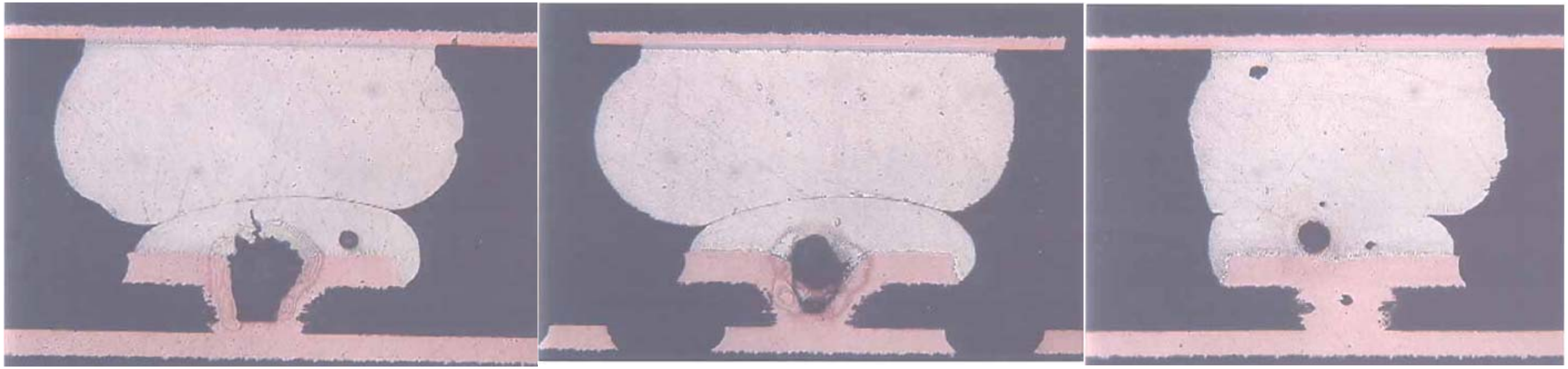
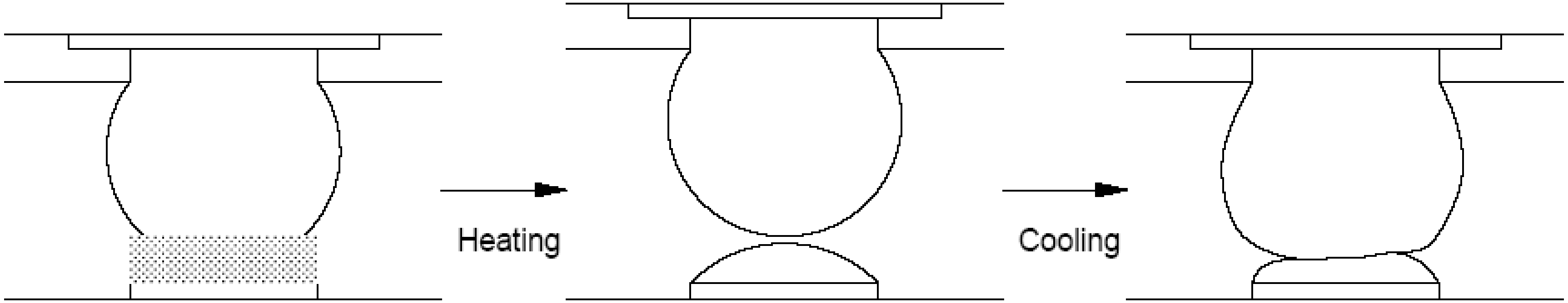
Reliability of BGA Assembly

Dr. Ning-Cheng Lee
Indium Corporation

HIP (Head-In-Pillow)

Unwetted SAC387 BGA Joints



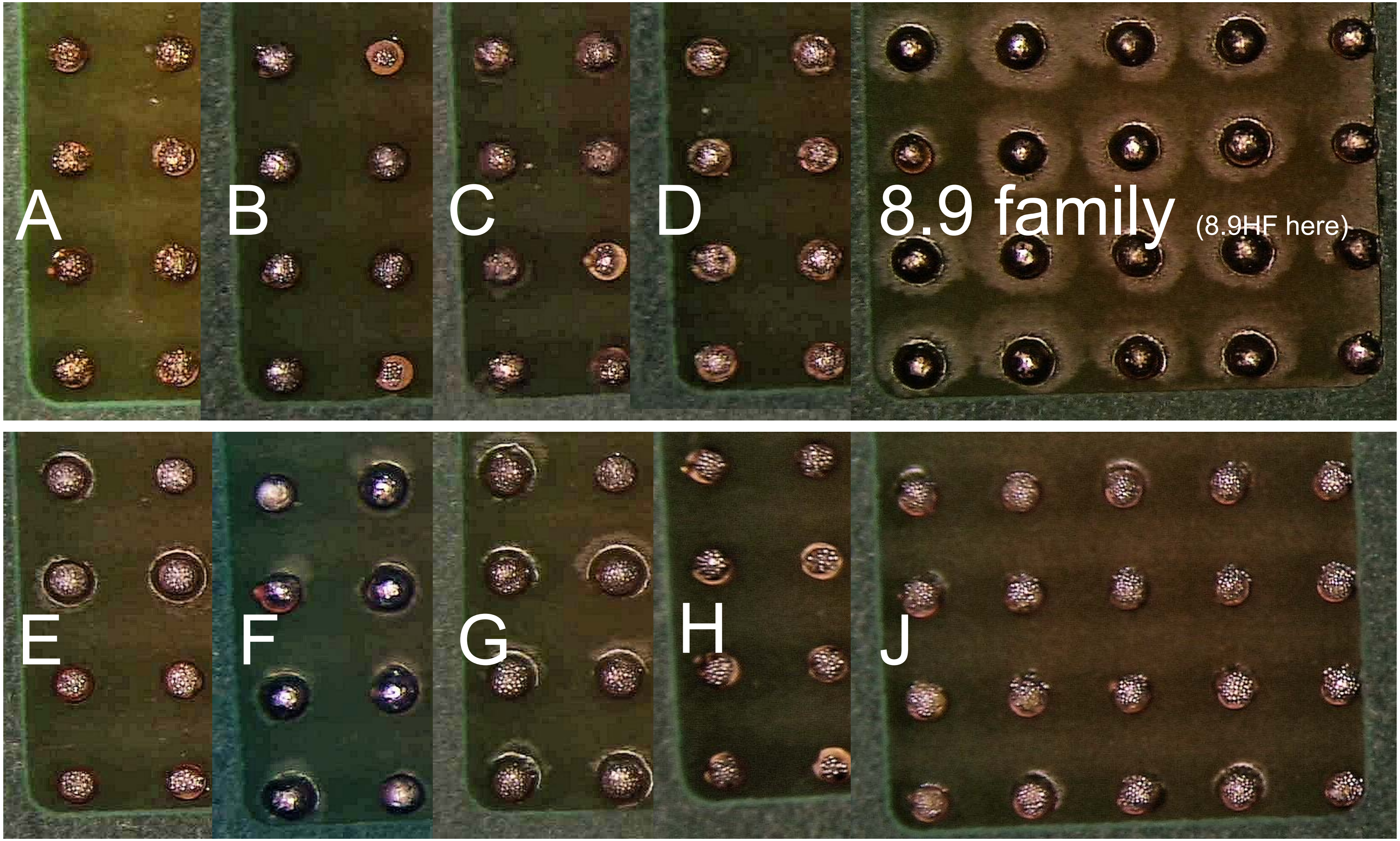


BGA placed on solder paste

Increased spacing due to warping.
Both sides in liquid state.

Spacing closed down at cooling,
contacting each other after solidification

Oxidation Barrier Capability Examples



Oxygen & Warpage Gap Effect

- Small warp (Nitrogen)
  - Good joints
- Small warp (Air)
  - Some opens (oxygen effect)
- Large warp (Air)
  - All opens (oxygen + gap effect)

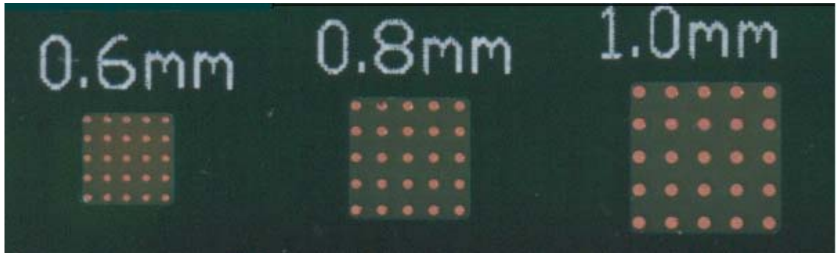
Warpage + Excessive Oxidation

- Cure:
  - Warpage
    - Approaches used for Type 2 to reduce the impact of warpage
  - Oxidation
    - Process:
      - Use reducing atmosphere (reduce oxygen concentration)
      - Reduce preheat/soaking/dwell time & temperature
      - Dip BGA balls in tacky flux prior to placement
      - Print more paste volume
      - Dip BGA in creamy flux, then place on printed solder paste
    - Material:
      - Use solder alloy with more oxidation resistance
      - Use flux with greater oxidation barrier capability
      - Use flux with greater resistance against burn-off
      - Use flux with greater flux capacity

Oxidation Barrier Capability Assessment

(Tiny Dot Paste Method)

- Test pattern design
  - Circular pads with the following NSMD OSP pad/pitch dimension
    - 245 µ / 600 µ
    - 325 µ / 800 µ
    - 406 µ /1000 µ

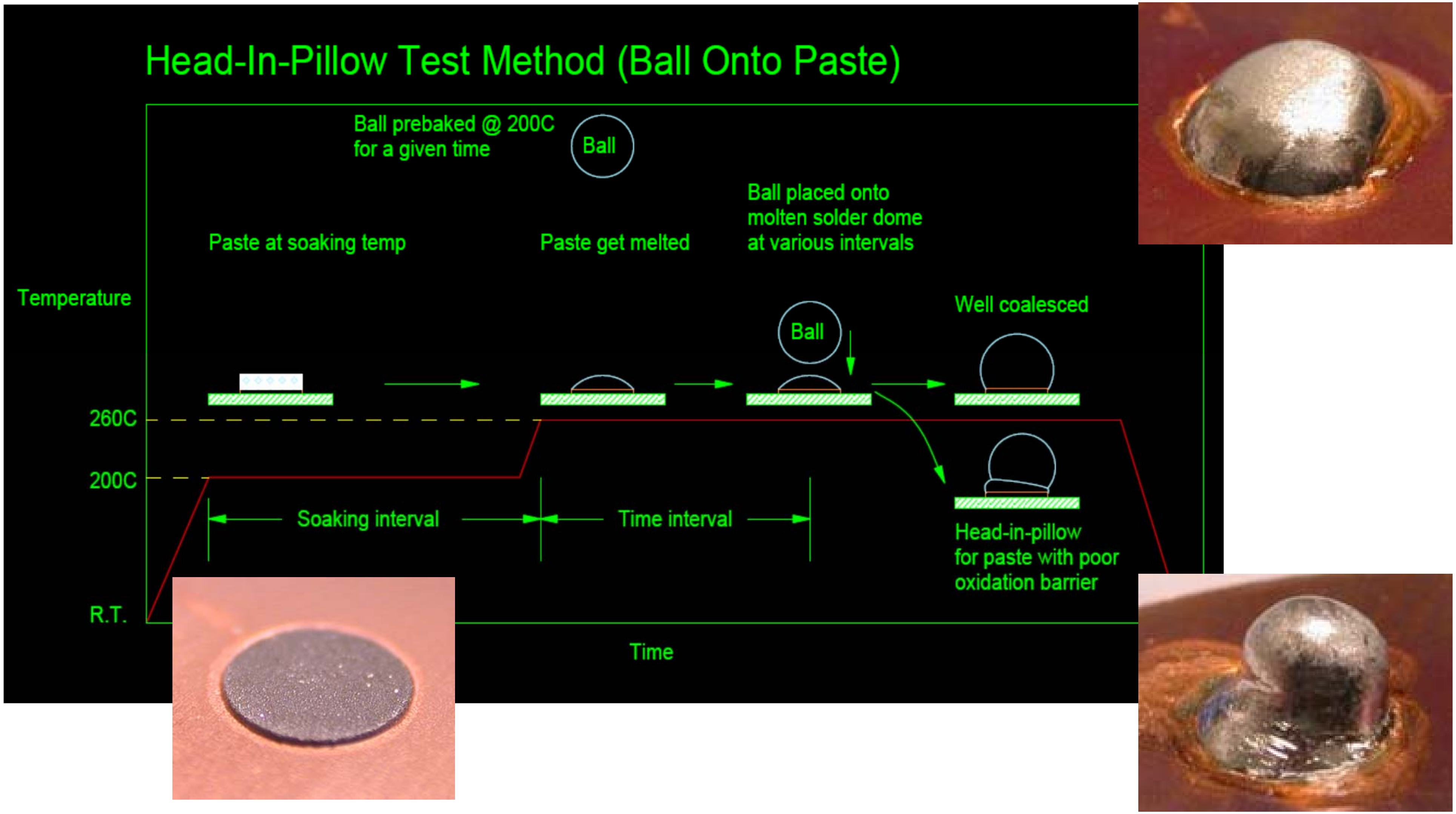


  - Stencil with 127 µ thickness, and opening the same as pad dimension

- Test Procedure
  - Print solder paste onto pads
  - Reflow through SS (short soaking) and LS (long soaking) profiles under air (see next slide)
  - Examine under microscope for graping performance
    - LS profile with smaller deposit is more vulnerable toward graping/HIP
    - The graping symptom of pastes can be ranked accordingly.
    - **The one with least graping is also the one most resistant toward HIP**

Oxidation Barrier Capability Assessment

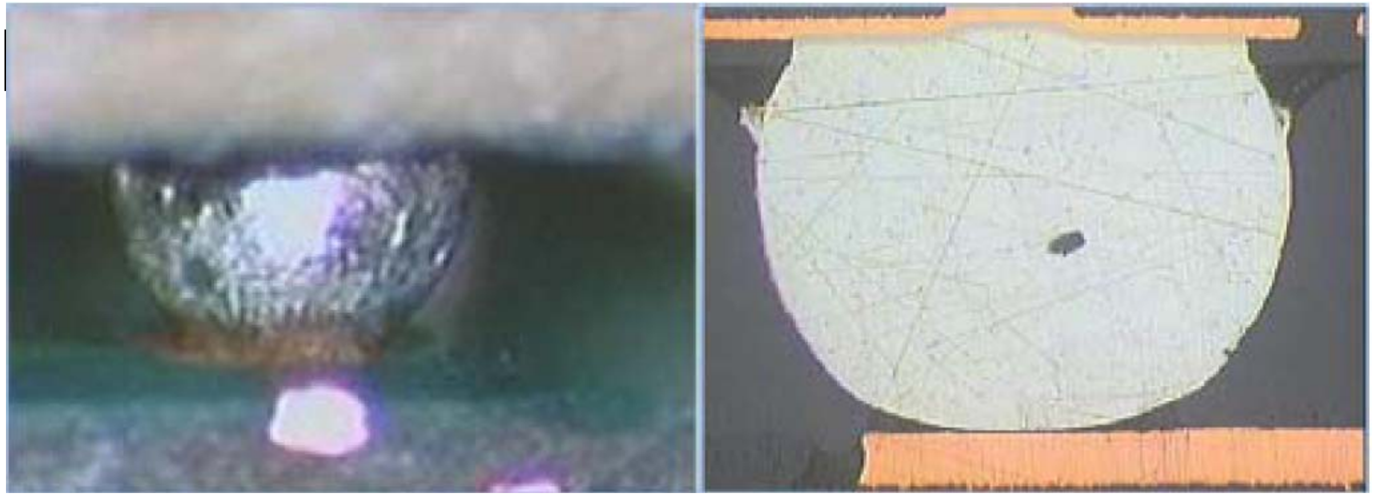
(Ball Onto Paste Method)



NWO (Non-Wet Open)

“Non Wet Open” Definition

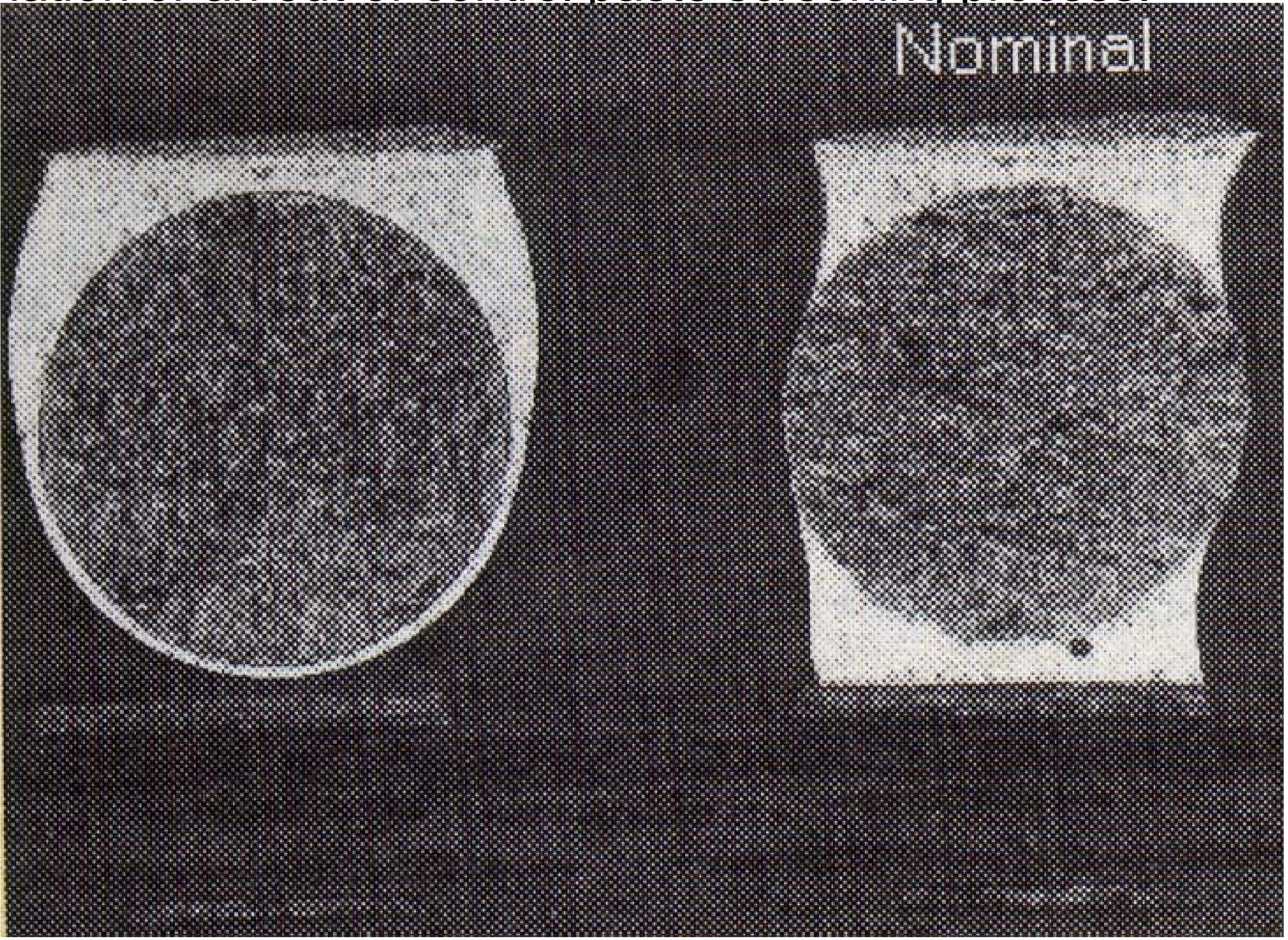
- A joint that is comprised of one metallurgical mass formed from the BGA ball and reflowed solder paste or flux with incomplete or no coalescence to the PCB pad. In most cases there is no evidence of so



Dudi Amir, Satyajit Walwadkar, Srinivasa Aravamudhan, and Lilia May (Intel), “THE CHALLENGES OF NON WET OPEN BGA SOLDER DEFECT”, SMTAI proceedings, p684-694, Oct. 14-18, 2012, Orlando, FL

Opens in Non-Collapsible BGA Joints

The open (left) is caused by pad contamination. Since the solder cannot wet to the PCB pad, it wicks up the solder ball to the component interface. An electrical test can not differentiate whether the open is caused by pad contamination or an out-of-control paste screening process.



Ref: S. Rooks, “Controlling BGA Assembly using X-ray Laminography”, EP&P, p. 24-30, Jan. 1997

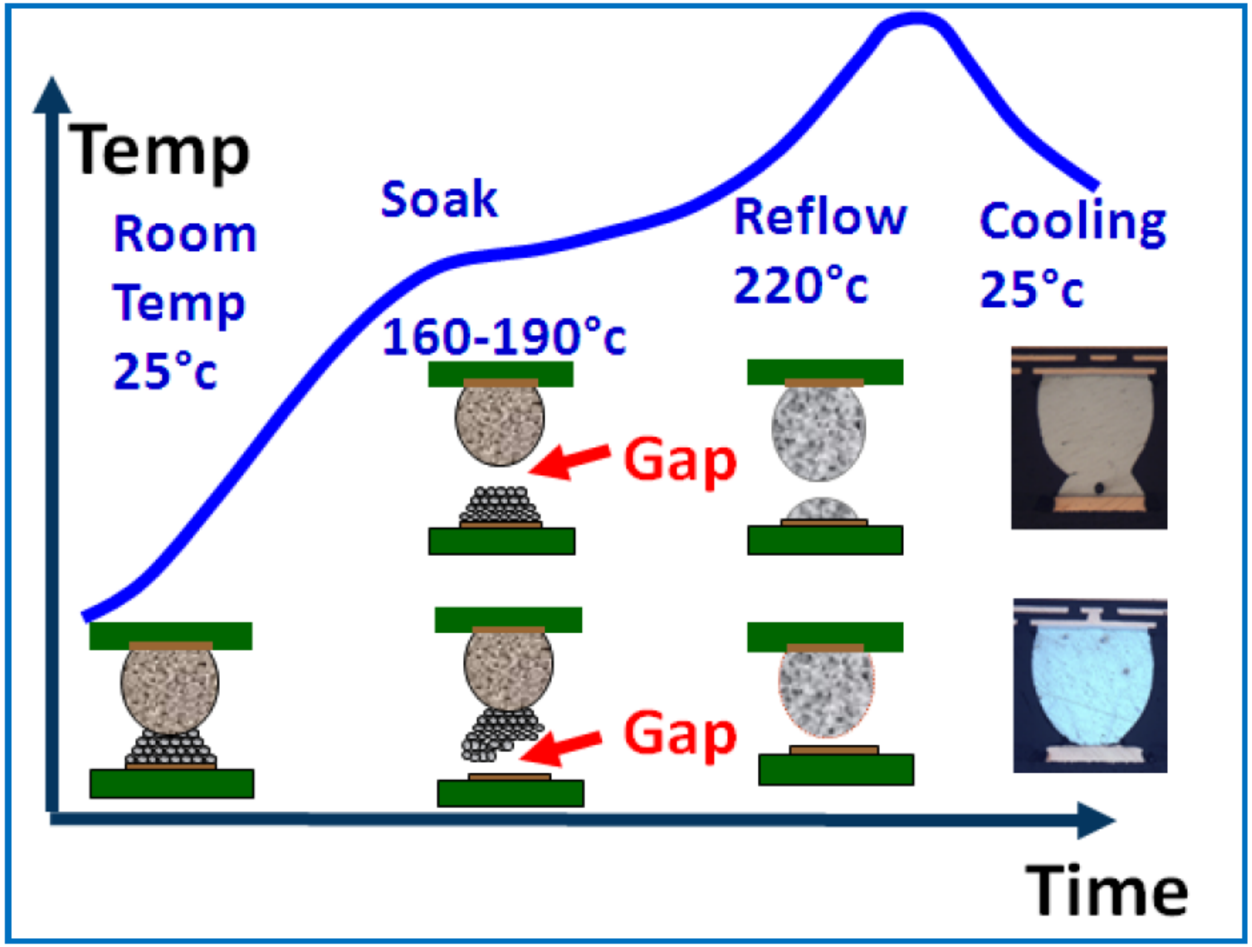


Figure 23. Formation of SMT defects

the main mechanism of NWO is the lifting of the solder paste from the PCB lands. This stage occurs when the package dynamic warpage is fairly low. However HoP's main mechanism is the ball to paste gap that exist during reflow when the dynamic warpage is at the highest point.

