1

Low Cost High Reliability Solder Materials

Dr. Ning-Cheng Lee

Indium Corporation

Feb, 2017

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Cost

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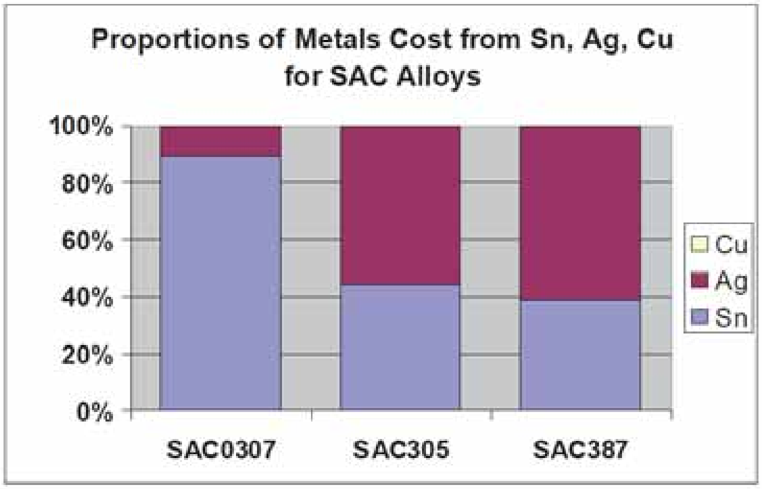
SAC Alloy Metals Cost Contributions



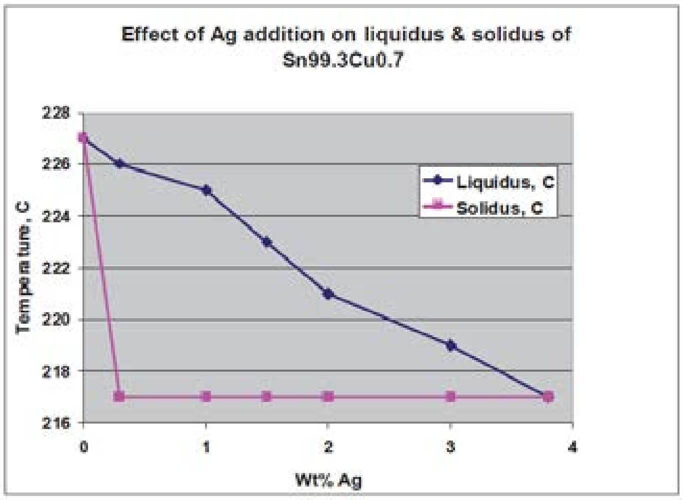
Low Ag solders: reduced sensitivity to Ag price

4

Ag on Physical Properties

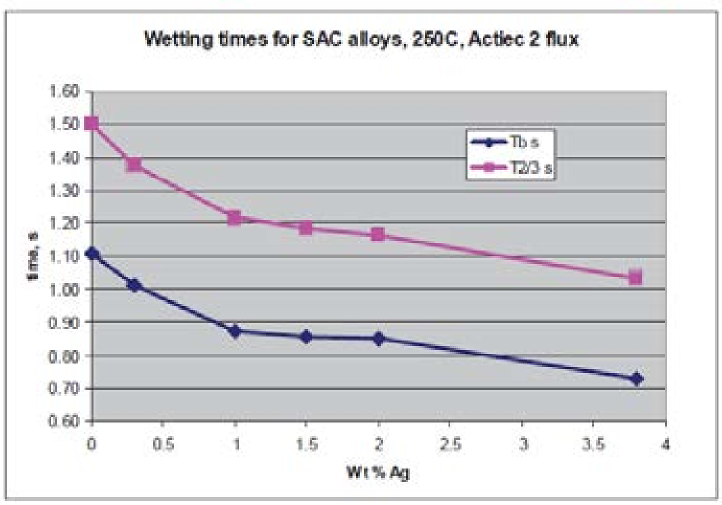
5

Effect of Ag on SAC Melting Points



6

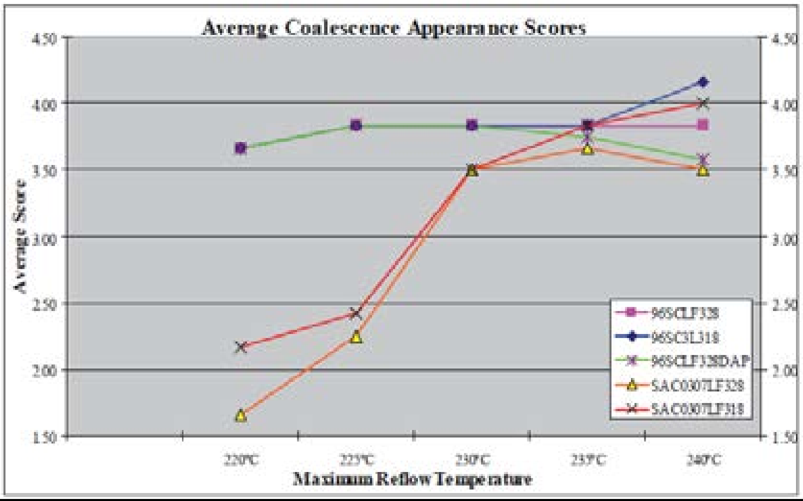
Effect of Ag Content on Wetting Times



Wetting times decrease with Ag content

7

Joint Coalescence Index vs. Reflow Temperature for SAC0307 & SAC387



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Ag on Reliability

9

Effect of Ag Content

BGA Package		
Designation	192CABGA	84CTBGA
Die Size	12x12 mm	5x5 mm
Package Size	14x14 mm	7x7 mm
Ball Array	16x16	12x12
Ball Pitch	0.8 mm	0.5 mm
Ball Diameter	0.46 mm	0.3 mm
Pad Finish	Electrolytic Ni/Au	Electrolytic Ni/Au
PCB		
Thickness	2.36 mm (93mils)	
Surface Finish	High temp OSP	
No. Cu Layers	6	
Pad Diameter	0.356 mm	0.254 mm
Solder Mask Dia.	0.483 mm	0.381 mm

High Ag result in long TCT life

All BGA assembled with SAC305 paste

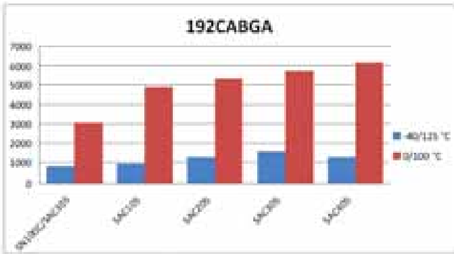

Figure 3: Bar chart comparing characteristic lifetime as a function of alloy composition (Ag content) and thermal cycle for the 192CABGA.

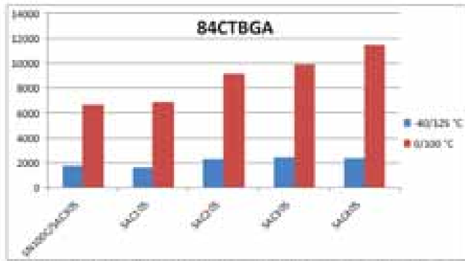

Figure 4: Bar chart comparing characteristic lifetime as a function of alloy composition (Ag content) and thermal cycle for the 84CTBGA.

Richard Parker, Richard Coyle, Gregory Henshall, Joe Smetana, Elizabeth Benedetto, "iNEMI Pb-FREE ALLOY CHARACTERIZATION PROJECT REPORT: PART II - THERMAL FATIGUE RESULTS FOR TWO COMMON TEMPERATURE CYCLES", SMTAI, p.348-358, Orlando, FL, Oct. 14-18, 2012

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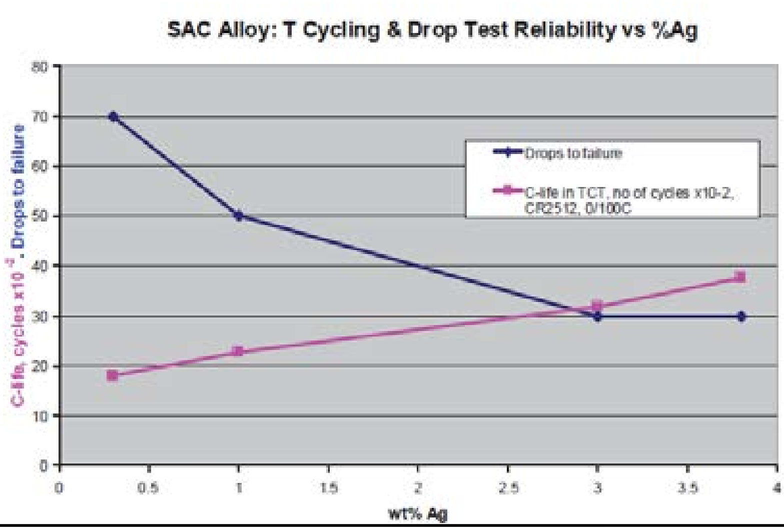
INDIUM CORPORATION

SAC Alloy Reliability vs. %Ag



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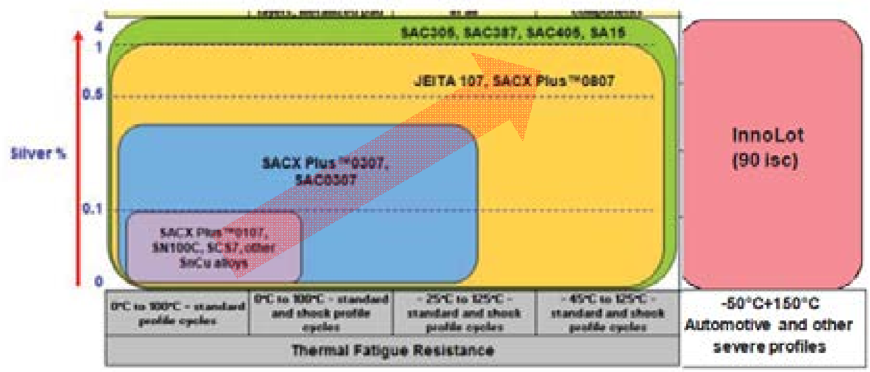
Low Ag less thermal fatigue resistant than high Ag

Thermal Fatigue Resistance



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What can be done on improving reliability of low Ag?

