Understanding and Reducing Component Soldering Defects

Head-In-Pillow: Are we still Snoozing?

A Continuation Study of Known Chemical and Mechanical Factors in BGA Non-Wet

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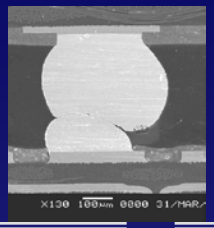
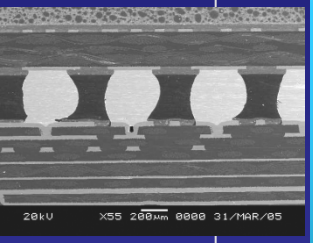
SMIC
Senju Metal Industry Co., Ltd.

Point of view for Head in Pillow risk

Failure (HIP)



Fusion



Remaining Margin

Other latent risks

Abnormality in surface condition of solder sphere

Abnormality in height of sphere against printed paste

Variable SMT factors

Reflow temp & time
Atmosphere

Property of
Solder paste

Printing condition

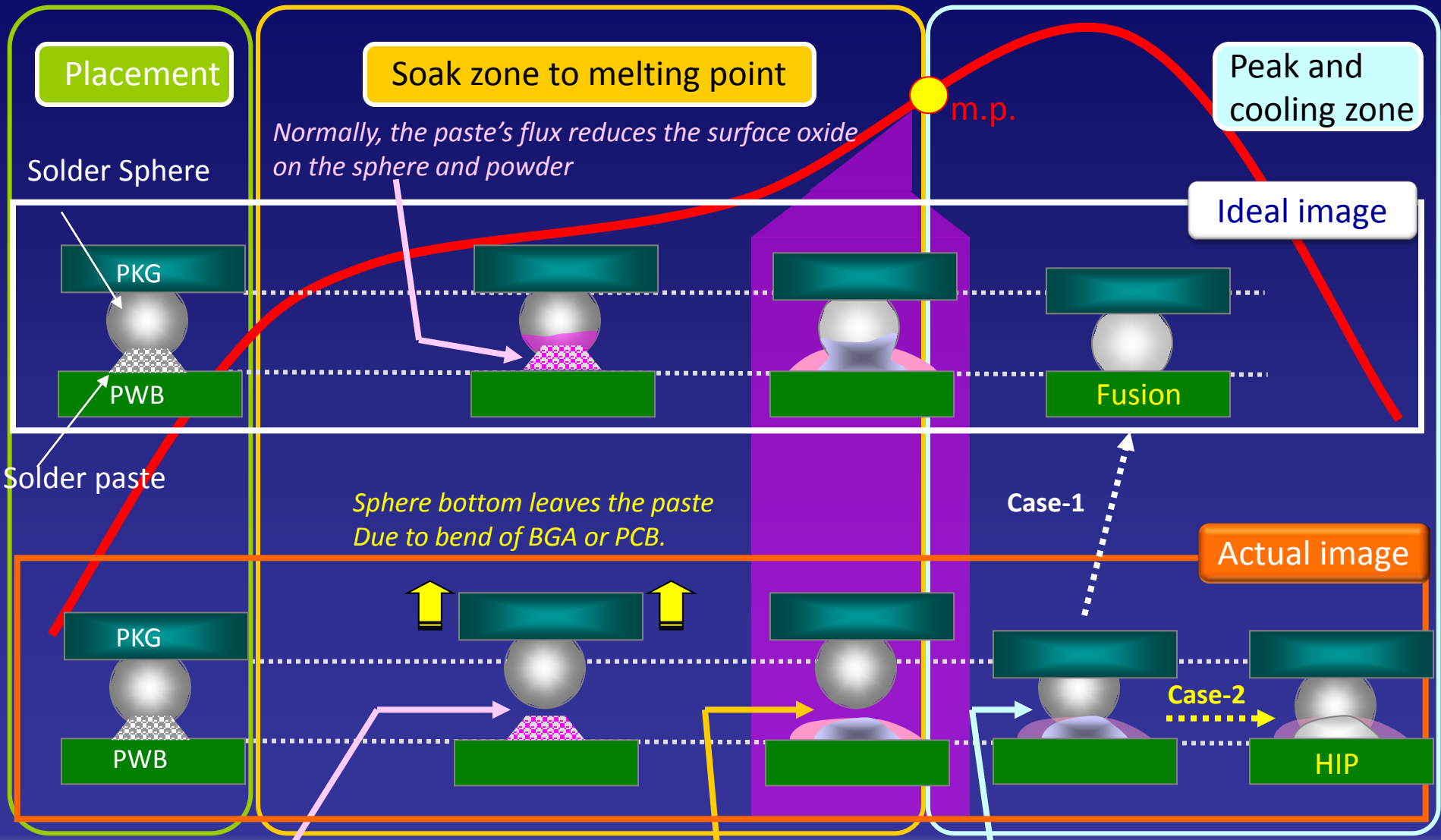
etc..