Dudi Amir, Satyajit Walwadkar, Srinivasa Aravamudhan, and Lilia May (Intel), "THE CHALLENGES OF NON WET OPEN BGA SOLDER DEFECT", SMTAI proceedings, p684-694, Oct. 14-18, 2012, Orlando, FL

Corner Joint

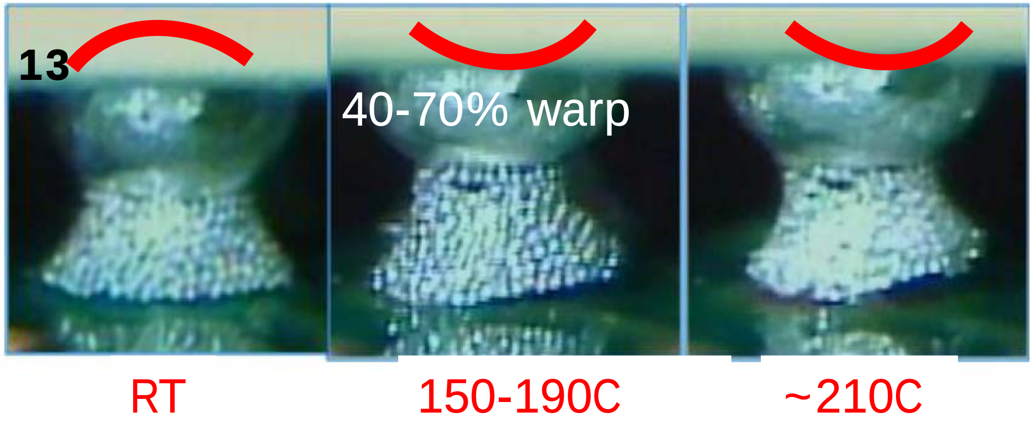


Figure 3. NWO defect formation pre-reflow

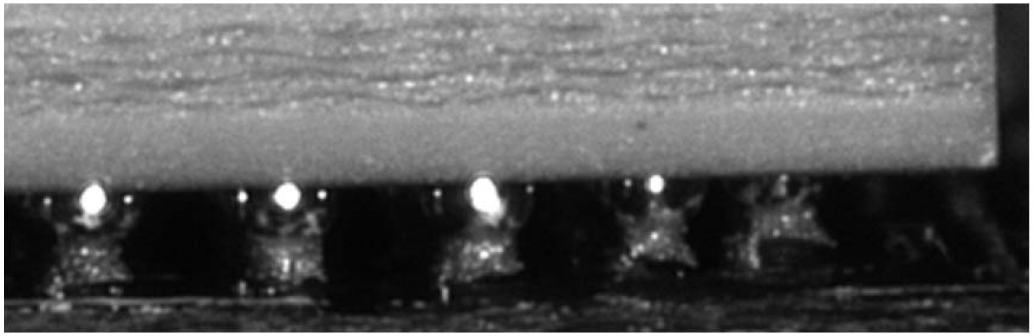


Figure 4. Lifted solder paste

(a) (b) (c)

Figure 5. NWO defect formation at reflow

Video

Dudi Amir, Satyajit Walwadkar, Srinivasa Aravamudhan, and Lilia May (Intel), “THE CHALLENGES OF NON WET OPEN BGA SOLDER DEFECT”, SMTAI proceedings, p684-694, Oct. 14-18, 2012, Orlando, FL

Paste Volume Control

Package Attributes	Package A	Package B
Package Size	31x24mm	32x37.5mm
Minimum Pitch	0.65mm	0.7mm
BGA Ball Size	16mil	17mil
Corner Pad Size	15mil	16mil

Table 2. Package Attributes

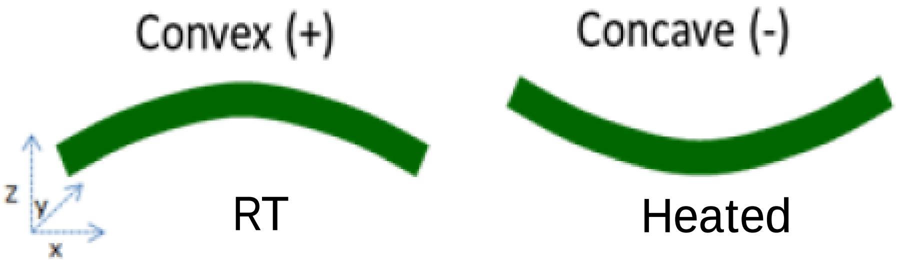
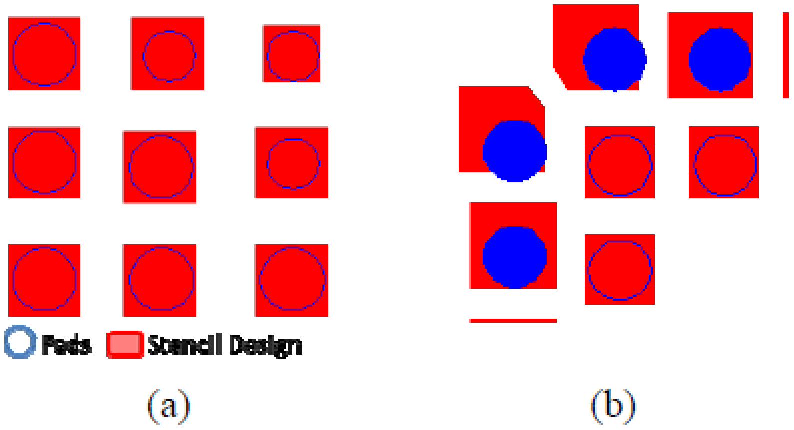


Figure 14. FCBGA warpage shape

Additional solder paste volume provides margin to overcome open defects.



(a) (b)

Figure 15. (a) Square over-print stencil design. (b) Additional over-print stencil design

Dudi Amir, Satyajit Walwadkar, Srinivasa Aravamudhan, and Lilia May (Intel), “THE CHALLENGES OF NON WET OPEN BGA SOLDER DEFECT”, SMTAI proceedings, p684-694, Oct. 14-18, 2012, Orlando, FL

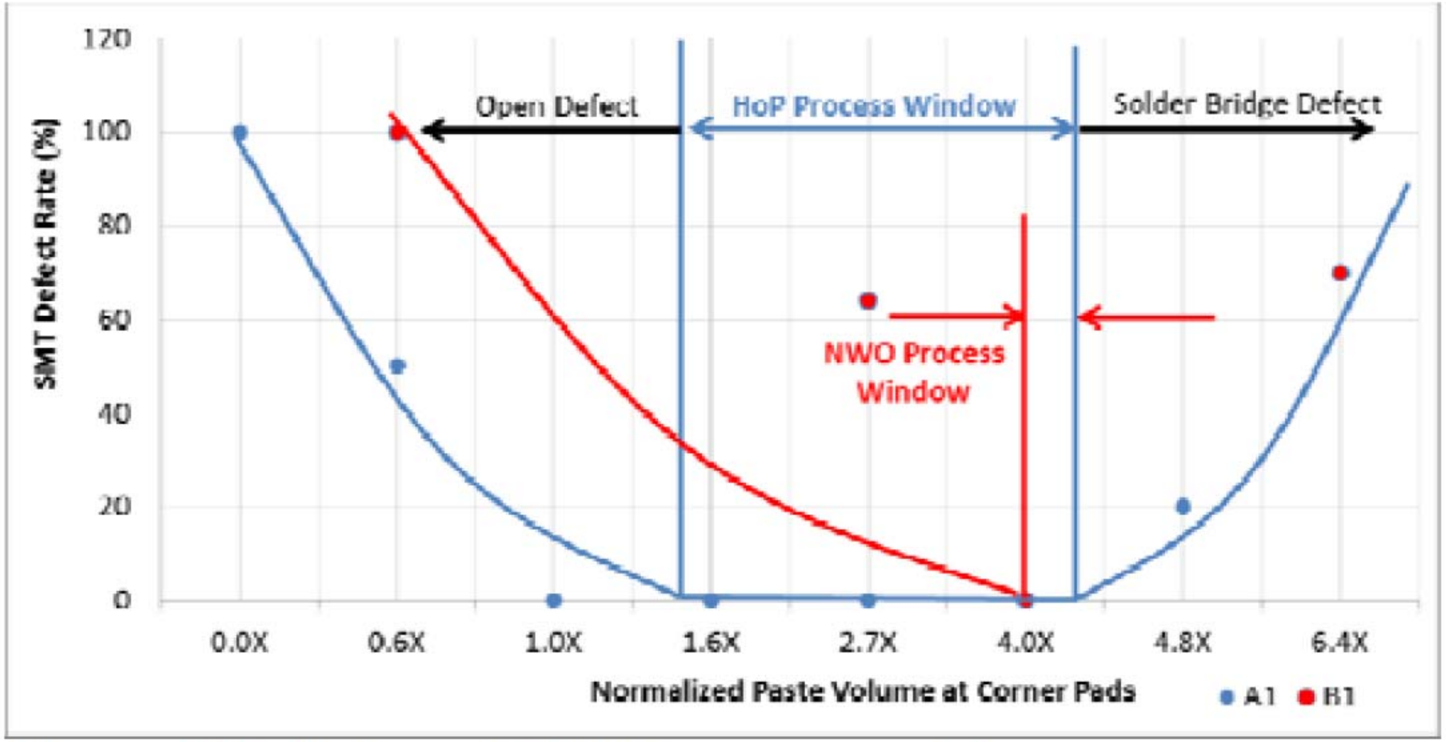
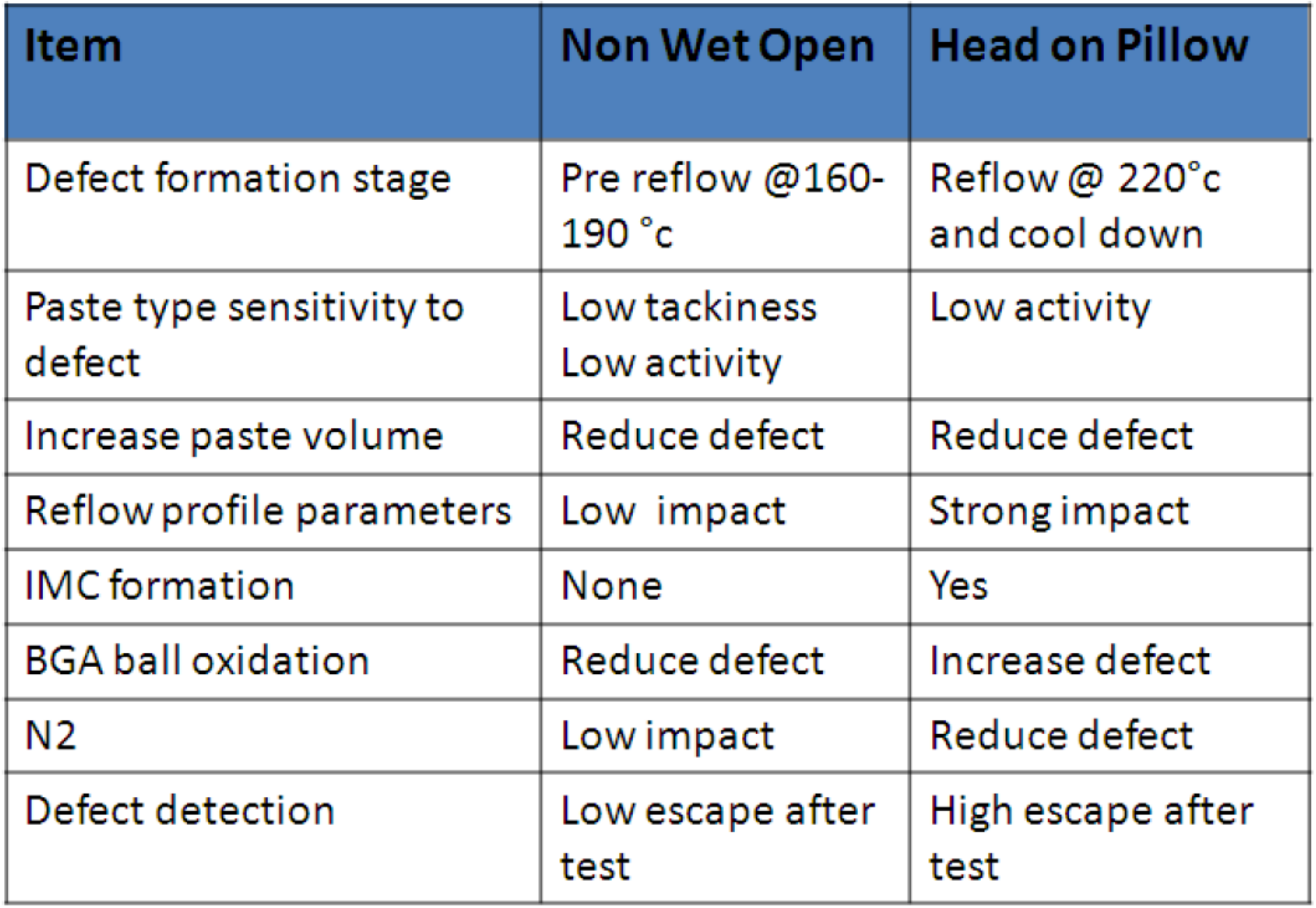


Figure 24. HoP and NWO process window

Dudi Amir, Satyajit Walwadkar, Srinivasa Aravamudhan, and Lilia May (Intel), “THE CHALLENGES OF NON WET OPEN BGA SOLDER DEFECT”, SMTAI proceedings, p684-694, Oct. 14-18, 2012, Orlando, FL

NWO vs HOP



Item	Non Wet Open	Head on Pillow
Defect formation stage	Pre reflow @160-190 °c	Reflow @ 220°c and cool down
Paste type sensitivity to defect	Low tackiness Low activity	Low activity
Increase paste volume	Reduce defect	Reduce defect
Reflow profile parameters	Low impact	Strong impact
IMC formation	None	Yes
BGA ball oxidation	Reduce defect	Increase defect
N2	Low impact	Reduce defect
Defect detection	Low escape after test	High escape after test

Table 9. HoP and NWO comparison table

Dudi Amir, Satyajit Walwadkar, Srinivasa Aravamudhan, and Lilia May (Intel), “THE CHALLENGES OF NON WET OPEN BGA SOLDER DEFECT”, SMTAI proceedings, p684-694, Oct. 14-18, 2012, Orlando, FL

Design for NWO Elimination

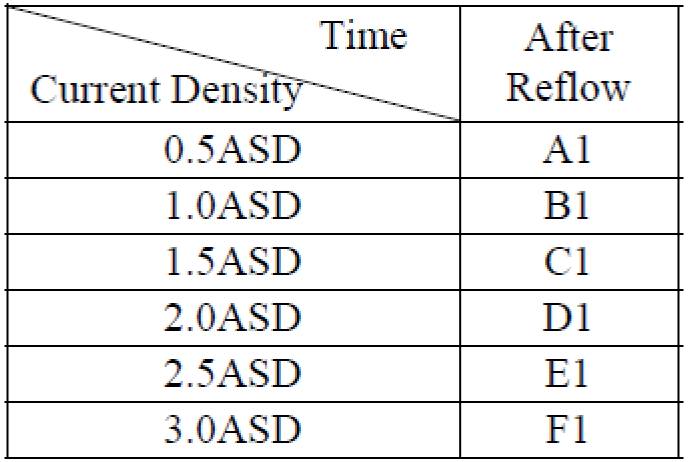
- Material Design
  - Select solder paste with solid state diffusion at hot stage (160-190C) (and with good oxidation resistance)
  - Print more paste volume at pads where BGA showed upward thermal warpage
  - Predip BGA in creamy flux (or epoxy flux), then place onto printed paste
- Process Design
  - Use long soaking profile will moderately reduce NWO
- Parts Design
  - Avoid use of OSP surface finish
  - Stiffen BGA package to reduce thermal warpage
  - Pre-oxidize solder bump of BGA

Design for Reliability

- Effect of Cu Pad Grain Size

Cu Grain Size Increase with Increasing Plating Current Density

ASD: amp per sq decimeter



Time Current Density	After Reflow
0.5ASD	A1
1.0ASD	B1
1.5ASD	C1
2.0ASD	D1
2.5ASD	E1
3.0ASD	F1

Cu surface roughness increased rapidly as plating current density increased (Fig.3).

From the FIB picture (Fig.4), the grain become larger with plating current increasing, the Cu grain size of F1 is 1-2μm, but the Cu grain size of A1 is 0.2-0.3μm.

Kenny Cao, KH Tan, CM Lai, Li Zhang (Jiangyin Changdian Advanced Package Company), “Solder Joints Reliability with Different Cu Plating Current Density in Wafer Level Chip Scale Packaging (WLCSP)”, 2009 International Conference on Electronic Packaging Technology & High Density Packaging (ICEPT-HDP), p.819-823

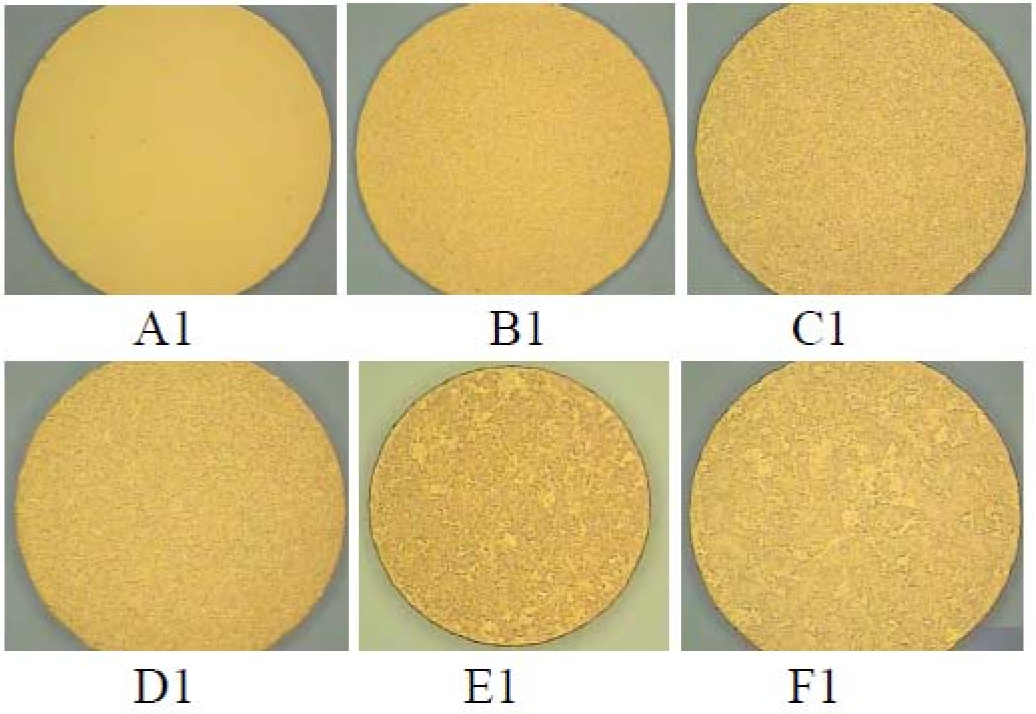

A1 B1 C1
D1 E1 F1

Fig.3. Plating Cu UBM surface picture for different plating current density

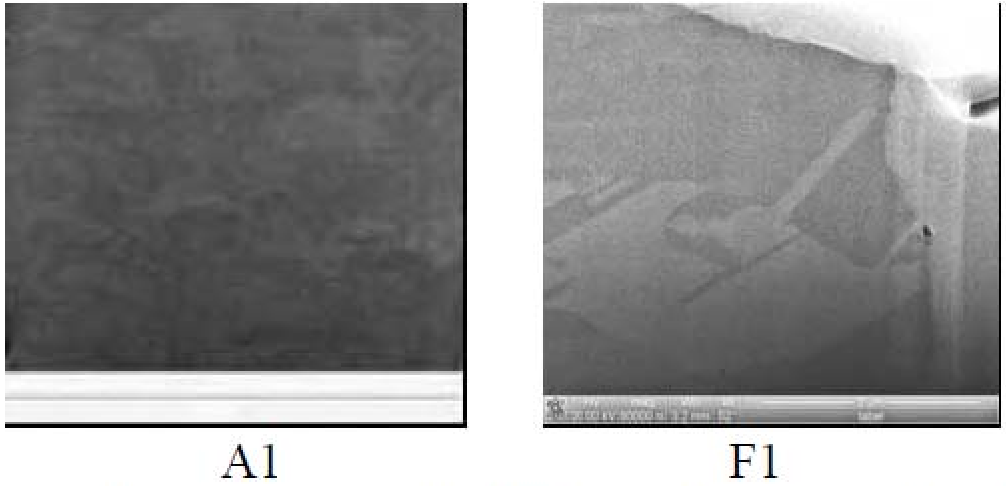

A1 F1

Fig.4. Cu grain picture for different plating current density

Atom Diffusion at Grain Boundary Faster Than at Grain

- In polycrystal Cu, the grain boundary would be as the direct path for atom diffusion, which have much greater diffusion rate than that in grain itself. The Cu grain size for larger plating current density is much greater than that lower plating current density, grain boundary supplies the easier diffusion path for fine grain structure.
- Kirkendall Voids: In fine grain microstructure vacancy should start forming at the site of grain boundary and Cu_3Sn interface, then the vacancies were accumulated together and formed the void, when the grain size is very small, voids will be linked and the initial crack generate.

H.F. Zou, "Morphologies, orientation relationships and evolution of Cu6Sn5 grains formed between molten Sn and Cu single crystals," *Acta Materialia*, No. 56 (2008), pp. 2649-2662.

Relation Between Plating Cu UBM Microstructure, IMC Layer Growth and Cu Plating Process

- The growth rate of total IMC layer and Kirkendall voids increased with decreasing Cu grain and increasing thermal aging time. After long aging time, there will be delamination between IMC and UBM layer.

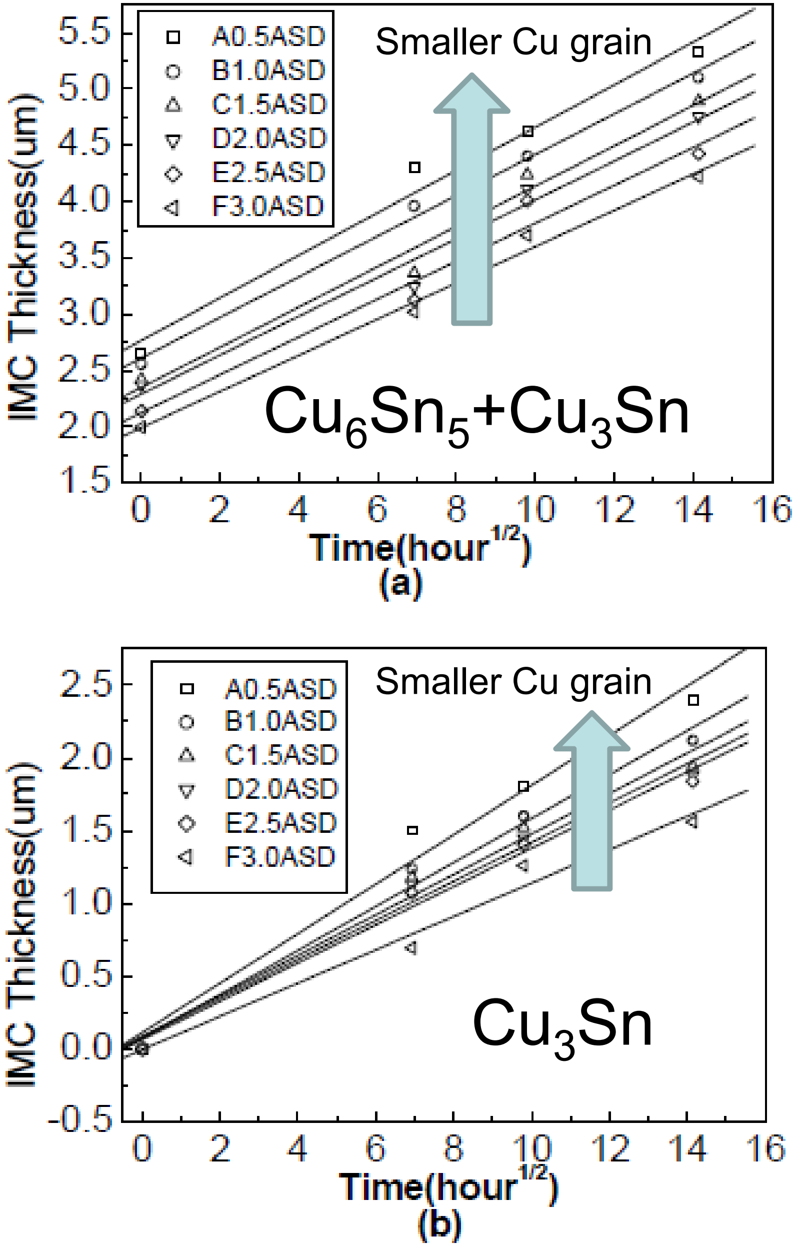
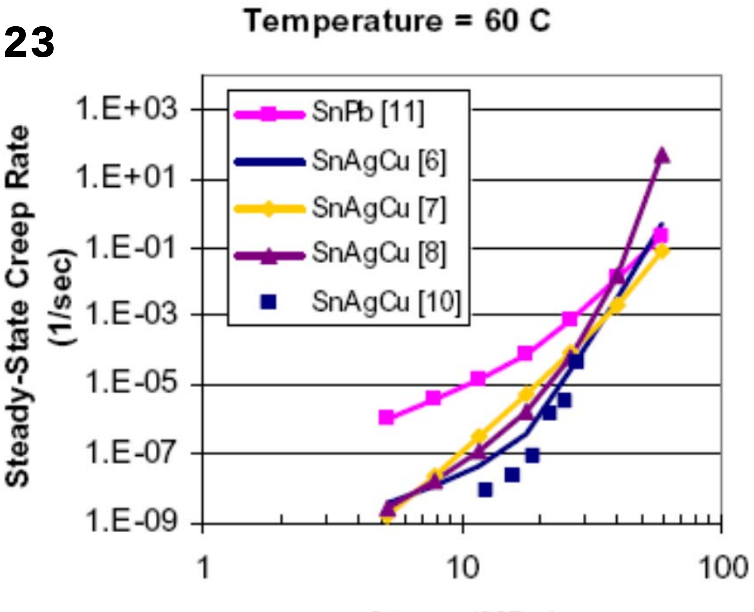


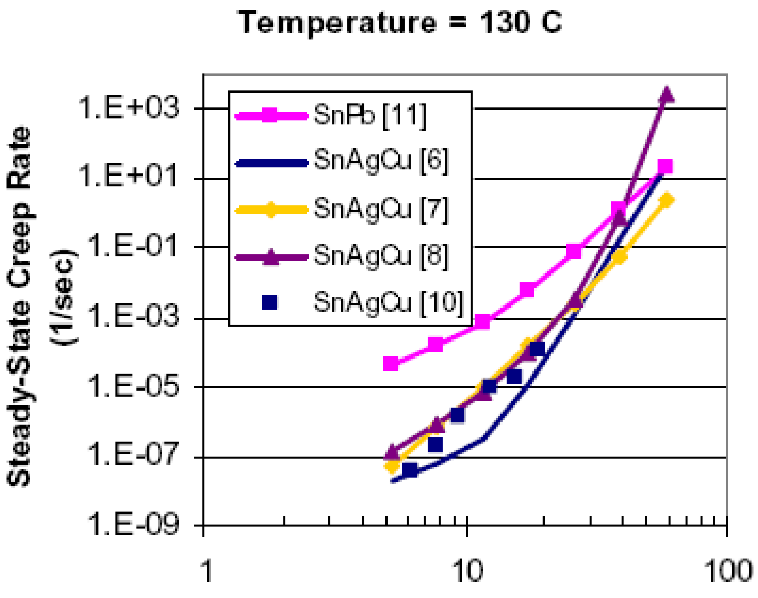
Fig.9. IMC layer thickness and Cu_3Sn versus time

Kenny Cao, KH Tan, CM Lai, Li Zhang (Jiangyin Changdian Advanced Package Company), “Solder Joints Reliability with Different Cu Plating Current Density in Wafer Level Chip Scale Packaging (WLCSP)”, 2009 International Conference on Electronic Packaging Technology & High Density Packaging (ICEPT-HDP), p.819-823

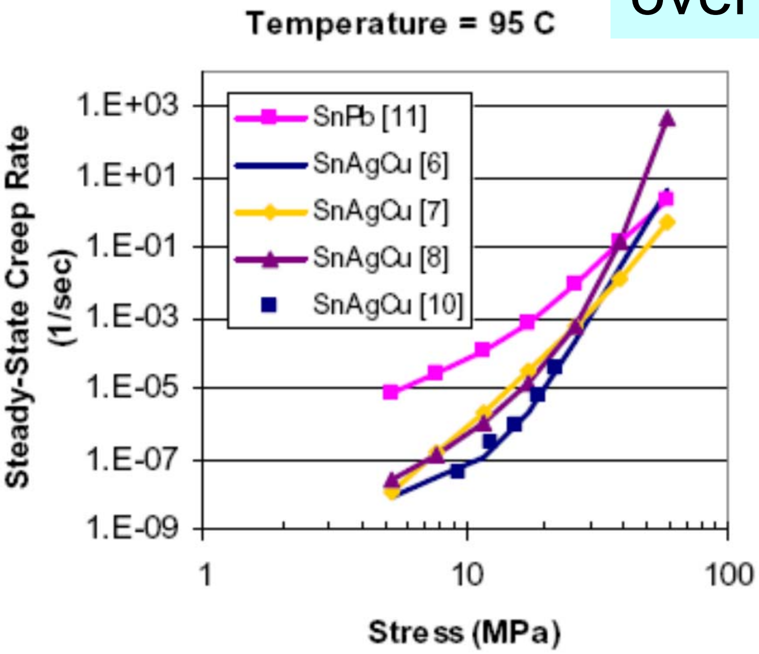
Design for Reliability

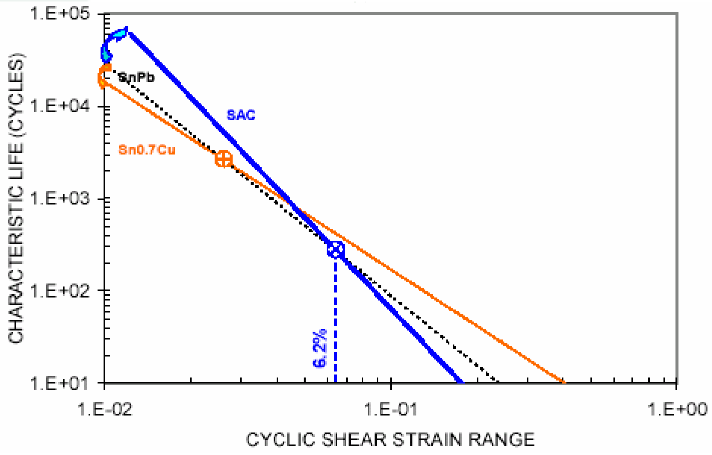
- Solder Alloy vs IMC





SAC creep rate curve cross over SnPb

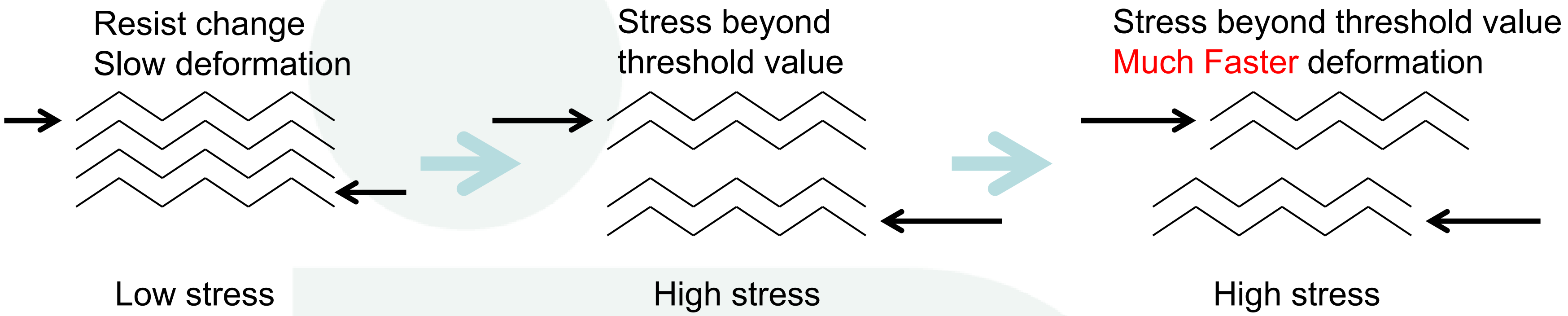




Ref: Ahmer Syed, " Accumulated Creep Strain and Energy Density Based Thermal Fatigue Life Prediction Models for SnAgCu Solder Joints", 54th ECTC, P.737-746, June 1-4, 2004, Las Vegas, Nevada.

