Lead-free packaging for semiconductor devices

E4 presentation
Infineon Technologies / ST Microelectronics / Philips Semiconductors / Freescale Semiconductor

24 March 2005

Content

1 Aim of this document
2 Legislation
3 Target / Status
4 Standardisation
5 Moisture Sensitivity Level (MSL) statements
6 Technology
7 Compatibility = Processability, Solderability, Reliability
8 Conversion Roadmap
9 Conclusion

Appendix: whisker

Aim of document

Information exchange

- Inform about ST / Philips SC / IFX / Freescale (E4) activities on lead-free packaging
- Collect feedback regarding preferred approach and roadmap

Legislation

Effect of EU Directive

- On 13th of February 2003, directive 2002/95/EC of the European Parliament and of the Council of 27th January 2003 on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS) entered into force. The directive will be applicable throughout EU by 1st July 2006 for the ban on the use of certain substances including lead (Pb)
- Considering that semiconductor devices as well as finished electronics can be stored before usage or selling, conversion to lead-free should take place with suitable advance on the 1st July 2006 deadline

RoHS compliance, green package

- The E4 classifies a product as "green" when it is compliant to RoHS: free*
  from the substances Pb, Hg, Cd, Cr6+,PBB and PBDE

  * Max. concentration limits to be respected.

- The actual packages do NOT contain Hg,Cd,Cr6+,PBB and PBDE! Therefore the elimination of Pb will result in the package classification "green".

  It may be remarked that the presence of exempted Pb does not affect the classification "green" (e.g. Pb based die-attach alloys).

- Part of the packages is halogen free. The industrial availability of this type of materials is still limited and full implementation might take some years.

Target / Status

Pb-free Programs in the Industry

Two Targets:

- Compatibility with both SnPb and Pb-free board soldering (with extended temperature range)
- Elimination of Pb in package terminals (leads, balls, bumps)

Status

- Main Japanese consumer market converted to lead-free soldering
- Major conversion to lead free components by 1H05

Standardisation

IPC/JEDEC J-STD-020C

- IPC/JEDEC published an updated spec per July 2004 : J-Std-020C
- Main changes compared to J-Std-020B :
  - 9 categories (3x thickness, 3x volume) in stead of 4 today :

Package Thickness	Volume < 350 mm^3	Volume 350 - 2000 mm^3	Volume > 2000 mm^3
<1.6 mm	260	260	260
1.6 mm - 2.5 mm	260	250	245
> 2.5 mm	250	245	245

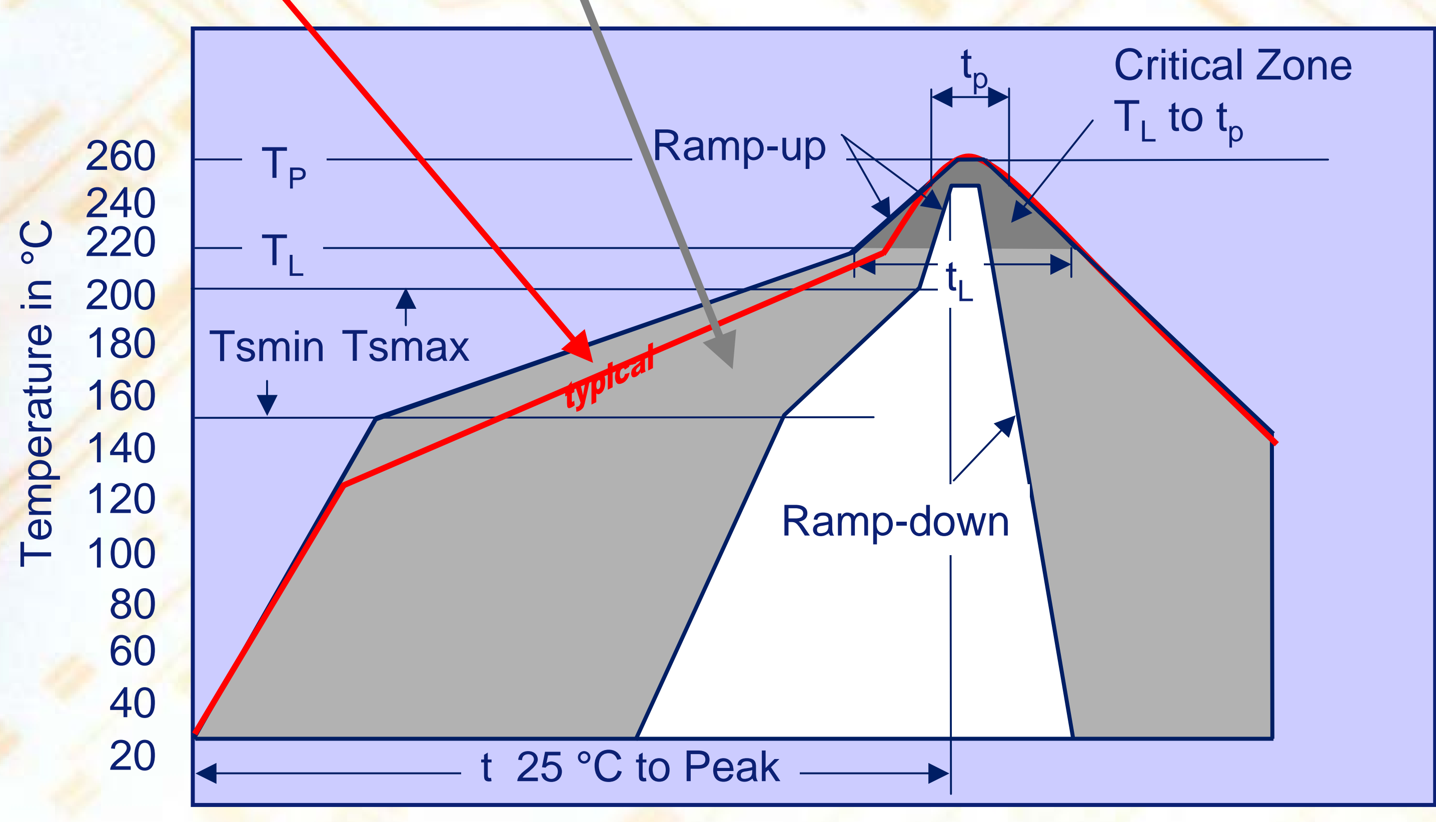
  - 245°C, 250°C and 260°C as specified package peak temperatures.