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Minor Alloying Additions to low silver SAC alloys Claimed Effects

- Bi
  - Lower melting point.
  - Increased strength (a proven solid solution strengthener)
- Ni, Co, Mn, Ce
  - Reduced intermetallic layer growth to improve mechanical shock resistance.
  - Grain refinement
- P, Ge, Ga
  - Reduced dross (wave soldering)
- Rare Earths
  - Claimed improved reliability (??)

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Low Cost Alternatives

- Sn992 (Sn0.5Cu0.3Bi0.005Co)
- Sn995 (Sn0.5Cu0.06Co)
- SN100C (Sn0.7Cu0.05Ni+Ge)
- SN100C+2Bi
- SC+0.15Zn
- SC+0.05Ni+0.1Zn
- SC+0.1Au
- SC+0.05Ni+0.1Au
- SC+0.2In
- SC+0.05Ni+0.2In
- SC+0.5In
- SC+0.4Zn
- SCAN-Co (Sn0.5Cu0.2Sb0.05Ni0.05Co)
- SAC0307
- SACX0307
- SAC0307+(0.09)Bi
- SAC0307+0.08Bi0.01Sb0.01Pb
- SAC0307+0.005Ni0.005Ge
- SAC0510+0.05Mn
- SAC0607-3Bi
- SAC0807
- SAC105
- SAC105+0.05Mn
- SAC105+Ni
- SAC107
- S1XBIG (Sn1.1Ag0.7Cu1.8Bi0.06Ni)
- SAC1205
- SAC1205+Ni
- SACi (Sn1.7Ag0.6Cu0.4Sb)
- SAC205
- SAC205+Ni
- SAC2508+NiBi
- SACQ
- SAC3207+5.5Sb

More Ag (↓)

15

Sn995
(Sn0.5CuCo)

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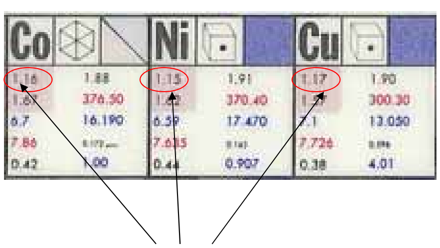
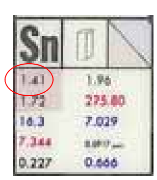
Solid Solutions - Alloys



< 2% difference



Ni: 81.6%

Co: 82.3%

Cu: 83.0%

Co closer in size to Cu than Ni

Hume Rothery rules for the formation of substitutional solutions [Alloys]

1. Crystal structure factor: For complete solubility elements should have the same crystal structure
2. Relative size factor: For high solubility the atomic radii should be less than 15% difference
3. Chemical affinity factor: Generally, two metals close in the periodic table will likely form a solid solution
4. Relative valence factor: Must have available valence electrons

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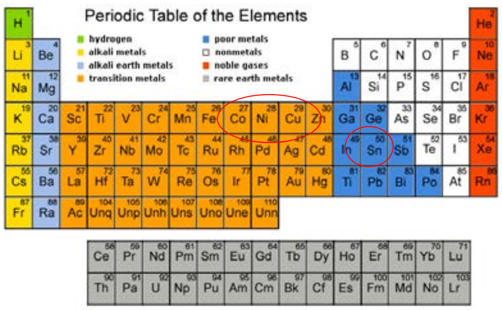
Solid Solutions - Alloys



Co: 1.88	
Ni: 1.91	Sn: 1.96
Cu: 1.90	

Pauling's scale of electronegativity

Hume Rothery rules for the formation of substitutional solutions [Alloys]

1. Crystal structure factor: For complete solubility elements should have the same crystal structure
2. Relative size factor: For high solubility the atomic radii should be less than 15% difference
3. Chemical affinity factor: Generally, two metals close in the periodic table will likely form a solid solution. EU: +/- 0.4
4. Relative valence factor: must have available valence electrons

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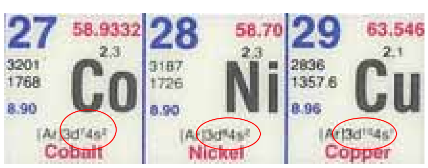
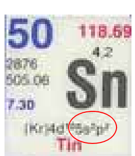
Solid Solutions - Alloys





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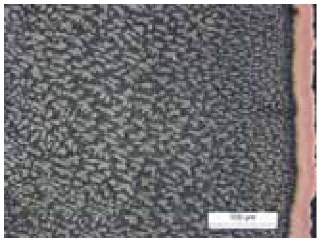
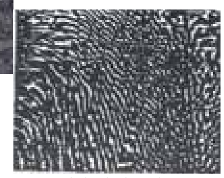
Higher Magnification With Contrast



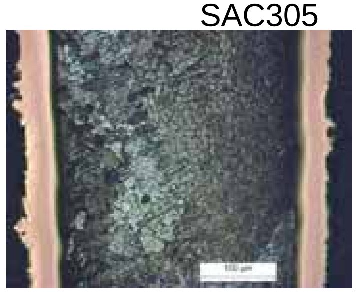
Sn995 [SnCu-Co]

SAC305

SnPb



Askeland, The Science & Engineering of Materials, 1984, p 248



SnCu-Ni

Cobalt is better at refining grain structure in SnCu alloys.

1. Limited solubility in Cu
2. Higher solubility in Sn

100X

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Shear Test SAC305 /Sn995™

- Shear Test:
  - **Crosshead speed of 0.1mm/ minute**
  - **Crosshead lowered at a rate of 0.1mm/minute until device sheared from circuit board**

Sn995 gives slightly weaker shear joints, but more consistent

Device Location	Maximum Shear Force (N)	
	SAC305	Sn995
R19	76.13	64.93
R21	82.27	85.01
R34	68.83	78.62
C13	103.6	90.43
C14	103.65	92.69
C15	99.16	77.28
C22	74.65	69.03
C34	68.32	72.42
Average Resistor	75.74	76.19
Deviation Resistor	6.73	10.26
Average Capacitor	89.88	80.37
Deviation Capacitor	17.03	10.66
Overall Average	84.58	78.80
Overall Deviation	15.24	9.98

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Thermal Cycling SAC305 /Sn995™

- Thermal cycling: IPC 9701A
  - -10 to +110°C
  - 1,000 thermal cycles
  - Temperature rate of change = 10 to 20ºC/minute
  - 5 minutes soak time at each temperature (to relax solder)
- Thermal Cycling Results
  - Neither SAC305 nor Sn995™ showed deterioration after 1,000 cycles
  - The Sn995™ showed an average inter-metallic thickness of 2.18 microns prior to thermal cycling and 2.32 microns after
  - The SAC305 showed an average inter-metallic thickness of 2.00 microns prior to thermal cycling and 3.43 microns after
  - Both were within the 1-5 micron desired thickness

995 < 305 in IMC thickness

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SN100C (Sn0.7Cu+0.05Ni+0.006Ge)

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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SN100C

- Chemical Composition
  - Based on Sn-0.7Cu
  - Addition of Ni in the range 0.04-0.08%
  - Addition of Ge in the range 30-100ppm
  - Manufactured on a base of standard purity tin
  - No other elements added

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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SN100C

- Function of Alloying Elements
  - The Ni addition transforms the basic Sn-Cu alloy
    - Selectively incorporates into the Cu_6Sn_5 intermetallic in the eutectic and at the solder/substrate interface
    - Facilitates nucleation of the Cu_6Sn_5 so that eutectic solidification can occur at low undercooling before there is an opportunity for primary tin dendrites to start growing
    - The resultant $(Cu,Ni)_6Sn_5$ is stable so that the microstructure does not coarsen during ageing to the extent that it does in the unmodified Sn-0.7Cu alloy.
    - The stability of the $(Cu,Ni)_6Sn_5$ at the solder/substrate interface means:
      - » Low rate of copper dissolution
      - » Slower growth of interfacial intermetallic

