IPC Midwest 2011

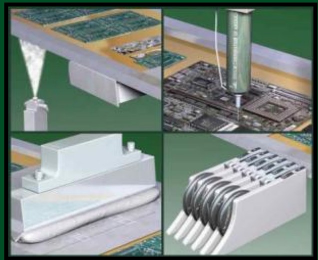
Low Silver Solder Alloys with Good Drop Shock and Thermal Cycle Reliability

Ronald Lasky, Ph.D., P.E.

Indium Corporation

Executive Summary

SAC105 was shown to have better drop shock reliability than SAC305; however SAC105 thermal cycle performance was not necessarily as good at SAC305. Small quantities (0.1% or so) of some elements appear to improve both drop shock and thermal cycle reliability of SAC105. This paper will be an overview of work performed to demonstrate this phenomenon.



Low Silver Alloys:
A Review of TC and DS Reliability

Ronald C. Lasky, PhD, PE
Indium Corporation
rlasky@indium.com

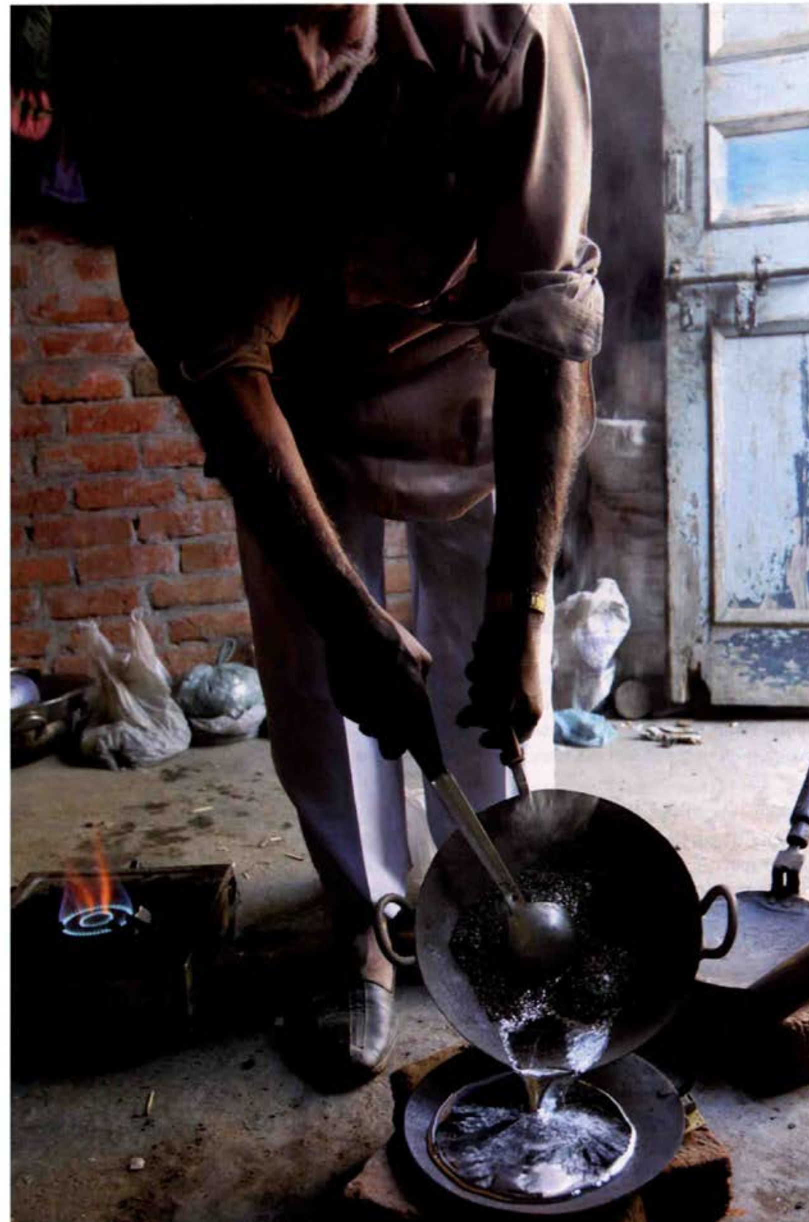
INDIUM CORPORATION®

RoHS: True of False

1. You are safer because of RoHS

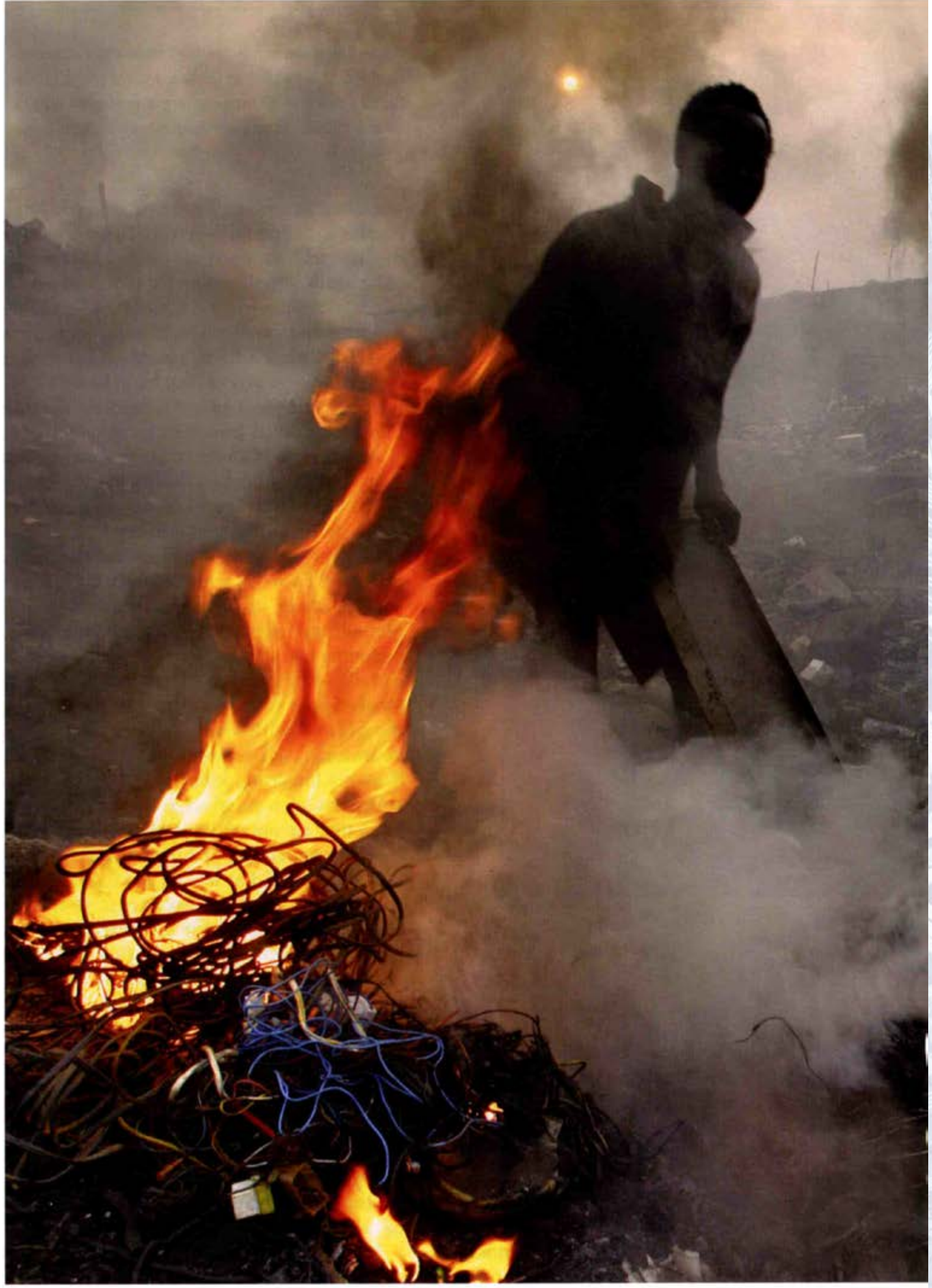
False

- But they are!



TOXIC MELT In a poor suburb of New Delhi, India, where informal e-waste processing is a common household business, a man pours molten lead smelted from circuit boards. His family uses the same pots for cooking–a potentially deadly practice.