- The E4 comply to the new conditions with following notes :
  - The more tough conditions will impact the MSL for a substantial part of the products; restore of the MSL will need engineering time and effort and will also depend on the availability of new materials.

Standardisation

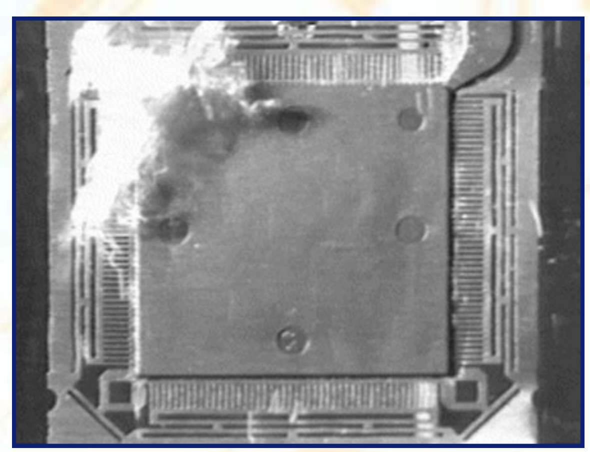
E4-profile vs. J-STD 020C - designed for lead-free MSL evaluation

e.g. @ 260°C for small packages



MSL statements

Lower MSL as temporary action, qualification of new materials (ongoing) as short/mid term action



Source Infineon

- Hundreds of packages in the 4 companies have been tested according to the agreed profiles, following JEDEC STD-020C for the pre-conditioning process and for failure criteria.
- With present materials and package design, in specific cases a degradation of MSL classification may be observed

Technology

Consolidated lead free solutions:

For lead frame based packages
- Post plate of matte tin
- Pre plate of NiPdAu

For Ball Grid Array packages
- SnAgCu

Note: technology may differ per package family / company

Technology

Postplate of matte tin (Sn)

Main characteristics

- Material availability is good
- Closest to SnPb in cost and process
- Good solderability with SnPb and Pb free solders
- Good solder joint reliability
- Good compatibility with SnPb Solder
- “Whisker free” process available [1)]

[1)] See whisker presentation

Technology

Preplate NiPdAu*

Main characteristics

- Good solderability with SnPb and Pb free solders
- Good solder joint reliability
- Used in high volume
- Offered by major lead frame suppliers

* NiPdAu lead finish is a selective alternative for some packages.

Technology

SnAgCu Spheres in Ball Grid Array

Main characteristics

- SnAg3.0-4.0Cu0.5-1.0 is the most applied range
- Good solderability with Pb free solders
- Offered by all major suppliers
- Limited backward compatibility with SnPb solders (board application process to be adopted)

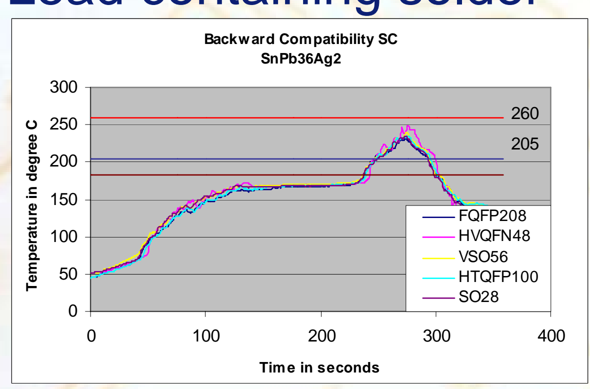
Lead-Frame packages Compatibility

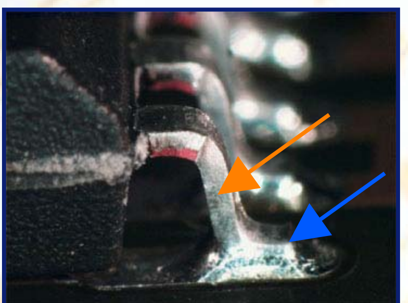
supplier (component finish) \ customer	Pb – solder (215-240C)	~~Pb~~ – solder (235-260C)
Pb	Today Experience of some decades of board assembly	Increase temp. by 20°C → Processability: o.k. Solderability: o.k. Reliability: o.k. (NCMS-, IDEALS-report,internal evaluations)
~~Pb~~	Processability: o.k. Solderability: o.k. Reliability: o.k.	Processability: o.k. Solderability: o.k. Reliability: o.k.