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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SN100C

- As cast surface reflects eutectic solidification

Sn-37Pb

SN100C

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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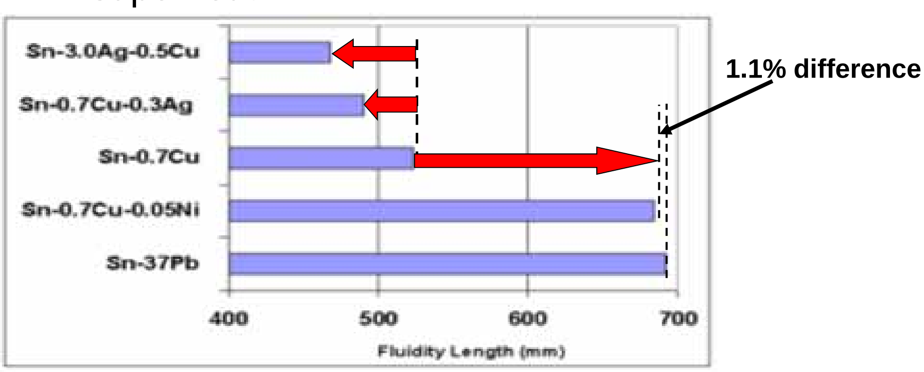
SN100C

- Eutectic behaviour is reflected in Ragone fluidity
  - SN100C matches the fluidity of Sn-37Pb at same superheat



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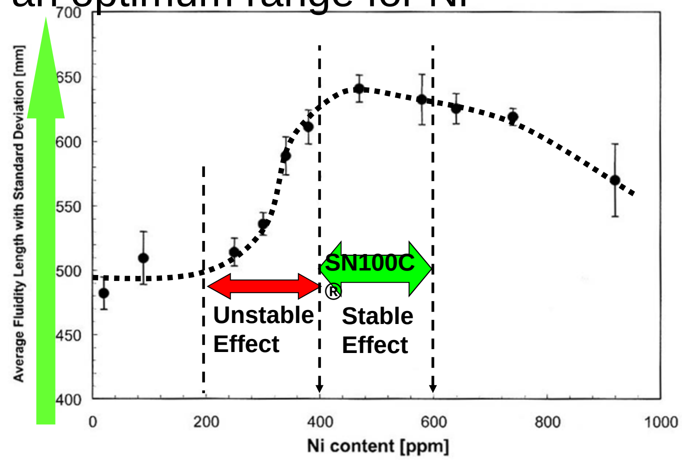
SN100C

- There is an optimum range for Ni

Fluidity Length



Journal of Electronic Material Oct 2007

"The Influence of 0–0.1 wt.% Ni on the Microstructure and Fluidity Length of Sn-0.7Cu-xNi", T Ventura, C M. Gourlay, K. Nogita,T Nishimura, M Pappaz,3 and A K. Dahle

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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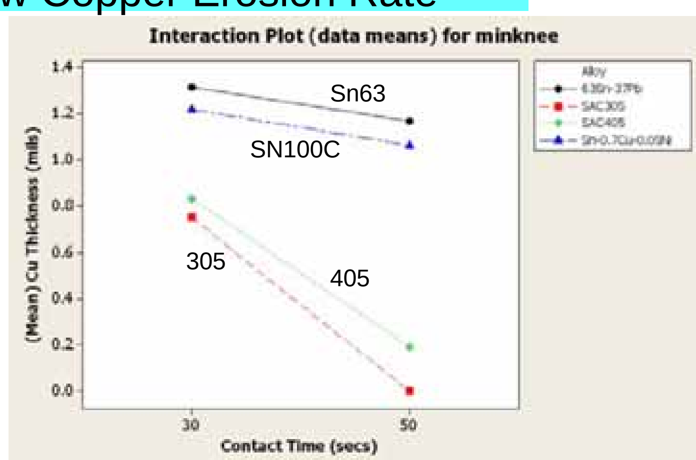
SN100C

- Low Copper Erosion Rate



Matt Kelly, Craig Hamilton, Polina Snugovsky, Pan Pacific International Conference January 2007

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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SN100C

- Function of Alloying Elements
  - The Ge acts as an antioxidant and surface active

15 minute
Ramp to 340°C
30 minute cool

Sn-0.7Cu-0.05Ni

Sn-0.7Cu-0.05Ni+Ge

K Watling, A Chandler, K Nogita. A Dahle, University of Queensland, Submitted for publication

Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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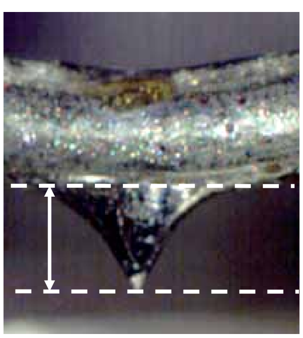
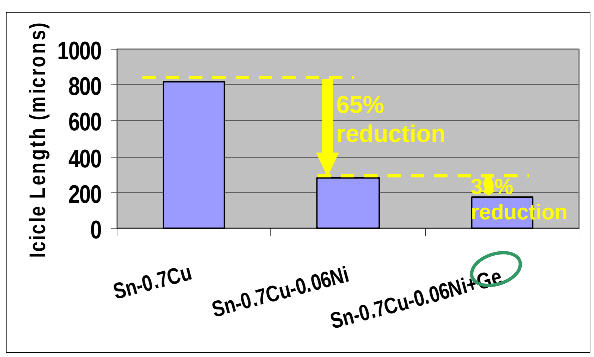
SN100C

- Function of alloying elements (continued
  - The Ge acts as an antioxidant and surface active agent



Icicle Length



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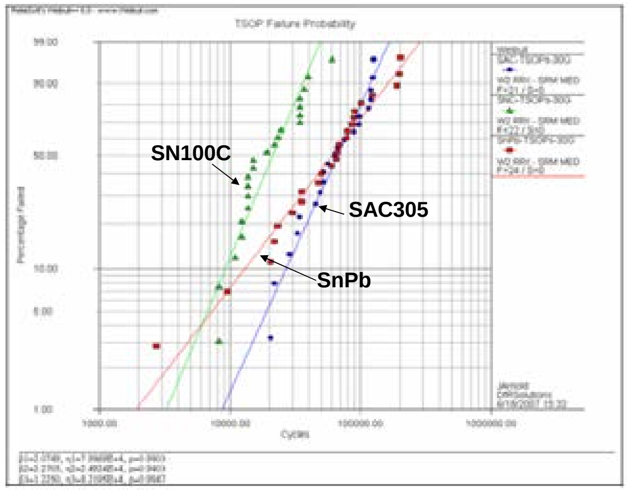
SN100C

- Vibration-30G-TSOP poorer than 305



Keith Sweatman Lead-free Alloy Alternatives workshop February 1, 2008

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SAC0510Mn (Sn0.5Ag1.0Cu0.05Mn)

Vahid Goudarzi and Matthew Brown, Motorola Mobile Inc.; Weiping Liu and *Ning-Cheng Lee, Ph.D., Indium Corporation; Jeffrey ChangBing Lee, IST-Integrated Service Technology Inc, “The Second Generation Shock Resistant and Thermally Reliable Low Ag SAC Solder Doped With Mn”, SMTA International, Fort Worth, TX, October 13-17, 2013

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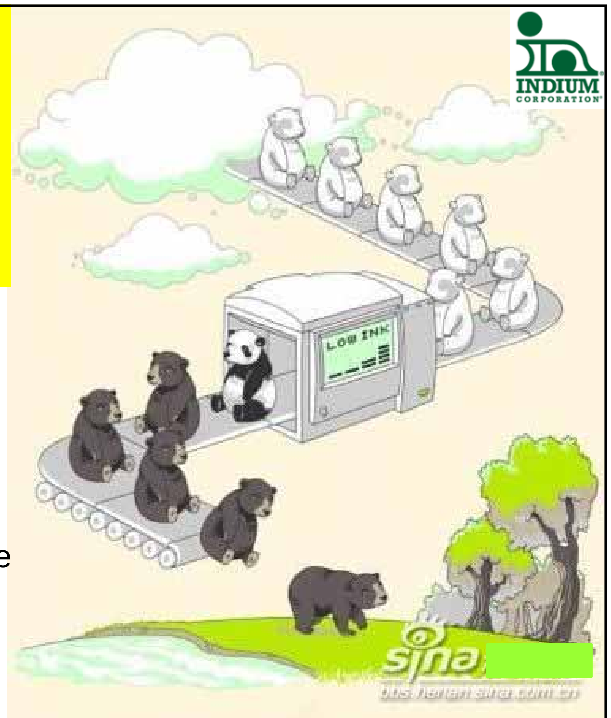
Shock Resistant And Thermally Reliable Low Ag SAC Solder Doped With Mn