Balance Cumulative Risk vs. Total Process Margin

Potential root cause & representative risk

- Warpage of device

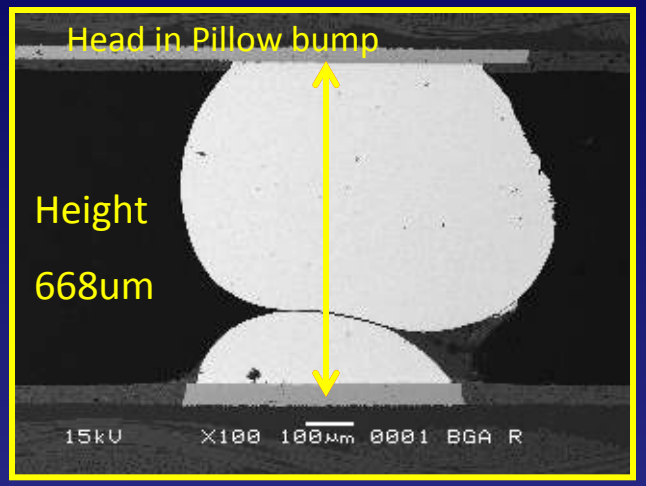
Lost contact point between solder materials due to physical cause



Potential root cause & representative risk

- Device warpage

Lost contact point between solder materials due to physical cause



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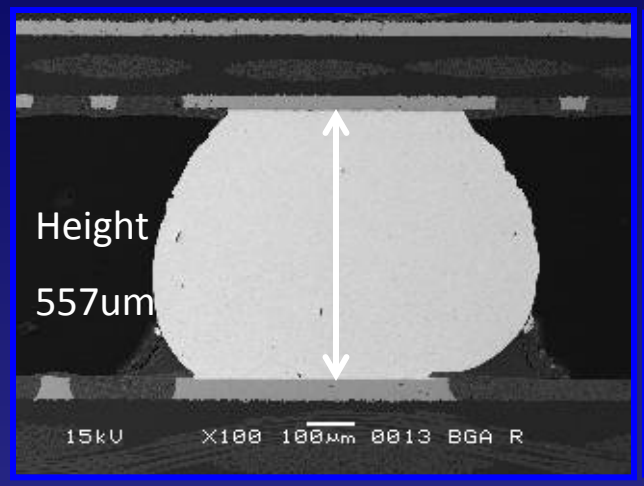

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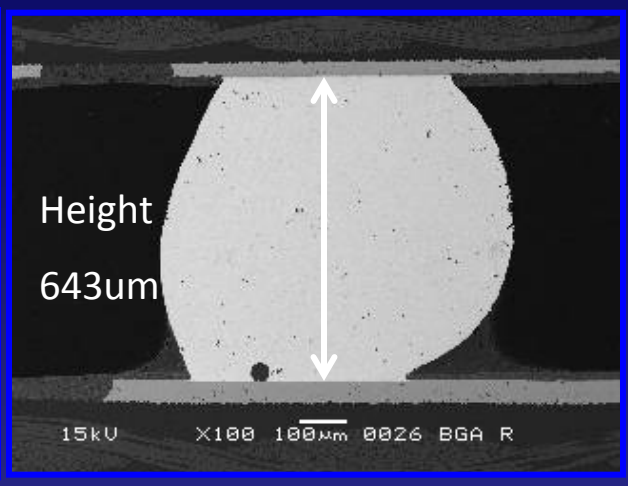