Lead-Frame Packages Processability

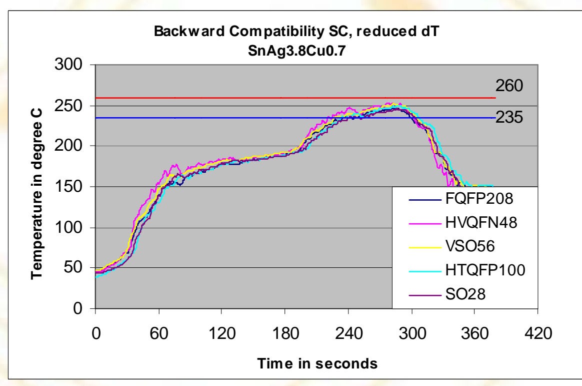
Reflow solder joints

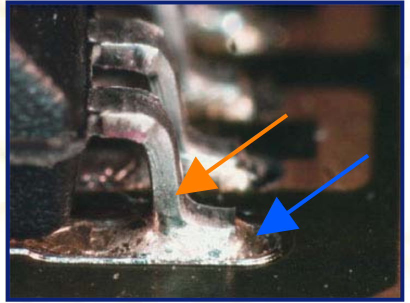
Lead containing solder





Lead-free solder





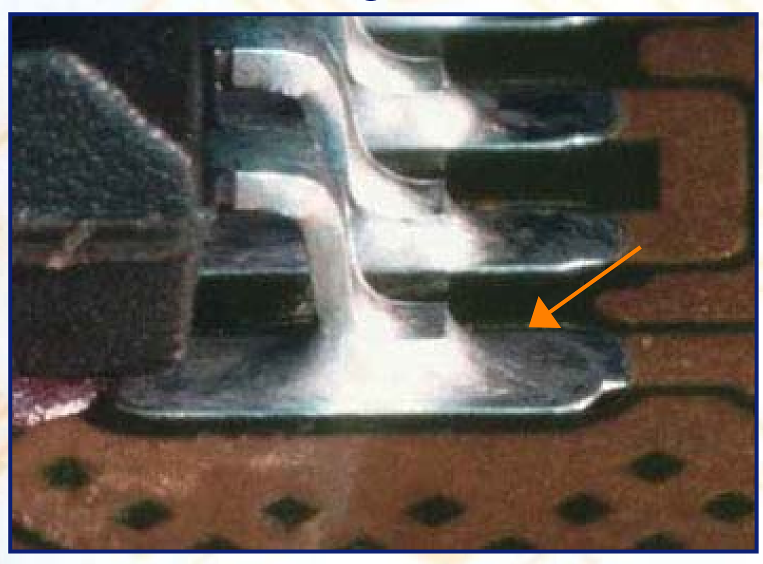
Source Philips

Only slight differences of wetting (←) , fillet (←)
Surface: less shiny for lead-free (see inserts)

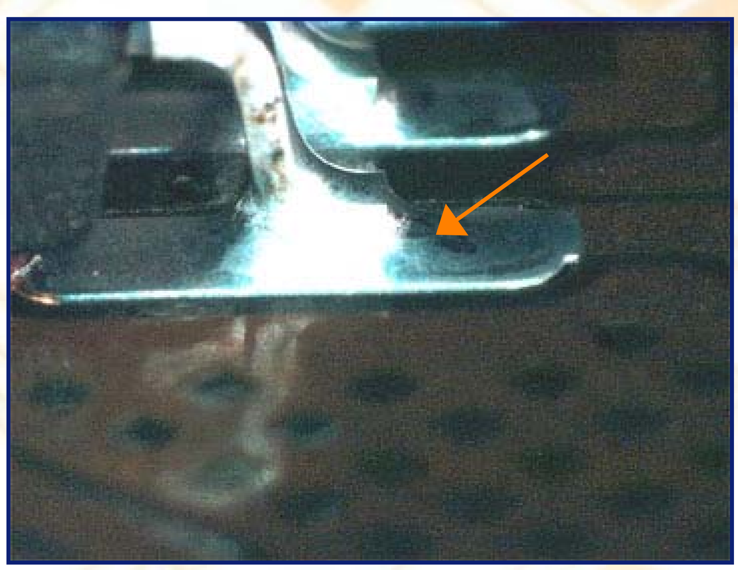
Lead-Frame Packages Processability

Wave solder joints

Lead containing solder



Lead-free solder



Process	Process speed [m/min]	Total soldering time/temp	Pre-heat temperature
Leaded	1.25	2.75±0.25s / 250°C	120±10°C
Lead-free	1.2	3.75±0.25s / 265°C	120±10°C

Only difference:
somewhat less shiny with lead-free

Source Philips

Lead-Frame Packages Processability

Processability in lead containing vs. lead-free process

- For reflow soldering: paste application, component placement do not require special measures
- For wave soldering: glue application, component placement, glue cure do not require special measures
- Differences in soldering process are time and temperature
- SnPb plating and Sn plating do not show a different behavior in the soldering processes (more than a decade of experience!)

Lead-Frame Packages Solderability

SO 8

Wetting force mN/mm

No forced ageing

0.10mN/mm

3s.

Ageing : 16H150°C

0.10mN/mm

3s.

Ageing : 8H Steam

0.10mN/mm

3s.