Burning Insulation
From Wires

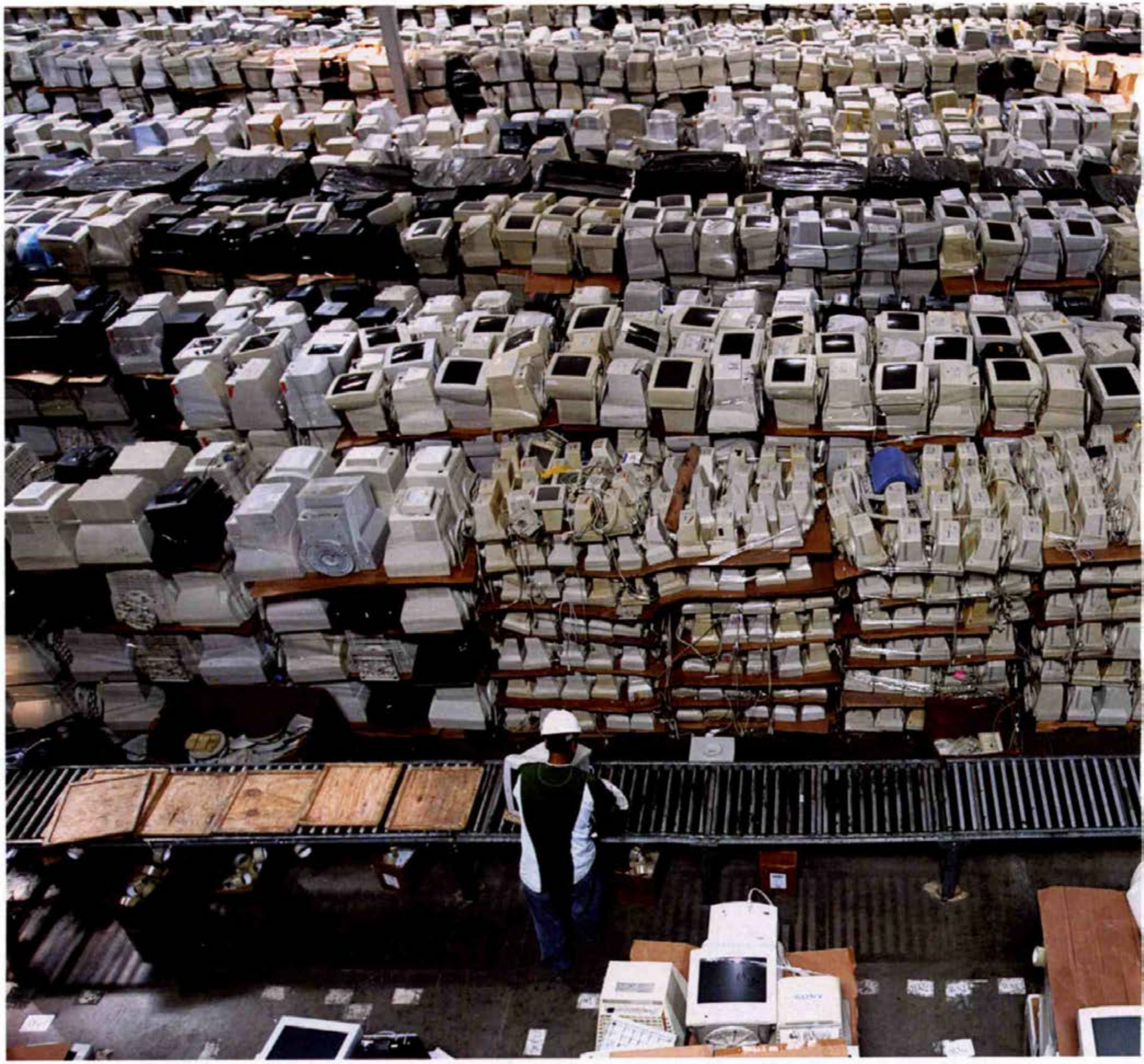


68 NATIONAL GEOGRAPHIC • JANUARY 2008

RoHS was established to…

- The purpose of this Directive is to approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health **<u>and the environmentally sound recovery</u>** and disposal of waste electrical and electronic equipment

Hopefully done like this!

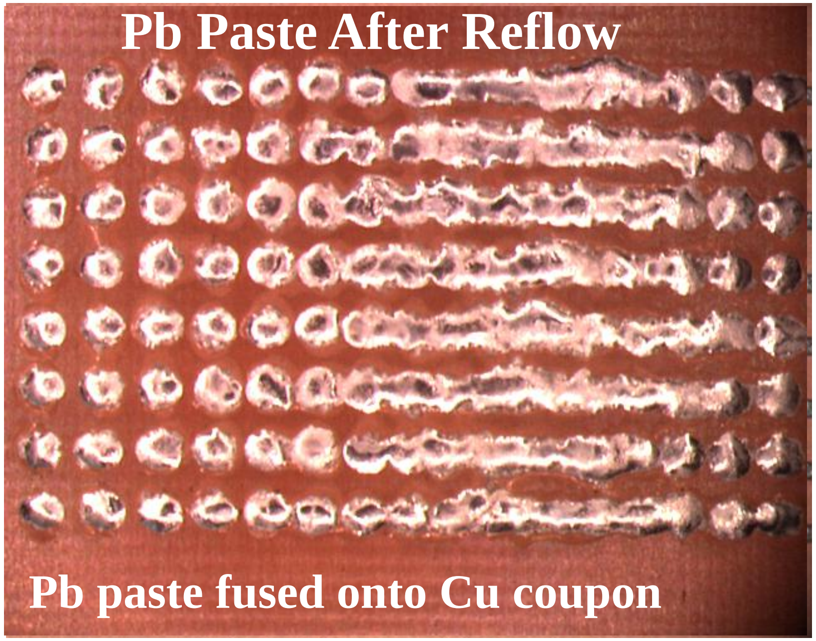


REUSE Workers strip picture tubes from thousands of used computer monitors piled at Monitex, a Grand Prairie, Texas, recycler. Tubes that work will be exported to a factory in Thailand, where they'll be used in low-cost TVs. Broken ones are recycled domestically.

True or False #2

- Lead-Free has no process or performance benefits.

False: LF: The Good News: Coalescent Performance Comparison



Lead-Free Reliability Thought

- “Everyone knows there is no data on LF reliability right?”
- Wrong
  - >$3,000 B of products made, some since 2001
    - No major reliability issues
  - >$100M of R&D
- Long term (>5 years) data still sketchy

Acknowledgments

- This overview relies on the work of:
  - **Greg Henshall, etal**
    - *Low Silver BGA Sphere Metallurgy Project,*

    SMTAI 2010, Orlando, FL
  - **Richard Coyle, etal**
    - *The Effect of Silver Content on the Solder Joint Reliability of a Pb-free PBGA Package,* SMTAI 2010, Orlando, FL
  - **Ning-Cheng Lee, etal**
    - *ACHIEVING HIGH RELIABILITY LOW COST LEAD-FREE SAC SOLDERJOINTS VIA MN OR CE DOPING,* ECTC 2009
    - And Older Work

A Brief History of SAC Alloys

- Circa 1999: Near Eutectic SAC387 is initial LF Alloy of Choice
  - Eutectic is alloy of choice as it is replacing eutectic SnPb
  - 100s millions of mobile phones assembled with this alloy to date
- SAC305 becomes IPC's SVPC Alloy of Choice Circa 2006
  - Exhibits less tombstoning than SAC387
  - Uses less silver
- SAC105 has wide acceptance in 2007-2008 to now
  - Less silver
  - Performs better in drop shock than SAC305, but worse in Thermal Cycle (TC)
  - Disadvantage: Tm is 225C vs. SAC305 217C
- Is there an alloy that is better in both drop shock and TC?

Older Work: NEMI Test Plan

Component	Source	Description	Reliability Testing	
			-40 to 125°C	0 to 100°C
Type 1 TSOP	AMD	48 Pin TSOP with leads on short sides, SnPb and NiPd finishes	Solectron	
2512 Resistor	Koaspeer	zero ohm chip resistor, SnPb and pure Sn finishes	Sanmina-SCI	
169 CSP	Lucent	0.8mm pitch, 11x11mm, 7.7 x 7.7 mm die, SnAgCu and SnPb balls	Kodak	Lucent
208 CSP (HDPUG)	ChipPac	0.8mm pitch, 15x15mm, 8.1 x 8.1 mm die, SnAgCu and SnPb balls	Kodak (both SnAgCu alloys)	Sanmina-SCI
256 BGA (NCMS)	Amkor	1.27mm pitch, 27x27 mm, 10.0 x 10.0 mm die, SnAgCu and SnPb balls	Celestica	Sanmina-SCI
256 CBGA	Vendor part; IBM ball attach	1.27mm pitch, no die, SnAgCu and SnPb balls		Motorola

SnAgCu balls: Sn4.0Ag0.5Cu - provided by Heraeus

Ref: Bradley; *Summary of Pb-Free Solder Reliability;* Motorola Quick Start Seminar-; Ft. Lauderdale, FL; February 2005