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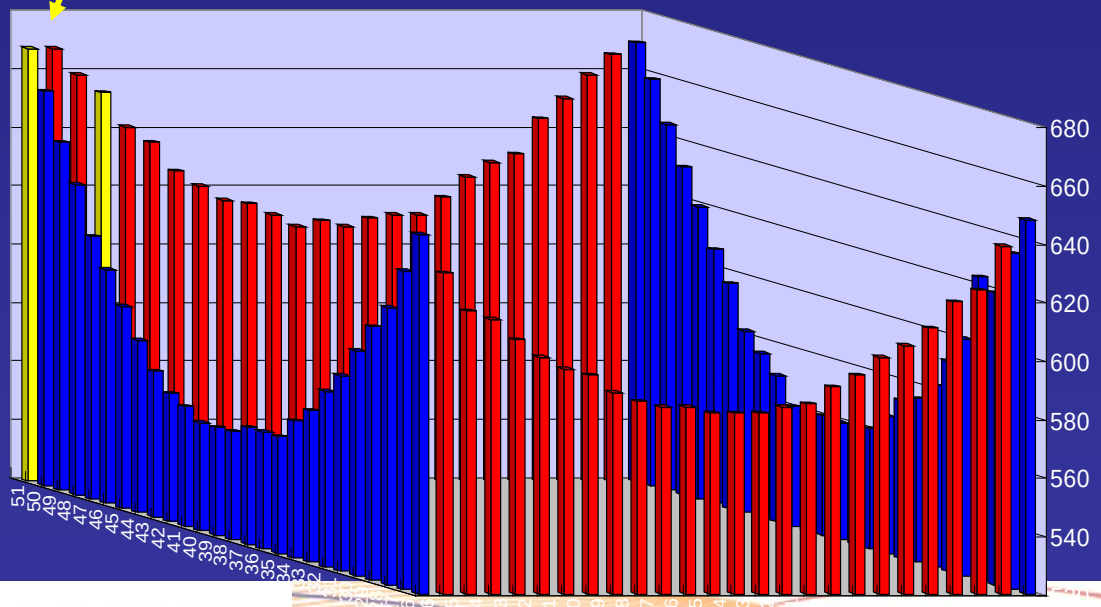
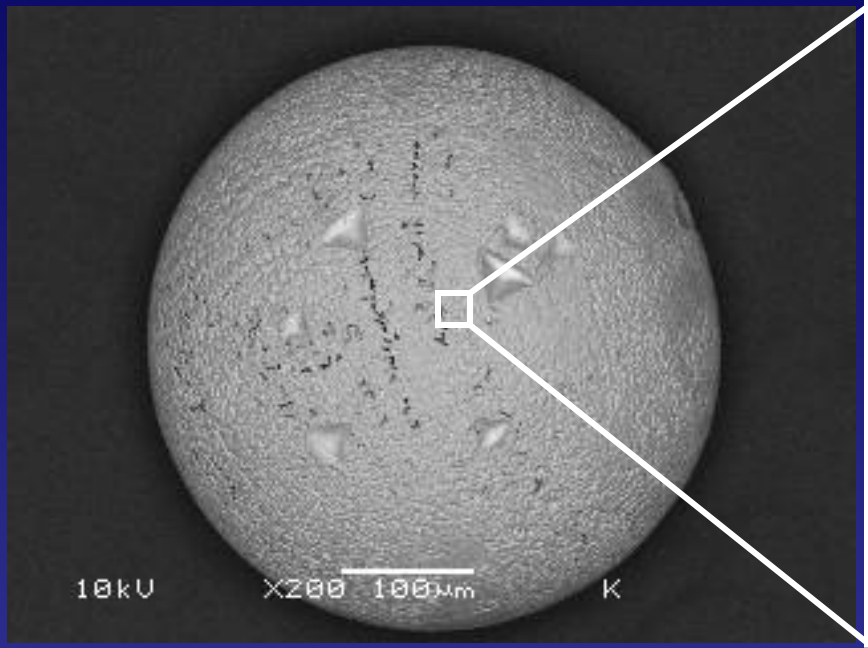