Immersion 10seconds

Good solderability of Sn coated components in SnPb

Wetting balance test
- 235°C
- Zero cross time << 3 seconds
- Wetting force >> 0.10mN/mm

Source ST Microelectronics

Lead-Frame Package Reliability

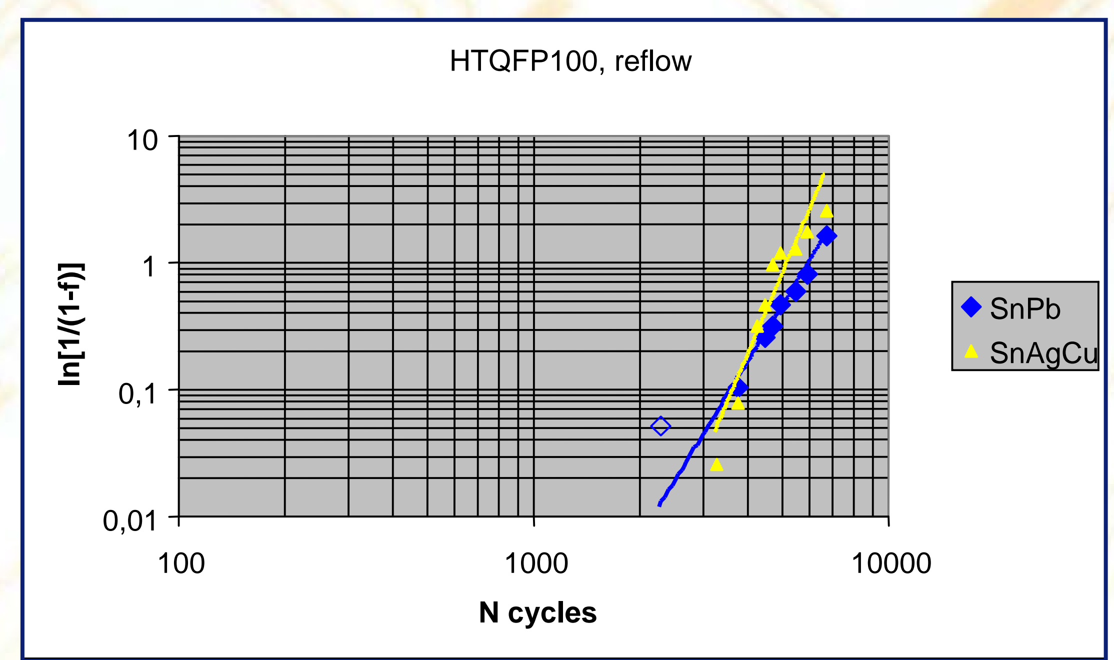
Temperature Cycling as reliability test for solder joint

- Temperature cycling causes thermo-mechanical solder fatigue
- Degradation/failure goes along the following path:
  - Diffusion and re-crystallization
  - Crack initiation and growth
  - Failure by macroscopic solder fracture
- Solder fatigue failure is visualized and analyzed according Weibull statistics

Equal or better solder joint reliability performance is documented in following slides.

Lead-Frame Package Reliability

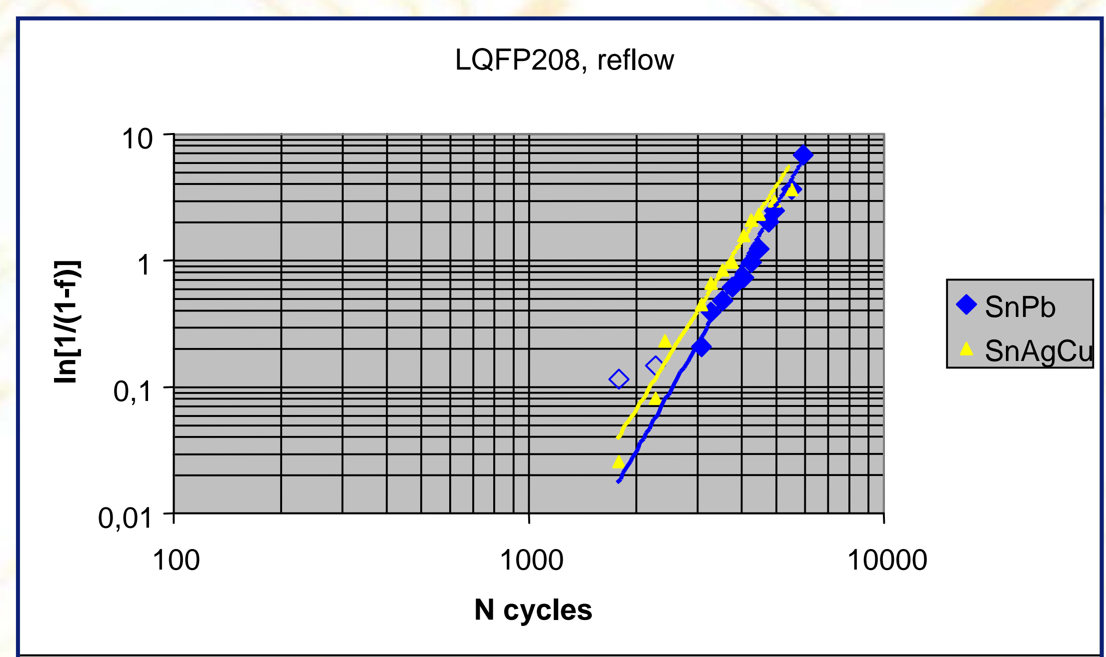
Weibull analysis of failure in temperature cycle test (-40/+125 ^{o}C) Pb-free and Pb-containing reflow solder Sn plated HTQFP100 components (Cu-based lead-frame)