Summary of NEMI Results

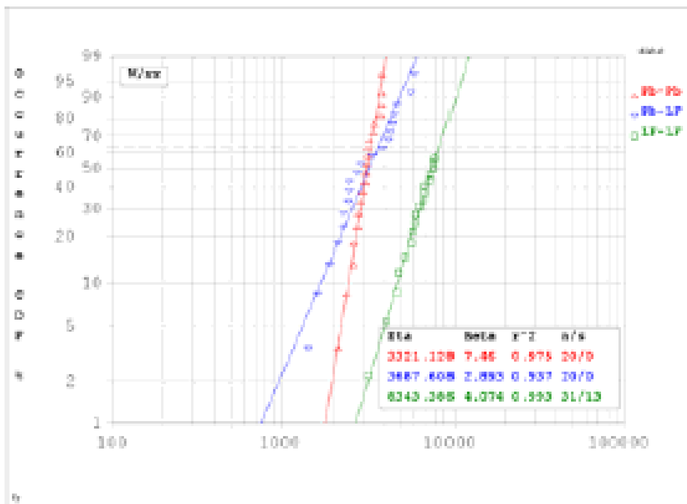
Component	Temp Cycle, °C	Lead-free vs. Sn-Pb	Mixed vs. Sn-Pb
48 TSOP	-40 to 125	0	-
2512 resistor	-40 to 125	0	0
256 CBGA	0 to 100	+	-
256 PBGA	-40 to 125	0	0
256 PBGA	0 to 100	0	0
169 CSP	-40 to 125	+	+
169 CSP	0 to 100	+	0
208 CSP	-40 to 125	+	0
208 CSP	0 to 100	+	+

\+ statistically better than Sn-Pb to 95% confidence
\- statistically worse than Sn-Pb to 95% confidence
0 statistical differences less than 95% confidence

Ref: Bradley; *Summary of Pb-Free Solder Reliability;* Motorola Quick Start Seminar-; Ft. Lauderdale, FL; February 2005

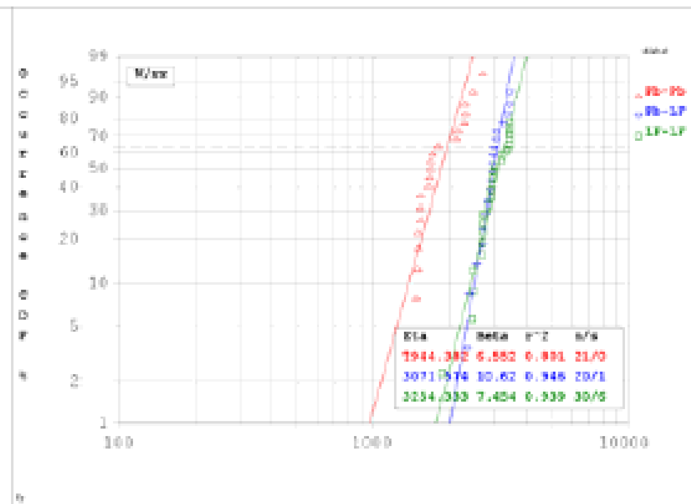
169 CSP Results

0 to100°C cycling



	Pb-Pb	Pb-LF	LF-LF
η (N63)	3321	3688	8343
β	7.5	2.9	4.1

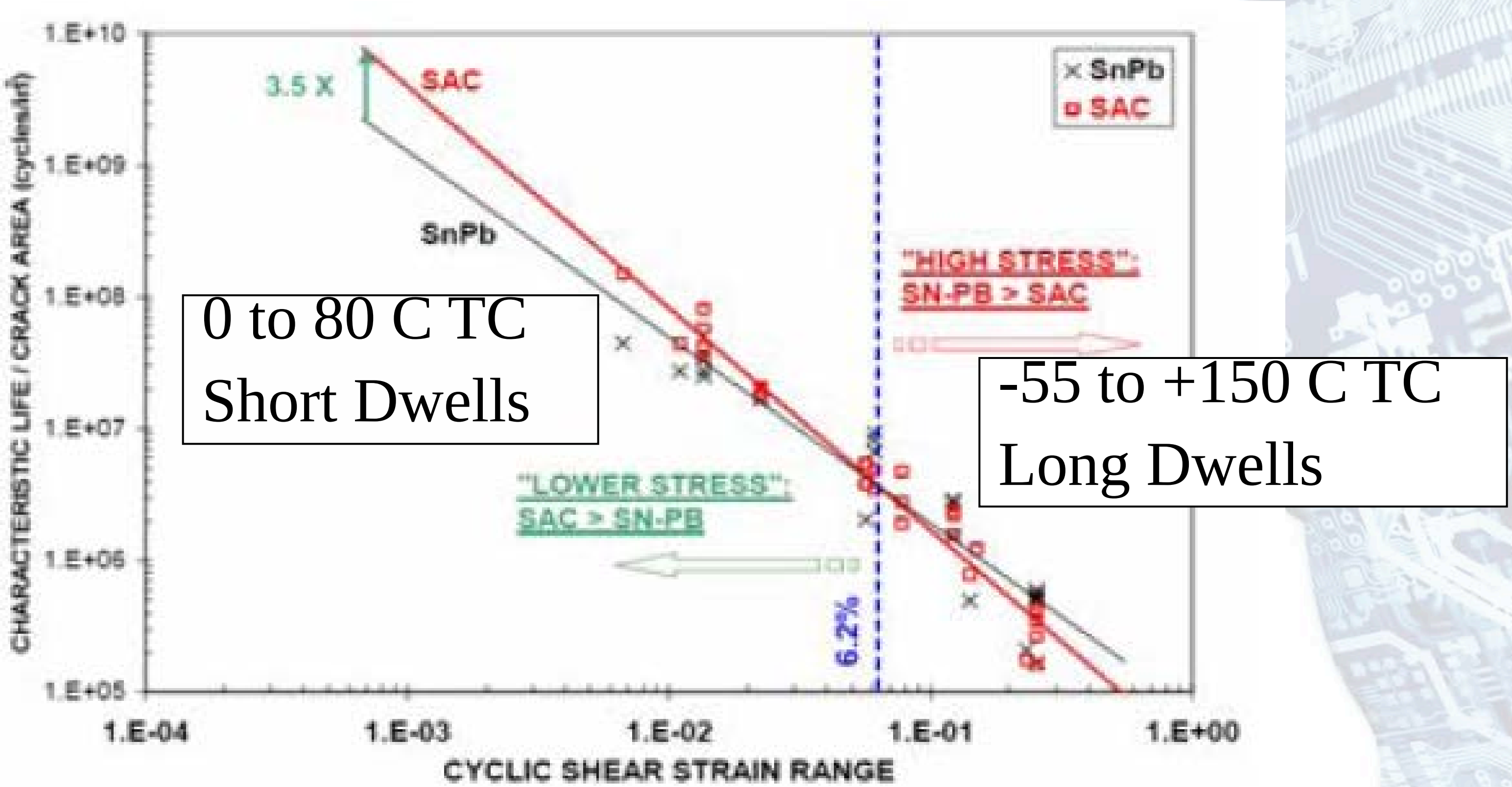
-40 to +125°C cycling



	Pb-Pb	Pb-LF	LF-LF
η (N63)	1944	3071	3254
β	6.6	10.6	7.5

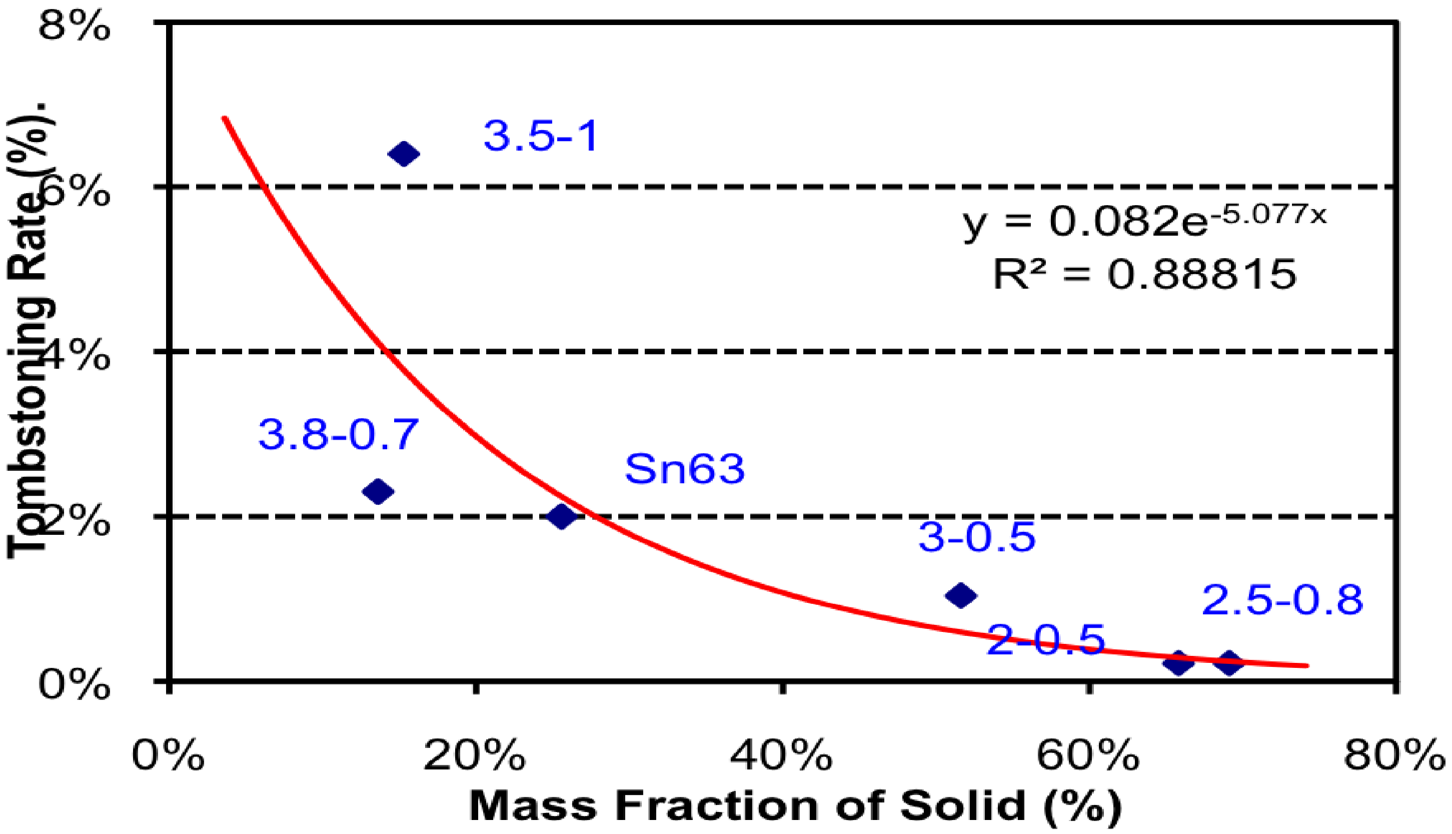
Ref: Bradley; *Summary of Pb-Free Solder Reliability;* Motorola Quick Start Seminar-; Ft. Lauderdale, FL; February 2005