Over 100um difference In height of bumps in same row of BGA device

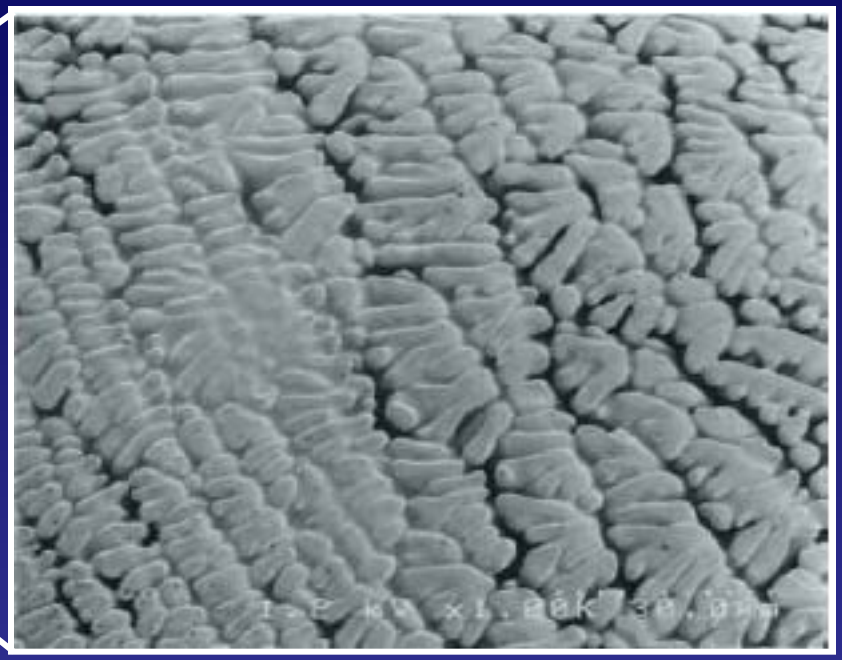
Potential root cause & representative risk

Reduced Flux Wetting Ability
by thermal or chemical causes

☐ Surface condition of solder sphere

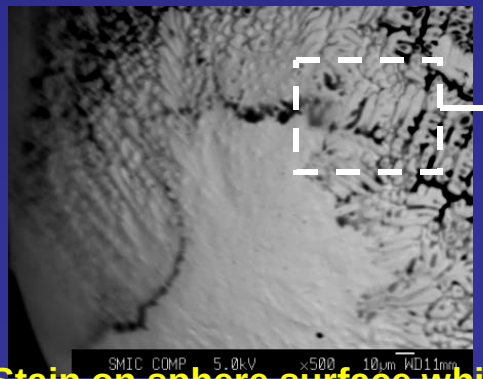


Surface of attached SAC sphere



Cavernous surface with Sn dendrite

- Hard to wash & dry in every ‘cave’
- Easy to trap foreign substances (Ex. Si, Cl)
- Large surface area (Increase oxidation risk)



C	0.556
O	3.840
Si	**1.089**
Ag	3.723
Sn	89.07

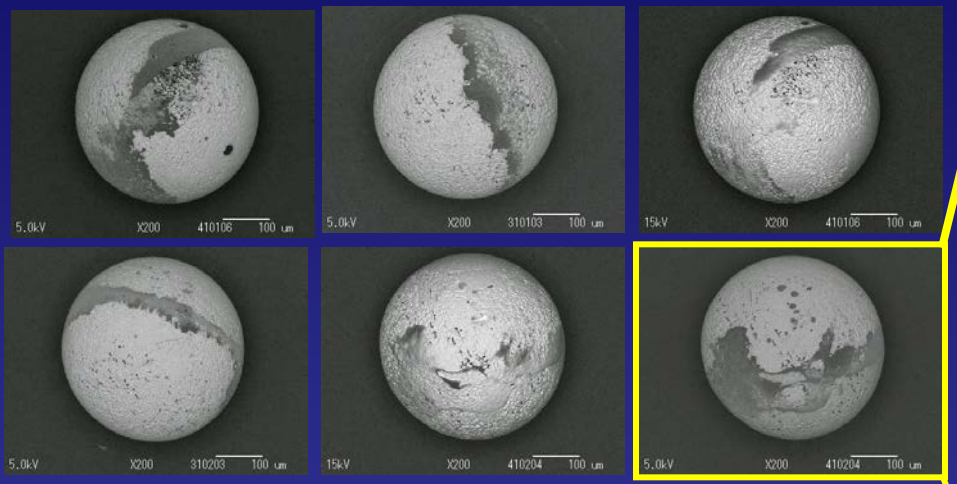
Stain on sphere surface which including Silica