Source Philips

Lead-Frame packages Reliability

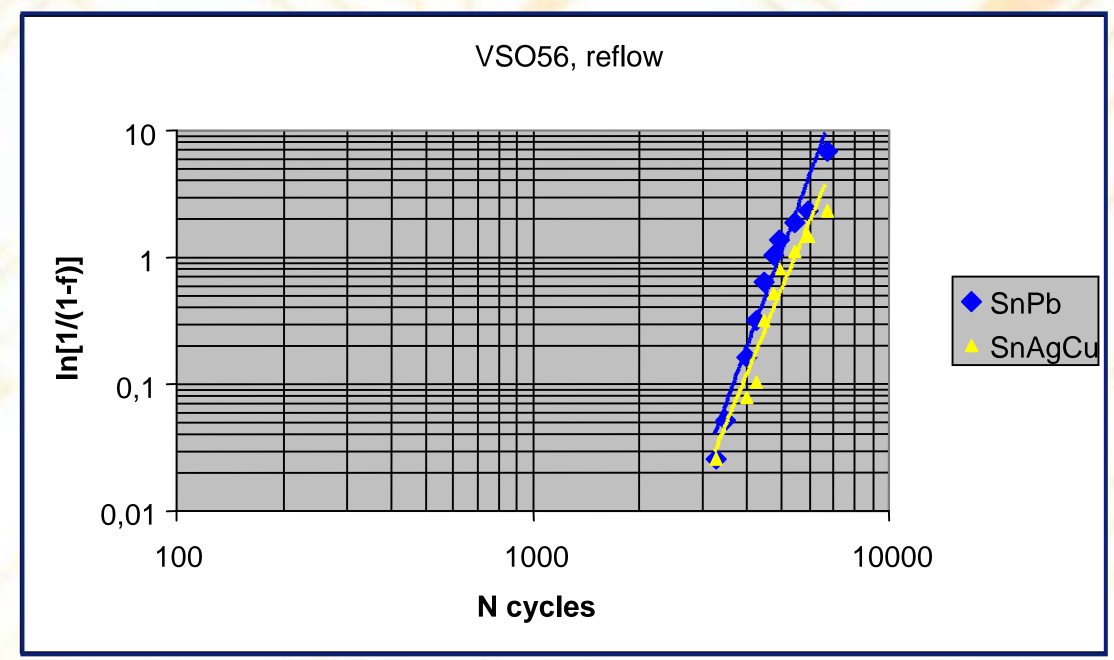
Weibull analysis of failure in temperature cycle test (-40/+125 ^{o}C) Pb-free and Pb-containing reflow solder Sn plated LQFP208 components (Cu-based leadframe)



Source Philips

Lead-Frame packages Reliability

Weibull analysis of failure in temperature cycle test (-40/125 ^{o}C) Pb-free and Pb-containing reflow solder Sn plated VSO56 (FeNi42-leadframe)



Source Philips

Lead-frame packages Reliability

132 PQFP Board-Level Air-Air Temperature Cycling

-50°C/150°C

% Packages Failed

90
80
70
60
50
40
30
20
10
5
2
1

W/rr

1000 10000 100000

Number of Temperature Cycles

Both combinations, Sn finish with SnPb solder and Sn finish with SnAgCu solder, perform equal to or better than SnPb finish with SnPb solder.

Board assembly with SnPb solder paste was performed at the standard SnPb profile.

Eta	Beta	r^2	n/s
7992	10.38	0.86	23/3
7742	8.439	0.87	30/5
9860	12.93	0.949	30/21
8712	7.162	0.976	30/8

Finish-Solder

- ▽ SnPb-SnPb1
- △ Sn-SnPb2
- ◇ SnPb-SnAgCu3
- □ Sn-SnAgCu4

1) Current, 220°C reflow
2) Backwards compatible, 220°C reflow
3) Forwards compatible, 240°C reflow
4) Pb-free, 240°C reflow

Source Freescale

Lead-Frame Packages Reliability

64LQFP Board-Level Air-Air Temperature Cycling

Weibull analysis of failure in temperature cycle test (-40/+125C) comparing Pb-free and Pb-containing reflow solder

% Packages Failed

90
80
70
60
50
40
30
20
10
5
2
1

W/rr

Both combinations, Sn finish with SnPb solder and Sn finish with SnAgCu solder, perform equal to or better than SnPb finish with SnPb solder.

Board assembly with SnPb solder paste was performed at the standard SnPb profile.

Sn-SnAgCu4 has no fails as of 13407 cycles, dashed line represents worse case estimation.

Eta	Beta	r^2	n/s
13610	9.355	0.979	32/15
14170	6.992	0.925	31/14
17086	8.022	0.753	32/29
20743	8		

1000 10000 100000

Number of Temperature Cycles

Finish-Solder

SnPb-SnPb[1]
Sn-SnPb[2]
SnPb-SnAgCu[3]
Sn-SnAgCu[4]

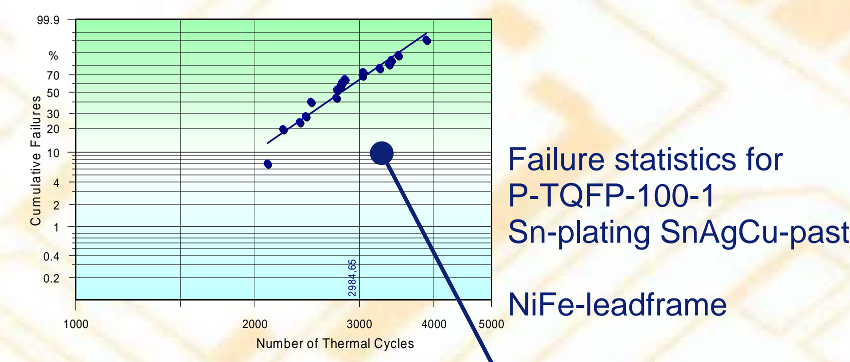
1) Current, 220°C reflow
2) Backwards compatible, 220°C reflow
3) Forwards compatible, 240°C reflow
4) Pb-free, 240°C reflow

Source Freescale

Lead-Frame packages Reliability

Reliability result for solder joint reliability with Pb-free components metallization by the 'Fraunhofer Institute' (-40C/125C)

P-TQFP-100-1 on Au/Ni (SnAg3.8Cu0.7-after 4000 Cycles)