High Stress vs. Low Stress Reliability

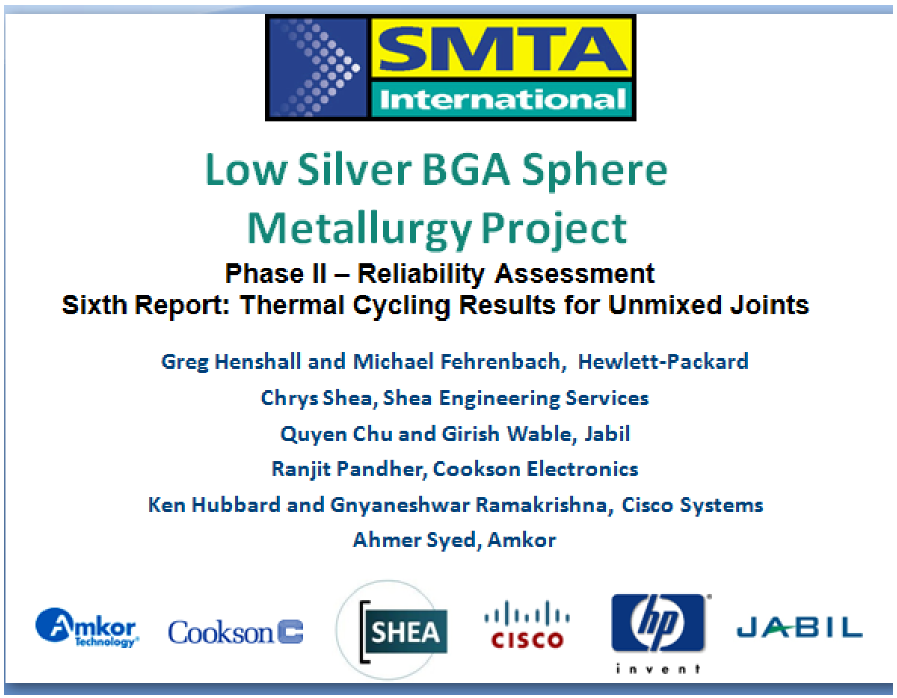


Ref: Clech, JP; *Lead-Free and Mixed Assembly Solder Joint Reliability Trends;* APEX, S28-; Anaheim, CA; Feb. 2004

SAC Tombstoning



Henshall:
Low Silver Investigation


SMTA International

Low Silver BGA Sphere Metallurgy Project

Phase II – Reliability Assessment

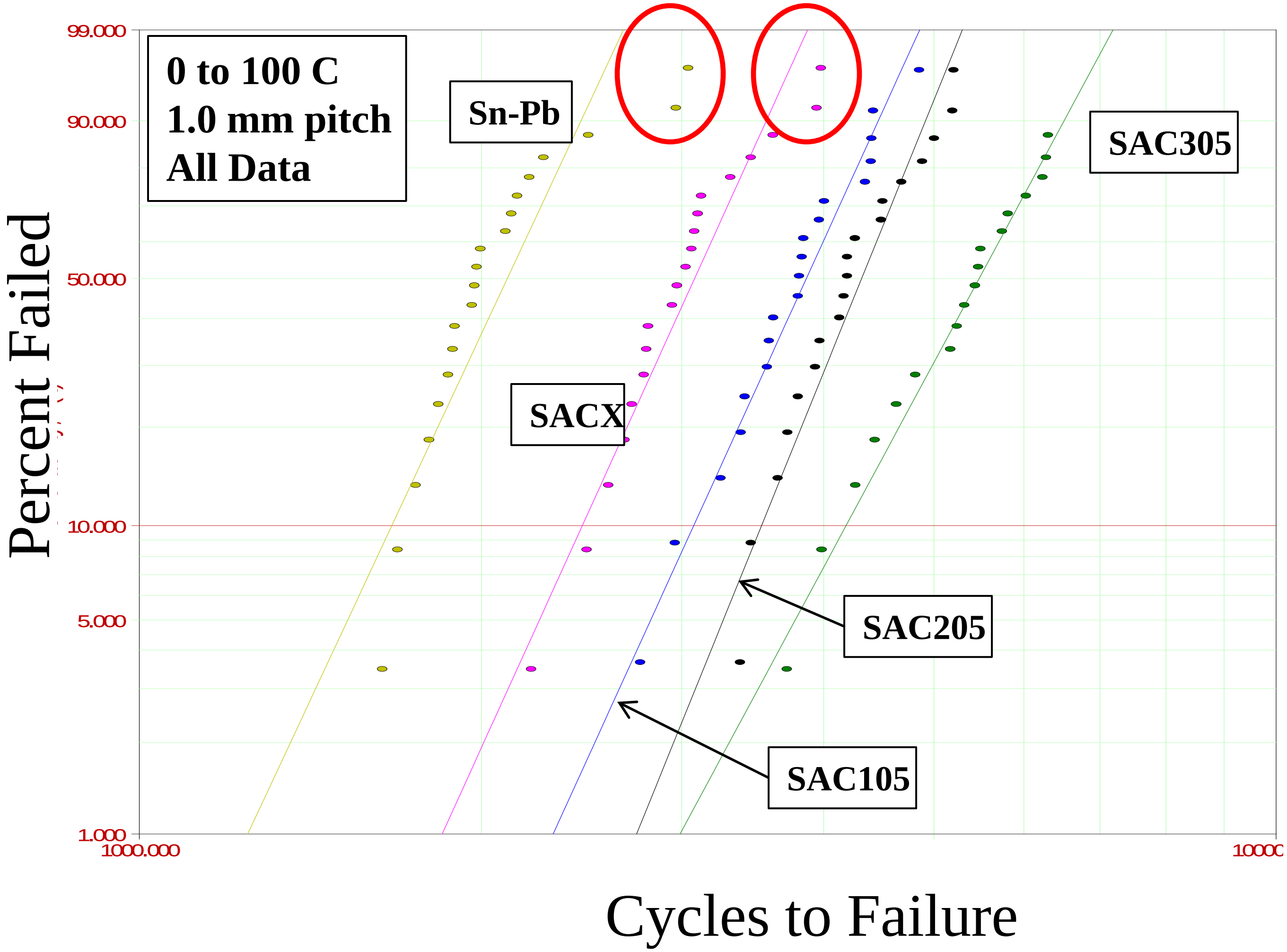
Sixth Report: Thermal Cycling Results for Unmixed Joints

Greg Henshall and Michael Fehrenbach, Hewlett-Packard
Chrys Shea, Shea Engineering Services
Quyen Chu and Girish Wable, Jabil
Ranjit Pandher, Cookson Electronics
Ken Hubbard and Gyaneshwar Ramakrishna, Cisco Systems
Ahmer Syed, Amkor

Amkor Technology Cookson SHEA cisco hp invent JABIL

- Compared SAC305, low silver and Pb BGA solder balls
- SAC305 paste
- OSP, NSMD pads
- Tg=170^{o} C PWB
- 1.27 to 0.5 mm pitch
- 0.32-0.62 mm ball dia
- Pack Size: 8-45 mm
- 0-100 and -40-125 CTC

Henshall's Weibull Plot



- **Most data sets "clean"**
- **Common anomaly was "late" failures**
- **Investigating cause**