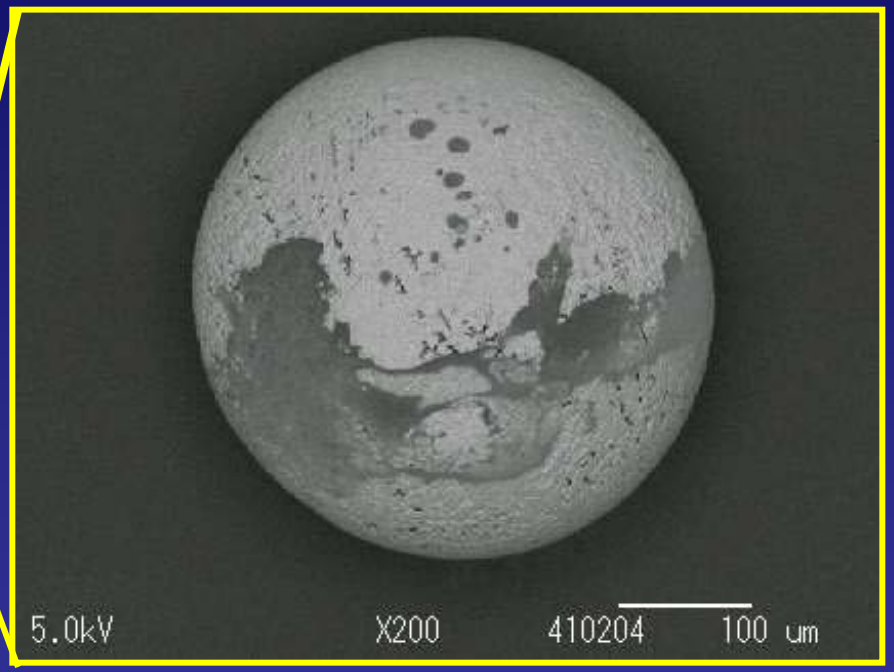
Potential root cause & representative risk

- Surface condition of solder sphere

Reduced Flux Wetting Ability
by thermal or chemical causes

SEM observation of solder sphere attached on BGA (before soldering)





Remaining Flux residue (water soluble) for ball attachment possible due to an insufficient washing process.
Generally water soluble flux has high activity which can corrode Sn after adhesion on solder sphere for a long time .

- About Head in Pillow issue
- Potential root cause & representative risk
  - Warpage of device
  - Surface condition of solder sphere
- DOE
  - Influences of various soldering parameter & materials

    (Ball-attach materials, Storage, Reflow Temp & Atmosphere, SMT-Paste)
- Alternative test method for HIP
- Summary

DOE: Influences of various soldering parameter & materials

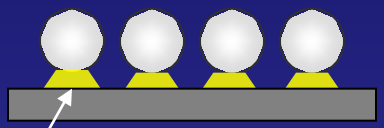
Test Procedure & Factors

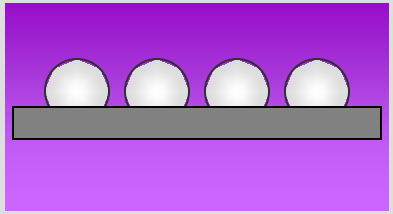
Step-1 → BGA making (Ball attach)