Failure statistics for P-TQFP-100-1 Sn-plating SnAgCu-paste on AuNi

NiFe-leadframe

	SnPb36Ag2				SnAg3.8Cu0.7			
	Cu/OSP		Au/Ni		Cu/OSP		Au/Ni	
	Cumulated Failures (4000 Cycles)	Characteristic Lifetime (cycles)	Cumulated Failures (4000 Cycles)	Characteristic Lifetime (cycles)	Cumulated Failures (4000 Cycles)	Characteristic Lifetime (cycles)	Cumulated Failures (4000 Cycles)	Characteristic Lifetime (cycles)
P-DSO-12-2	(11)	n.e.	(10)	n.e.	(6)	n.e.	(2)	n.e.
P-VQFN-48-4	8	5233	12	4134	17	3704	17	3891
P-TQFP-100-1	24	2281	24	2480	24	2208	24	2985
P-TQFP-100-5	0	n.e.	2	n.e.	0	n.e.	0	n.e.

(x) = package internal contact failure

Source: Infineon - IZM report UB.412.DL.2003.01

MINIMUM REQUIREMENTS for Product Qualification Matte tin (Sn), Whisker related tests

Test	Condition	Duration	Criterion
1. High temp. / high humidity	55-60°C / 85% rel. Hum. 2*	1000h	max. 50µm whisker 1*
2. Temperature cycle	-40°C / +85°C	1000TC	max. 50µm whisker
3. Ambient	Uncontrolled ambient	8 weeks	max. 20µm whisker

Positive results on above test will lead to a release of the Sn-plating technology regarding whisker issue.

The E4 Product Qualification criteria were established to meet the specifications of a majority of customers requiring Pb-free product shipments today. They will be used until relevant Standard is released. Members actively contribute to the ongoing definition of these Standards by performing extended tests beyond the targets indicated above.

1* whisker length is measured by adding sub-sections. Density or distribution are not relevant.
2* if corrosion occurs test is to be repeated

BGA Package Compatibility

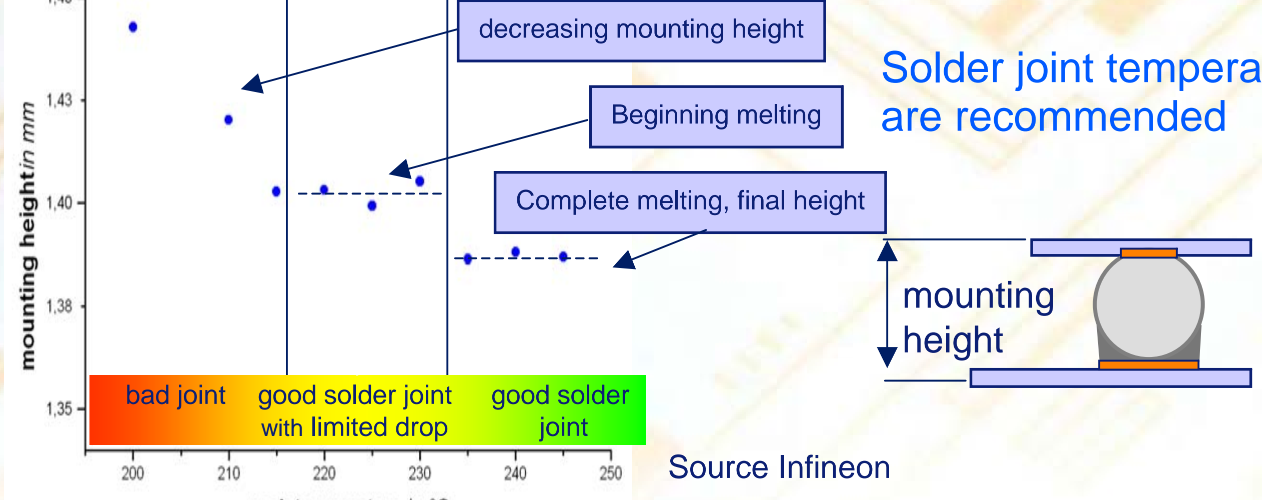
supplier \ customer (component finish)	Pb – solder (215-240C)	~~Pb~~ – solder (235-260C)
Pb	Today Experience of some decades of board assembly	Increase temp. by 20°C → Processability: o.k. Reliability: o.k. ✓
~~Pb~~	Processabilty below 230°C critical Reliability: o.k. (improved to SnPb) Solder joint formation for low temperatures critical ✓	Processability: o.k. Reliability: o.k. ✓

BGA Processability

Motivation:
For array-package the processability has been tested. Different temperature at the ball result in different mounting height.

Conclusion:
The combination Pb-free BGA/SnPb-paste can be processed with a minimum temperature of 230°C (at the ball).
Due to limited self-alignment, a solder joint temperature at 220°C should only be chosen in exceptional cases

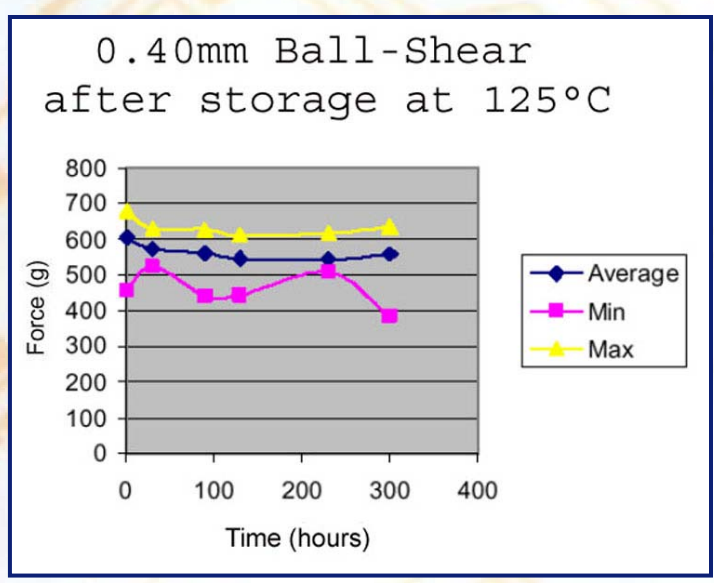
Solder joint temperatures over 230°C are recommended