Vahid Goudarzi and Matthew Brown, Motorola Mobile Inc.; Weiping Liu and *Ning-Cheng Lee, Ph.D., Indium Corporation; Jeffrey ChangBing Lee, IST-Integrated Service Technology Inc, "The Second Generation Shock Resistant and Thermally Reliable Low Ag SAC Solder Doped With Mn", SMTA International, Fort Worth, TX, October 13-17, 2013

Less is More



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Modified JEDEC Drop Test Results

Bump Alloy	Test Board Assembly Condition	Number of drops to failure: Ave	Number of drops to failure: Ratio (0510M/105)	Number of drops to failure: STDEV	Drop Height (m)
SAC0510M	SAC305 paste	52.5 Lower	13.1	12.7 (25%)	1
SAC105		4		0.8 (20%)	1
SAC0510M	Flux	117.2 Higher	7.7	22.8 (19%)	1
SAC105		15.3		5.5 (36%)	1

1. Mn always much higher than 105
2. Assembled with 305 paste lower than with flux due to alloy dilution effect

Vahid Goudarzi and Matthew Brown, Motorola Mobile Inc.; Weiping Liu and *Ning-Cheng Lee, Ph.D., Indium Corporation; Jeffrey ChangBing Lee, IST-Integrated Service Technology Inc, "The Second Generation Shock Resistant and Thermally Reliable Low Ag SAC Solder Doped With Mn", SMTA International, Fort Worth, TX, October 13-17, 2013

-55C/125C

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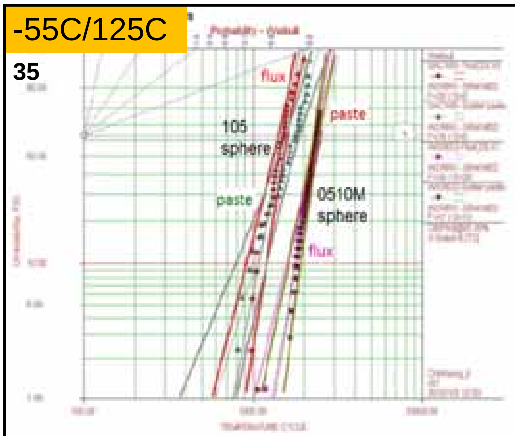

Thermal Cycling Test Results

TCT (-40°C/125°C) performance of BGA assemblies

Bump Alloy	Characteristic Life 63.2% (η)	
	Value	Ratio (alloy/105)
SAC105	1468	1
SAC105M	2034	1.39
SAC305	1905	**1.30**

Liu etc, SMTAI, p.920-934, October 4-8, 2009, San Diego, CA.

Bump Alloy	Assembly Condition	Characteristic Life 63.2% (η)		Characteristic Life 50%		Weibull Slope (β)
		Value	Ratio (Mn/105)	Value	Ratio (Mn/105)	
SAC0510M	Flux	2427	**1.61**	2317	1.62	7.26
SAC105		1510		1431		6.68
SAC0510M	SAC305 paste	2361	**1.37**	2258	1.45	8.03
SAC105		1726		1559		4.36

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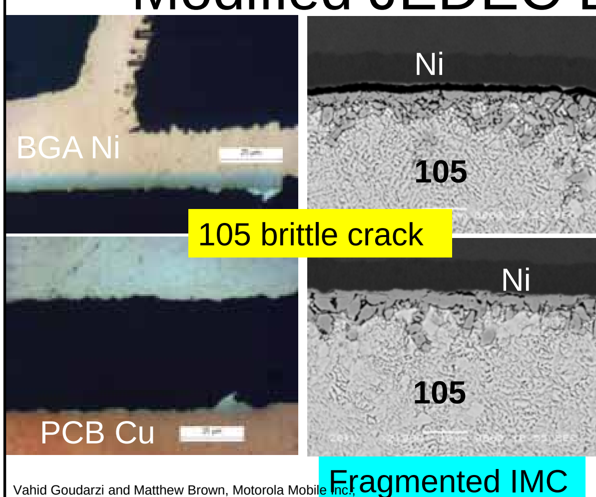
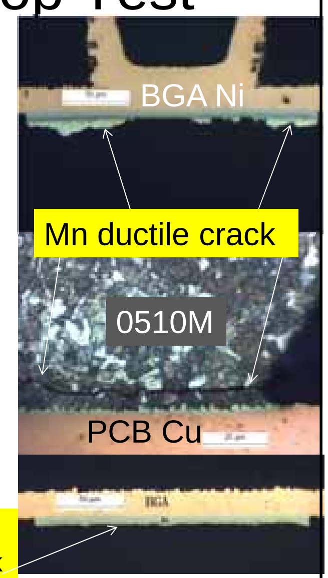
Dynamic Bending Test & Modified JEDEC Drop Test





Vahid Goudarzi and Matthew Brown, Motorola Mobile Inc; Weiping Liu and *Ning-Cheng Lee, Ph.D., Indium Corporation; Jeffrey ChangBing Lee, IST-Integrated Service Technology Inc, "The Second Generation Shock Resistant and Thermally Reliable Low Ag SAC Solder Doped With Mn", SMTA International, Fort Worth, TX, October 13-17, 2013

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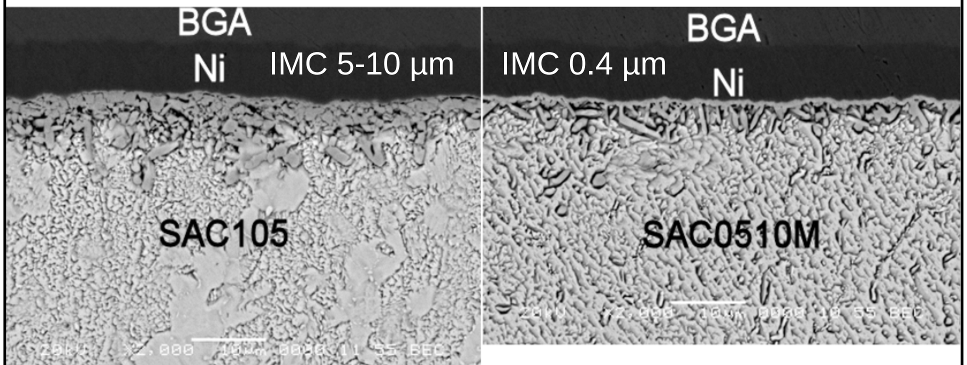
Mn Suppress IMC Thickness



Earlier work Mn suppress IMC growth

Liu etc, SMTAI, p.920-934, October 4-8, 2009, San Diego, CA.

Vahid Goudarzi and Matthew Brown, Motorola Mobile Inc.; Weiping Liu and *Ning-Cheng Lee, Ph.D., Indium Corporation; Jeffrey ChangBing Lee, IST-Integrated Service Technology Inc, "The Second Generation Shock Resistant and Thermally Reliable Low Ag SAC Solder Doped With Mn", SMTA International, Fort Worth, TX, October 13-17, 2013

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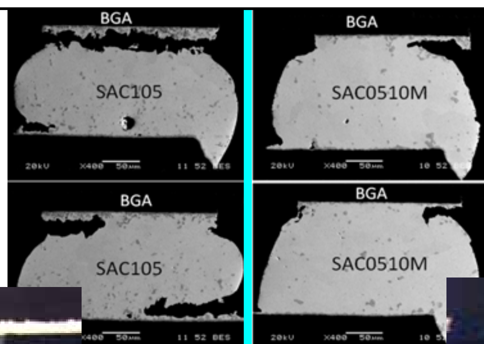
darzi and Matthew
torola Mobile Inc.;
u and *Ning-Cheng Lee, Ph.D., Indium Corporation; Jeffrey ChangBing Lee, IST-Integrated Service Technology Inc, "The Second Generation Shock Resistant and Thermally Reliable Low Ag SAC Solder Doped With Mn", SMTA International, Fort Worth, TX, October 13-17, 2013

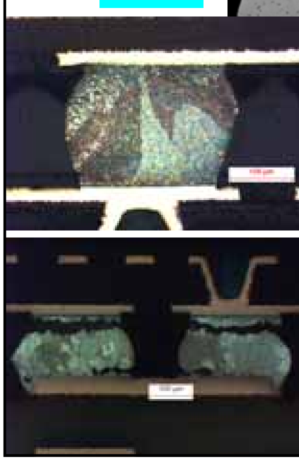
TCT Results

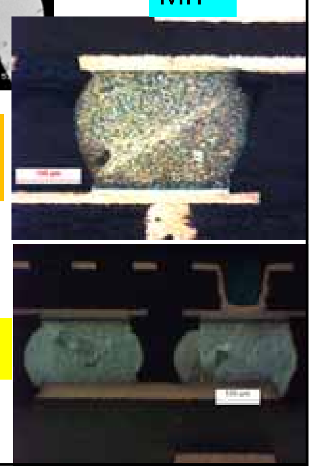
105



0510M

Mn





Earlier work Mn stabilize microstructure

Liu etc, SMTAI, p.920-934, October 4-8, 2009, San Diego, CA.