Creep Behavior

System with Long Range Order



Resist change
Slow deformation

Low stress

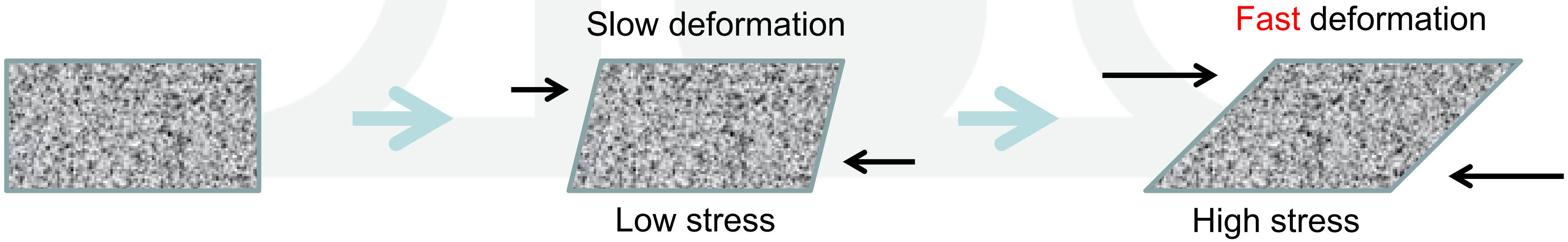
Stress beyond
threshold value

High stress

Stress beyond threshold value
Much Faster deformation

High stress

System without Long Range Order



Slow deformation

Low stress

Fast deformation

High stress

Reliability:

At low medium temp,

LF > SnPb (L)

At high medium temp,

SnPb > LF

Reliability decreases with increasing medium temp (ave of low & high) & increasing dwell time.

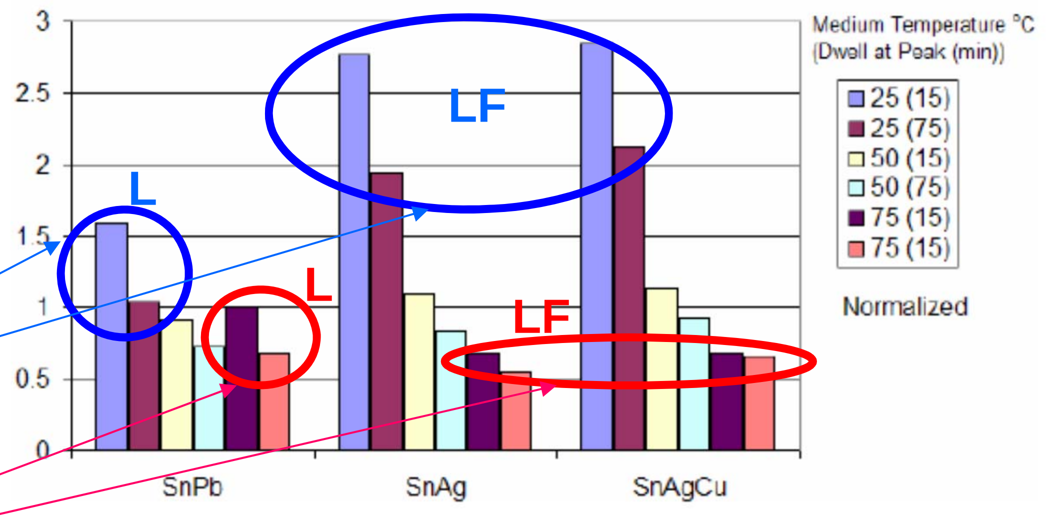


Figure 2 Normalized Fatigue Life of 68 IO CLCC

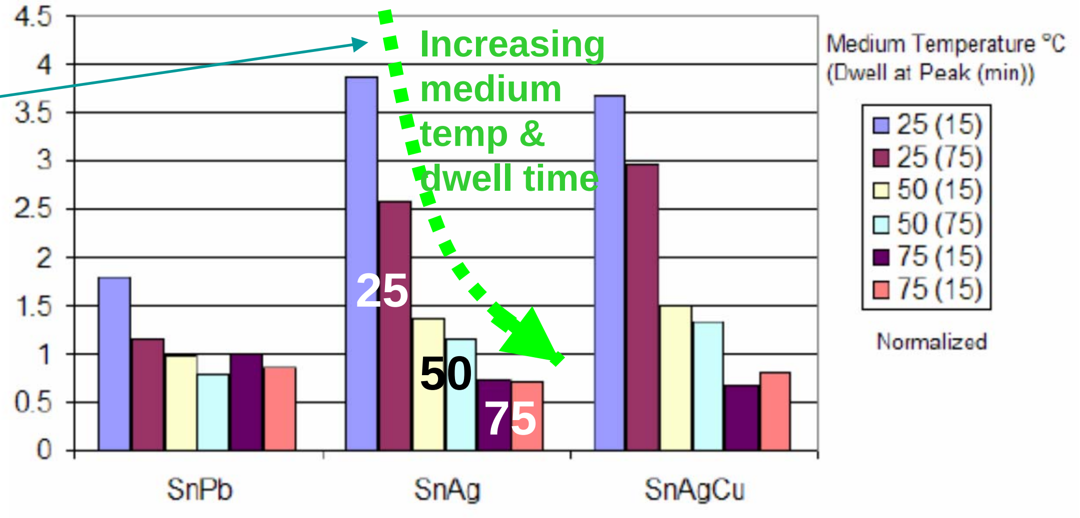
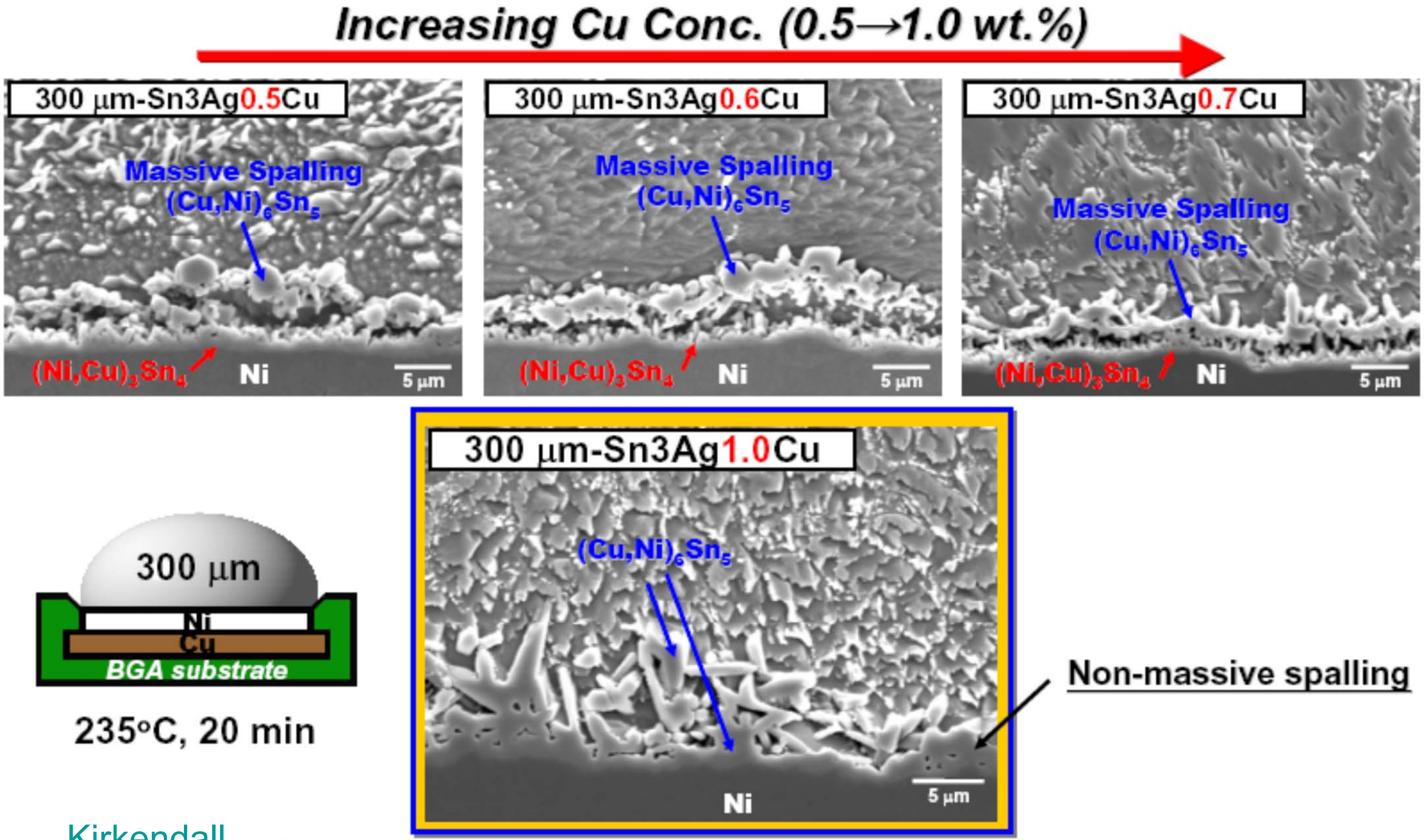


Figure 3 Normalized Fatigue Life of 84 IO CLCC

Michael Osterman, Abhijit Dasgupta, and Bongtae Han (University of Maryland), “A Strain Range Based Model for Life Assessment of Pb-free SAC Solder Interconnects”, Bala Nandagopal, Zequn Mei and Sue Teng (Cisco Systems, Inc.), “Microstructure and Thermal Fatigue Life of BGAs with Eutectic Sn-Ag-Cu Balls Assembled at 210°C with Eutectic Sn-Pb Solder Paste”, 56th ECTC Proceedings, P. 884-890, San Diego, CA, May 30-June 2, 2006

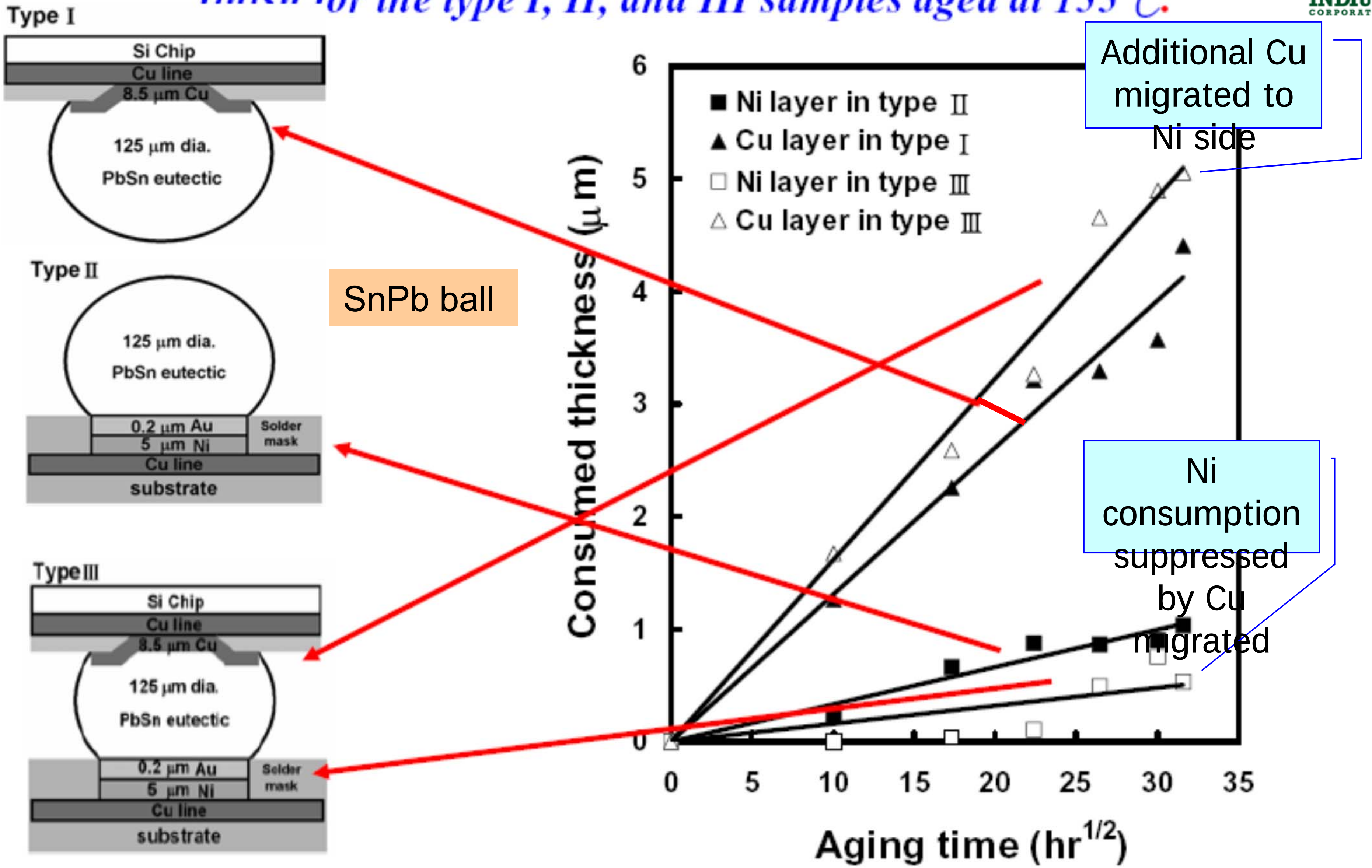
Using High Cu-Content Solders to Inhibit Massive Spalling



Kirkendall

C. Robert Kao, "Cross-interaction between Cu and Ni in lead-free solder joints", TMS Lead Free Workshop, San Antonia, TX, March 12, 2006.

Consumed thickness of the Cu in the UBM and Ni in the surface finish for the type I, II, and III samples aged at 155 ℃.



SnPb ball

Additional Cu migrated to Ni side

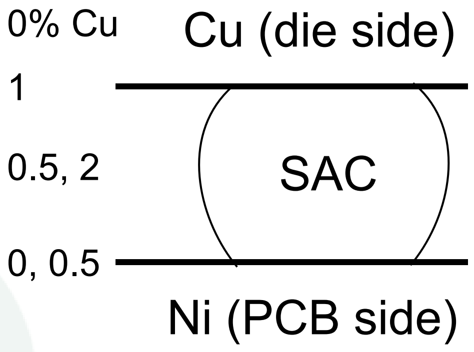
Ni consumption suppressed by Cu migrated

C. Robert Kao, “Cross-interaction between Cu and Ni in lead-free solder joints”, TMS Lead Free Workshop, San Antonia, TX, March 12, 2006.

Evolution of Interface with Increasing Cu Conc.

Ref: Henry Y. Lu, Haluk Balkan, Joan Vrtis, and K.Y. Simon Ng, " Impact of Cu Content on the Sn-Ag-Cu Interconnects", 55th ECTC, P.113-119, May 31-June 3, 2005

Crack location



0% Cu

1

0.5, 2

0, 0.5

Cu (die side)

SAC

Ni (PCB side)

High Cu result in more ductile failure (bulk solder) than brittle failure (IMC interface) at shear test

Cu

(Cu, Ni)6Sn5

SnAg

(Ni,Cu)3Sn4

NiPSn (500 nm)

Ni3(P,Sn) (300 nm)

Ni (3.84 um)

Cu

(Cu, Ni)6Sn5 (2.7 um)

SAC305

(Cu, Ni)6Sn5 (2.8 um)

NiSnP + Ni3(P,Sn) (250 nm)

Ni (4.68 um)

Cu

(Cu, Ni)6Sn5

SAC3010

(Cu, Ni)6Sn5

NiSnP (240 nm)

Ni

Cu

(Cu, Ni)6Sn5

SAC3020

(Cu, Ni)6Sn5

Ni

Cu conc. →

No Ag3Sn plates in any locations of the solder joints for the 0.0Cu and 0.5Cu at time zero

High Cu lead to flourishing growth of Cu-Sn IMCs, which promotes the growth of Ag3Sn platelets.

Cu suppress dissolution of Ni. Hence, Ni3(P,Sn) disappear first, followed by NiPSn. But it also promotes more IMC formation on PCB (Ni) side & nucleation of Ag3Sn plates.

Effect of Heat History on IMC

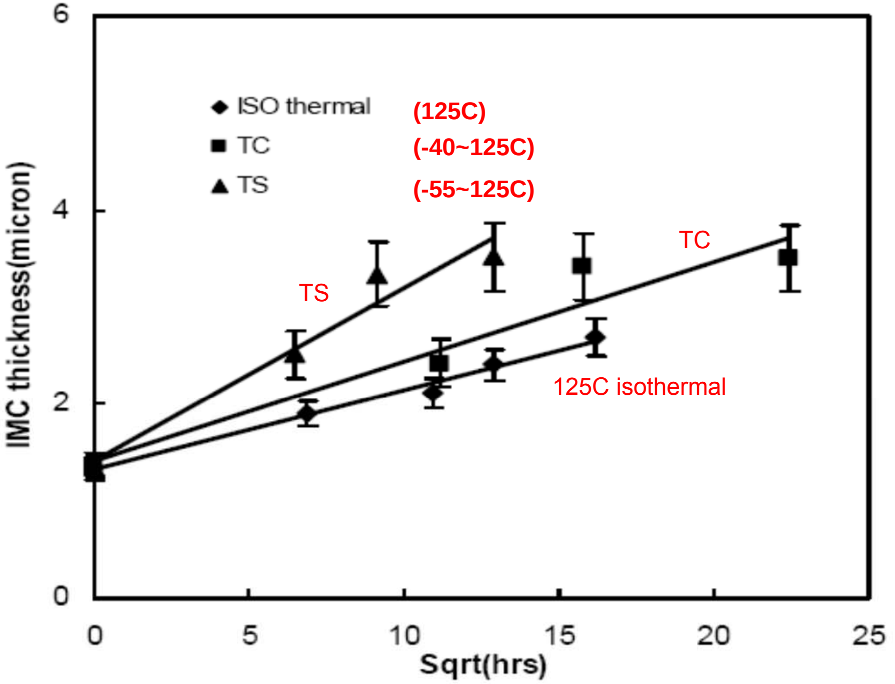


Fig 4 Comparison of IMC thickness: TC, TS and Isothermal Aging, Sn-3.8Ag-0.7Cu/Ni-Au couple

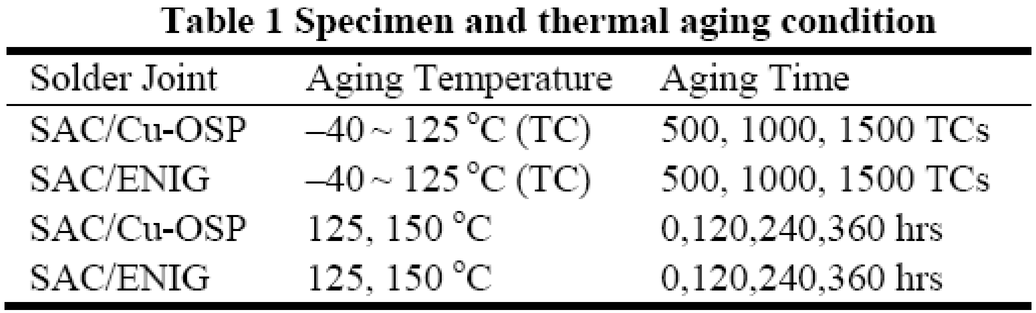


Table 1 Specimen and thermal aging condition

Solder Joint	Aging Temperature	Aging Time
SAC/Cu-OSP	–40 ~ 125 °C (TC)	500, 1000, 1500 TCs
SAC/ENIG	–40 ~ 125 °C (TC)	500, 1000, 1500 TCs
SAC/Cu-OSP	125, 150 °C	0,120,240,360 hrs
SAC/ENIG	125, 150 °C	0,120,240,360 hrs

TC(-40 ~ 125C, 15min high T dwell, 1 hr/cycle) and TS(-55 ~ 125 C, 5 min high T dwell, 17 min/cycle) aging, were conducted on Sn-3.8Ag-0.7Cu/Ni-Au BGA specimen for 500, 1000, 1500 and 2000 cycles. The IMC growth behavior measured for TC, TS and isothermal aging at 125oC are plotted in Fig 4.