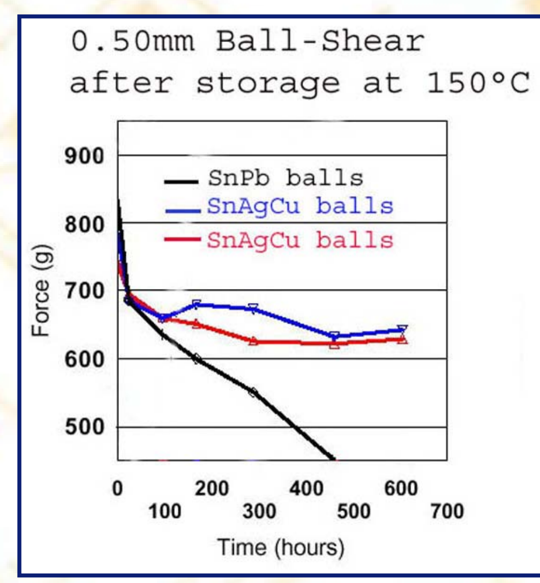


Source Infineon

BGA On Board Reliability

Pb-free solder balls shear test





Source ST Microelectronics

Pb-free solder balls are showing same initial shear strength than SnPb balls but shear values remains more stable during ageing

388 PBGA, Board-Level
Air-to-Air Thermal Cycling, -40 to +125°C

388 PBGA Solder-Joint Reliability
Varied Constructions and Solder Alloys

% Packages Failed

W/rr

	Material/Ball/Paste
△ SnPb	Current/SnPbAg/SnPb
▽ Std.	Current/SnAgCu/SnAgCu
□ Green	Halide-Free/SnAgCu/SnAgCu

Eta	Beta	r^2	n/s
6264	17.91	0.953	30/6
8266	14.13	0.942	30/7
9491	11.88	0.943	32/5

Number of Temperature Cycles (-40/125C)

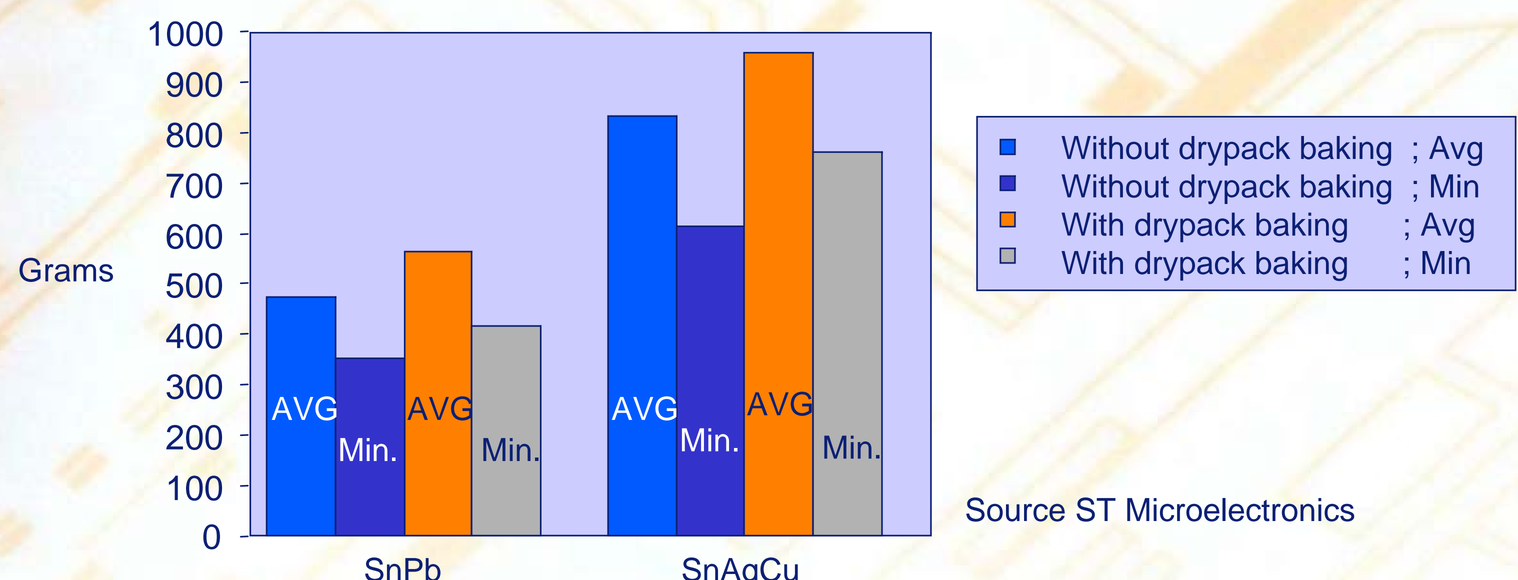
Courtesy Thomas Koschmieder

Source Freescale

BGA Reliability

Lead Free solder balls pull Test

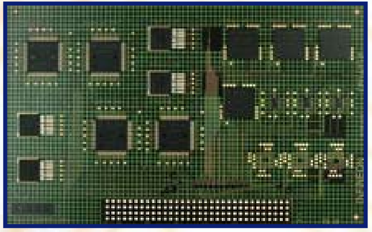
0.40mm solder ball; Pull Test on 0.35mm pad diameter (Ni/Au)