Significant recrystallization

Minute recrystallization

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S1XBIG (Sn1.1Ag0.7Cu1.8Bi0.06Ni)

*Jasbir Bath, Bath and Associates Consultancy LLC; Munehiko Nakatsuma, Takehiro Wada, Kimiaki Mori, Koichi Shimokawa, Takeshi Shira, Atsushi Irisawa, and Roberto Garcia, Koki Company Limited, "A Study of Lead-free, Low Silver Solder Alloys with Nickel Additions", SMTA International, Fort Worth, TX, October 13-17, 2013

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Table 2. Lead-free solder alloy compositions investigated (in wt%) compared with Sn3Ag0.5Cu

Sn	Cu	Ag	Bi	Ni	Co	Designation
Bal.	0.5	3				S3X (SAC305)
Bal.	0.7	1.1	1.8	0.06		S1XBIG
Bal.	0.7	1.1		0.07		S1XIG
Bal.	0.7	1.1				S1X (SAC107)
Bal.	0.7	0.1			0.03	S01X7C
Bal.	0.7	2				S2X

*Jasbir Bath, Bath and Associates Consultancy LLC; Munehiko Nakatsuma, Takehiro Wada, Kimiaki Mori, Koichi Shimokawa, Takeshi Shira, Atsushi Irisawa, and Roberto Garcia, Koki Company Limited, "A Study of Lead-free, Low Silver Solder Alloys with Nickel Additions", SMTA International, Fort Worth, TX, October 13-17, 2013

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Items		S1X	S2X	S3X (Ref)
Composition (%)	Sn	Bal.	Bal.	Bal.
	Ag	1.1	2.0	3.0
	Cu	0.7	0.7	0.5
Melting point (°C)		217-224	217-222	217-219

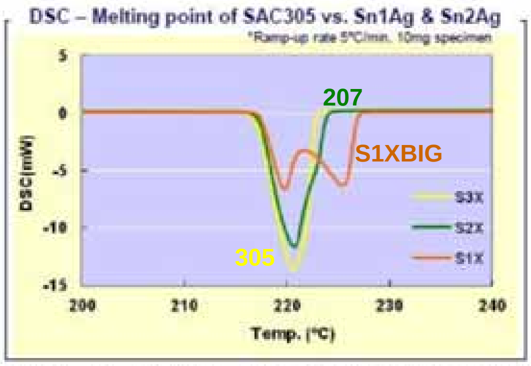


Figure 13. Effect of silver content versus melting temperature for SnAgCu solders (Sn1.1Ag0.7Cu versus Sn2Ag0.7Cu versus Sn3Ag0.5Cu).

*Jasbir Bath, Bath and Associates Consultancy LLC; Munehiko Nakatsuma, Takehiro Wada, Kimiaki Mori, Koichi Shimokawa, Takeshi Shira, Atsushi Irisawa, and Roberto Garcia, Koki Company Limited, "A Study of Lead-free, Low Silver Solder Alloys with Nickel Additions", SMTA International, Fort Worth, TX, October 13-17, 2013

42

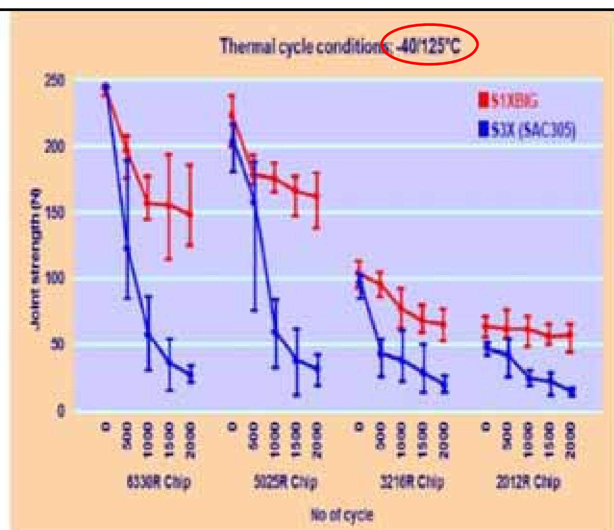


Figure 29. Summary of thermal cycling results for S1XBIG versus Sn3Ag0.5Cu after shear testing of soldered joints up to 2,000 ATC thermal cycles from -40°C to +125°C for 6330, 5025, 3216 and 2012 chip components

*Jasbir Bath, Bath and Associates Consultancy LLC; Munehiko Nakatsuma, Takehiro Wada, Kimiaki Mori, Koichi Shimokawa, Takeshi Shira, Atsushi Irisawa, and Roberto Garcia, Koki Company Limited, "A Study of Lead-free, Low Silver Solder Alloys with Nickel Additions", SMTA International, Fort Worth, TX, October 13-17, 2013

43

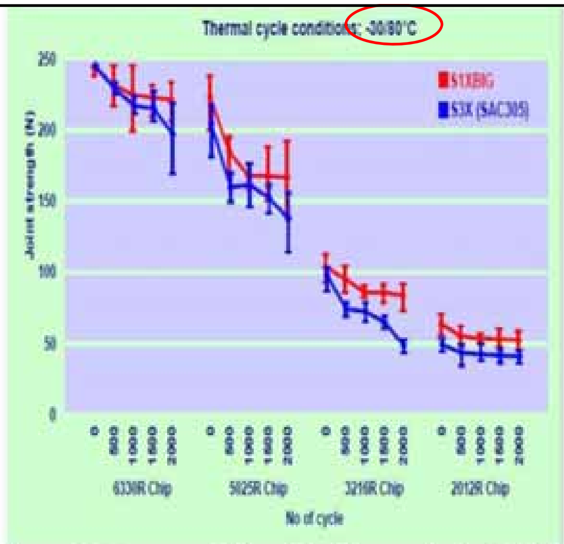


Figure 33. Summary of thermal cycling results for S1XBIG versus Sn3Ag0.5Cu after shear testing of joints up to 2,000 ATC thermal cycles from -30°C to +80°C for 6330, 5025, 3216 and 2012 chip components.

*Jasbir Bath, Bath and Associates Consultancy LLC; Munehiko Nakatsuma, Takehiro Wada, Kimiaki Mori, Koichi Shimokawa, Takeshi Shira, Atsushi Irisawa, and Roberto Garcia, Koki Company Limited, "A Study of Lead-free, Low Silver Solder Alloys with Nickel Additions", SMTA International, Fort Worth, TX, October 13-17, 2013

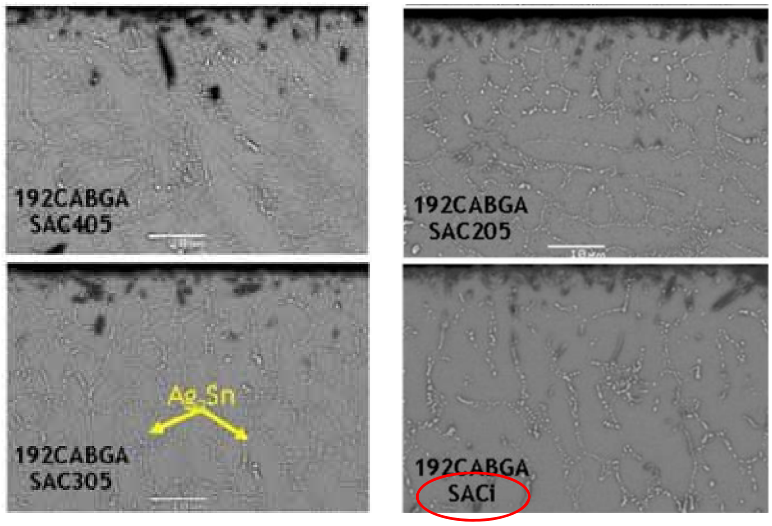
44

SACi (Sn1.7Ag0.6Cu0.4Sb)

*Richard Coyle, Ph.D., Joseph Smetana and Peter Reed, Alcatel-Lucent; Richard Parker, iNEMI; Aileen Allen and Elizabeth Benedetto, Hewlett-Packard Co.; Keith Howell and Keith Sweatman, Nihon Superior Co. Ltd.; Stuart Longgood, Delphi; Babak Arfaei, Universal Instruments Corporation and Francis Mutuku, Binghamton University, "iNEMI PB-Free Alloy Characterization Project Report: Part VIII – Thermal Fatigue Results for High-AG Alloys at Extended Dwell Times", SMTA International, Rosemont, IL, Sept 28-Oct 2, 2014

45

Backscattered electron micrographs of baseline microstructures of SAC405, SAC305, SAC205, and SACi for the 192CABGA.