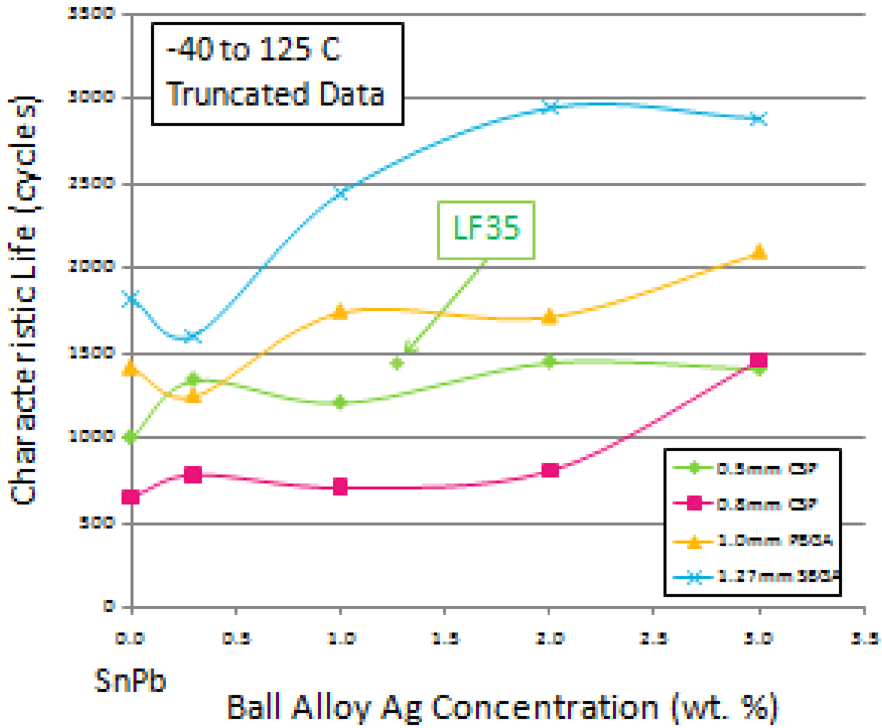
-40-125C results were mixed!

Dopants they studied do not affect TC

SAC 305>SAC105>Pb

Henshall’ s Effect of Silver Plot

Effect of Silver Concentration on N63: -40/+125C (Truncated)



- Behavior more complex than for 0/100 conditions
- Sn-Pb joints less reliable than Pb-free joints for:
  - Small pkgs - All Pb-free alloys
  - Large pkgs – All Pb-free alloys except SACX0307
- “Plateaus” in N63 with [Ag]; location depends on pkg.
- SAC305 has highest reliability for 0.8 & 1.0 mm pkgs; reliability similar to SAC205 for 0.5 & 1.27 mm pkgs.
- Results continue to be examined; validation needed

Coyle Etal

The Effect of Silver Content on the Solder Joint Reliability of a Pb-free PBGA Package

Richard Coyle[1], Heather McCormick[2], John Osenbach[3] Peter Read[1], Richard Popowich[1], Debra Fleming[1] and John Manock[4]

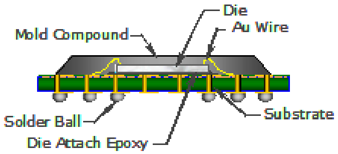
[1]Alcatel-Lucent, [2]Celestica Inc., [3]LSI Corp, [4]formerly Alcatel-Lucent

richard.coyle@alcatel-lucent.com hmccormi@celestica.com

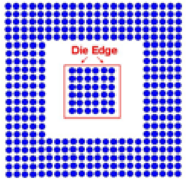
SMTAI 2010
October 26, 2010

Experimental - Test Package

Package Parameter	Value
Package Type	PBGA
I/O	680
Body Size	35 x 35 mm
Die Size	13 x 13 mm
Die Thickness	13 mils
Ball Pitch	1.0 mm
Ball Diameter	0.63 mm
Solder Ball Alloy	SnPb, SAC305, SAC105
Substrate Pad Design	Circular SMD
Substrate Pad Solder Mask Opening Diameter	0.45 mm
Substrate Pad Surface Finish	Electrolytic Ni/Au
Substrate Type	BT, 4 metal layer
Substrate Thickness	0.61 mm
Package Thickness	1.78 mm



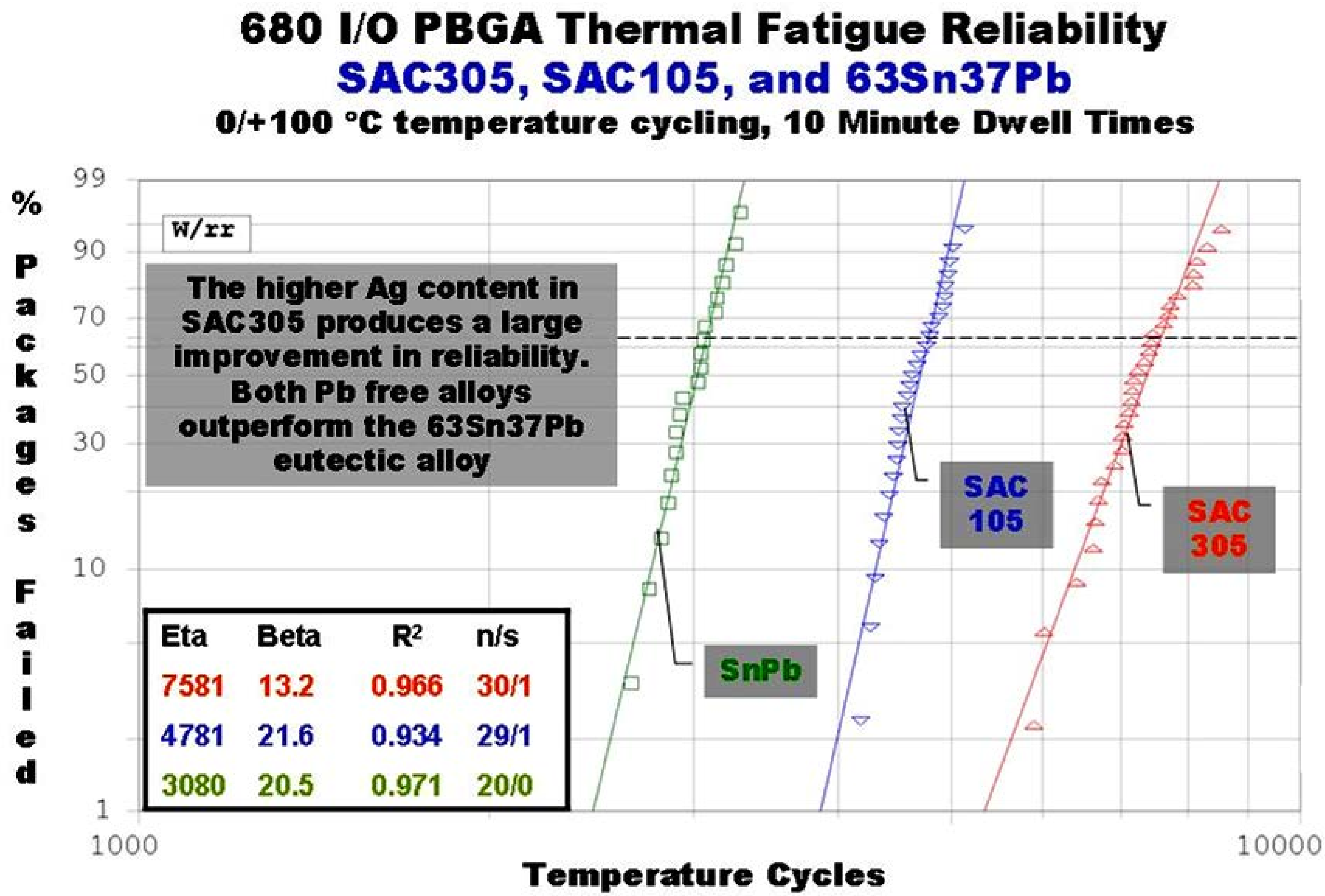
PBGA



4

- 0-100C
- Dwell from 10, 30, 60 min

Coyle's ATC Weibull Plot for 10 Minute Dwell Time



Work Performed by Lee etal on SACM and SACC

- SACM
  - 98.5Sn1Ag0.5Cu0.05Mn
- SACC
  - 98.5Sn1Ag0.5Cu0.02Ce
- Two Tests:
  - JEDEC Drop Test (JDT)
    - 0-250 hours for aging at 150C or 250 TCT
  - Thermal Cycle (-40 to 125C)
    - 0-250 hours aging at 150C