Both high temp and stress accelerate IMC growth.
Effect of TS > TC

Luhua Xu and John H.L. Pang (Nanyang Technological University), “Effect of Intermetallic and Kirkendall Voids Growth on Board Level Drop Reliability for SnAgCu Lead-free BGA Solder Joint”, 56th ECTC Proceedings, P. 275-282, San Diego, CA, May 30-June 2, 2006

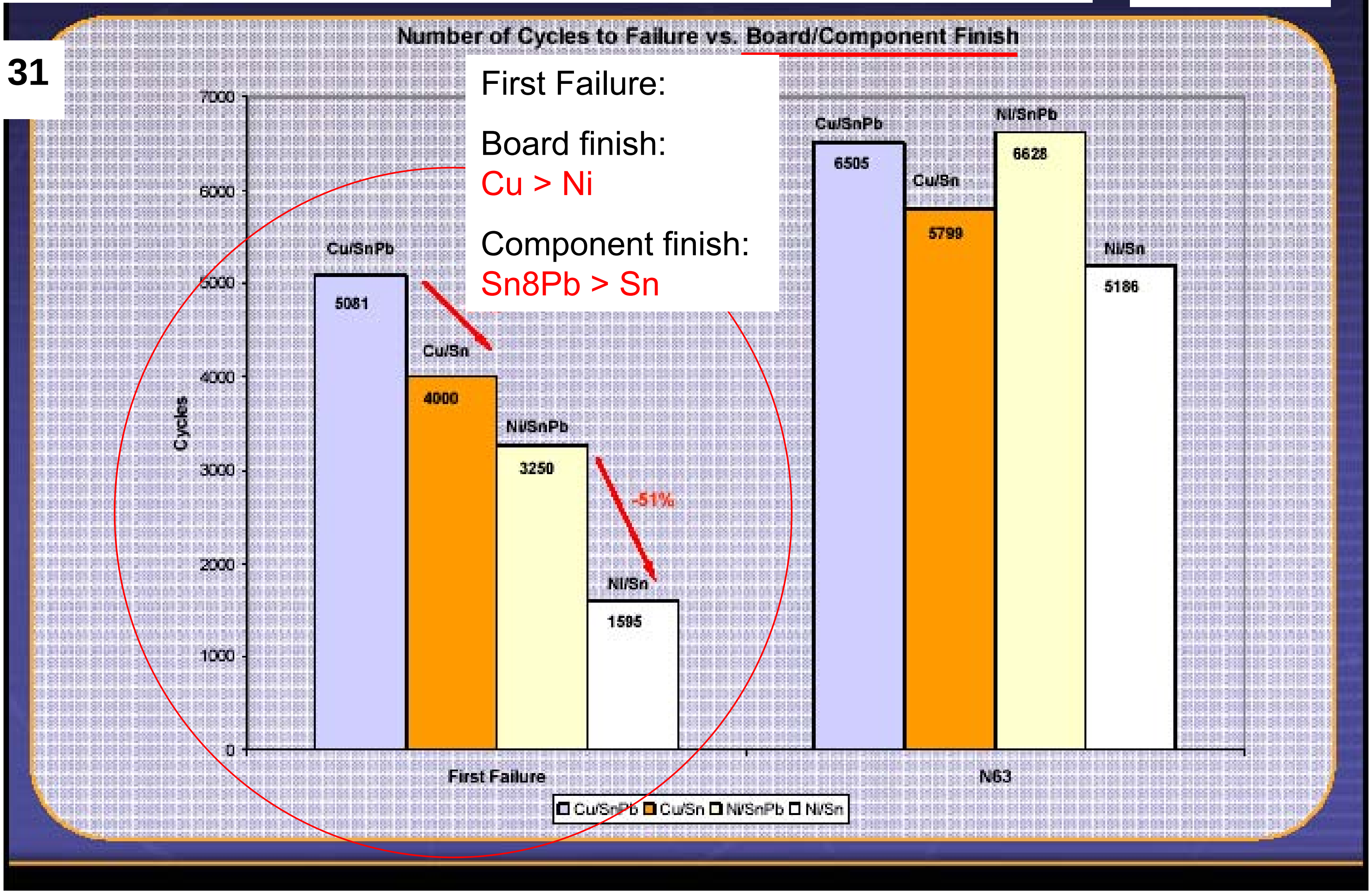
Design for Reliability

- Thermal Cycle Reliability

ATC Results

SAC387

Solder joints to copper showed a significantly higher number of cycles to first failure than the joints on nickel. Better reliability of the copper joints will be explained in terms of the copper content in the bulk. (Cu > Ni)



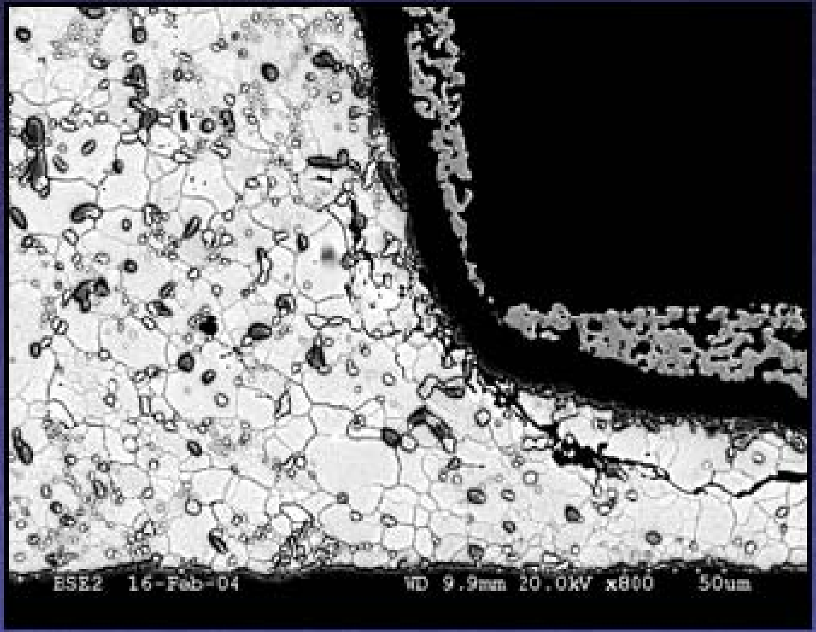
First Failure:

Board finish:
Cu > Ni

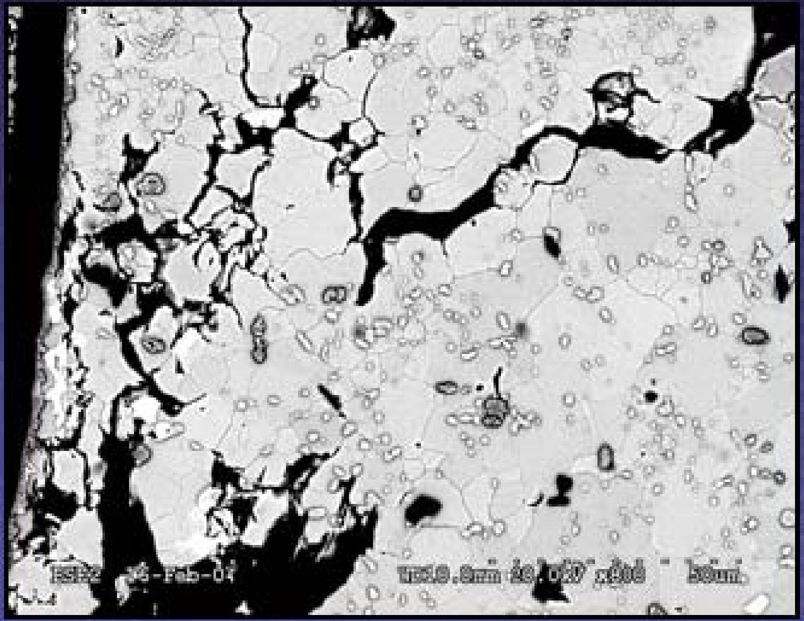
Component finish:
Sn8Pb > Sn

A.R. Zbrzeznya, P. Snugovskya, (Celestica) D.D. Perovicb (Univ. of Toronto), “Reliability of Lead-Free Chip Resistor Solder Joints Assembled on Boards with Different Finishes Using Different Reflow Cooling Rates”, IPC/JEDEC 5th International Conference on Lead Free Electronic Components and Assemblies, San Jose, CA, March 18-19, 2004

Grain Size



Joint on Cu after 2000 cycles



Joint on Ni after 2000 cycles

A.R. Zbrzeznya, P. Snugovskya, (Celestica) D.D. Perovicb (Univ. of Toronto), “Reliability of Lead-Free Chip Resistor Solder Joints Assembled on Boards with Different Finishes Using Different Reflow Cooling Rates”, IPC/JEDEC 5th International Conference on Lead Free Electronic Components and Assemblies, San Jose, CA, March 18-19, 2004

High Ag High TCT Life

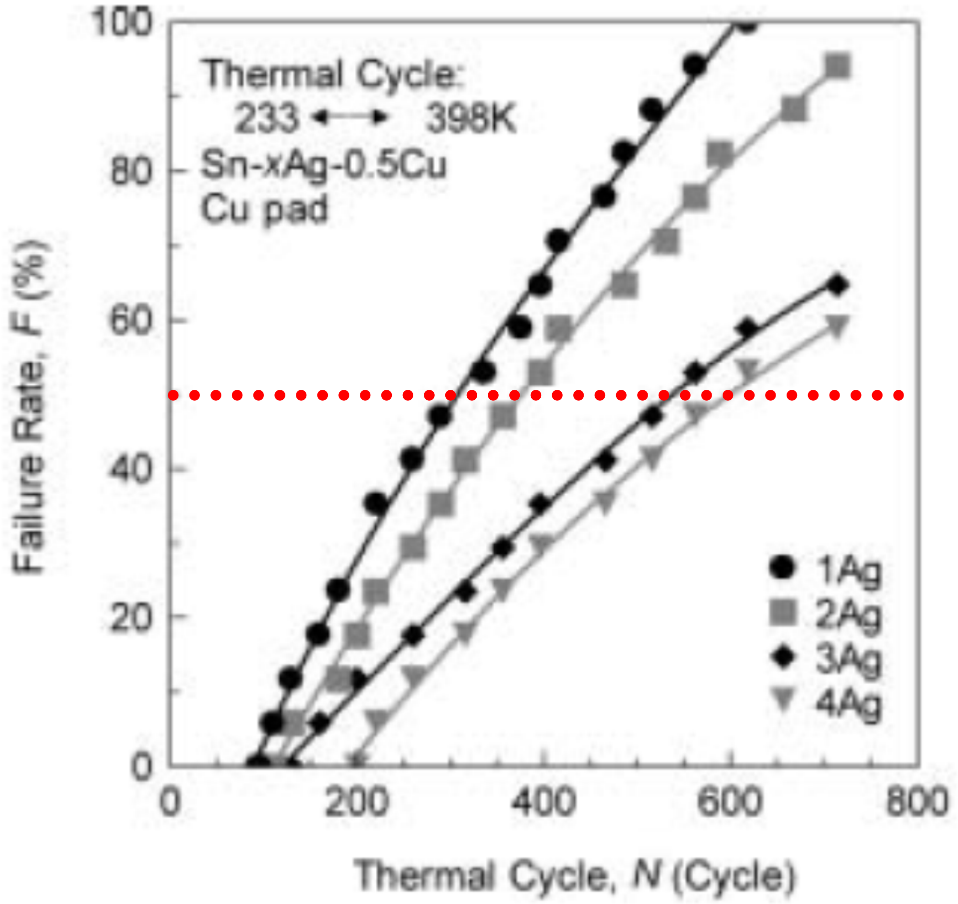
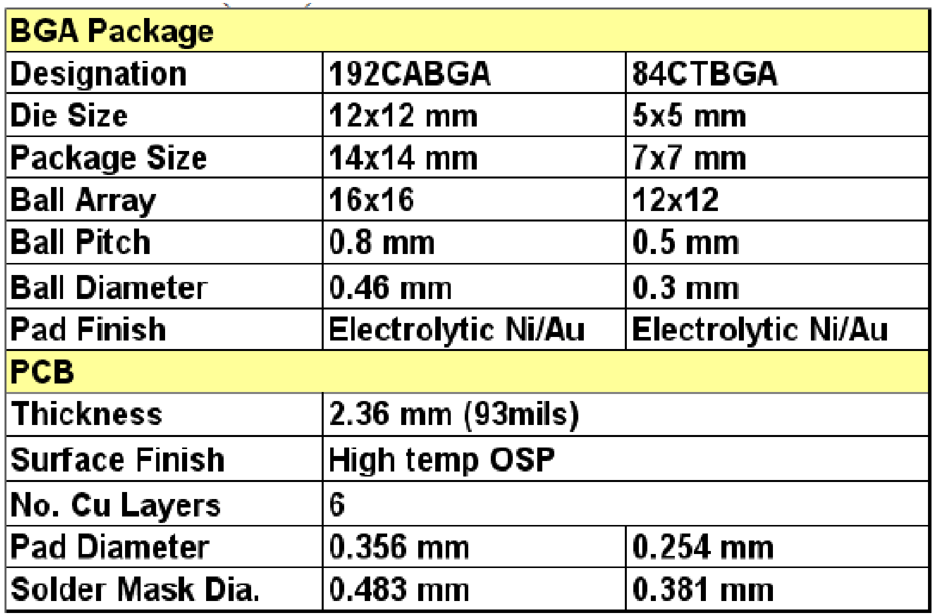


Fig. 6. Effect of thermal cycles on the failure rate of Sn-xAg-0.5Cu (x = 1, 2, 3, and 4) solder joints on the Cu pads.

- Changes in Ag content can have significant impact on thermal fatigue reliability
- Terashima et al. found that a decrease of Ag content from 4% to 1% decreases the thermal fatigue life (first failure) by a factor of about 2
  - -40/125°C, 10 min dwell.
  - All alloys had 0.5% Cu
  - Performance relative to eutectic Sn-Pb not reported
- Addition of other alloying elements which affect undercooling, formation of various IMCs, matrix properties & microstructure not well understood

S. Terashima, et al., J. Elec. Mater., Vol. 32, No. 12, p.1527 (2003).

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

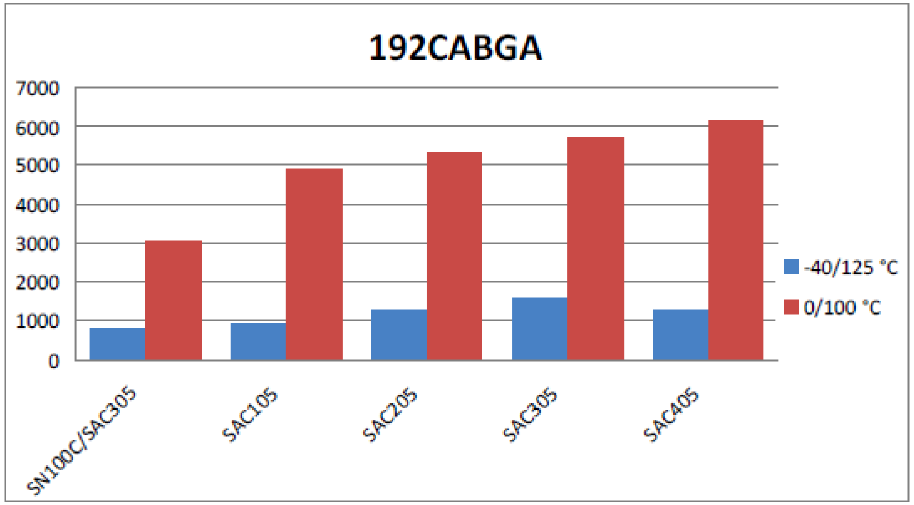


Figure 3: Bar chart comparing characteristic lifetime as a function of alloy composition (Ag content) and thermal cycle for the 192CABGA.

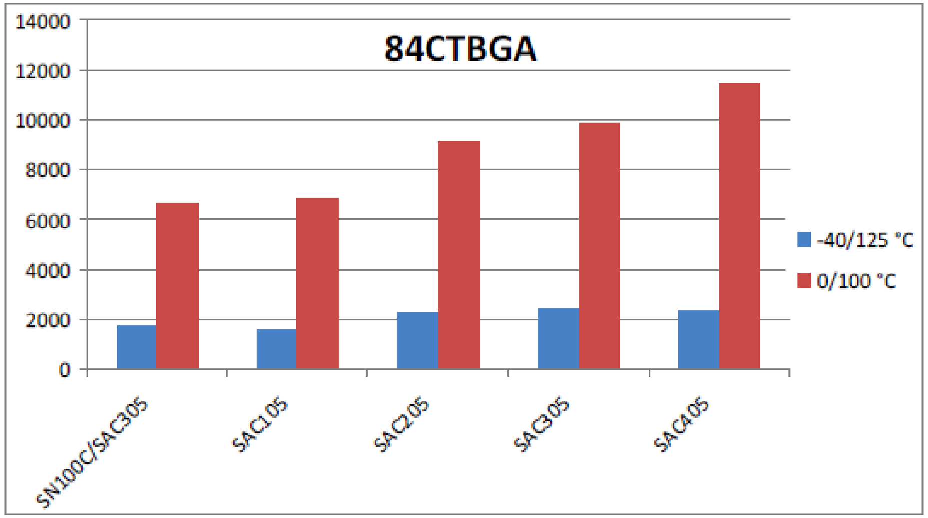


Figure 4: Bar chart comparing characteristic lifetime as a function of alloy composition (Ag content) and thermal cycle for the 84CTBGA.

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

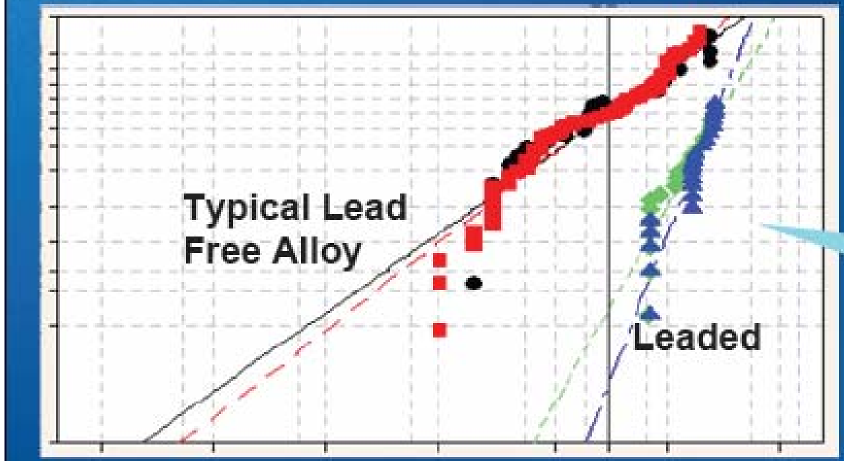
Design for Reliability

- Fragility

ad Free 2ndLI Solder Joint Reliability

Lead Free SJR (DROP) failure

Typical SAC Alloy Failure Mode – Interfacial fracture

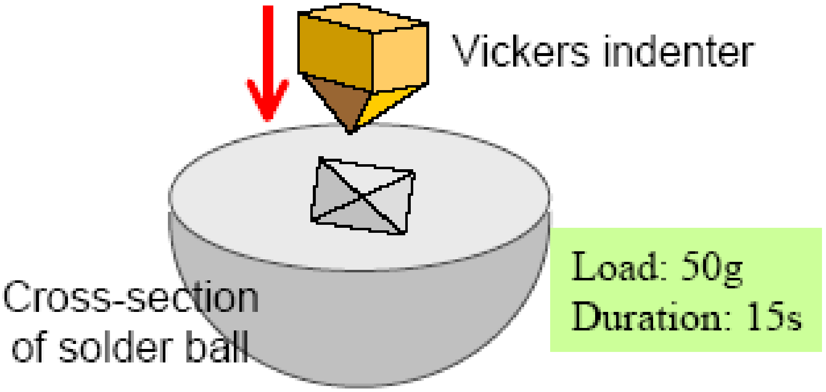


Typical Lead Free solder alloy exhibits significantly lower "DROP" performance than Leaded

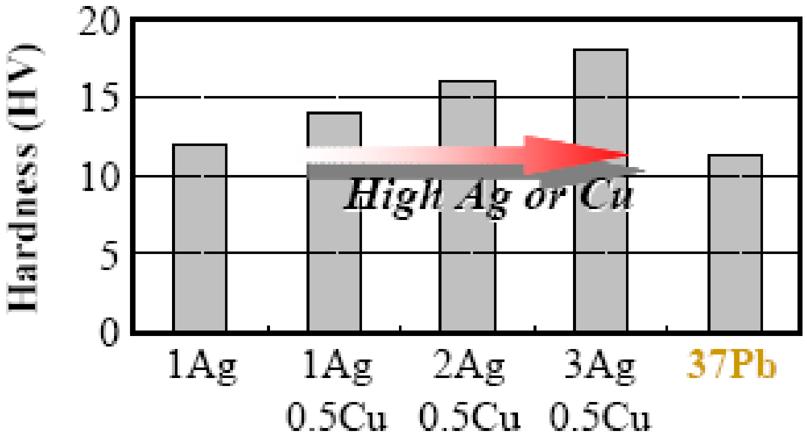
Ref:Vijay Wakharkar& Ashay Dani, "Microelectronic Packaging Materials Microelectronic Packaging Materials Development & Integration Development & Integration Challenges for Lead Free Challenges for Lead Free", Lead-free workshop, TMS, San Antonio, TX, March 12, 2006.

How Hard is SAC Alloys

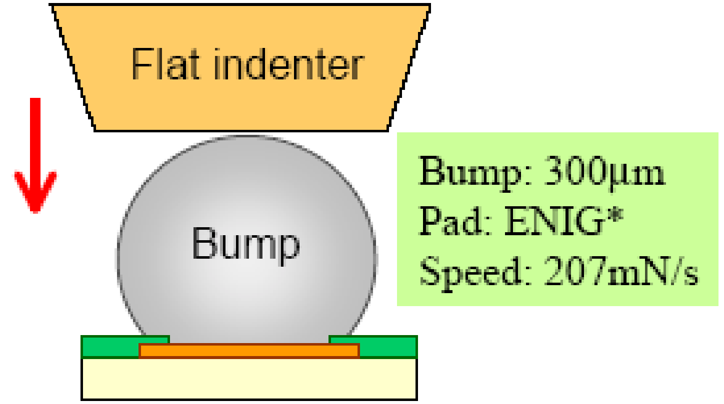
Vickers hardness of solder ball



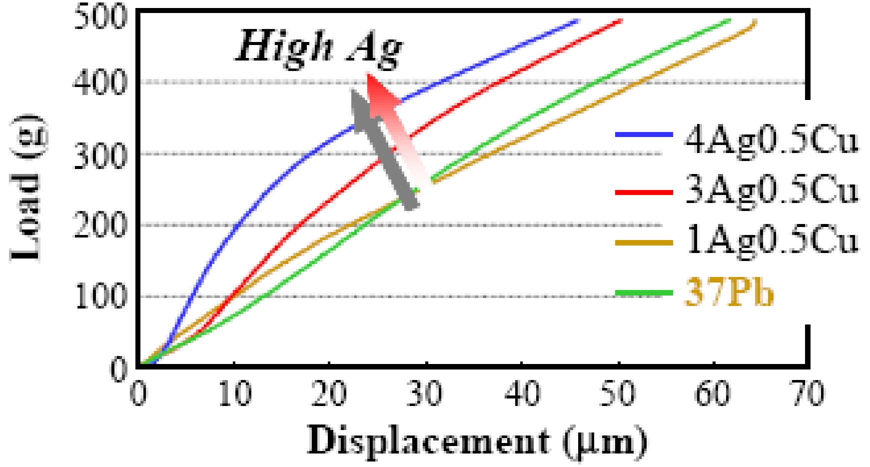
Load: 50g
Duration: 15s



Bump compression strength



Bump: 300μm
Pad: ENIG*
Speed: 207mN/s



- Ag and Cu should be reduced to make solder softer.
- Solder without Cu (Sn-Ag solder) is not good at all.

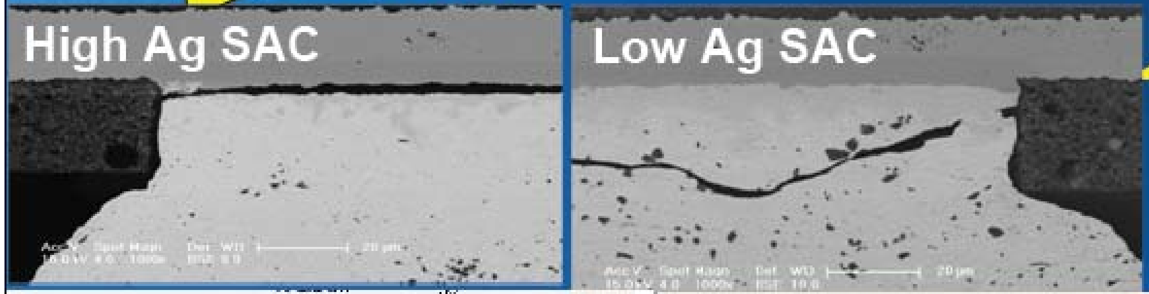
ENIG: Electroless Nickel Immersion Gold

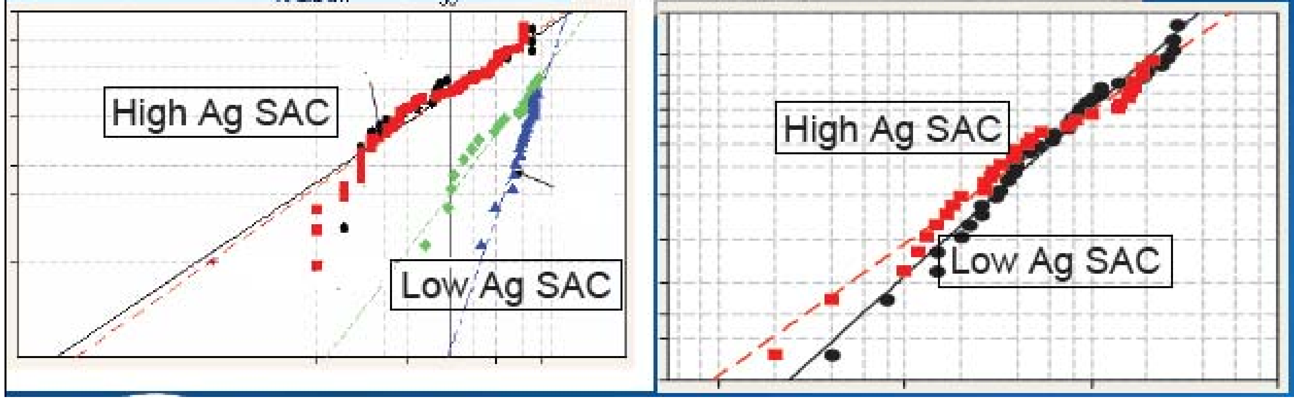
M. Date, T. Shoji, M. Fujiyoshi, and K. Sato (Hitachi), “Pb-free Solder Ball with Higher Impact Reliability”, Intel Pb-free Technology Forum, 18th – 20th July 2005, Penang, Malaysia

Lead Free Drop Improvements

- Optimize Solder Alloys for Drop

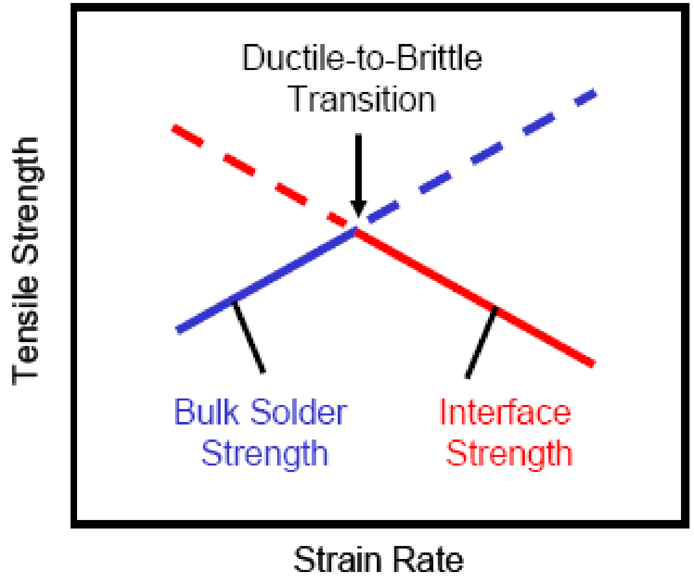
Reduce SAC Alloy Yield Stress
Lowering Ag content in SAC



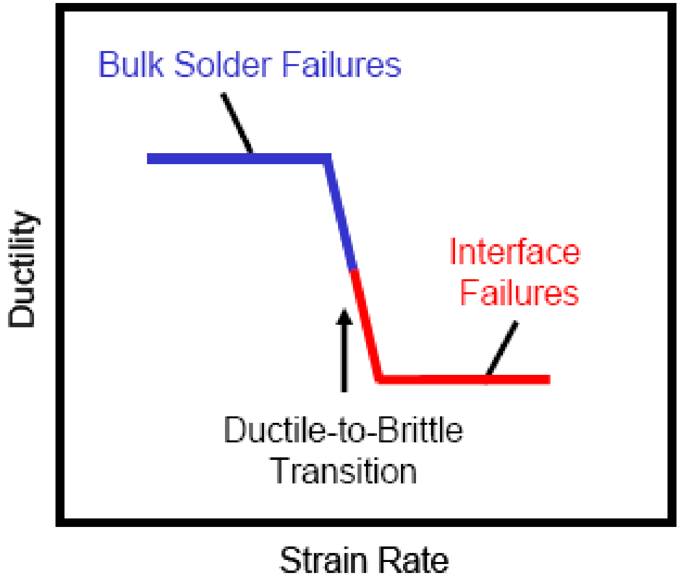


Increasing IMC fracture toughness
SAC Solder Doping
Cu content optimization in SAC

Ref:Vijay Wakharkar& Ashay Dani, "Microelectronic Packaging Materials Microelectronic Packaging Materials Development & Integration Development & Integration Challenges for Lead Free Challenges for Lead Free", Lead-free workshop, TMS, San Antonio, TX, March 12, 2006.