*Richard Coyle, Ph.D., Joseph Smetana and Peter Reed, Alcatel-Lucent; Richard Parker, iNEMI; Aileen Allen and Elizabeth Benedetto, Hewlett-Packard Co.; Keith Howell and Keith Sweatman, Nihon Superior Co. Ltd.; Stuart Longgood, Delphi; Babak Arfaei, Universal Instruments Corporation and Francis Mutuku, Binghamton University, "iNEMI PB-Free Alloy Characterization Project Report: Part VIII – Thermal Fatigue Results for High-AG Alloys at Extended Dwell Times", SMTA International, Rosemont, IL, Sept 28-Oct 2, 2014

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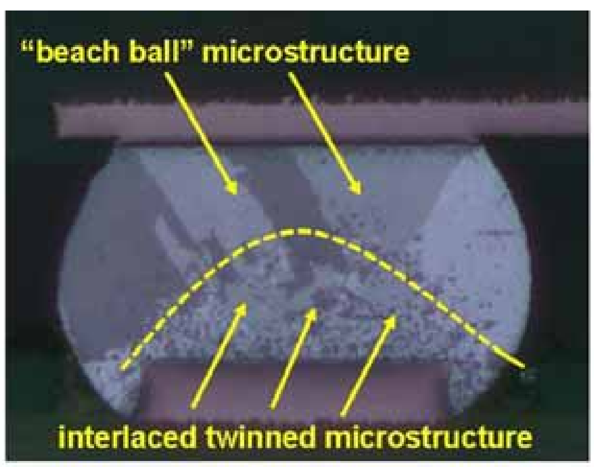

Figure 4: Polarized light micrograph of a SAC405 ball containing regions with beach ball and interlaced twinned microstructures.

*Richard Coyle, Ph.D., Joseph Smetana and Peter Reed, Alcatel-Lucent; Richard Parker, iNEMI; Aileen Allen and Elizabeth Benedetto, Hewlett-Packard Co.; Keith Howell and Keith Sweatman, Nihon Superior Co. Ltd.; Stuart Longgood, Delphi; Babak Arfaei, Universal Instruments Corporation and Francis Mutuku, Binghamton University, "iNEMI PB-Free Alloy Characterization Project Report: Part VIII – Thermal Fatigue Results for High-AG Alloys at Extended Dwell Times", SMTA International, Rosemont, IL, Sept 28-Oct 2, 2014

47

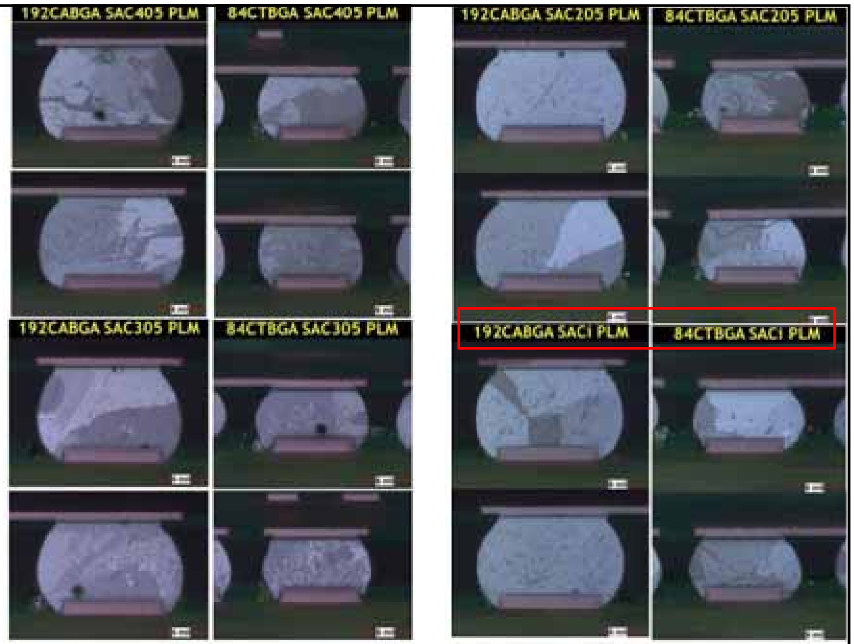

Figure 5: Polarized light micrographs of SAC405 and SAC305 baseline microstructures in the 192CABGA and 84CTBGA components. Additional micrographs for these alloys are provided in Appendix A.

Figure 6: Polarized light micrographs of SAC205 and SAC[i] baseline microstructures in the 192CABGA and 84CTBGA components. Additional micrographs for these alloys are provided in Appendix A.

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*Richard Coyle, Ph.D., Joseph Smetana and Peter Reed, Alcatel-Lucent; Richard Parker, iNEMI; Aileen Allen and Elizabeth Benedetto, Hewlett-Packard Co.; Keith Howell and Keith Sweatman, Nihon Superior Co. Ltd.; Stuart Longgood, Delphi; Babak Arfaei, Universal Instruments Corporation and Francis Mutuku, Binghamton University, "iNEMI PB-Free Alloy Characterization Project Report: Part VIII – Thermal Fatigue Results for High-AG Alloys at Extended Dwell Times", SMTA International, Rosemont, IL, Sept 28-Oct 2, 2014

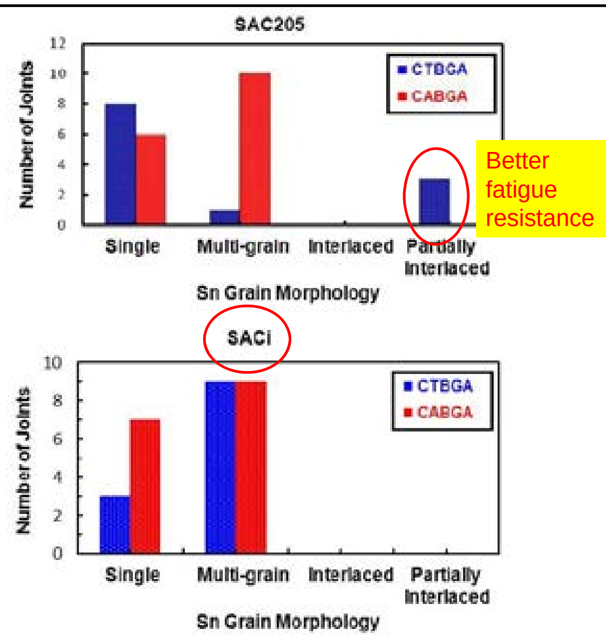

Figure 9: Bar charts summarizing the Sn grain morphology measurements for the SAC205 and SACi alloys.

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*Richard Coyle, Ph.D., Joseph Smetana and Peter Reed, Alcatel-Lucent; Richard Parker, iNEMI; Aileen Allen and Elizabeth Benedetto, Hewlett-Packard Co.; Keith Howell and Keith Sweatman, Nihon Superior Co. Ltd.; Stuart Longgood, Delphi; Babak Arfaei, Universal Instruments Corporation and Francis Mutuku, Binghamton University, "iNEMI PB-Free Alloy Characterization Project Report: Part VIII – Thermal Fatigue Results for High-AG Alloys at Extended Dwell Times", SMTA International, Rosemont, IL, Sept 28-Oct 2, 2014

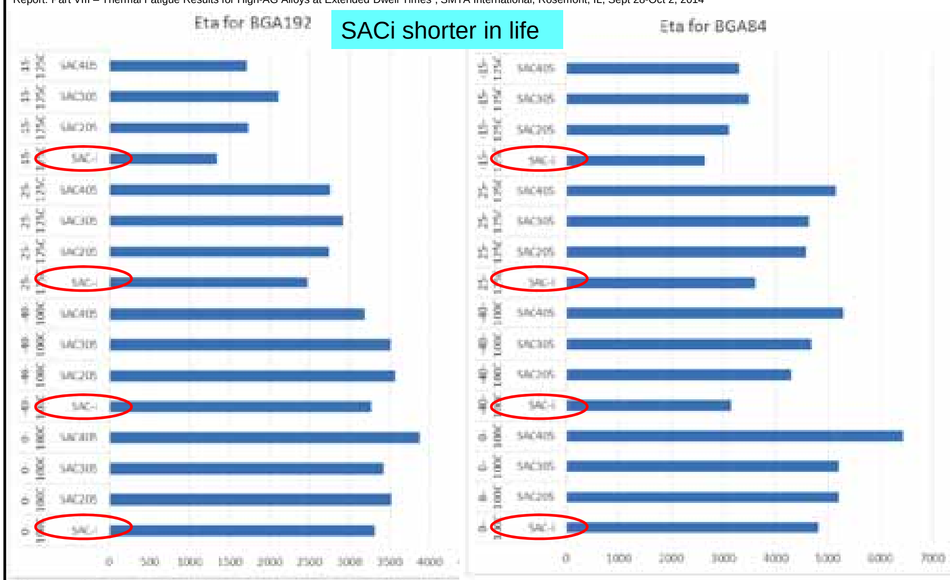

Figure 7: Bar charts illustrating the reliability of 192CABGA component.

Figure 8: Bar charts illustrating the reliability of the 84CTBGA component.