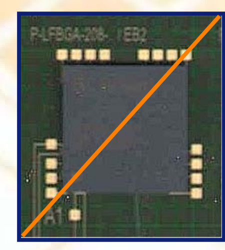
Source ST Microelectronics

Stable Pull strength after ageing. Higher strength for lead-free balls

BGA On board Reliability



LFBGA-208, Ball SnAgCu, solder SnPbAg
-40°C/+125°C, 2000 cycles
Results positive

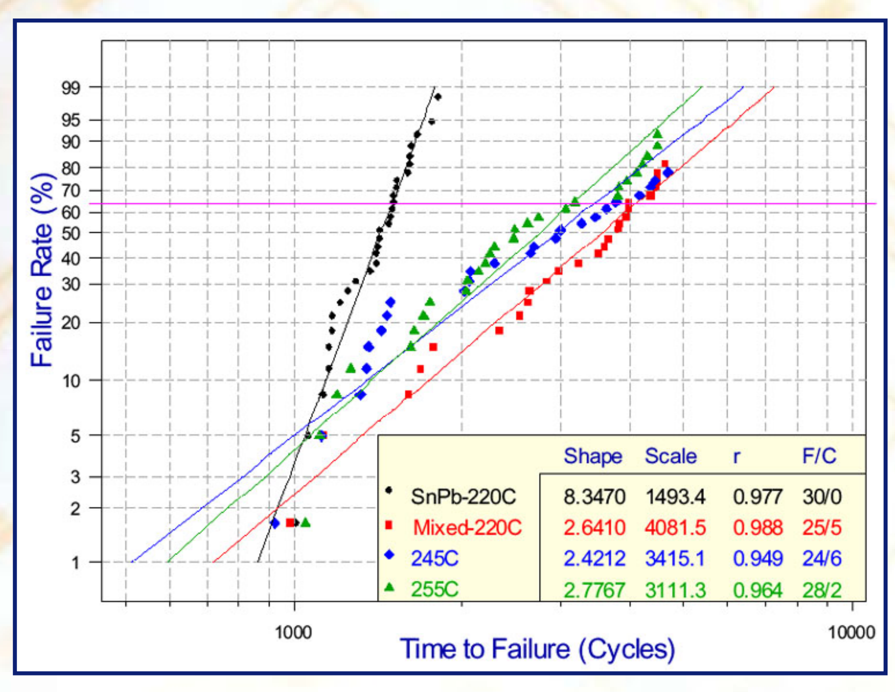


Source Infineon

Further reference: for large BGA's (35x35mm) positive results shown by:
"Thermal Fatigue Resistance of Pb-free Second Level Interconnect"; Patrick Roubaud; SMTA 2001

BGA On board Reliability

Weibull analysis of failure in temperature cycle test lead-free and lead-containing reflow solder TFBGA6x6-46 with 0.4mm solder balls (both SnPb-SnAgCu)



4 tested processes

SnPb balls + SnPb paste (220C)
SnAgCu balls + SnPb paste (220C)
SnAgCu balls +SnAgCu paste (245C)
SnAgCu balls +SnAgCu paste (250C)

-40°C/+125°C cycles

Source ST Microelectronics

Compatibility

Conclusion for compatibility

Leadframe-package

- Processability: Sn plated products show identical behaviour as SnPb plated products
- Solderability: Sn- and NiPdAu surfaces are solderable with SnPb and Pb-free solder paste
- Solder joint reliability tested at >> 2000 TC does show no failure

BGA-package

- Processability: good processabilty for temperature over 230°C
- Solder joint reliability is improved compared to SnPb-balls

Roadmap

General Conversion Roadmap (BGA excluded)

	ST	Philips	IFX	Freescale[1]
IC Commodities	Q2 05	Q2 05	Q2 05	Q2 05
IC ASICS	Q2 05	Q2 05	Q2 05	Q2 05
Discrete	Q1 05	Done	Done	N/A
Memories	Q2 05	N/A	Q2 05	N/A
Products for Automotive	05 ?	05 ?	05 ?	Q3 05

The dates indicate the completion of the volume conversion to lead free

1 FSL's dates indicate completion of final volume package qualification by end of period; individual products may be available now.

Roadmap

IC Package Conversion Roadmap

	ST	Philips	IFX	Freescale[1]
L/T/F BGA	Q2 05	Q3 05	Q2 05	Q1 05
M/L/T/QFP	Q1 05	done	Q2 05	Q3 05
QFN	done	done	done	Q2 05
SO	Q1 05	Q2 05	Q4 05	done
TSSOP	Q2 05	Q2 05	done	Q1 05
SSOP	Q1 05	Q2 05	=	Q1 05
PLCC	Q2 05	done	Q2 05	Q2 05

The dates indicate the completion of the volume conversion to lead free

1 FSL's dates indicate completion of final volume package qualification by end of period; individual products may be available now.

Conclusion

Leadframe packages

- Sn-plating or NiPdAu-plating is introduced as lead-free technologies
- For leadframe packages there is a full compatibility to SnPb- and Pb-free solder process

BGA packages

- For BGA packages SnAgCu is the chosen metallurgy
- On board reliability is proven
- In the case of BGA-packages the soldering temperature must be above 230°C for processability

Note: technology may differ per package family / company

Thank you