The Effect of Dopants: Ni

A Nickel Addition was found to be most effective

Ge

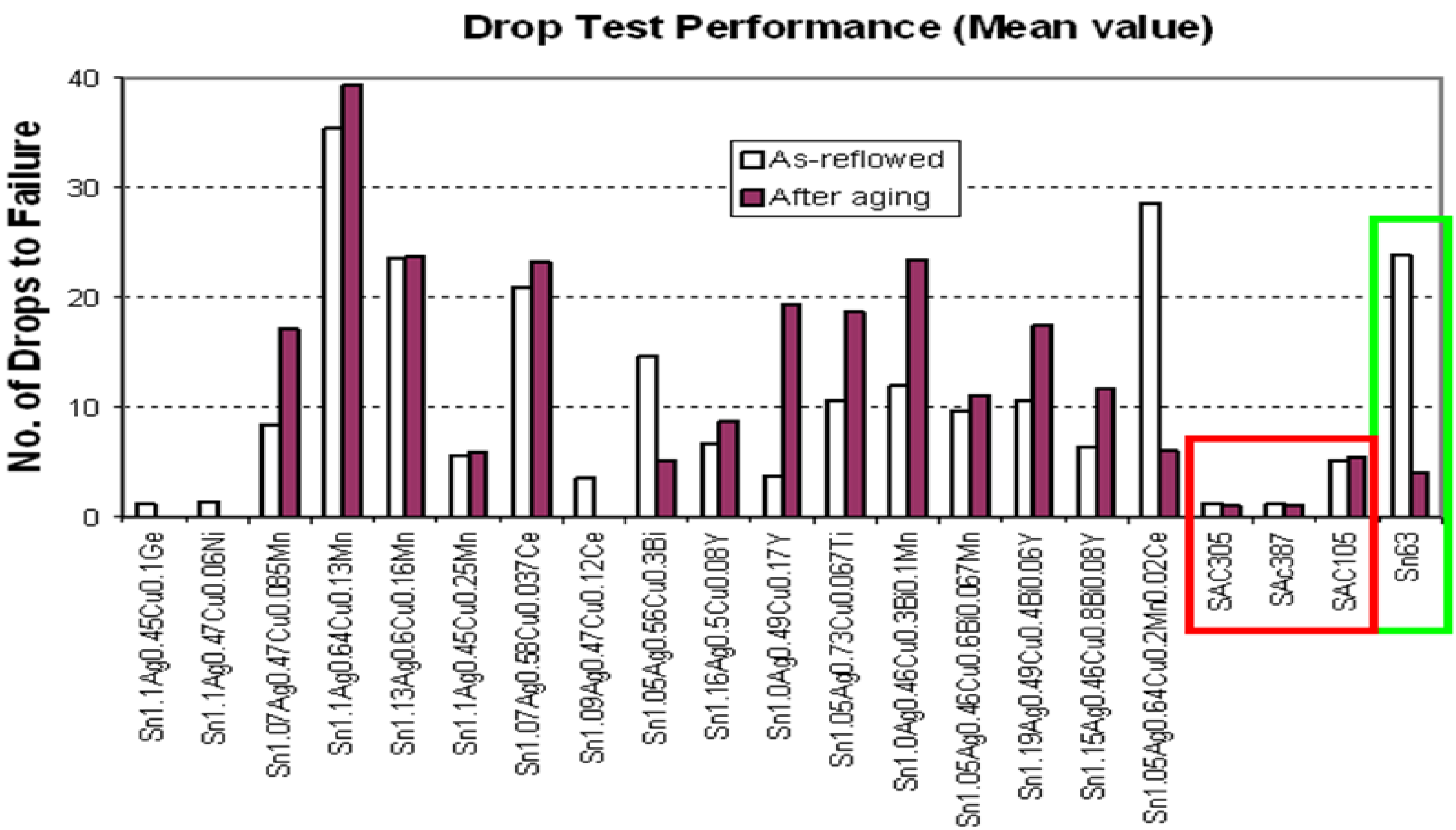
The Ge acts as an antioxidant and surface active agent

Sn-0.7Cu-0.05Ni

15 minute
Ramp to 340°C
30 minute cool

Sn-0.7Cu-0.05Ni+Ge

Older Work:
Doped SAC105 Alloys



Drop Test

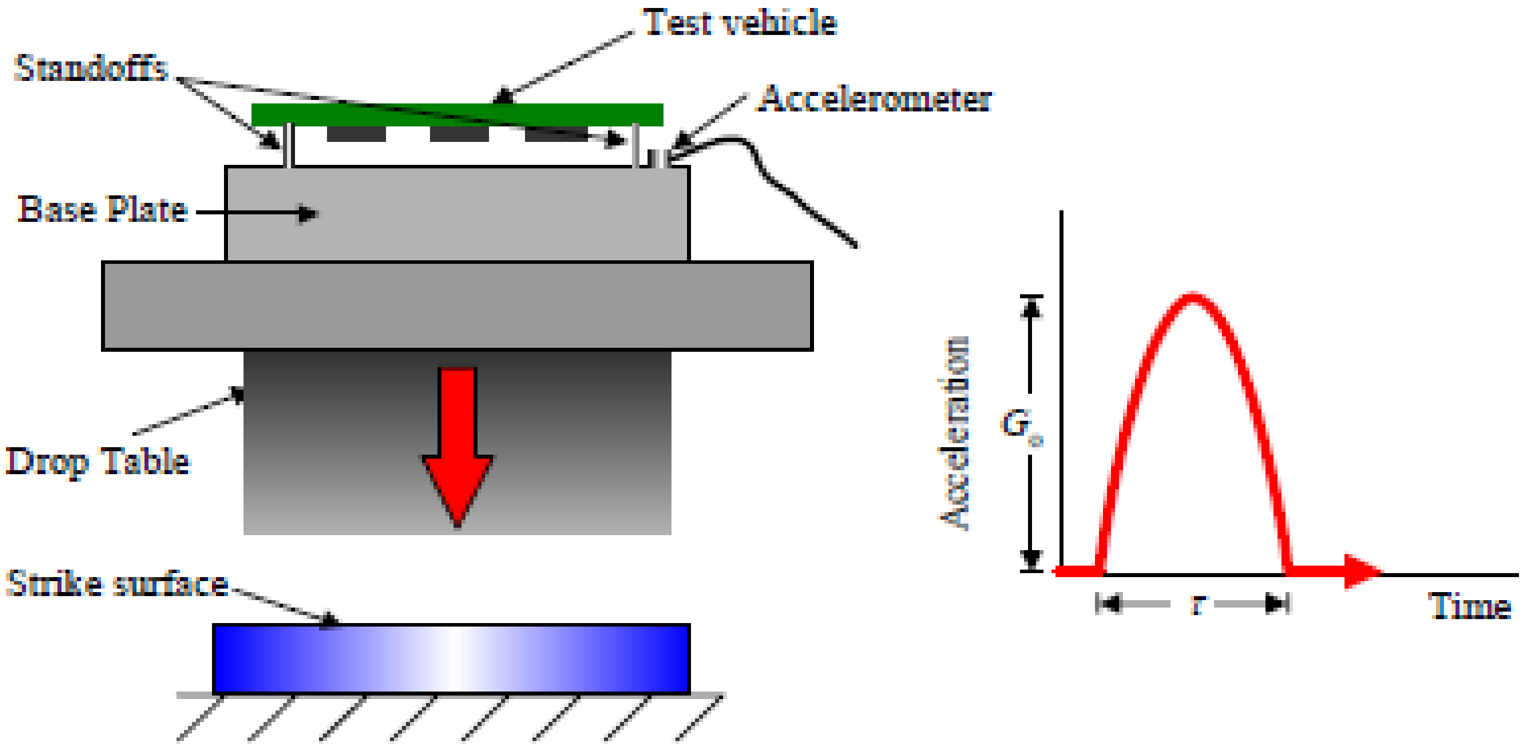
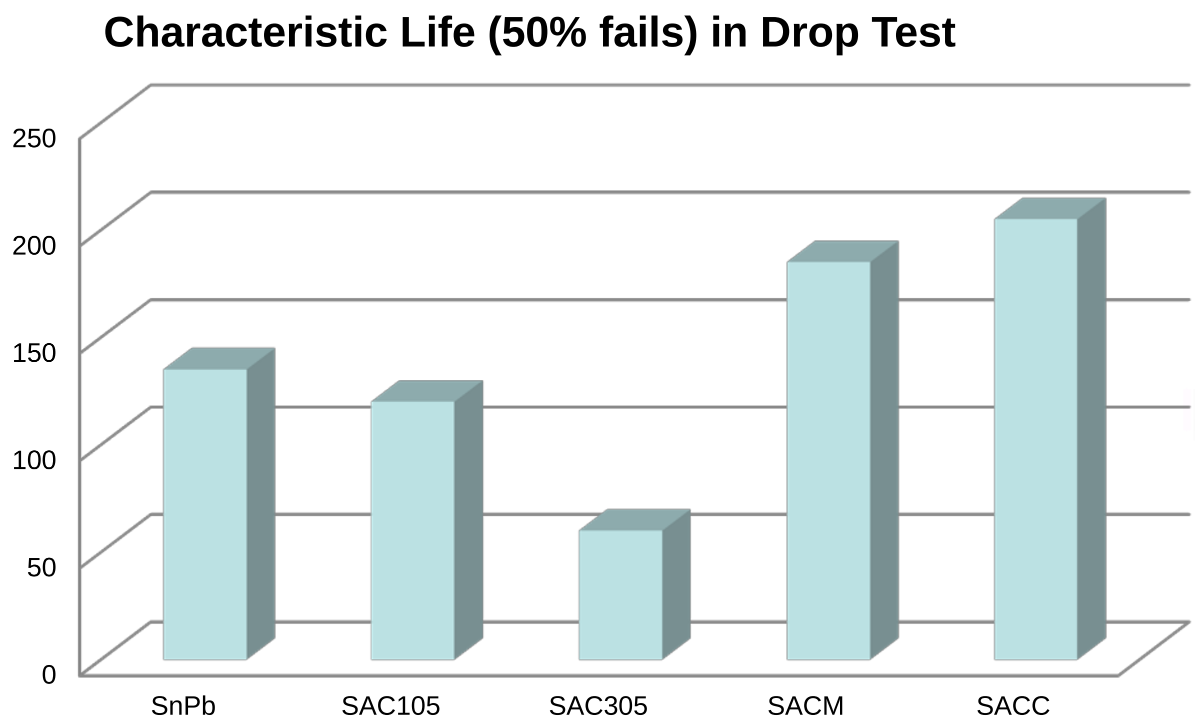