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SAC2508+NiBi

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

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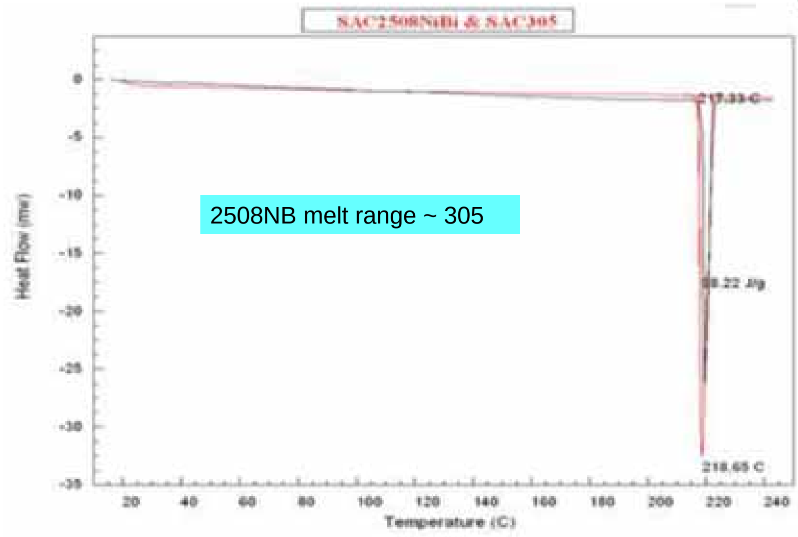

Figure 1. DSC curve of the solder alloys and hardness

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

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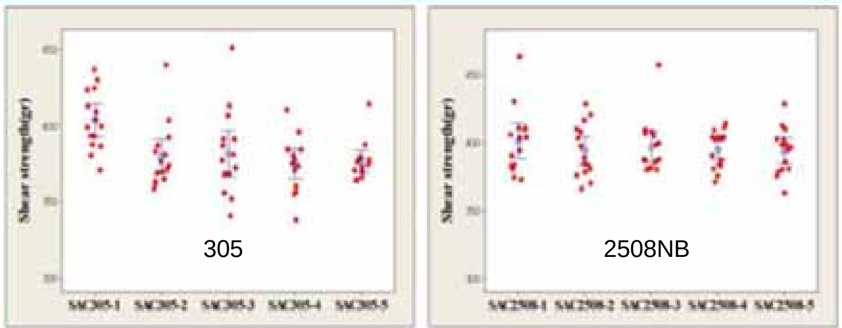
2508NB wet faster than others

Table 1. Wetting force and zero-cross time from graph of Fig. 2

Wetting time (sec)	Zero-cross time (sec)	Meniscus force (mN)
2508(ref)	1.30	6.41
2508-Ni	1.19	6.16
2508-Bi	0.96	6.36
SAC305	1.12	6.16
2508-Ni-Bi	0.89	6.77

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

53 Shear strength comparable at normal shear speed



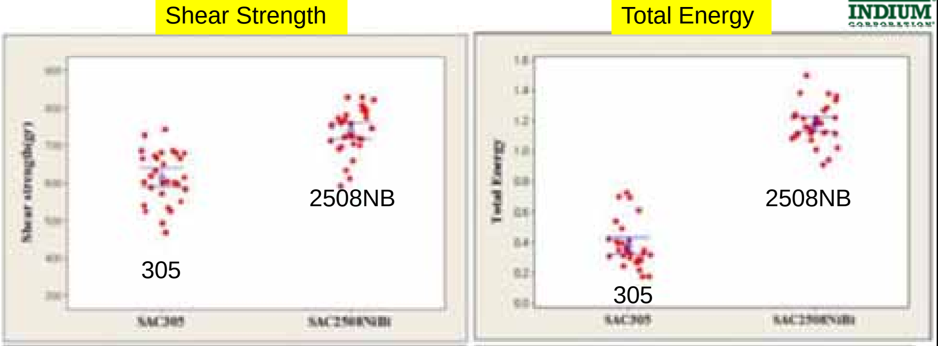
	Reflow #1	Reflow #2	Reflow #3	Reflow #4	Reflow #5
ADV.	401.6	379.3	380.6	373.4	376.5
SD.	19.3	20.7	27.5	17.7	12.7

	Reflow #1	Reflow #2	Reflow# #3	Reflow #4	Reflow #5
ADV.	401.4	393.7	397.5	395.8	394.4
SD.	23.5	19.4	20.0	14.0	16.9

Figure 4. Shear strength of solder alloys after different reflow times (Normal speed shear test).

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

54 At high speed shear test, 2508NB is tougher than 305



	SAC305	SAC2508NiBi
ADV.	614.05	739
SD.	60.8	61.8

	SAC305	SAC2508NiBi
ADV.	0.379	1.180
SD.	0.146	0.129

Figure 5. Shear strength and total energy of Sn-3.0Ag-0.5Cu and Sn-2.5Ag-0.8Cu-Ni-Bi solders in high speed shear test.

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

55

2508NB higher shear energy

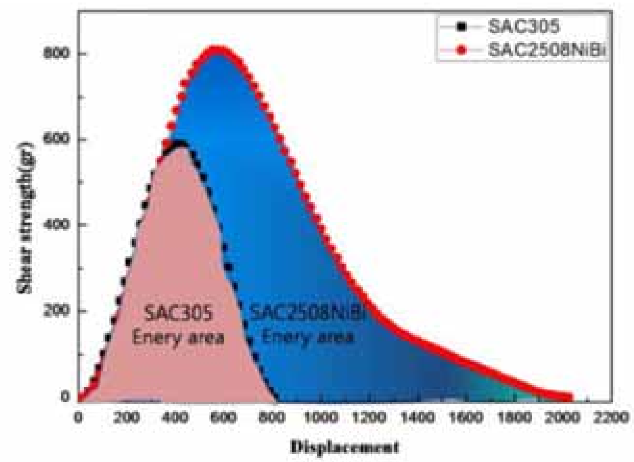


Figure 6. Shear strength-displacement curve of Sn-3.0Ag-0.5Cu and Sn-2.5Ag-0.8Cu-Ni-Bi solders (High speed shear test)

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

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Brittle failure

Ductile failure

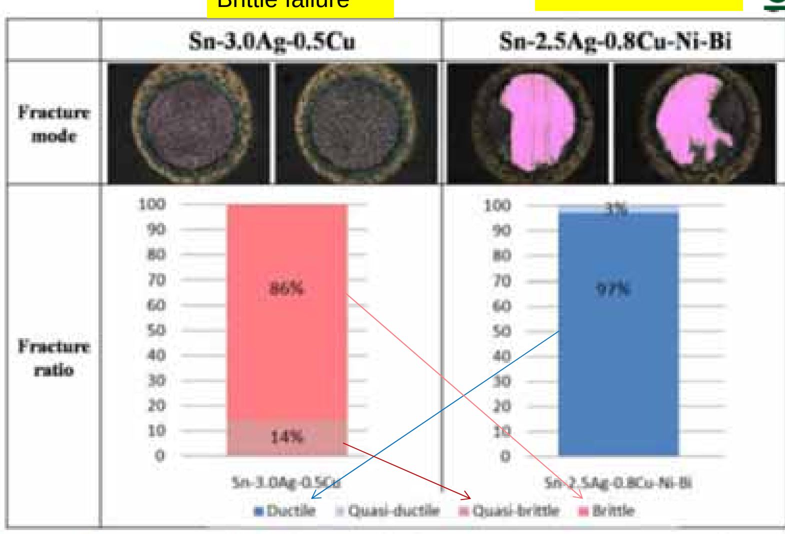

Figure 7. Result of high speed shear test (Fracture mode and fracture ratio)

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

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2508NB is free from Ag3Sn IMC platelet formation

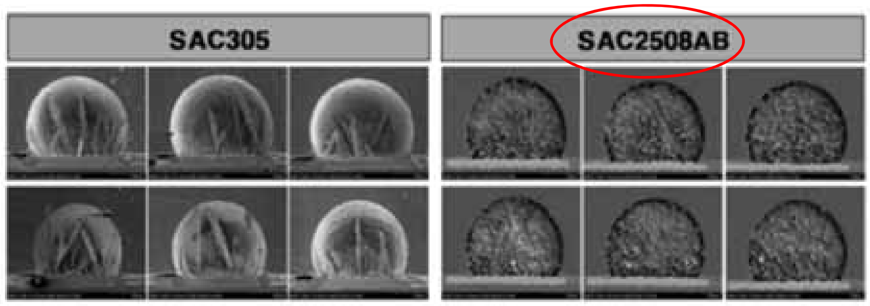

Figure 8. SEM image of solders after multiple reflows (Samples half etched)