22a) Trend of tensile strength with strain rate.



22b) Trend of ductility with strain rate.

Figure 22. Solder joint ductile-to-brittle transition with strain rate.

Robert Darveaux, Corey Reichman, Nokibul Islam (Amkor Technology, Inc.), "Interface Failure in Lead Free Solder Joints", 56th ECTC Proceedings, P. 906-917, San Diego, CA, May 30-June 2, 2006

Effect of Component Finish

Better wetting (heel fillet height) results in higher pull strength, but not better drop performance.

Wetting dictated by finish chemistries.

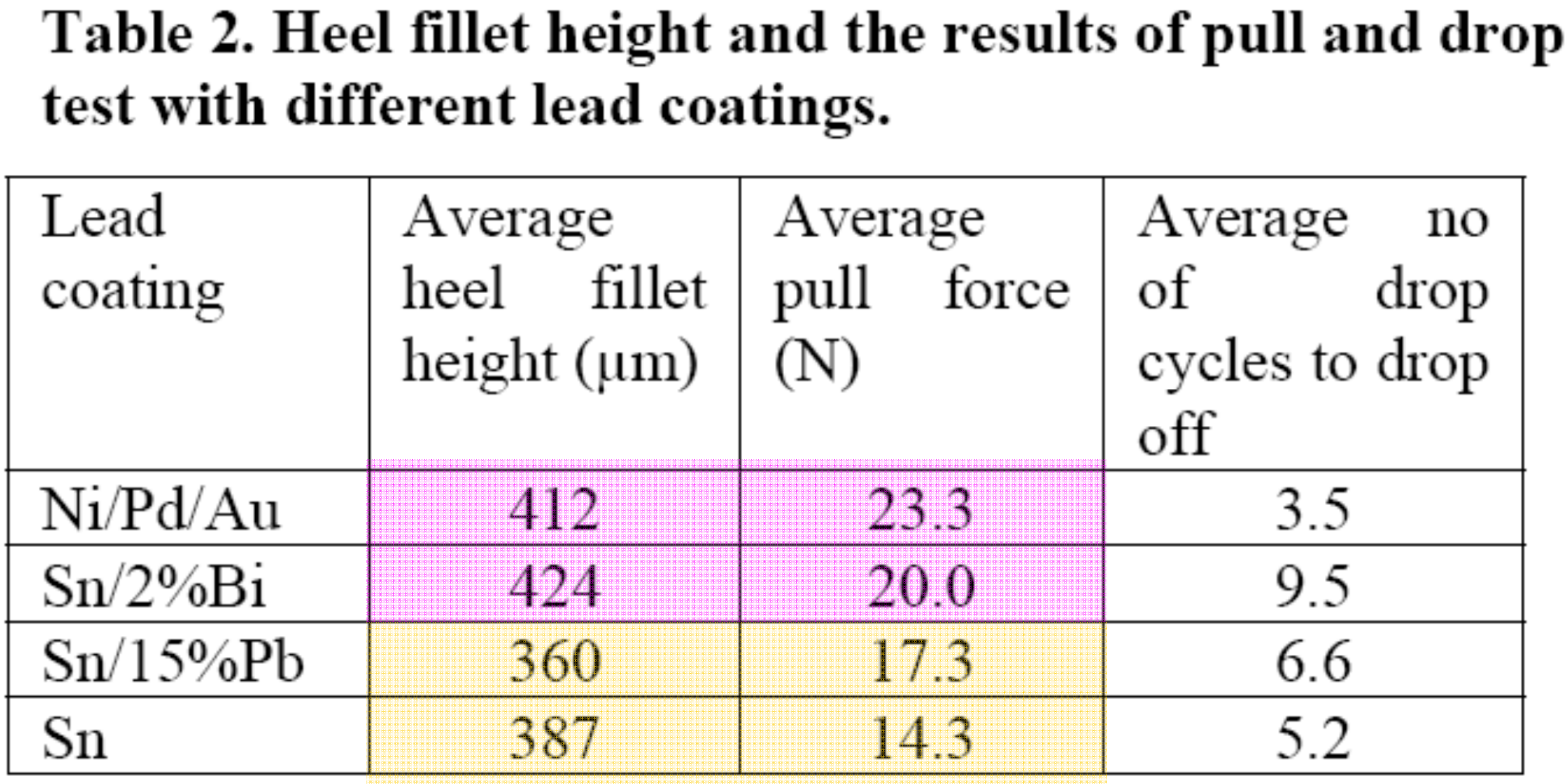


Table 2. Heel fillet height and the results of pull and drop test with different lead coatings.

Lead coating	Average heel fillet height (µm)	Average pull force (N)	Average no of drop cycles to drop off
Ni/Pd/Au	412	23.3	3.5
Sn/2%Bi	424	20.0	9.5
Sn/15%Pb	360	17.3	6.6
Sn	387	14.3	5.2

Ref: Minna Arra, Todd Castello, Dongkai Shangguan, Eero Ristolainen, " CHARACTERIZATION OF MECHANICAL PERFORMANCE OF SN/AG/CU SOLDER JOINTS WITH DIFFERENT COMPONENT LEAD COATINGS", SMTAI, p.728-734, Chicago, IL, September, 2003.

IMC Growth Rate – OSP vs ENIG

IMC growth rate:

SA > SAC

OSP > ENIG

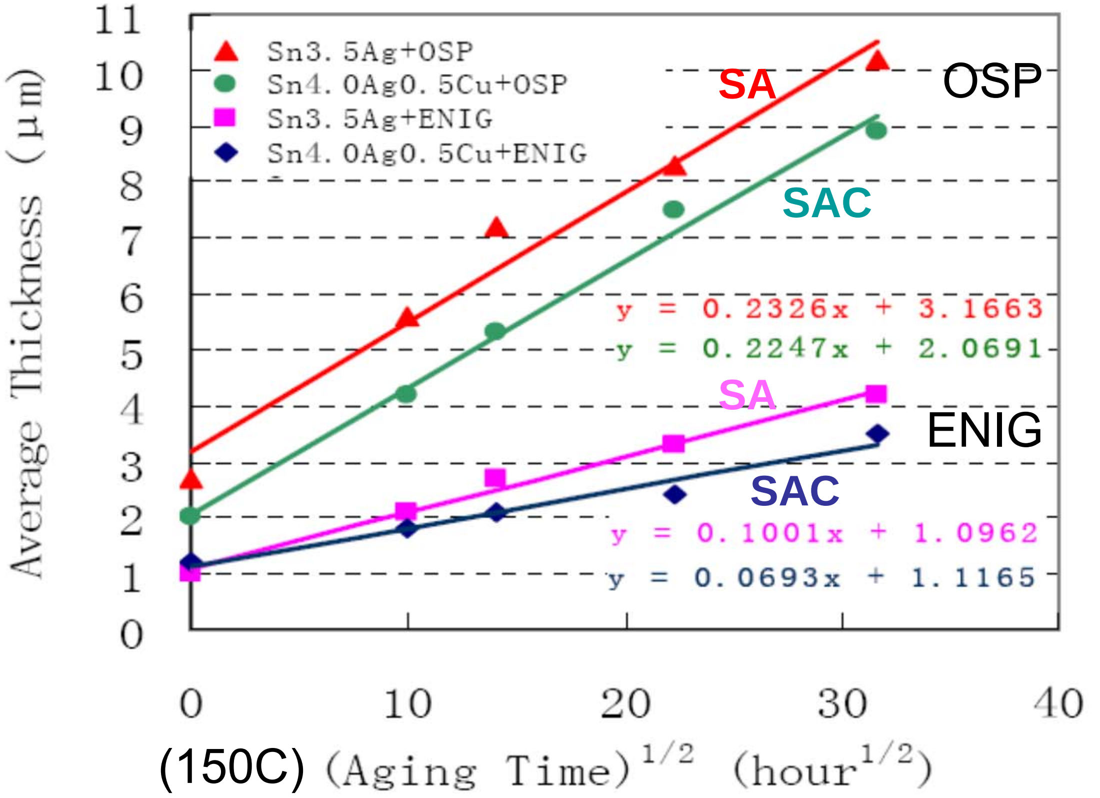


Figure 6. Correlation between IMC thickness and aging time (Cu-Sn phase in both SA and SAC on OSP; Ni-Cu-Sn phase in SAC on ENIG; Ni-Sn phase in SA on ENIG)

Fubin Song and S. W. Ricky Lee, “Investigation of IMC Thickness Effect on the Lead-free Solder Ball Attachment Strength: Comparison between Ball Shear Test and Cold Bump Pull Test Results”, 56th ECTC Proceedings, P. 1196-1203, San Diego, CA, May 30-June 2, 2006

Effect of Isothermal Aging

125C aging

Kirkendall voiding developed quickly at 125C

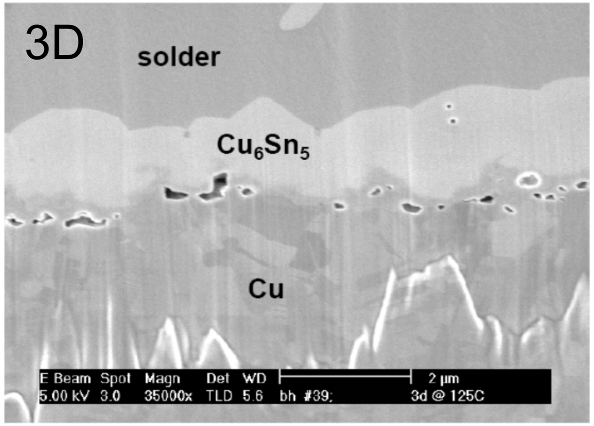


Figure 6. Package pad to solder joint interface after 3 days of 125°C aging. Kirkendall voids are initiated.

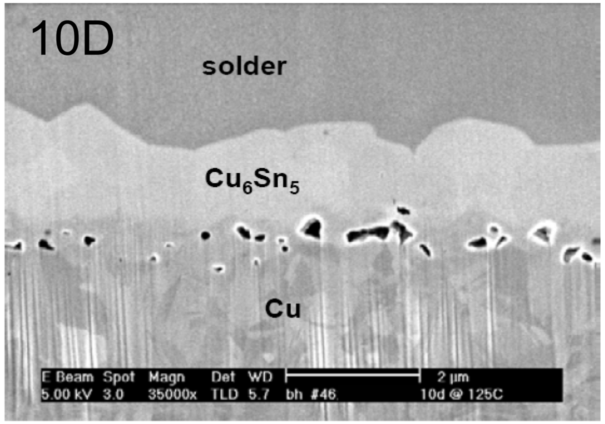


Figure 7. Package pad to solder joint interface after 10 days of 125°C aging. Growth of the Kirkendall voids is noted.

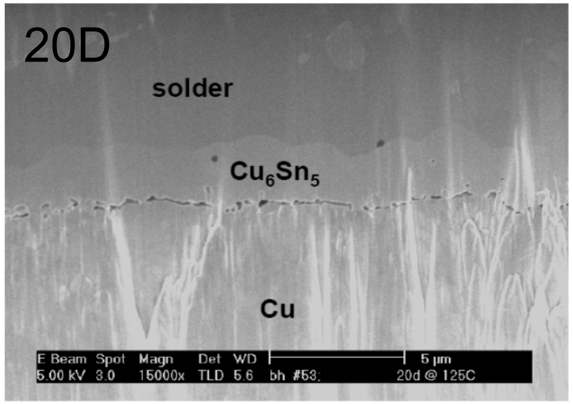


Figure 8. Package pad to solder joint interface after 20 days of 125°C aging. The Kirkendall voids have become so prevalent that a nearly continuous voided layer has formed.

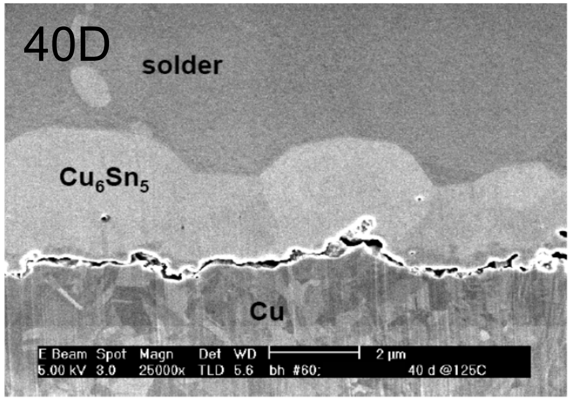


Figure 9. Package pad to solder joint interface after 40 days of 125°C aging. The void layer is nearly 100% continuous, resulting in dramatically weakened interfacial strength.

Ref: Tz-Cheng Chiu, Kejun Zeng, Roger Stierman and Darvin Edwards, Kazuaki Ano, " Effect of Thermal Aging on Board Level Drop Reliability for Pb-free BGA Packages", 54th ECTC, P.1256-1262, June 1-4, 2004, Las Vegas, Nevada.

Effect of Thermal Cycling

Fragility Reliability – OSP vs ENIG

Drop lifetime decreases with increasing TC aging.

Before TC aging, OSP has longer drop lifetime than ENIG.

After TC aging, OSP degrades rapidly & has shorter lifetime than ENIG

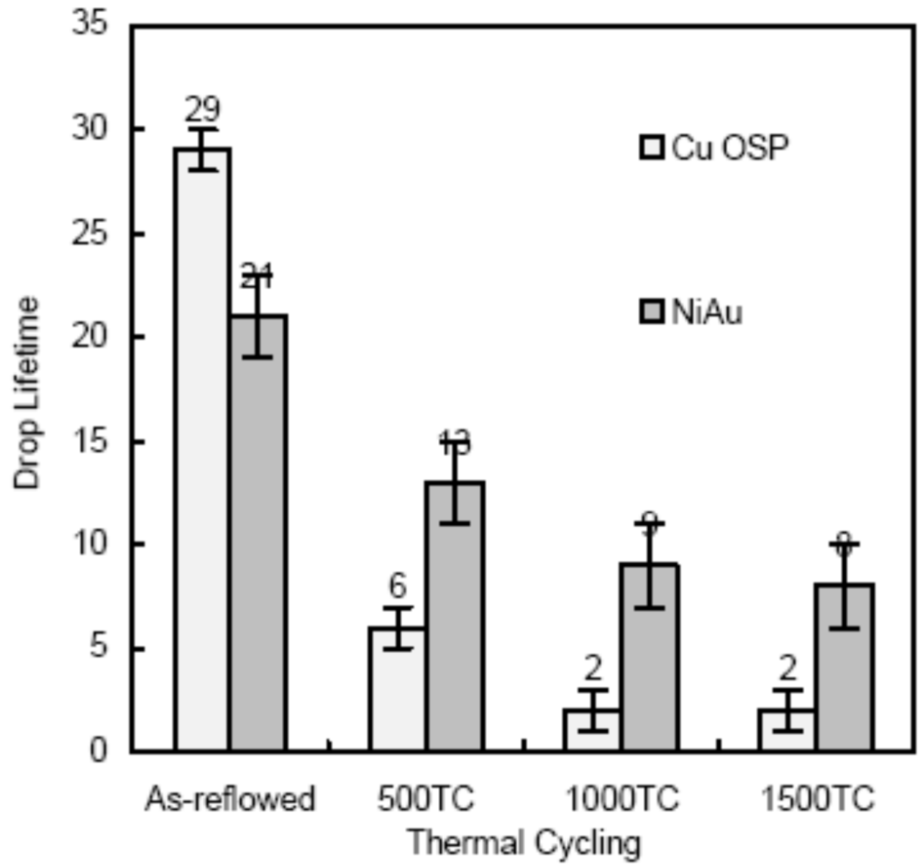


Fig. 8 drop lifetime for unit C3 and C13 before and after TC aging

Luhua Xu and John H.L. Pang (Nanyang Technological University), “Effect of Intermetallic and Kirkendall Voids Growth on Board Level Drop Reliability for SnAgCu Lead-free BGA Solder Joint”, 56th ECTC Proceedings, P. 275-282, San Diego, CA, May 30-June 2, 2006

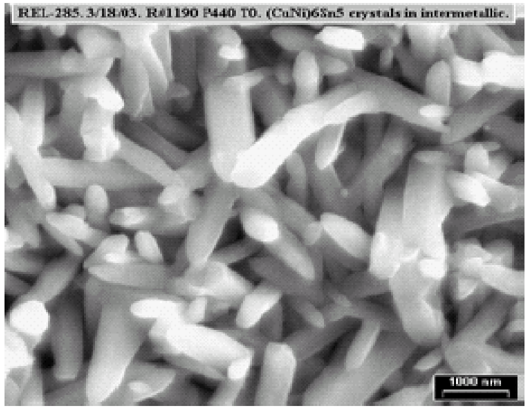
Effect of Intermetallic Morphology

Drop Test: Sn63 > SAC305

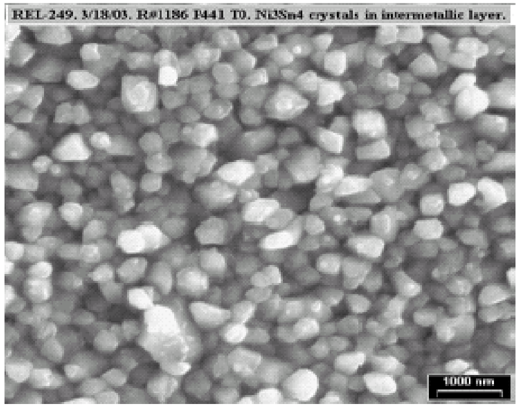
1500G, 0.5 ms pulse, face-down, 30 drops

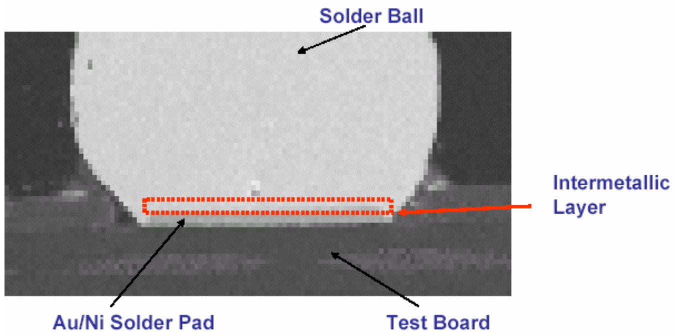
Intermetallic Crystal Morphology: Sn-Ag-Cu vs. Sn-Pb

Sn/3.0Ag/0.5Cu Solder Ball



Sn-Pb Solder Ball





NOTE: Images have the same scale

Comparison of the intermetallic structure (solder ball to solder pad) for Pb-free and Sn-Pb packages. (After solder dissolved away using sulfuric acid) Note the much coarser structure in the Pb-free sample, which MAY have contributed to the Pb-free drop test failure.

Gordon Gray (Tessera), “Lead-free soldering for CSP”, IPC/JEDEC 5th International Conference on Lead Free Electronic Components and Assemblies, San Jose, CA, March 18-19, 2004

