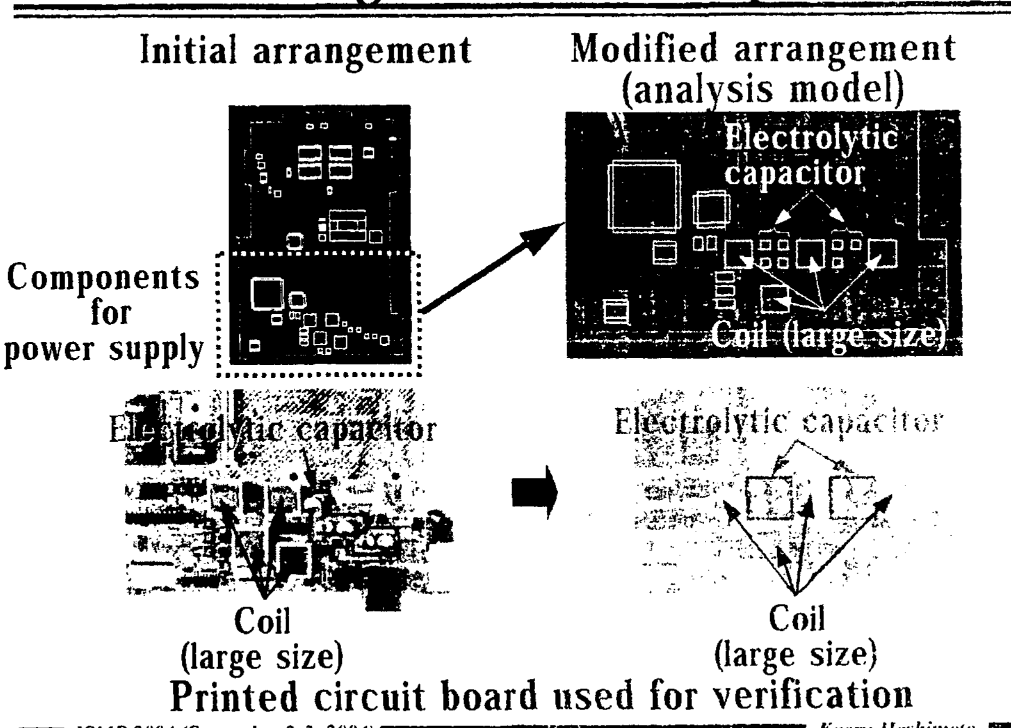


(a) Board temp. (b) Component temp.

Min. temp (board): coil (212 deg. C)
Max. temp (component): capacitor (231 deg. C)

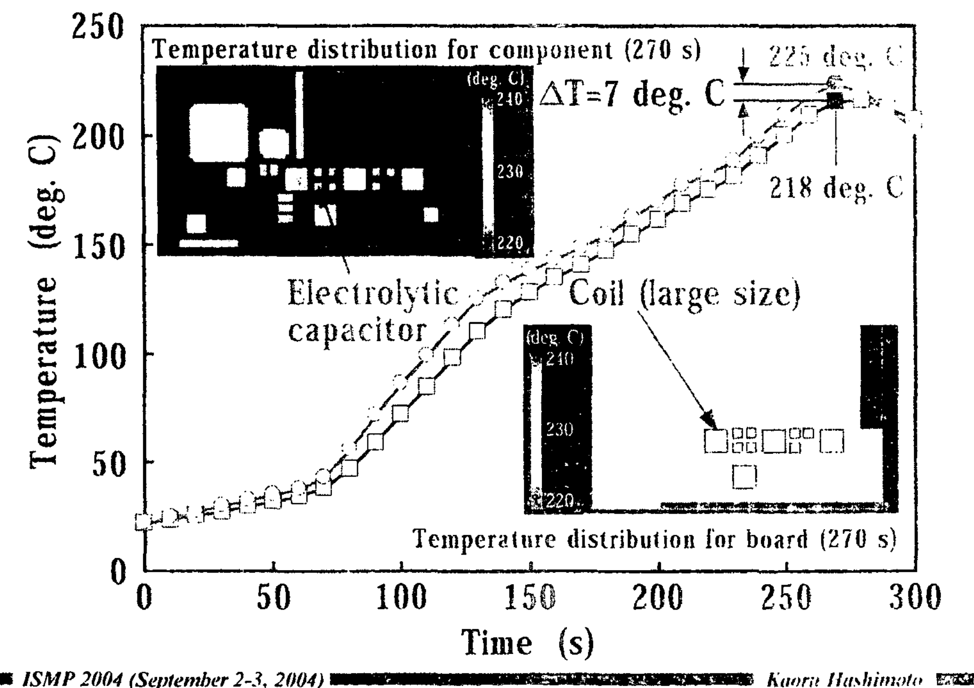
➡ ΔT=19℃

Rearrangement of Component



Printed circuit board used for verification

Temperature Distribution after Rearrangement



Decrease in Temperature Difference

Effect of component rearrangement (layout change)

		Min. Temp. (deg. C) Coil (large size)	Max. temp. (deg. C) Electrolytic capacitor	ΔT (deg. C)
Before layout change	Analysis	212	231	19
	Experiment	212	230	18
	Difference	0	+1	-
After layout change	Analysis	218	225	7
	Experiment	216	226	10
	Difference	+2	-1	-

Thermal Analysis in Reflow Soldering

1. Thermal analysis plays an important role to realize uniform heating of electronic components on printed wiring board and to establish optimum temperature profile during reflow soldering.

2. Thermal analysis allows us to design suitable component arrangement without assembling.
   This leads to shorter turn-arround-time.

3. Thermal analysis is a valuable tool for establishing high-quality and high-reliability printed circuit board assembly, especially in the assembly when using Pb-free solders.