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

58

2508NB better in TCT reliability than 305

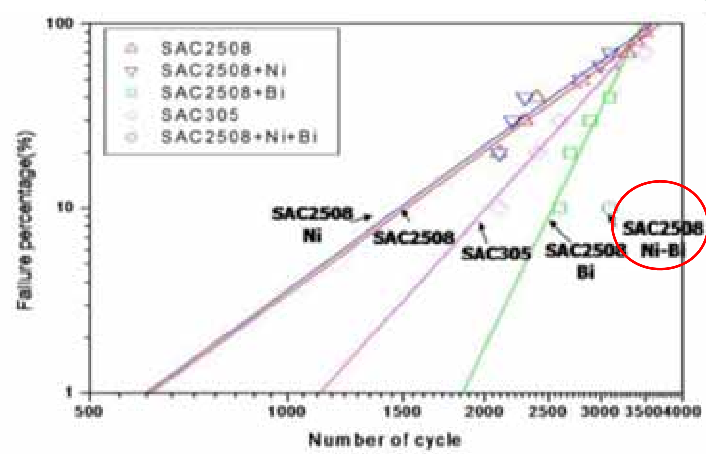

Figure 10. Weibull distribution curve showing Thermal cycling reliability (number of cycles to failure) of solder alloys

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

59

2508NB better in drop test reliability than 305 (& 105)

Drop Test

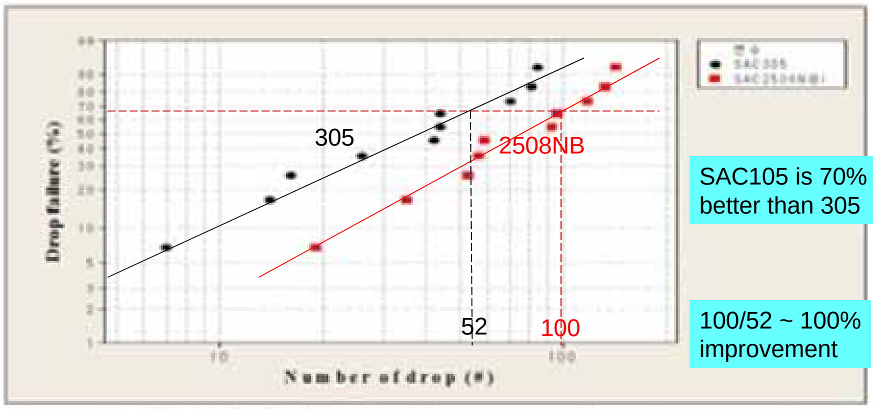

Figure 11. Weibull distribution curve showing number of drops to failure of solder alloys

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

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Conclusion

Following results are confirmed during the development of high drop and thermal cycling performance solder having composition Sn-2.5Ag-0.8Cu-Ni-Bi. 1) The effect of addition of Ni is to reduce the IMC thickness during the formation of solder joint and ageing. 2) The Bi effect is to refine the bulk microstructure and the formation of dense Ag3Sn network even after multiple reflows. 3) The shear strength and fracture toughness of Sn-2.5Ag-0.8Cu-Ni-Bi solder is higher than Sn-3.0Ag-0.5Cu solder. This confirms the higher ductility of Sn-2.5Ag-0.8Cu-Ni-Bi solder. 4) The hardness of Sn-2.5Ag-0.8Cu-Ni-Bi solder is lower than Sn-3.0Ag-0.5Cu solder. 5) Sn-2.5Ag-0.8Cu-Ni-Bi solder shows much higher drop and thermal cycling performance as compared to Sn-3.0Ag-0.5Cu solder.

Jae Hong Lee, MK Electron, Ltd.; Santosh Kumar, MK Electron, Ltd.; Hui Joong Kim, MK Electron, Ltd.; Young Woo Lee, MK Electron, Ltd.; Jeong Tak Moon, MK Electron, Ltd., "High Thermo-Mechanical Fatigue and Drop Impact Resistant Ni-Bi Doped Lead Free Solder", ECTC, p712-716, Orlando, FL, May 27-30, 2014

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(Indium 276)
Sn3.2Ag0.7Cu5.5Sb

(Automotive applications)

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Solder Powders and their compositions

Powder	Lot#	Sn	Ag	Cu	Bi	Sb	Co	Ni	Solidus	Liquidus
SAC305	PD1856	96.5	3	0.5						
Innolot/270	22085A	90.9	3.8	0.7	3	1.45		0.15		
M794	22086A	89.44	3.4	0.7	3.2	3	0.2	0.06		
ACBSCo	22087A	89.65	3.4	0.7	3.2	3	0.05		210.14	225.38
276	22084A	90.6	3.2	0.7		5.5			223.62	232.67
271	22097A	88.9	3.8	1	0.3	6			222.85	231.46

Flux: 8.9HF and 10.1HF

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TCT of using Si Die/Ni

-40C/125C temp cycling

Die Size: 3mmx3mm		Si Die										
		Si/Ni 10.1					271		276			
	Alloy	SAC305	Innolot	SI6005	SN30	SN60	SB6003	Sb3.5	Sb5.5	Sb8.0	SB2810	SB3810
As-reflowed	Mean (kg)											
	Std (kg)											
"-40~125@600	Mean (kg)	36.9	57.04	49.27	50.02	43.85	36.94	54.16	56.01	50.38	36.23	56.2
	Std (kg)	2.15	16.83	3.25	2.77	6.9	5.47	4.64	2.26	4.27	7.45	5.31
"-40~125@1500	Mean (kg)	27.36	53.37	32.37	37.81	34.19	20.4	40.13	47.32	39.7	21.43	40.69
	Std (kg)	1.72	12.42	3.38	7.32	7.62	5.64	2.43	3.63	1.04	8.26	9.51
Rank		12	1	11	8	9	14	5	2	6	13	4
				Indalloy #276 Similar								Indalloy #272 Similar

SAC3207+5.5Sb nearly the top for medium test condition.

Innolot perform best, 305 very poor.

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TCT of using Invar Die

-40 to 175°C temperature cycling

Invar Die on Cu coupon

Die Size 3mmx3mm	Invar Die											276		271
		Invar /Cu AF												
	Alloy	SAC305	Innolot	SI6005	SI3520Ni	SI3520Bi	SI3520	SI3025	SI3505	SI3540	Sb3.5	Sb5.5	Sb8.0	SB6003	SB3515
As-reflowed	Mean (kg)	62.25	62.39	80.86	71.76	77.46	69.26	68.32	74.21	77.25	75.07	86.54	84.64	79.84	83.62
	Std (kg)	3.28	5.18	15.08	9.51	11.08	8.19	7.44	13.41	1.58	6.77	8.86	5.34	13.24	5.03
"-40~175@1360	Mean (kg)	17.28	3.34	24.76	15.4	9.4	26.11	24.52	27.88	29.14	26.37	19.08	22.93	17.88	12.94
	Std (kg)	1.7	1.41	6.41	7.58	1.82	4.01	6.99	3.55	3.84	2.91	7.96	5.44	4	9.66
"-40~175@2760	Mean (kg)	12.48	2.62	9.38	10.12	8.45	12.35	11.66	12.06	8.89	7.18	11.93	9.19	7.91	3.43
	Std (kg)	3.28	0.69	4.09	3.96	3.17	0.99	2.78	2.98	1.8	1.81	2.3	3.5	2.61	2.53
Rank		1	16	7	6	10	2	5	3	9	13	4	8	11	14
			Innolot	276 similar		277 similar									272

Invar Die on Ni Coupon

		Invar / Ni													
	Alloy	SAC305	Innolot	SI6005	SI3520Ni	SI3520Bi	SI3520	SI3025	SI3505	SI3540	Sb3.5	Sb5.5	Sb8.0	SB6003	SB3515
As-reflowed	Mean (kg)	55.98	74.09	68.23	41.01	58.78	60.8	73.93	61.19	63.44	80.58	74.8	77.54	75.63	70.43
	Std (kg)	6.76	6.68	5.26	4.91	3.43	6.36	4.05	11.19	7.77	7.86	4.24	3.72	5.07	5.97
"-40~175@1360	Mean (kg)	26.37	15.86	37.54	27.67	14.81	36.05	46.51	42.17	31.19	33.59	30.56	24.45	23.67	38.59
	Std (kg)	4.65	2.44	10.84	3.73	4.18	3.99	6.5	11.47	3.51	5.41	7.55	5.44	6.16	3.1
"-40~175@2760	Mean (kg)	15.43	4.03	22.95	11.09	8.79	19.26	19.05	11.98	6.9	21.27	33.55	25.51	7.51	2.46
	Std (kg)	6.12	0.88	4.32	4.87	2.45	4.48	3.46	3.65	1.92	4.65	6.63	5.52	3.48	0.87
Rank		7	14	3	9	11	5	6	8	13	4	1	2	12	16
			Innolot	276 similar		277 similar									272
Total rank (@2760c)		8	30	10	15	21	7	11	11	22	17	5	10	23	30

At harsh test condition, SAC3207+5.5Sb best.

305 perform well. Innolot the worst.

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Summary

- Innolot best at medium condition, worst at harsh condition.
- 305 poor at medium condition, good at harsh condition.
- SAC3207+5.5Sb near top at medium condition, best at harsh condition.

- Innolot very creep resistant at medium condition, cracked at high dimension mismatch due to too rigid.
- 305 ductile, not creep resistant enough at medium condition, but won't crack at high dimension mismatch.
- SAC3207+5.5Sb balanced in both high creep resistant and ductile, thus perform well at both medium & harsh conditions.

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Thank You