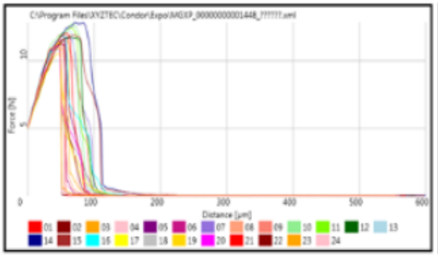
Design for Reliability

- Brittleness of Low Temperature Joints Containing 57Bi42Sn1Ag

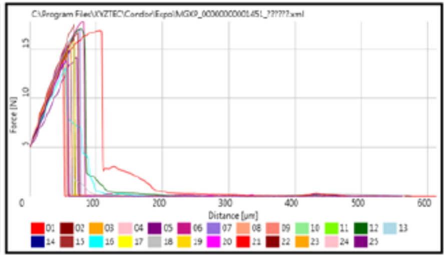
Paste-ball-profile

All Bi-containing joints are brittle

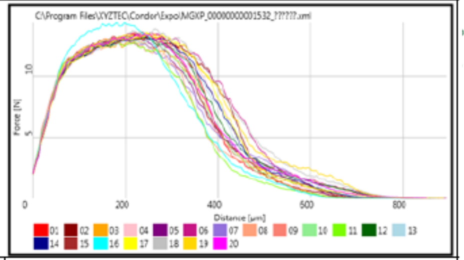
BiSnAg-BiSnAg LT



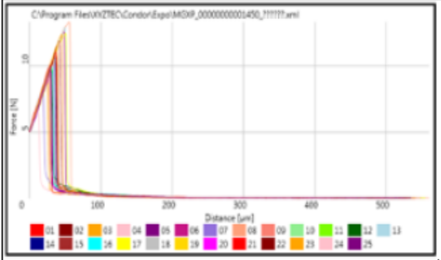
BiSnAg-305 HT



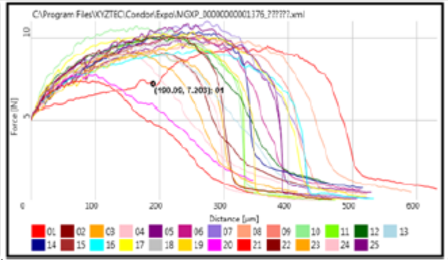
SnPb-SnPb MT



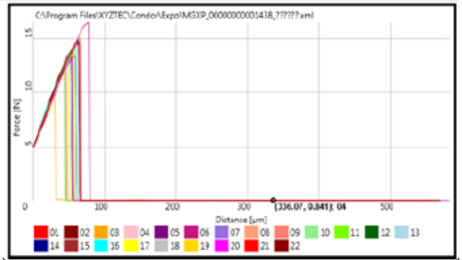
BiSnAg-BiSnAg HT



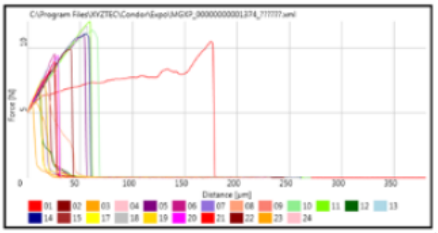
105-105 HT



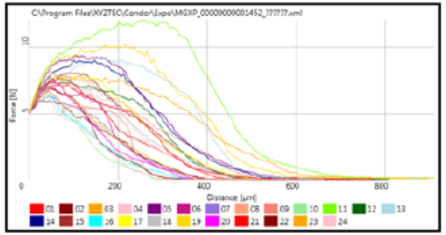
305-BiSnAg LT



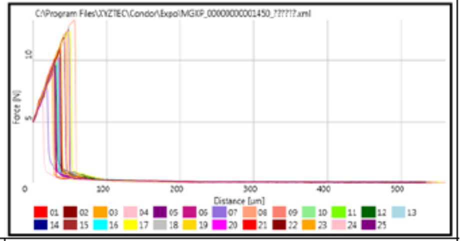
BiSnAg-105 LT



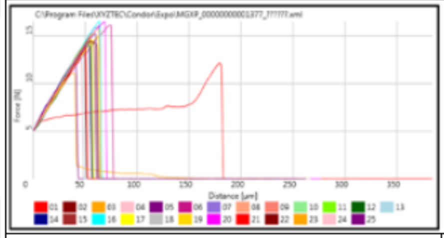
105-305 HT



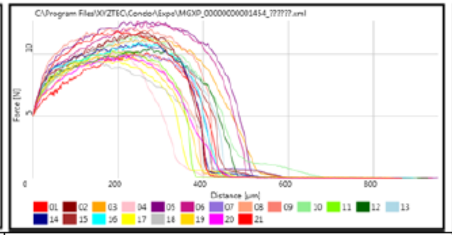
305-BiSnAg HT



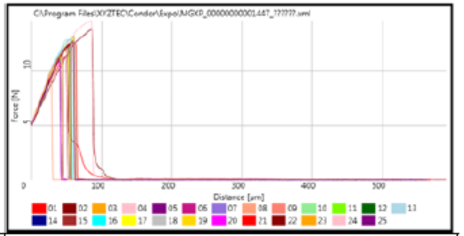
BiSnAg-105 HT



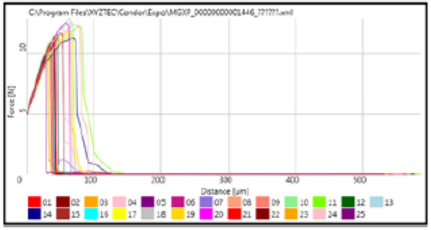
305-305 HT



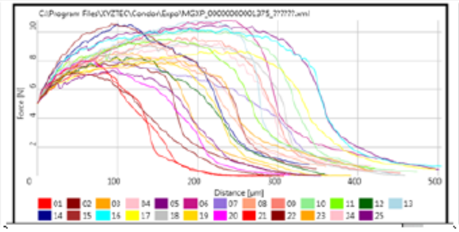
105-BiSnAg LT



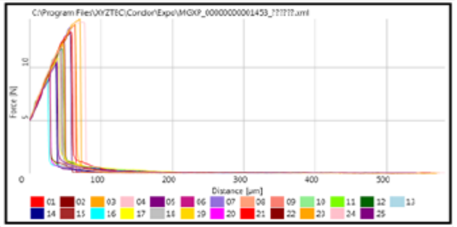
BiSnAg-305 LT



305-105 HT

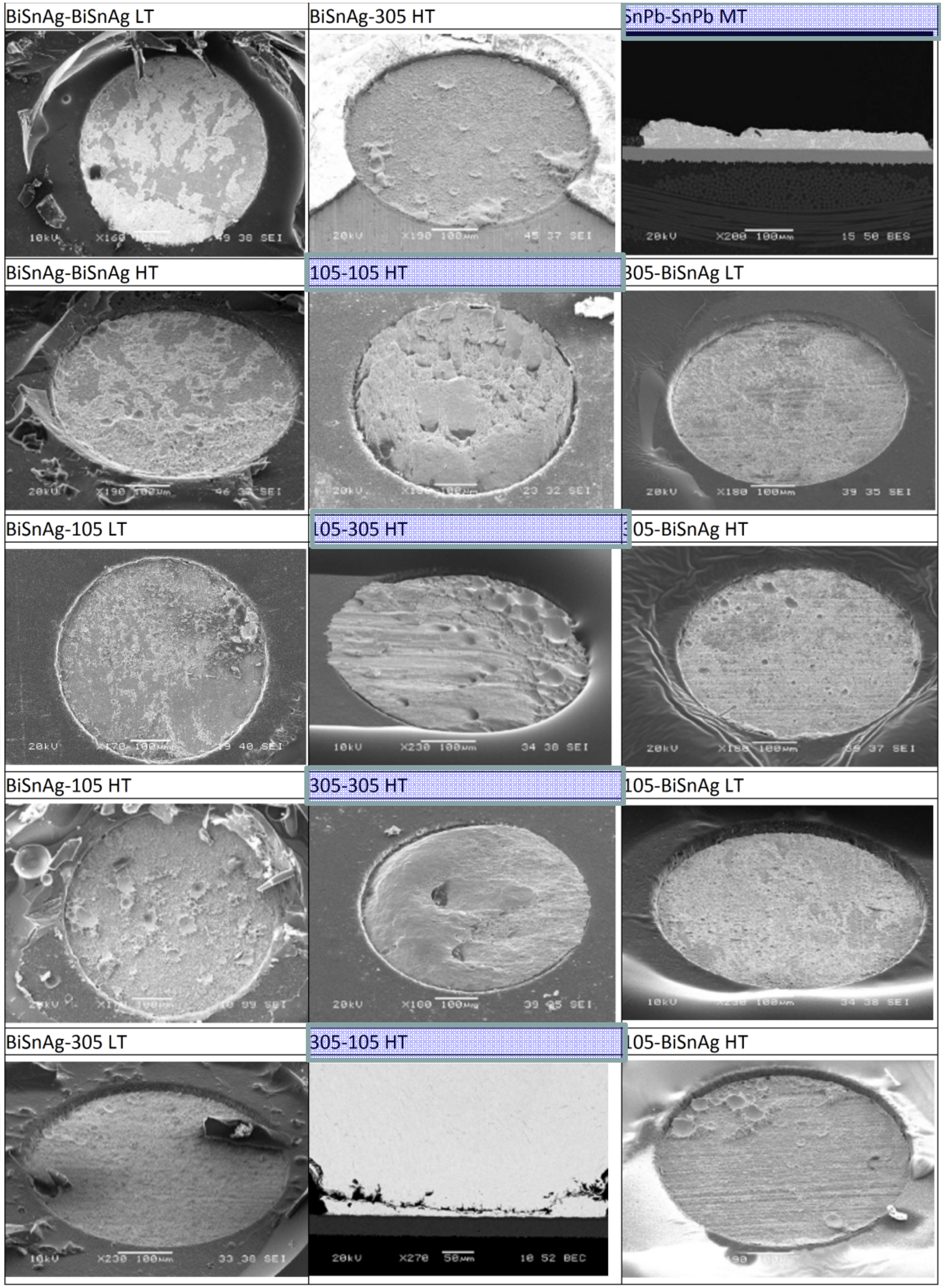


105-BiSnAg HT

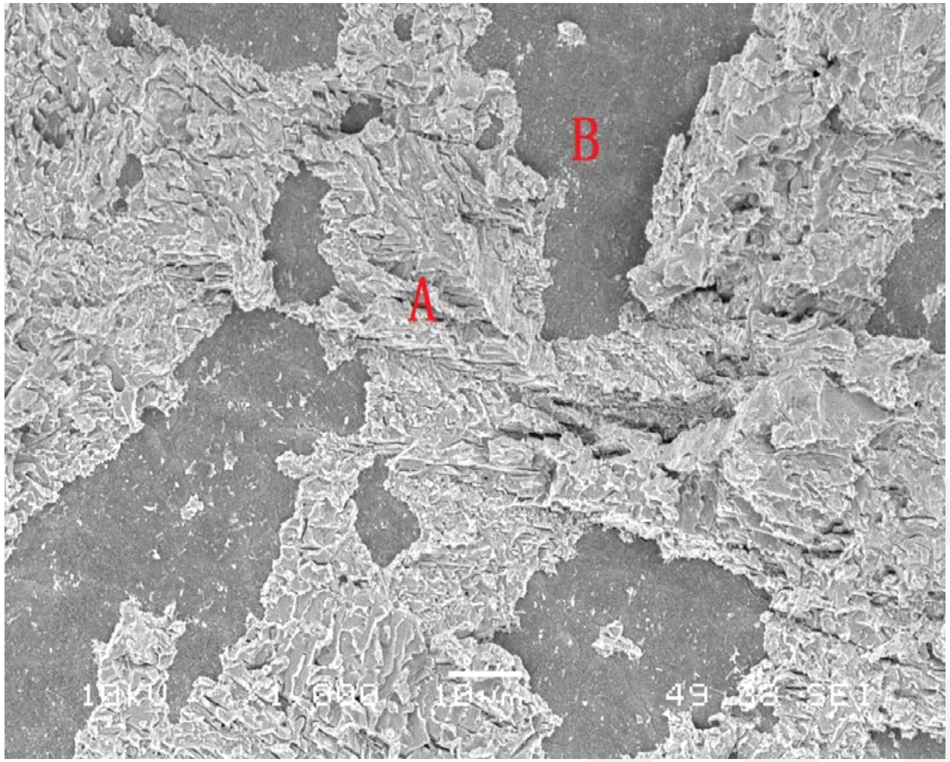


All Bi-containing joints are brittle.

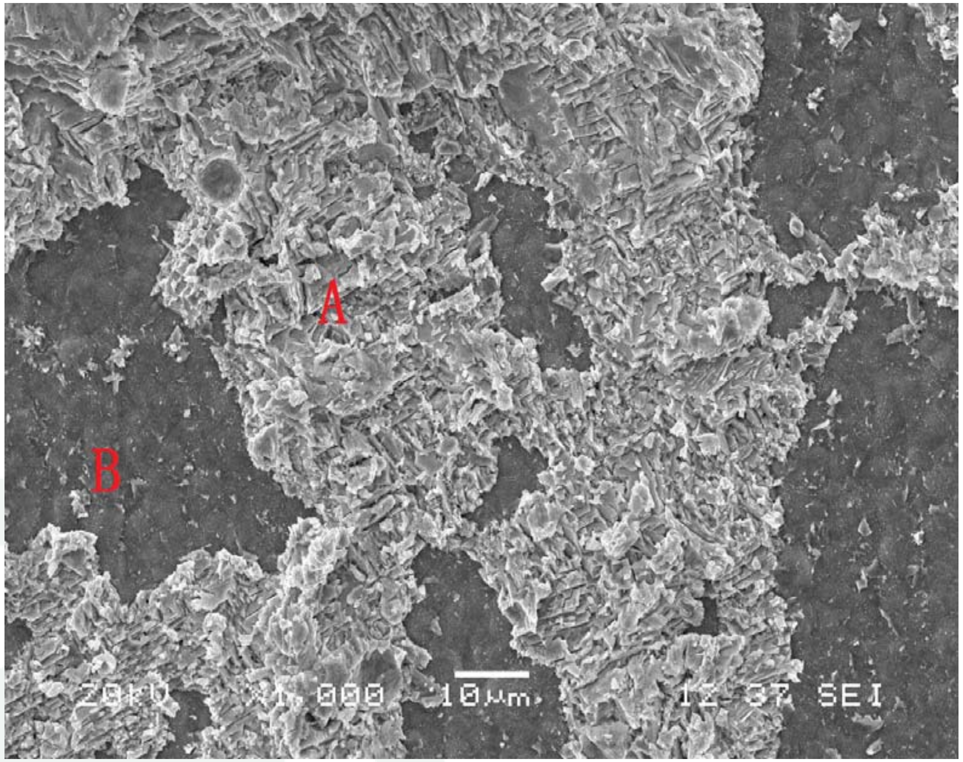
SAC & SnPb joints are ductile.



BiSnAg joints ruptured at crystalline BiSn & IMC CuSn



BiSnAg-BiSnAg LT

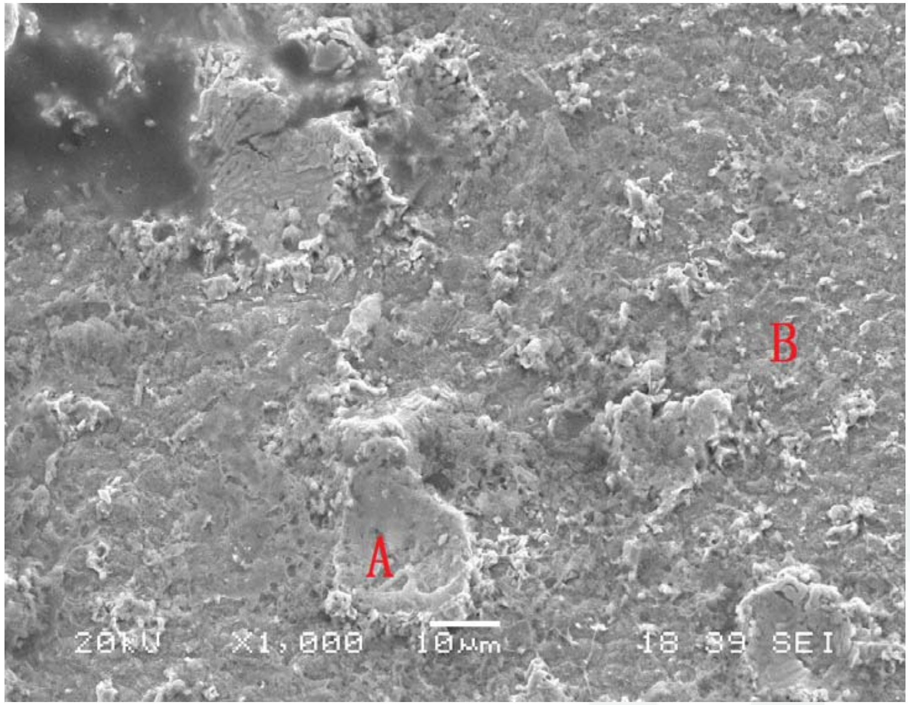


BiSnAg-BiSnAg HT

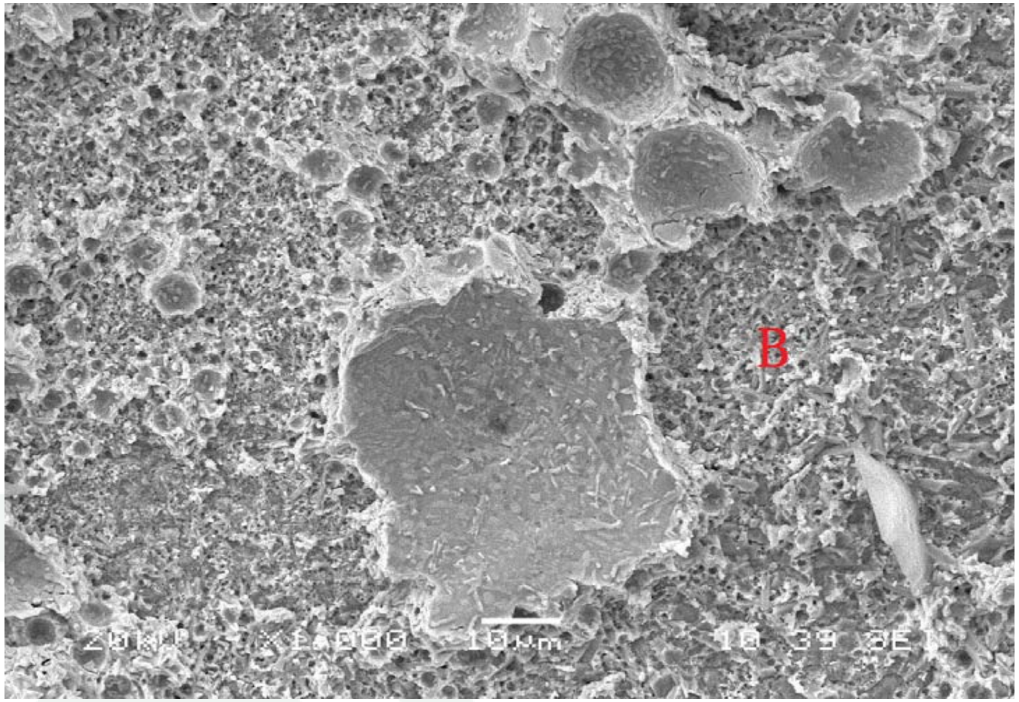
A: brittle crystalline BiSn
B: brittle CuSn IMC

Paste-Ball Profile		Atomic %			Weight %		
		Cu	Sn	Bi	Cu	Sn	Bi
BiSnAg-BiSnAg LT	A	2.99	55.78	41.24	1.23	42.91	55.86
	B	47.86	43.59	8.55	30.41	51.73	17.86
BiSnAg-BiSnAg HT	A	10.27	57.11	32.61	4.58	47.58	47.84
	B	68.36	29.63	2.01	52.46	42.47	5.07

BiSnAg-SAC joints ruptured at crystalline BiSn & IMC CuSn



BiSnAg-105 LT



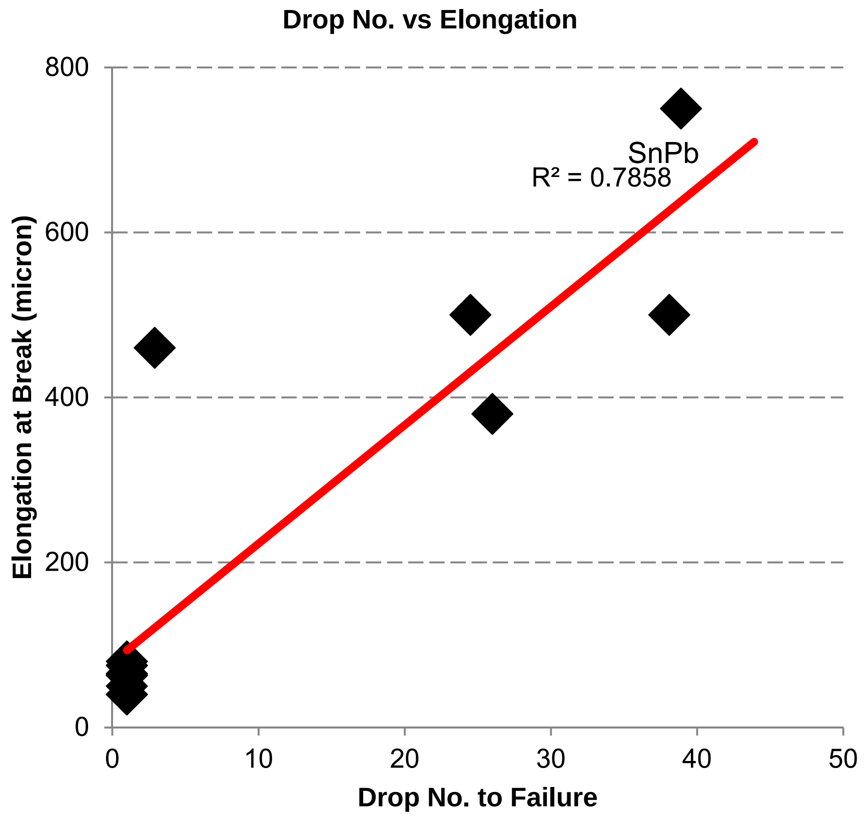
BiSnAg-105 HT

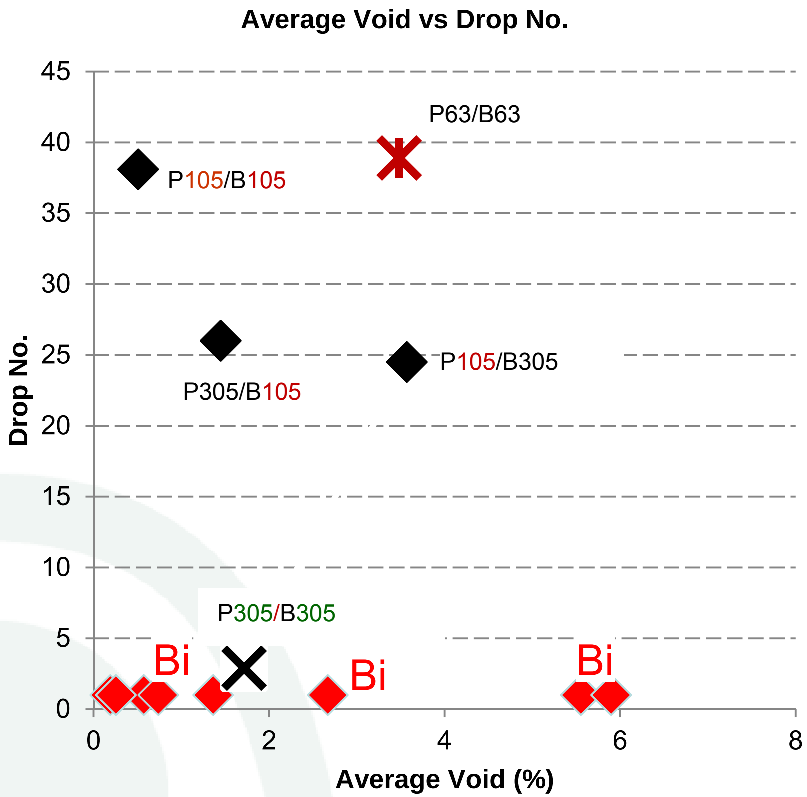
LT: brittle crystalline BiSn & CuSn IMC

HT: Only CuSn IMC at ruptured surface. HT drove more rupture to IMC interface

Paste-Ball Profile		Atomic %			Weight %		
		Cu	Sn	Bi	Cu	Sn	Bi
BiSnAg-105 LT	A	2.99	55.78	41.24	1.23	42.91	55.86
	B	56.62	37.88	5.51	38.92	48.63	12.45
BiSnAg-105 HT	A	No Bi-rich region found					
	B	61.32	35.66	3.03	44.48	48.31	7.22

Drop No. in proportional with ductility, poor for all Bi-containing joints





Majority of cracks occurred at the bottom pad on the PCB.

Bi - primary cause of poor drop test resistance

Design for Fragility Improvement for Joints Containing BiSnAg

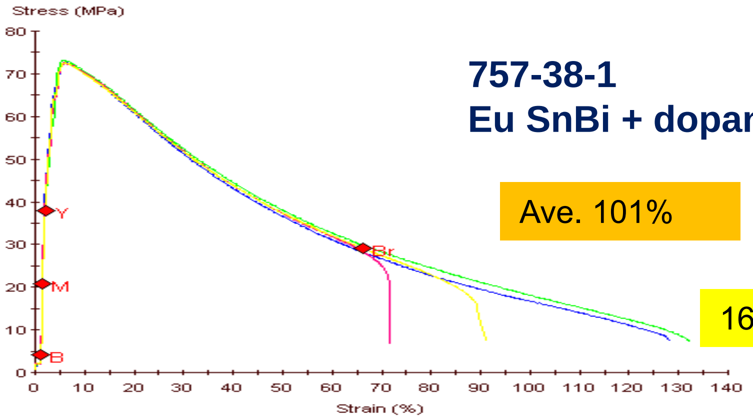
- All combinations involving Bi were brittle, caused by the stiffening effect of solder due to the homogenized presence of Bi in the joint, thus the brittle IMC interface became the weakest link upon shearing.
- Drop number increased with increasing ductility, poor for all Bi-containing joints.
- If BiSnAg used for portable devices BGA assembly, polymeric reinforcement desired.
- New low temperature alloys with improved fragility resistance desired.

Prospect of Low Temperature Soldering

- If BiSn(Ag) used for portable devices BGA assembly, polymeric reinforcement desired, unless significant alloy improvement is made.

BiSn + Proprietary Dopants
New Progress at Indium Corp

Ductility of new alloys much higher than BiSn

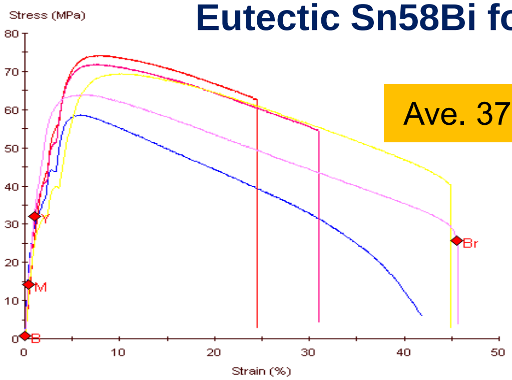


757-38-1
Eu SnBi + dopants

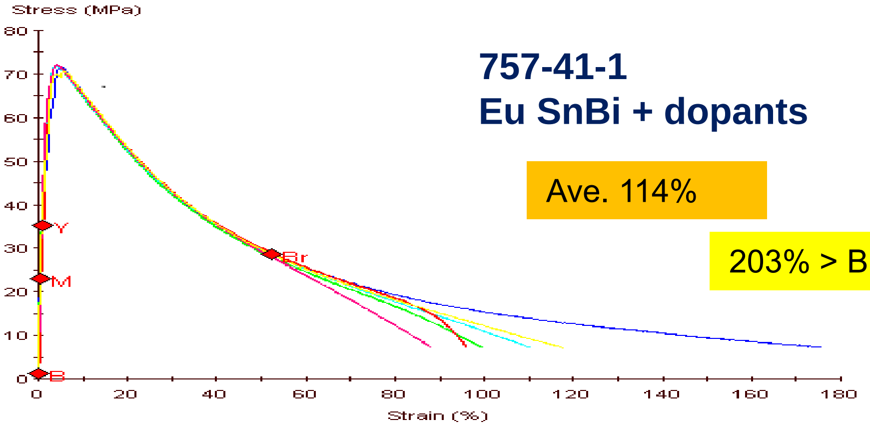
Ave. 101%

169% > BiSn

Eutectic Sn58Bi for control



Ave. 37.6%

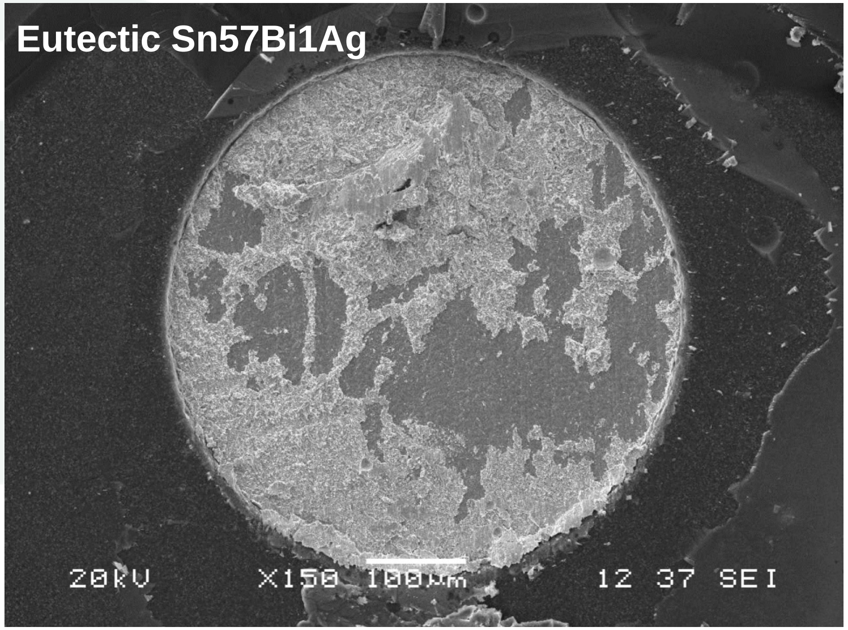


757-41-1
Eu SnBi + dopants

Ave. 114%

203% > BiSn

Eutectic Sn57Bi1Ag



Internal data of Indium Corporation

The Second Generation of SACM

Dr. Ning-Cheng Lee

Indium Corporation

Shock & Fatigue Resistant PCB Assembly/Semiconductor Packaging

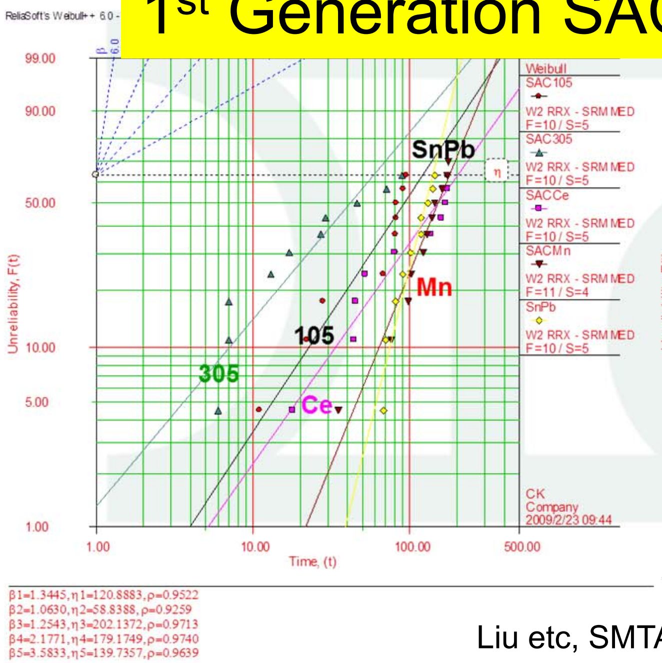
220°C SACY Shock Resistant CSP/BGA interconnect

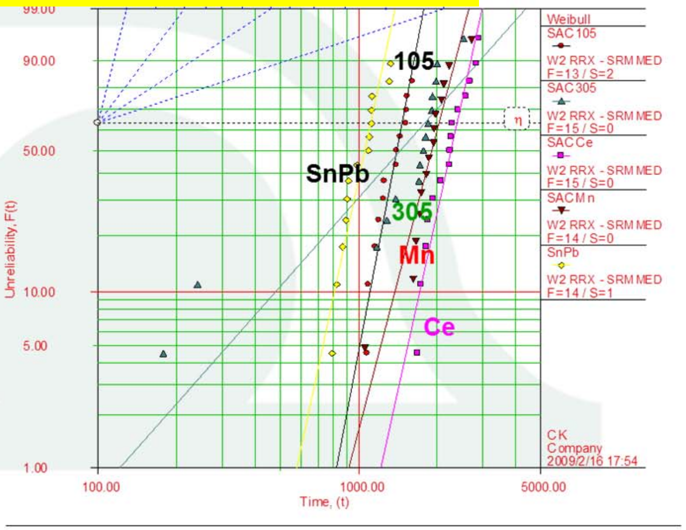
- Goal:
  - Shock resistance match SnPb
  - TCT match high Ag SAC
- Portable & large devices
- **SAC-Mn, Ti, Ce, Bi, Y**

Mn or Ce ~ SnPb > 105 > 305 in drop test.