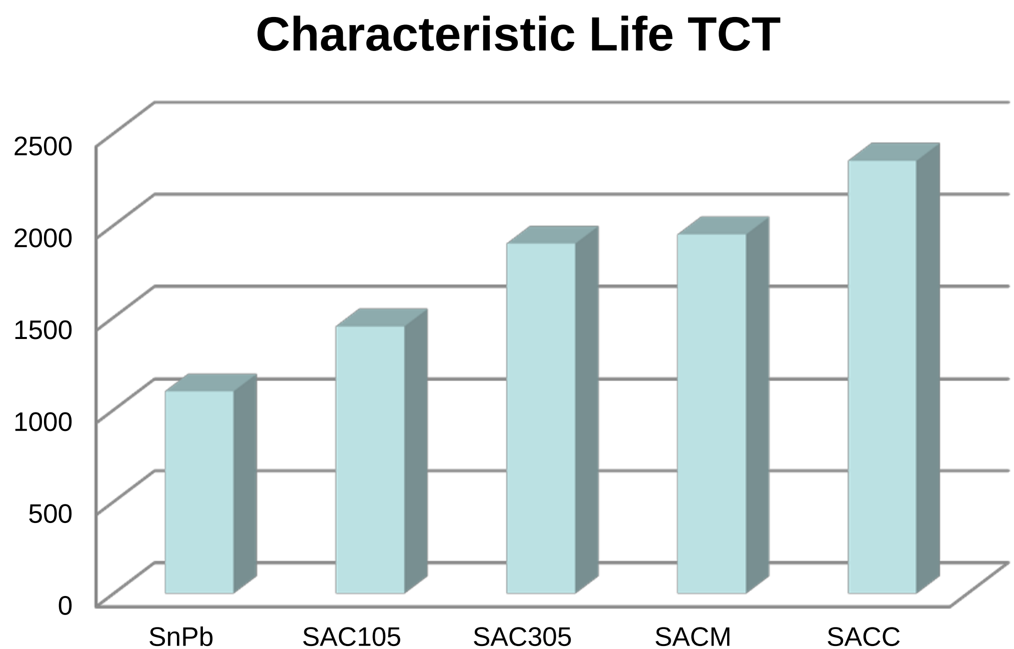
Fig. 1 Schematic for JEDEC board-level drop test.

JEDEC Drop Test (JDT)



- SACC>SACM>SnPb>SAC105>SAC305
  - TFBGA (NiAu leads) on OSP PWB pads
  - Aging: TCT 250 cycles

Thermal Cycle Test



- SACC>SACM>SAC305>SAC105>SnPb
  - TFBGA (NiAu leads) on OSP PWB pads aged 250 hrs 150C
  - Unaged samples SnPb is best in TC first fail

SACC > SACM ≥ SAC305 > SAC105 > SnPb

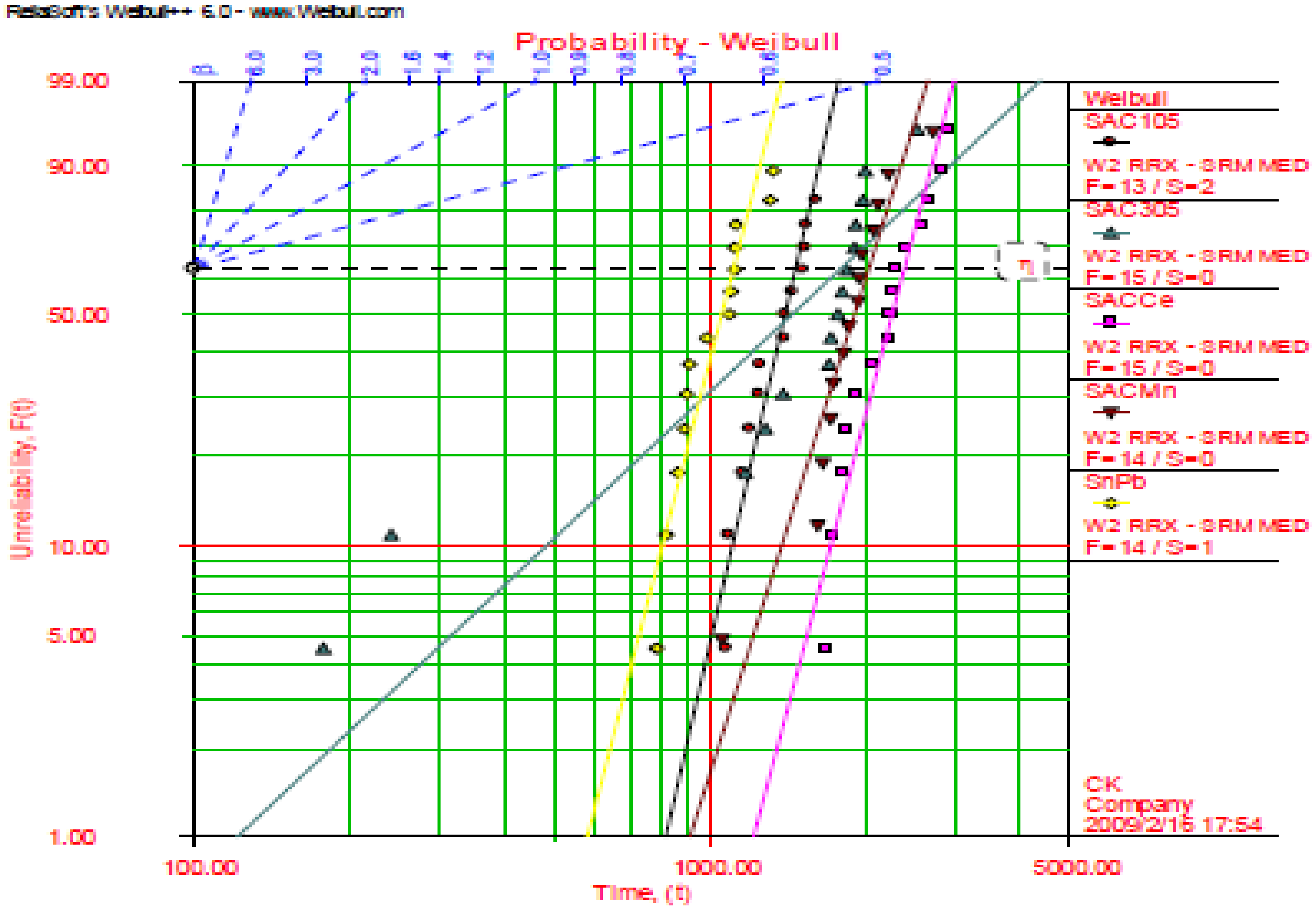


Fig. 12 Weibull plot for TCT performance for TFBGA (NiAu) with various sphere alloys assembled on PCB (OSP). Prior to TCT, the device was aged at 150C for 250 hrs.

The Effect of Aging

Sn:

T_{Melt} =505° K
$T_{Room\ Temp}$ = 300° K

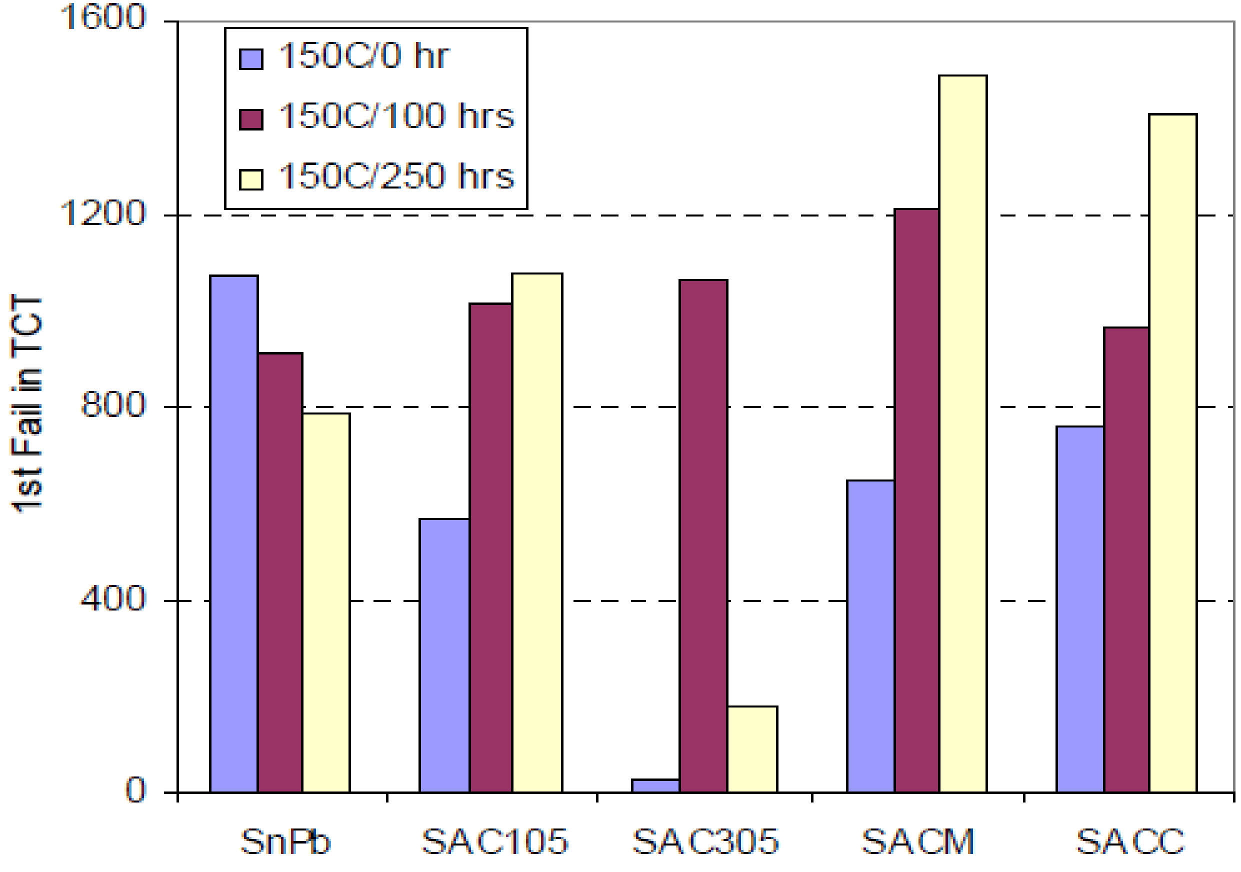


Fig. 14 First failure of TCT for TFBGA (NiAu) on PCB (OSP).

Aging and IMC Thickness

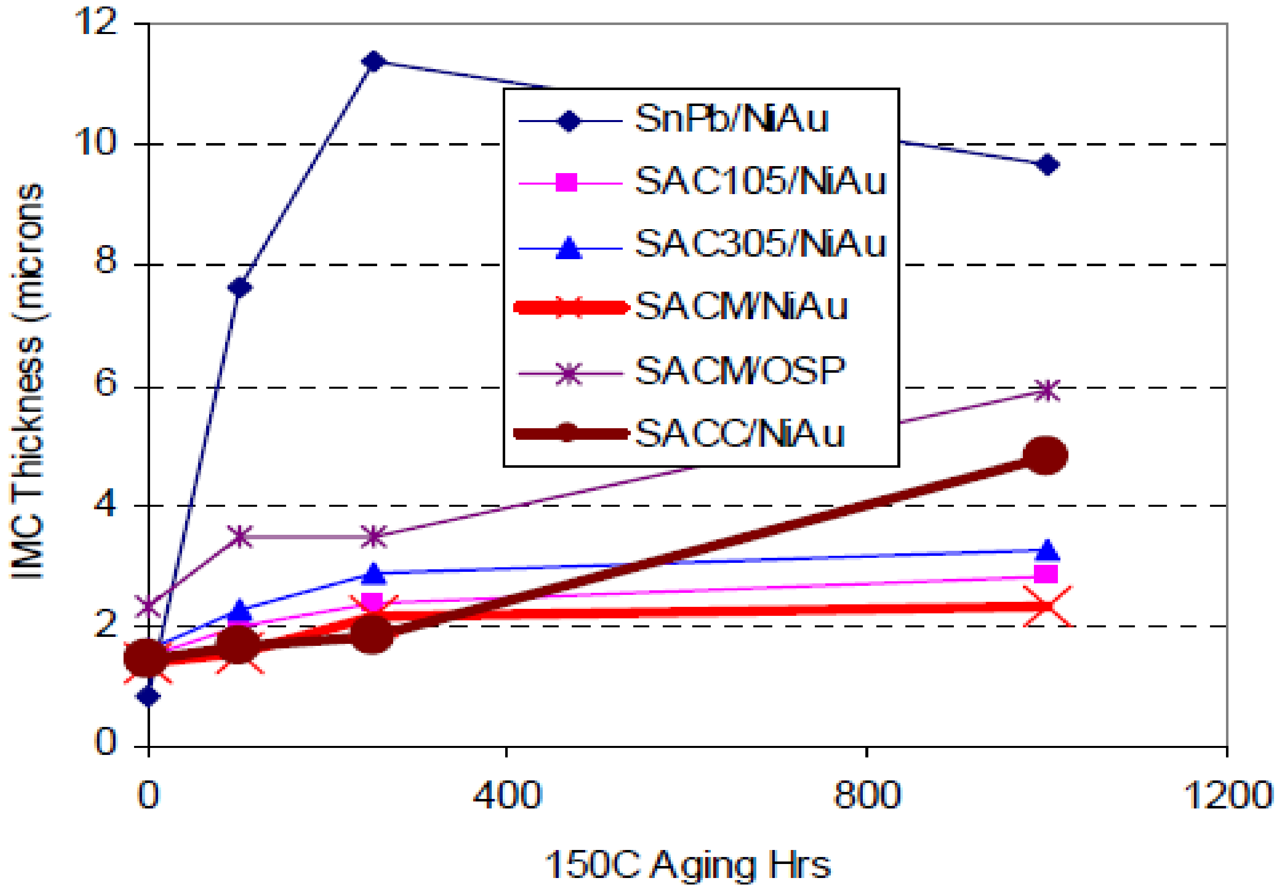


Fig. 28 IMC thickness of TFBGA joints at packaging side mounted on PCB (OSP).

Other Observations

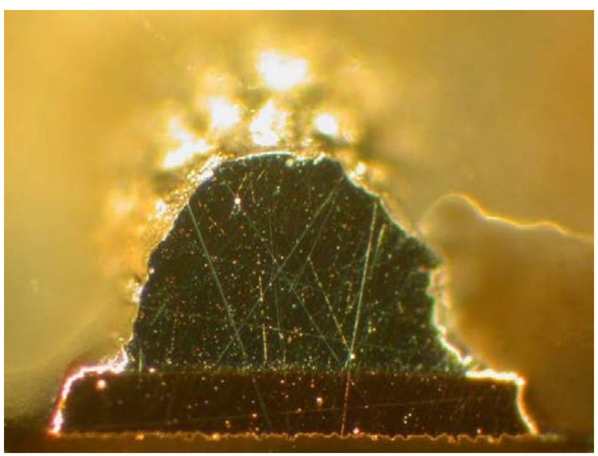
- Many claim harsh environment studies show lead-free not as robust as SnPb

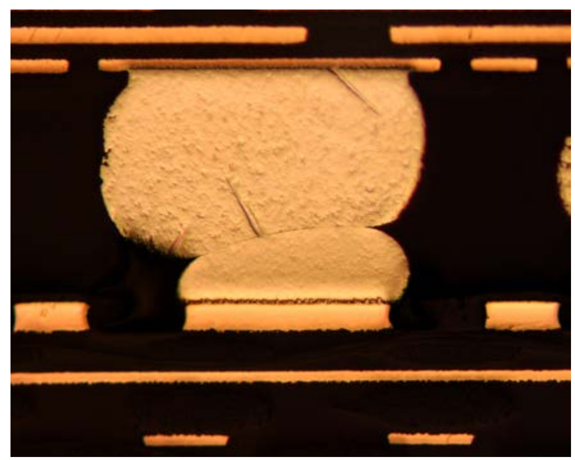
Conclusions

- For 0-100C type TC SAC305>SAC105>SnPb
- DS: SAC105 ≈ SnPb > SAC305
- For -40-125C TC the results are mixed
  - **LF reliability for this condition is still "unproven"**
- Adding dopants can improve results in DS and TC
  - **Both SACM and SACC have better drop shock performance than SAC105 and much better drop shock performance than SAC305**
  - **Both SACM and SACC match SAC305 in thermal cycle performance (-40-125C) and are better than SnPb Re characteristic life**
    - **Unaged SnPb is better than all SACs Re first failure**
  - **Hence, SACM and SACC are a better choice than SAC105 or SAC305**
  - **The mechanism for the improved performance is attributed to a stabilized microstructure with a uniform distribution of IMC particles**

Conclusions Con't

- Aging has a dramatic effect on both drop shock and thermal cycle life
- Low Silver SAC has $T_m > 217^o$ C
  - More Stress on PWB
- SAC has other process challenges: Graping, HIP:
  - Modern solder pastes can minimize these defects





Ronald C. Lasky, PhD, PE