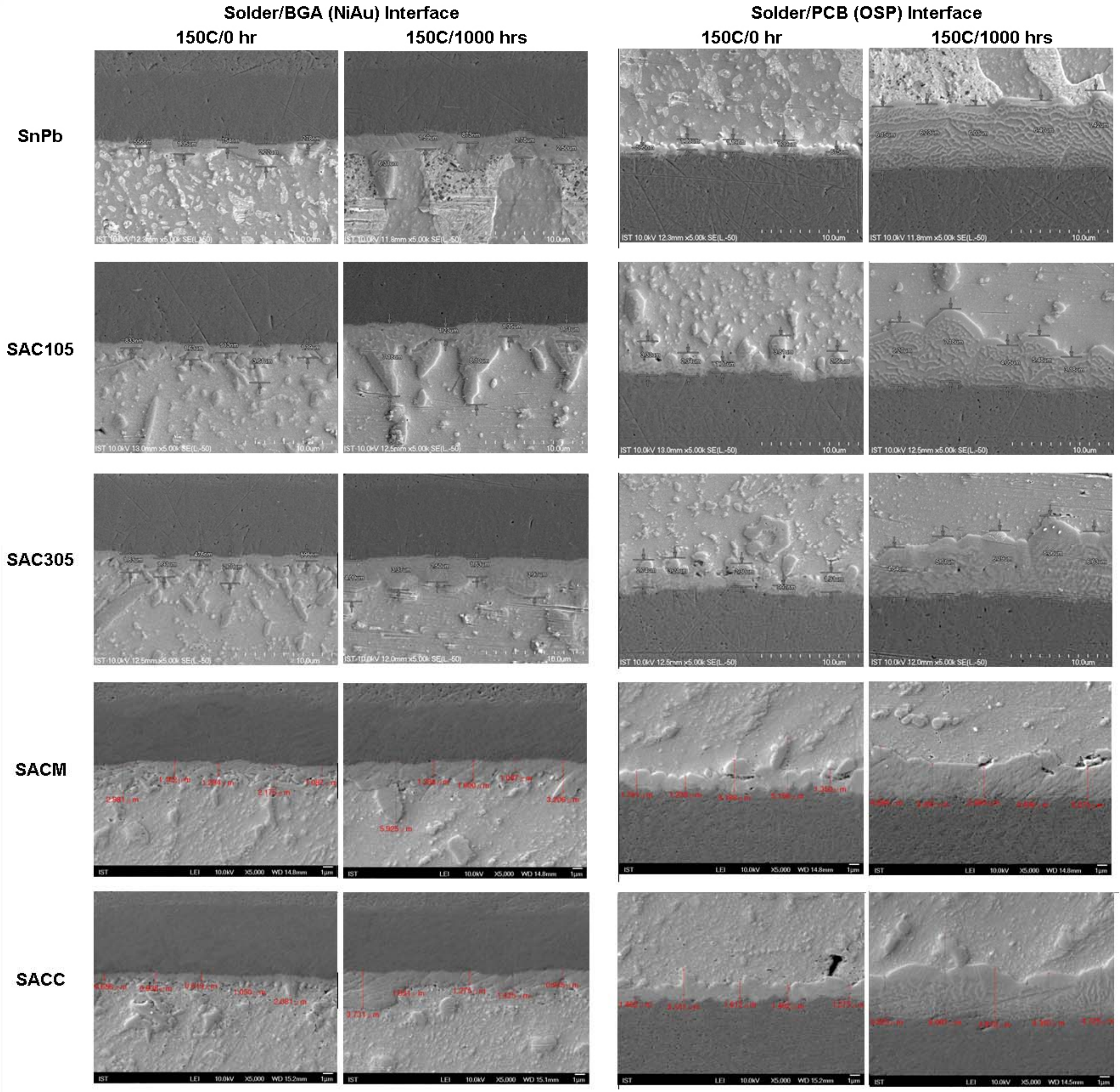
Ce > Mn ≥ 305 > 105 > SnPb in TCT (-40C/125C)

1st Generation SACM – SAC105M





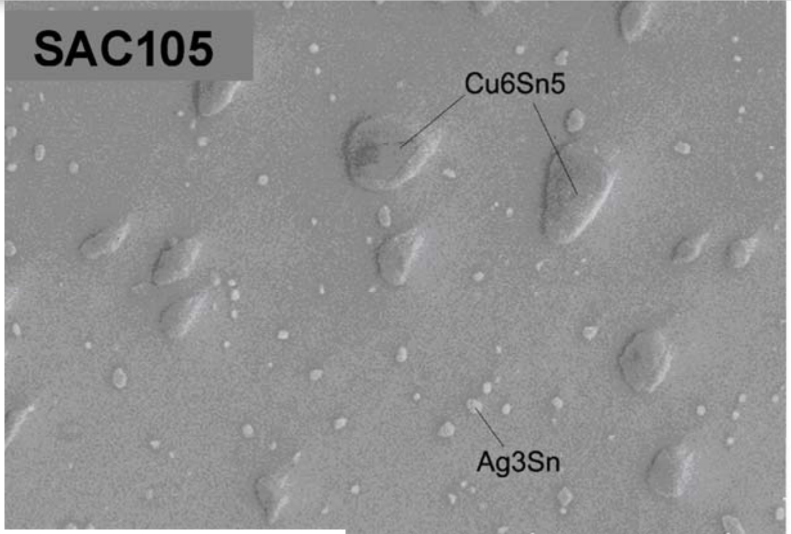
Liu etc, SMTAI, p.920-934, October 4-8, 2009, San Diego, CA.

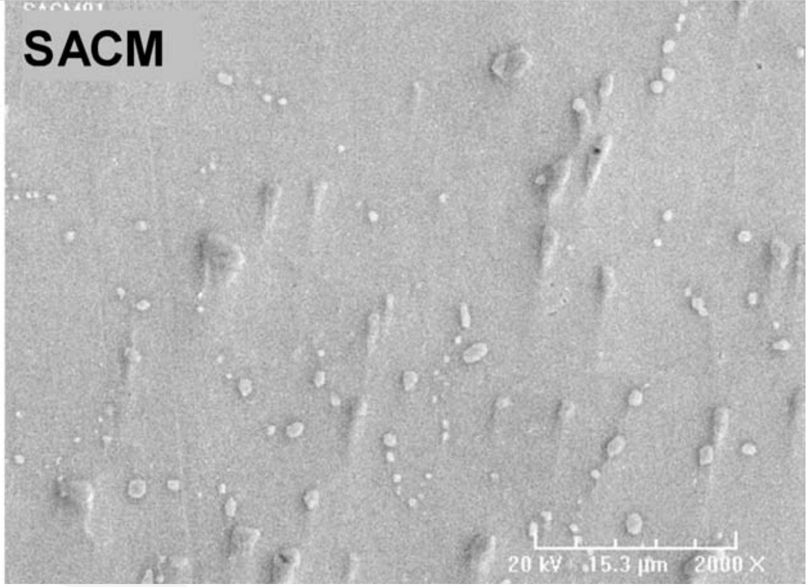


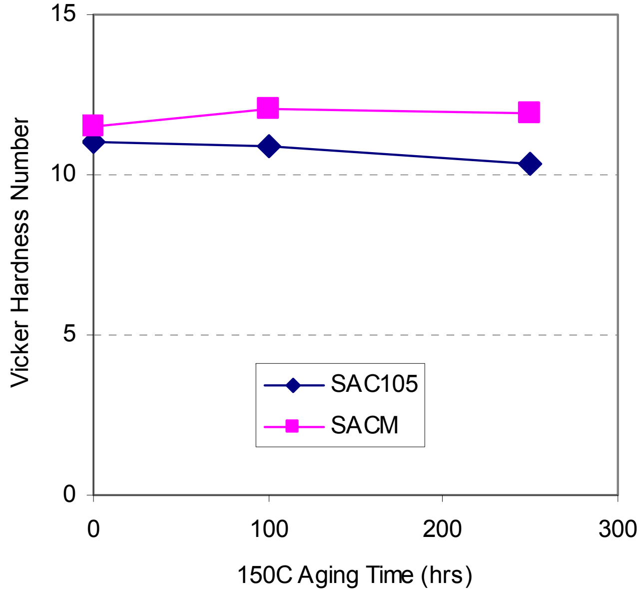
SACM and SACC displayed

- (a) thinner and smoother interfacial IMC layers
- (b) finer IMC particles within bulk solder

Microstructure of solder joints of TFBGA (NiAu) on PCB (OSP) after TCT



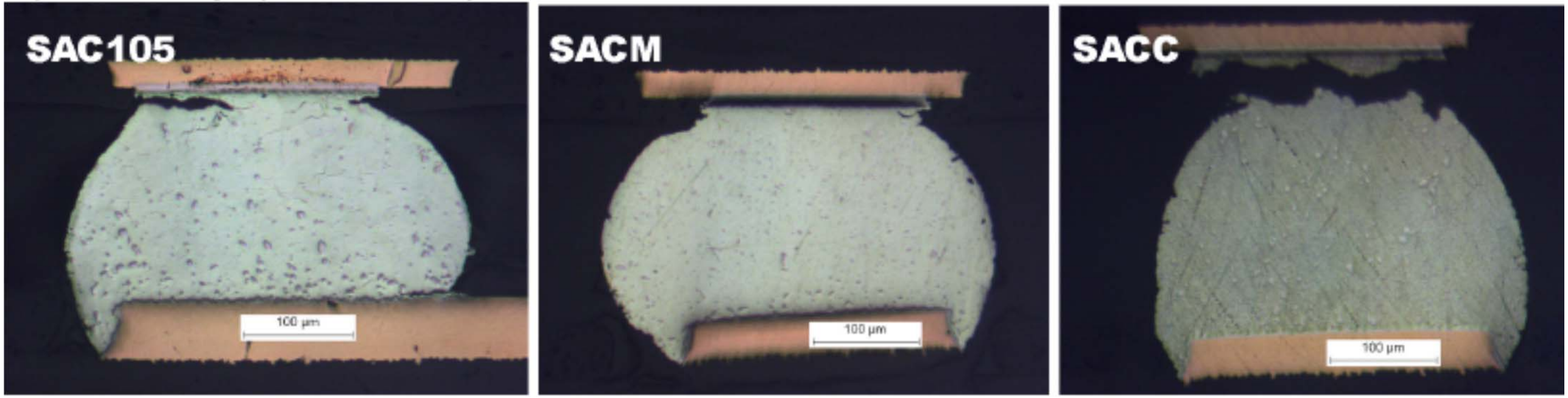




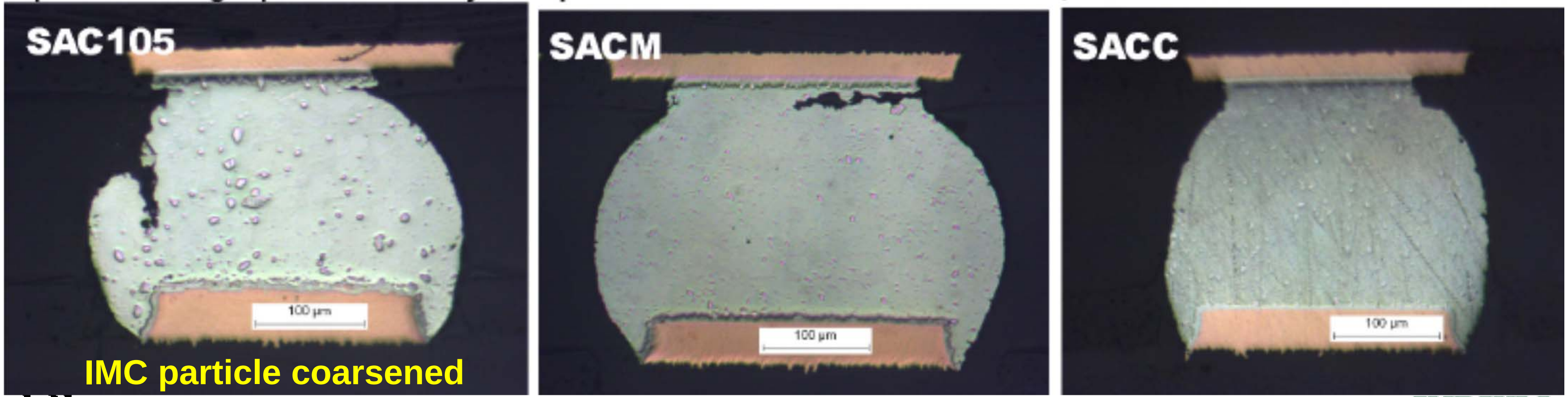
Mn suppressed coarsening of IMC particles, thus maintained hardness of joint

Mn & Ce suppressed IMC coarsening upon thermal aging, hence stabilized microstructure.

Optical micrographs of solder joints after TCT



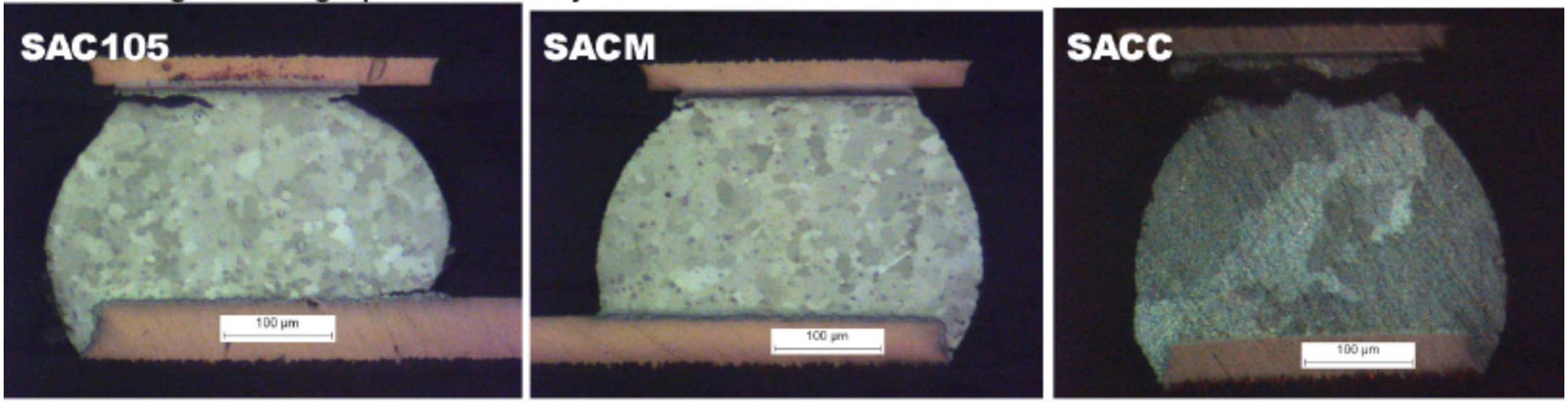
Optical micrographs of solder joints preconditioned at 150°C/250 hrs, followed with TCT



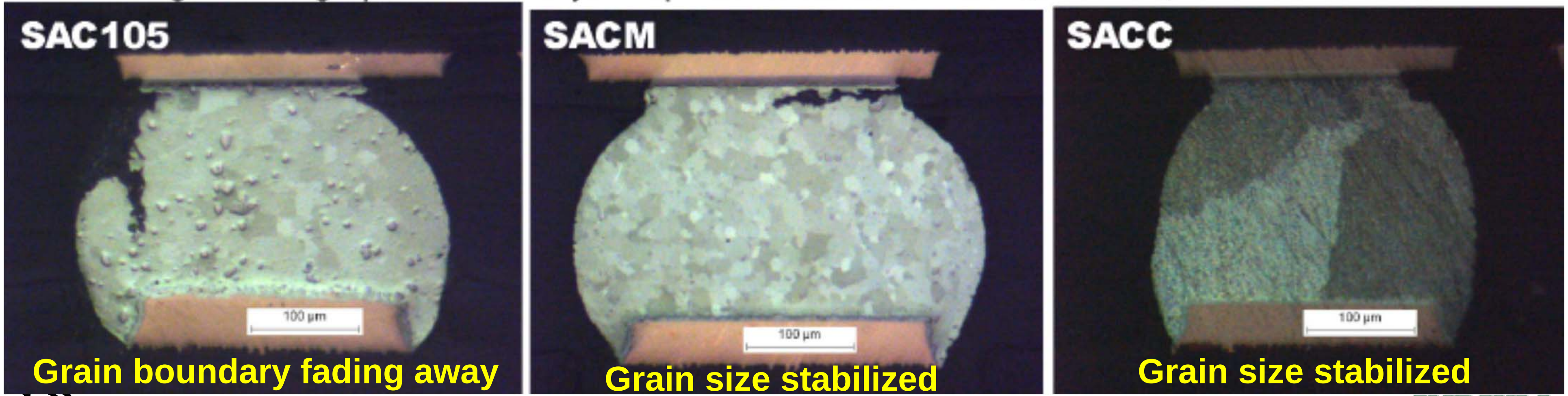
IMC particle coarsened

Mn & Ce stabilized grain size upon thermal aging, presumably through stabilizing IMC particles.

Polarized light micrographs of solder joints after TCT



Polarized light micrographs of solder joints preconditioned at 150°C/250 hrs, followed with TCT



Grain boundary fading away

Grain size stabilized

Grain size stabilized

2nd Generation SACM Alloy

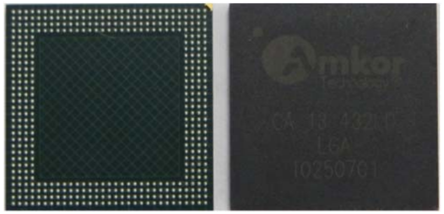
Sn0.5Ag1.0Cu0.05Mn

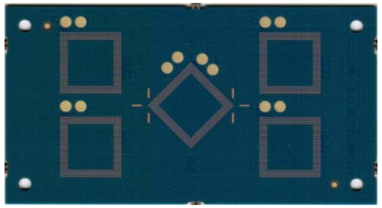
(SAC0510M)

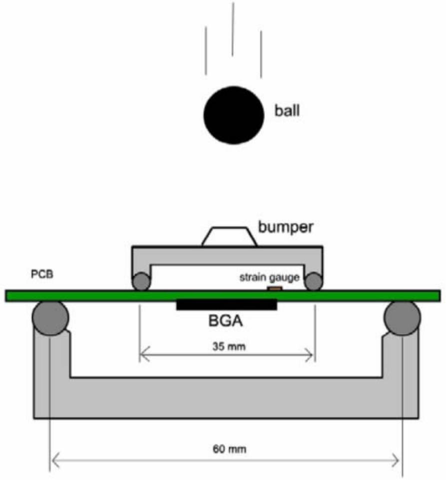
BGA Assembly

- BGA sphere alloys
  - SAC0510M
  - SAC105
  - Others
- BGA432, 12.3mmX12.3mm, 0.25 mm ball/0.4 mm pitch, electrolytic NiAu, with 432 bumps
- PCB:
  - Motorola: FR4, Solder Mask-Defined Pad (SMD), with OSP finish
  - JEDEC: High Tg FR4, NSMD pad, OSP finsih
- BGA assembled with flux and SAC305 paste

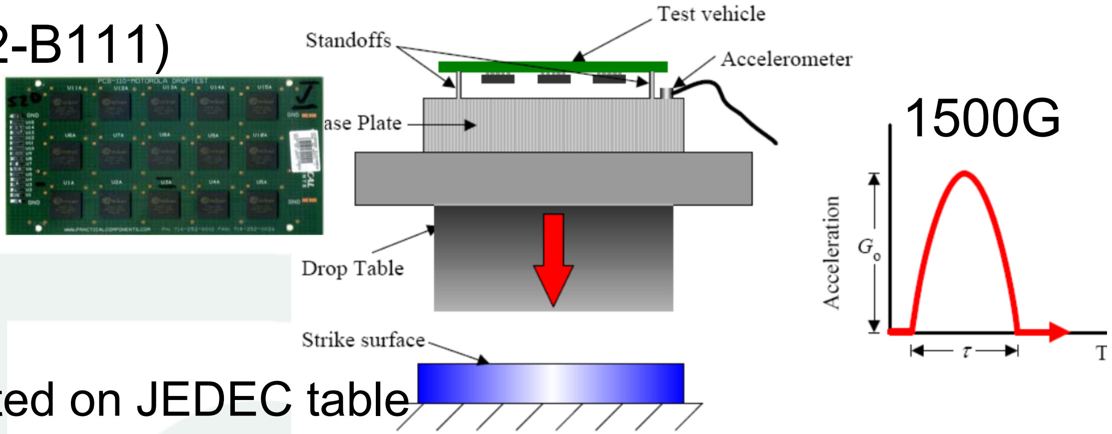
Reliability Test



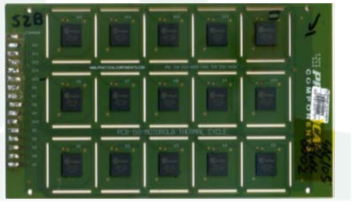




- Dynamic Bending Test
  - Board strain at 1st fail
  - Dye & pry
- JEDEC Drop Test (JESD22-B111)
  - Fail when > 1000 ohms



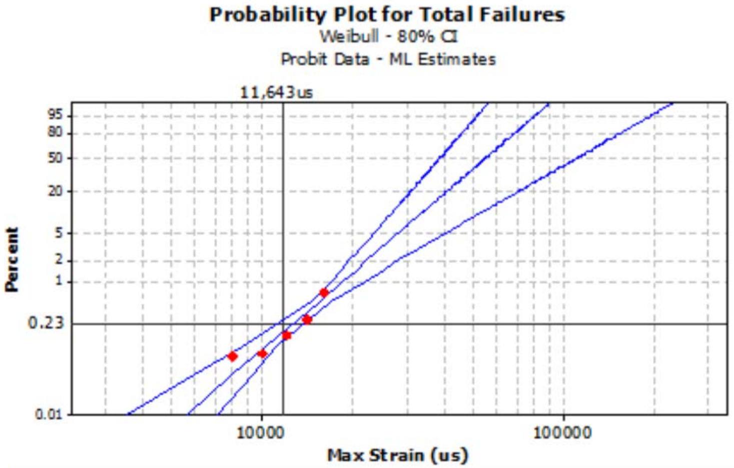
- Modified JEDEC Drop Test
  - Motorola test board mounted on JEDEC table
  - Drop until chip fall
- Thermal Cycling Test
  - - 55C/125C
  - 52 min/cycle, ramp 16 min, dwell 10 min
  - Fail when > 20% Resistance increase

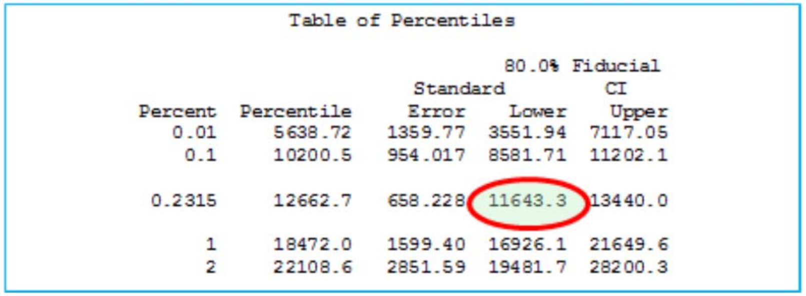


Dynamic Bending Test Results

BGA ball alloy	First failure strain value	Ratio of first failure strain value (Mn/105)
SAC105 ball	4,800με	1
SAC0510M ball (set 1)	>10,000 με	>2.08
SAC0510M ball (set 2)	11,643 με	2.43
SAC0510M ball (set 3)	11,899 με	2.48

all Mn show
> 2X in first failure strain value
when compared with SAC105.





```
                    Table of Percentiles

                                        80.0% Fiducial
                            Standard          CI
 Percent   Percentile         Error    Lower     Upper
    0.01      5638.72       1359.77  3551.94   7117.05
     0.1      10200.5       954.017  8581.71   11202.1

  0.2315      12662.7       658.228  11643.3   13440.0

       1      18472.0       1599.40  16926.1   21649.6
       2      22108.6       2851.59  19481.7   28200.3
```

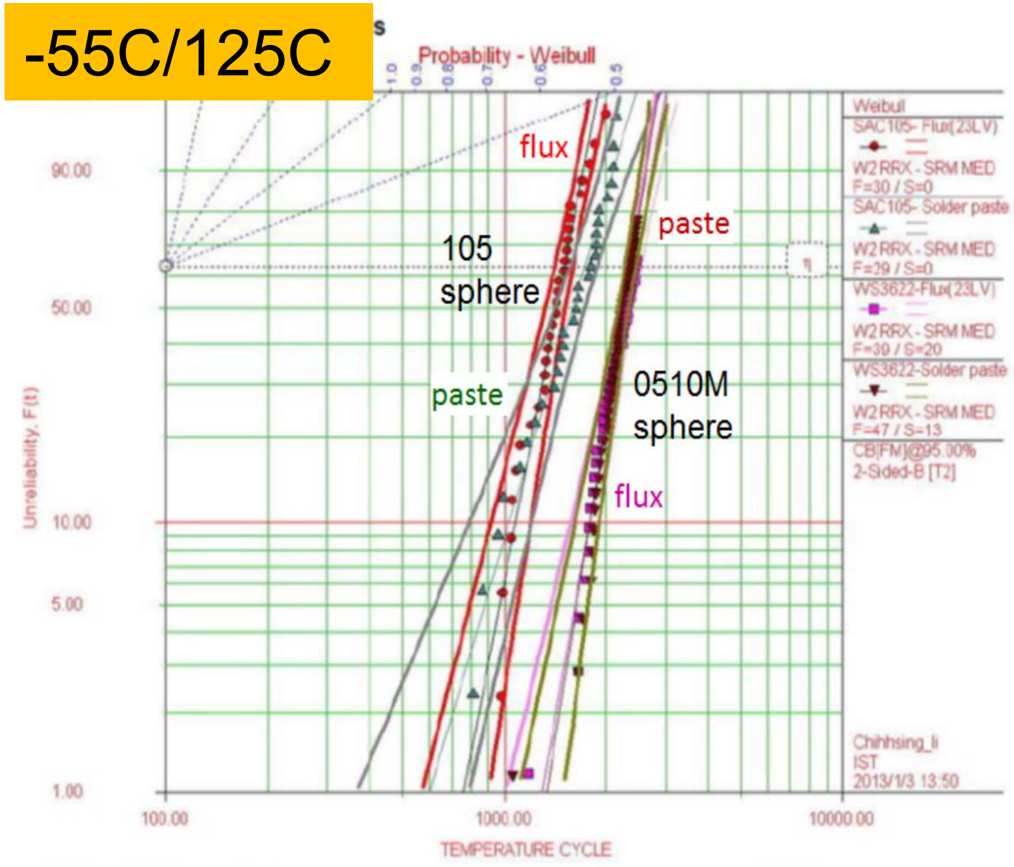
Modified JEDEC Drop Test Results

Bump Alloy	**Test Board Assembly Condition**	**Number of drops to failure**			**Drop Height (m)**
		Ave	Ratio (0510M/ 105)	STDEV	
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

Thermal Cycling Test Results

-55C/125C



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

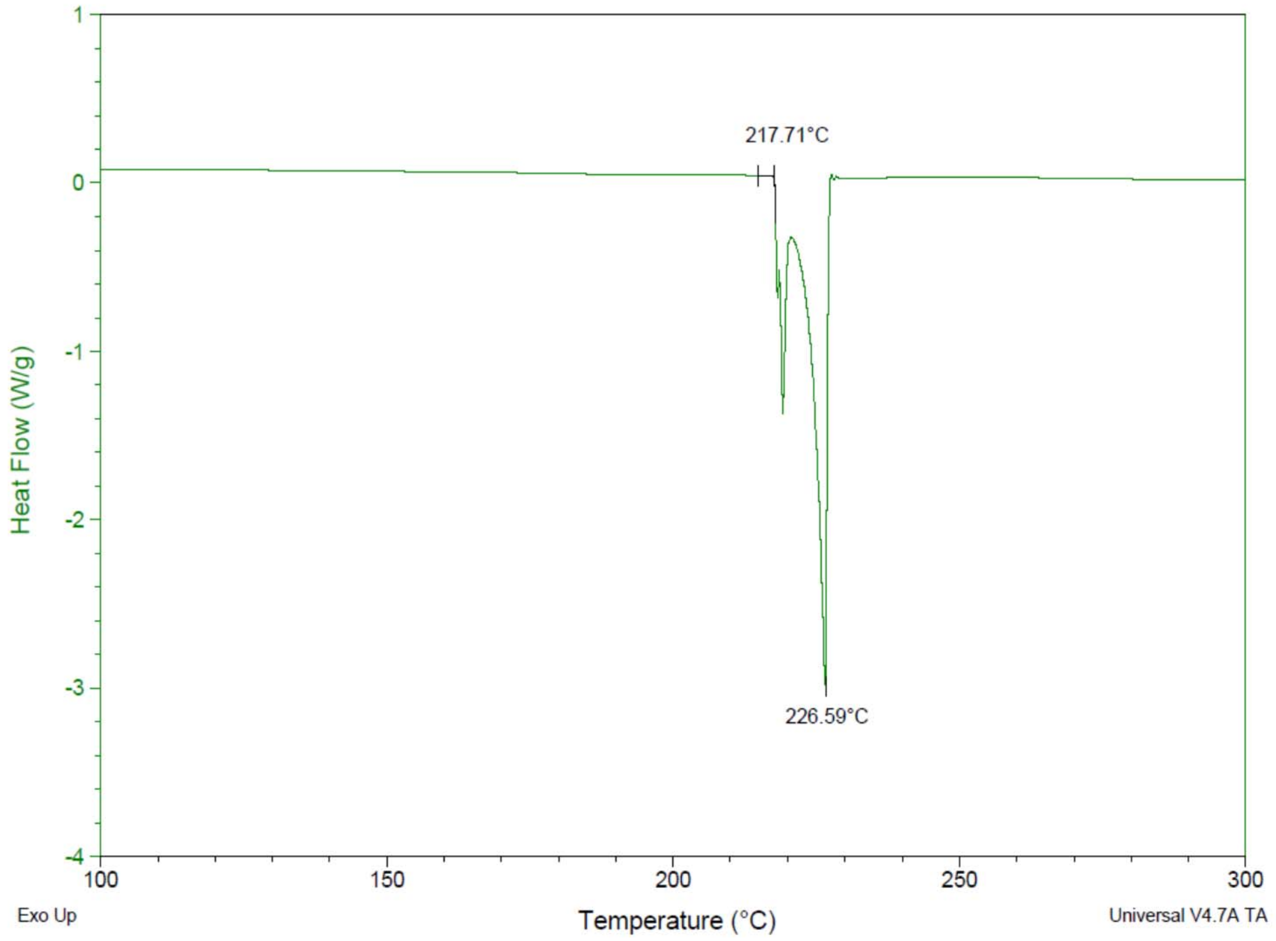
Bump Alloy	Characteristic Life 63.2% (η)	
	Value	Ratio (alloy/105)
SAC105	1468	1
SAC105M	2034	1.39
SAC305	1905	**1.30**

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

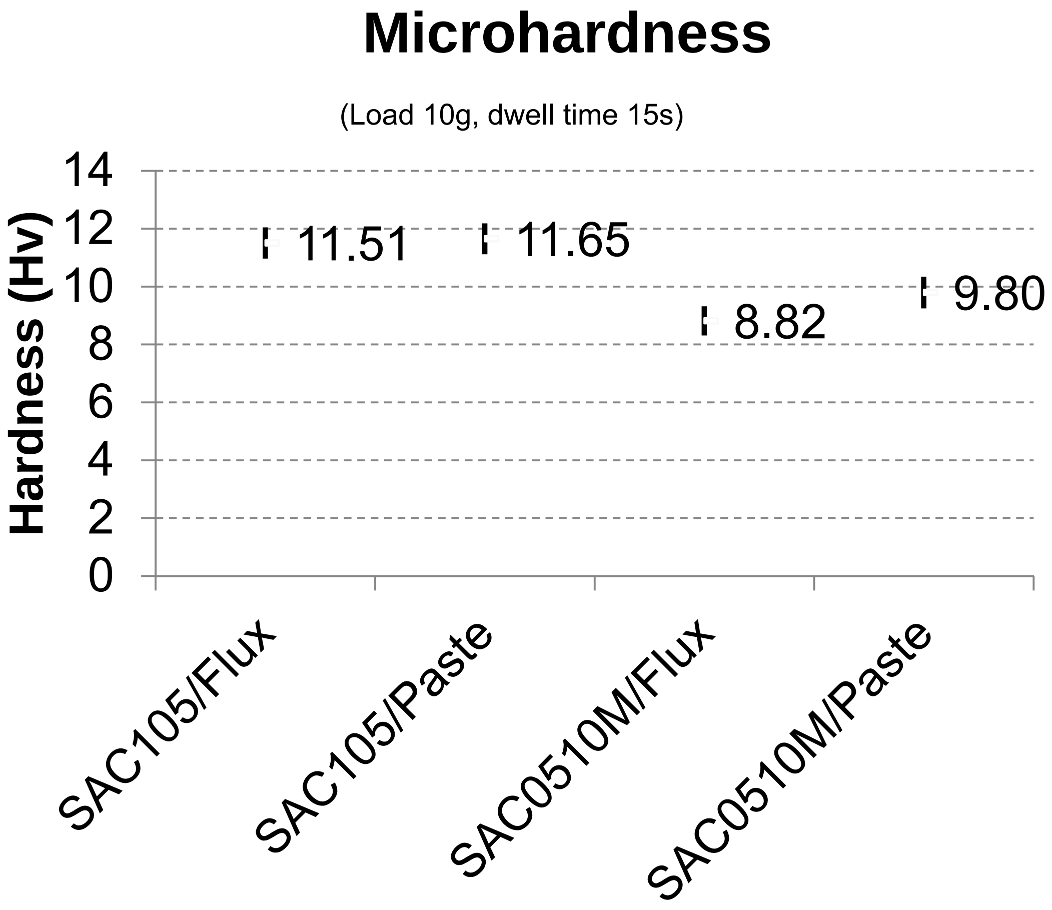
Bump Alloy	Assembly Condition	Characteristic Life 63.2% (η)		Characteristic Life 50%		Weibull Slope (β)
		Value	**Ratio (Mn/105)**	Value	Ratio (Mn/105)	
SAC0510M	Flux	2427	**1.61**	2317	1.62	7.26
SAC105		1510		1431		6.68
SAC0510M	SAC305 paste	2361	**1.37**	2258	1.45	8.03
SAC105		1726		1559		4.36

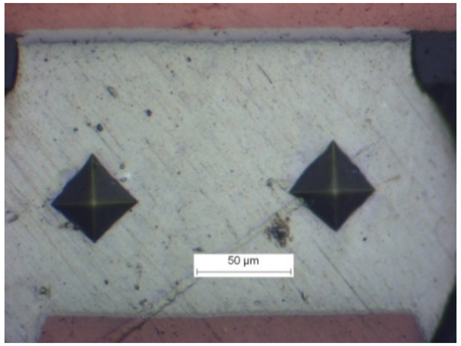
SAC0510M Melting Behavior Similar to SAC105

218C – 227C



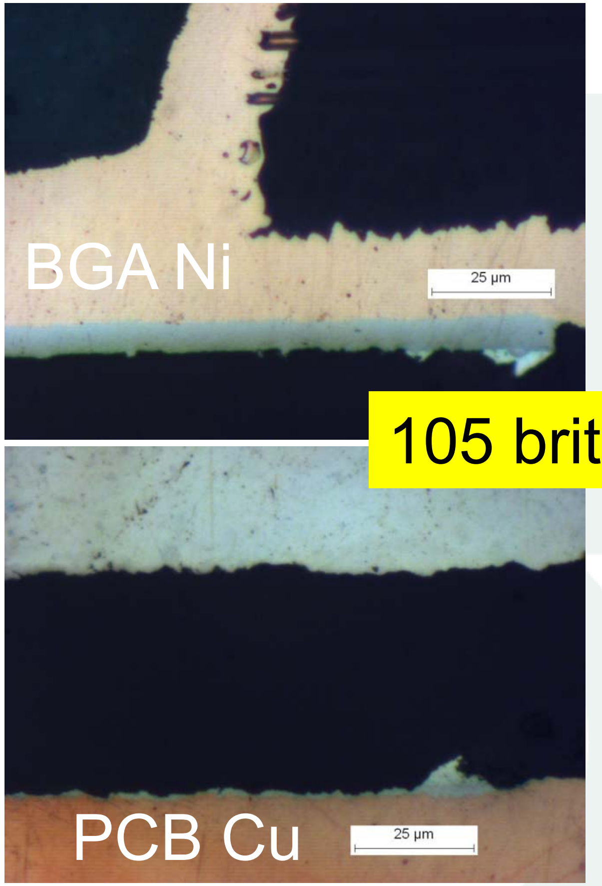
Vicker Hardness

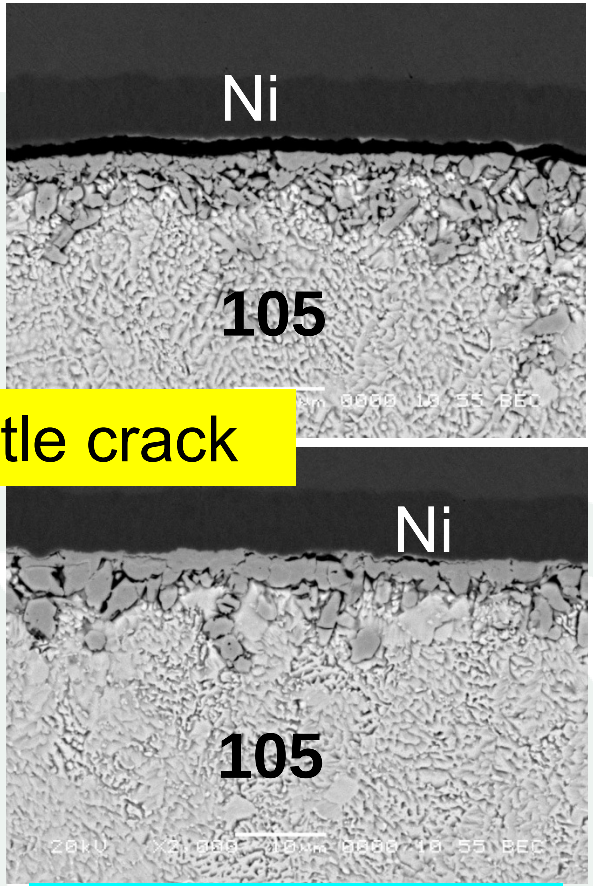




- Hardness $\propto$ Ag %
- 305 paste assembly raised hardness slightly
- Lower hardness favor better drop test performance

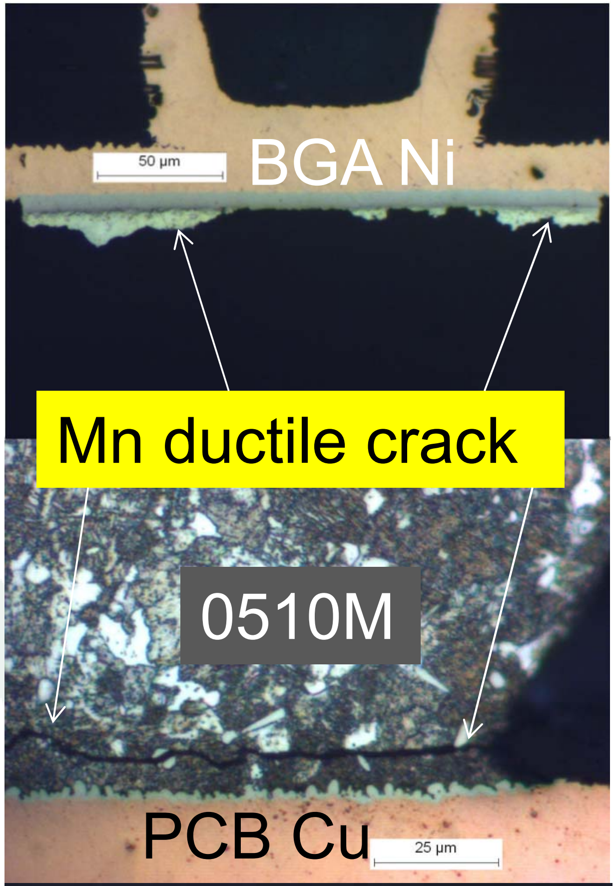
Dynamic Bending Test & Modified JEDEC Drop Test



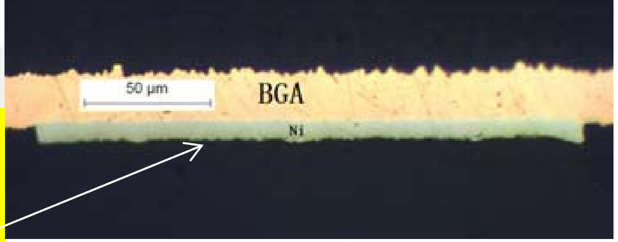


105 brittle crack

Fragmented IMC

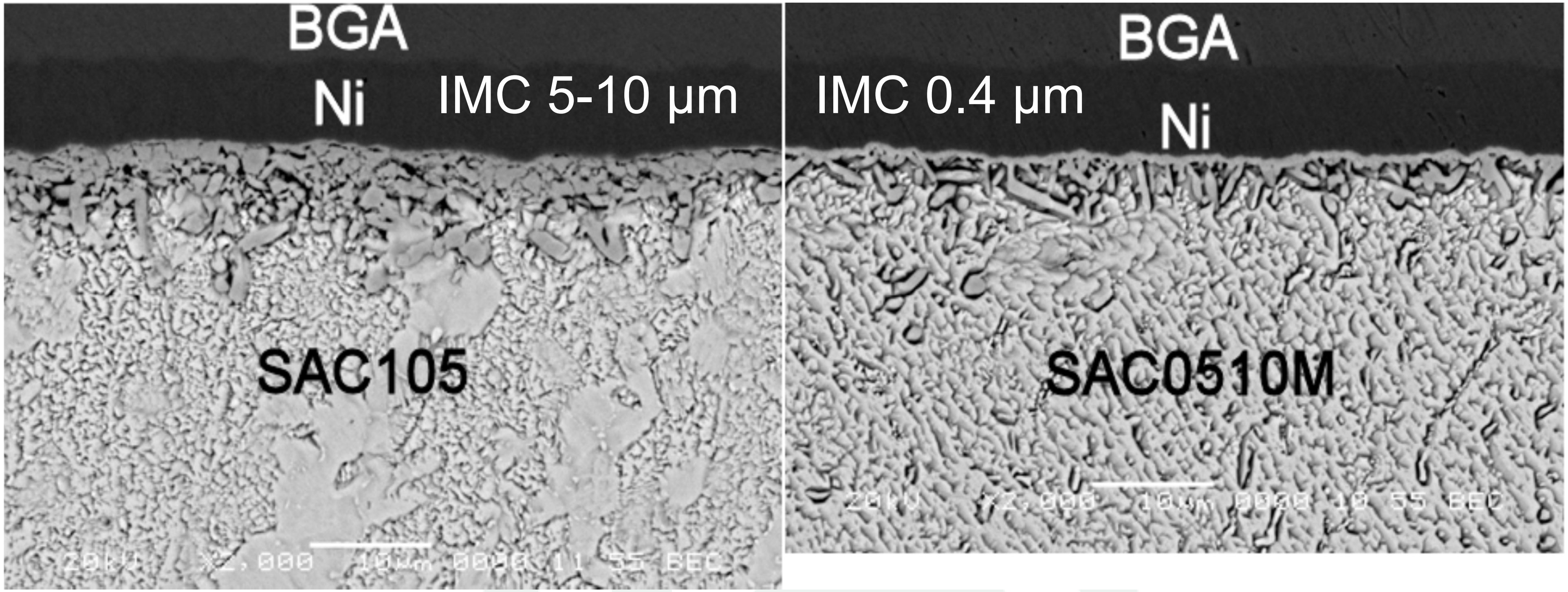


Mn ductile crack



0510
No Mn, brittle crack

Mn Suppress IMC Thickness



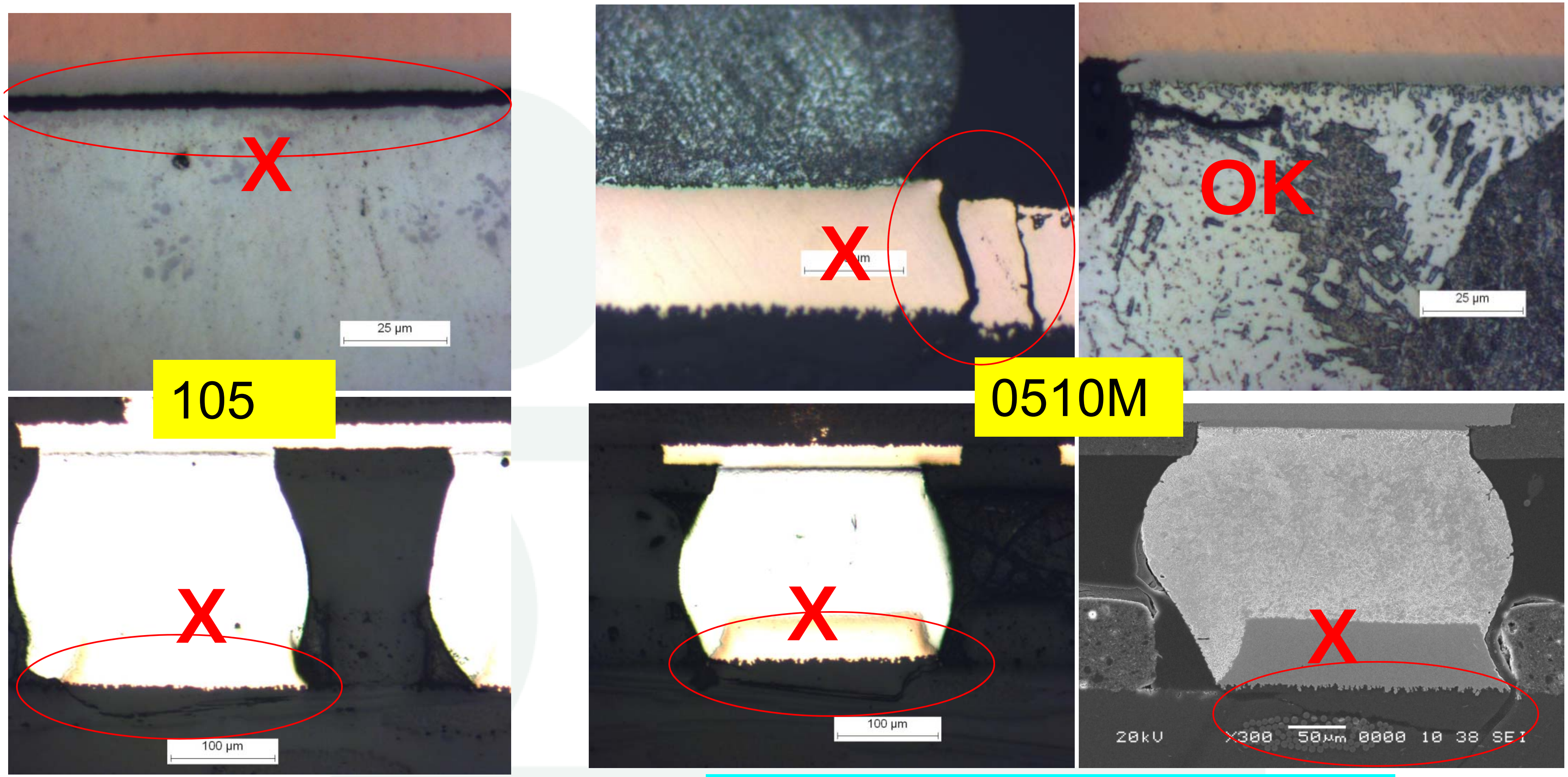
Earlier work Mn suppress IMC growth

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

0510 brittle failure

JEDEC Drop Test Results

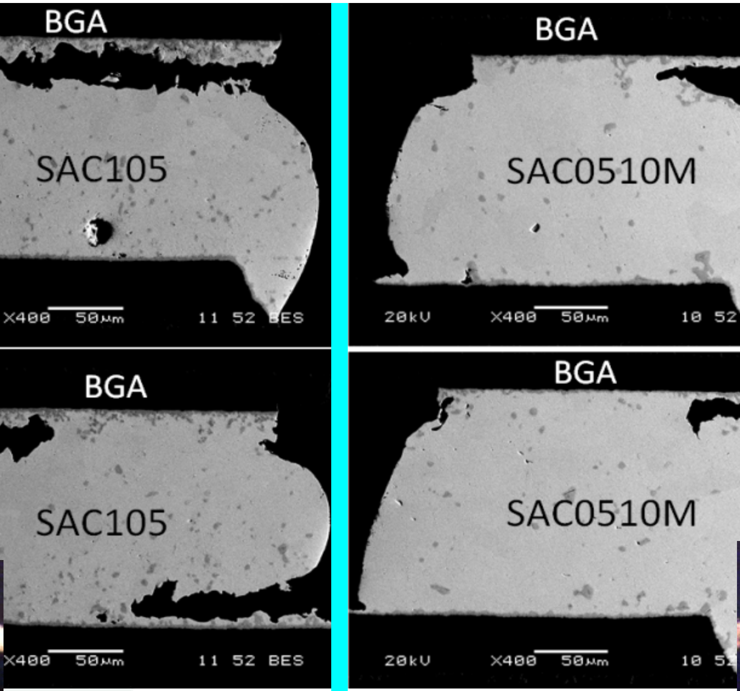
Test results invalidated by high Tg brittle PCB



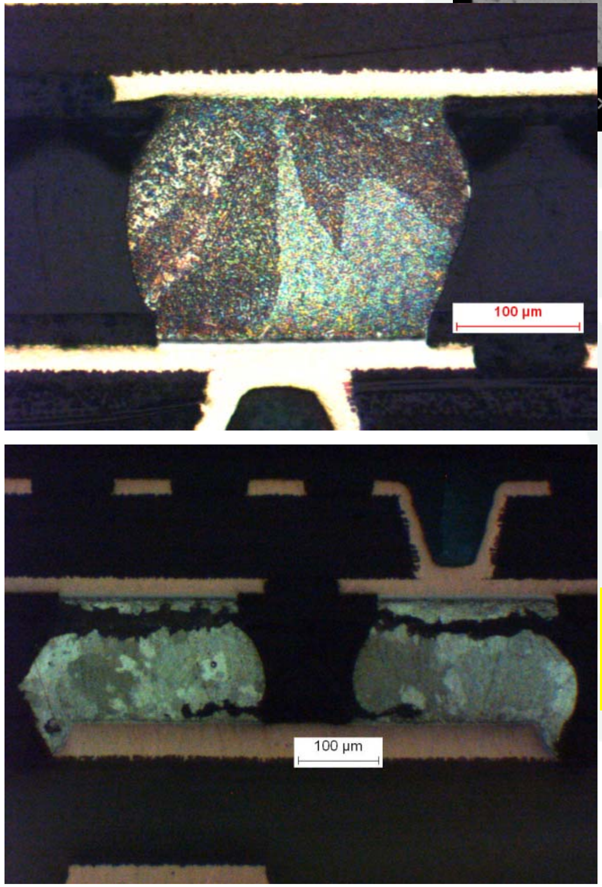
105 failed at both sides

0510M all failed at PCB side

High Tg brittle laminate cause pad cratering – the weakest link

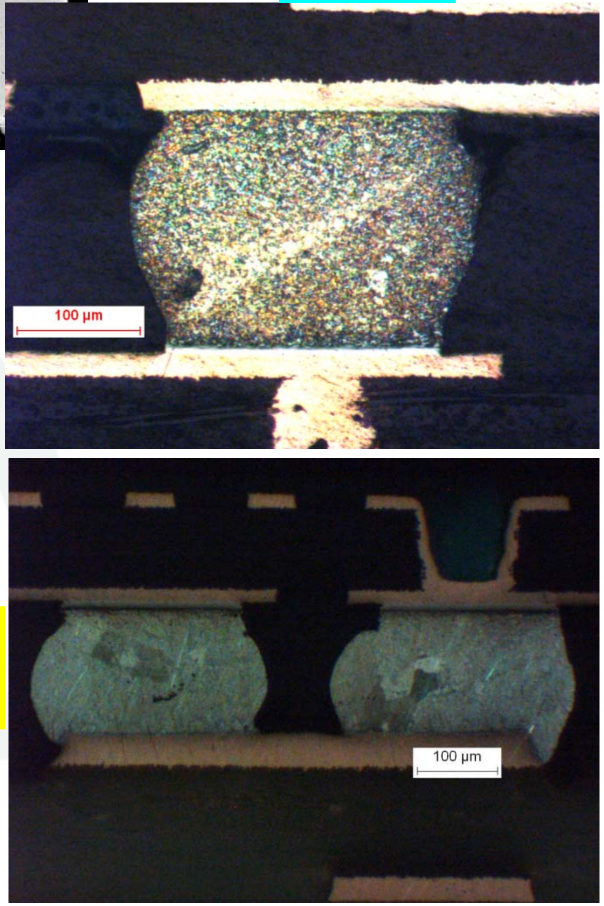


105



0510M

Mn



Earlier work Mn stabilize microstructure

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

Significant recrystallization

Minute recrystallization

Conclusion

- SAC0510M ~ SAC105 in melting
- SAC0510M/SAC105 sphere
  - > 2X in DBT
  - > 8X in modified JEDEC drop test
  - ~ 40-60% better in TCT (-55°C/125°C)
  - TCT of SAC0510M may outperform SAC305
- The reduced hardness and much thinner and stable IMC layer on Ni are responsible for the superior non-fragility, while the stabilized IMC and grain microstructure are responsible for the TCT performance.
- Thinner IMC layer on Ni is more important than reduced hardness in improving non-fragility.
- High Tg brittle laminate can cause pad cratering.