Step-2 → De-flux & Oxidize

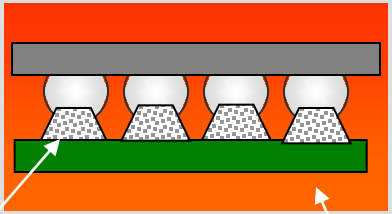
Step-3 → SMT

Step-4 → Inspection

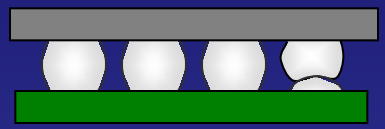




Humidity chamber



Reflow Oven



Material for Ball attach
- Water soluble flux
- No-clean solder paste

SMT paste
- LF Standard
- Improved model for HIP
- Improved HF model for HIP

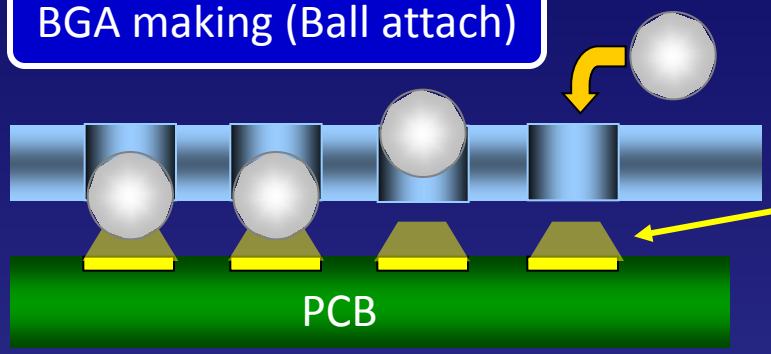
Reflow profile
- Preheat temp & time
- Peak temp & time
- Atmosphere (AIR & N2)

DOE: Influences of various soldering parameter & materials

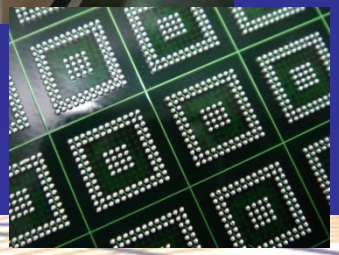
Test procedure & tested factor

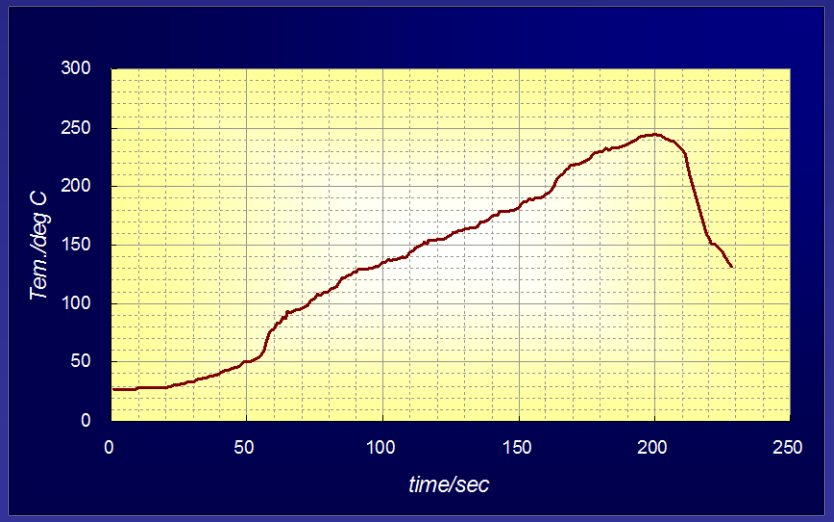
Step-1

BGA making (Ball attach)



Material for Ball attach
- Water soluble flux (WSF)
- No-clean solder paste (NCP)





PCB
- Pad pitch: 0.5mm Pitch
- Plating: ENIG 192pin

Printing condition
- Stencil aperture: 240um
- Thickness: 100um

Sphere
- Solder alloy: SAC305
- Size: 300um

Ball attach reflow
- Oven: SNR615
- Peak temp: 244degC
- TAL: 40sec
- Ramp rate: 1.07deg C/s
- Time to Peak: 200sec
- O2 conc.: <100ppm

DOE: Influences of various soldering parameter & materials

Test procedure & tested factor

Step-2

De-flux

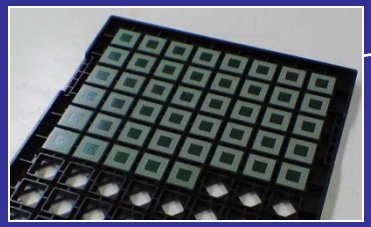
* For only water soluble flux

De-flux condition
- 60degC DI water
- Washing time: 3min

Aging

Oxidized in humidity chamber
85degC 85RH% x 12H

Baking in heat chamber
150degC x 3H

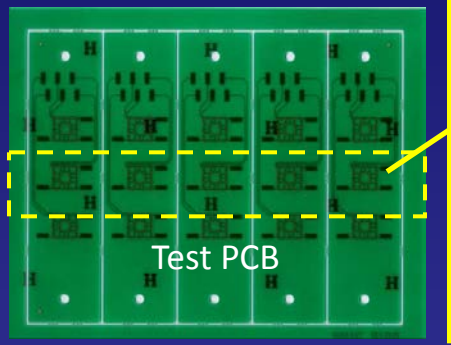


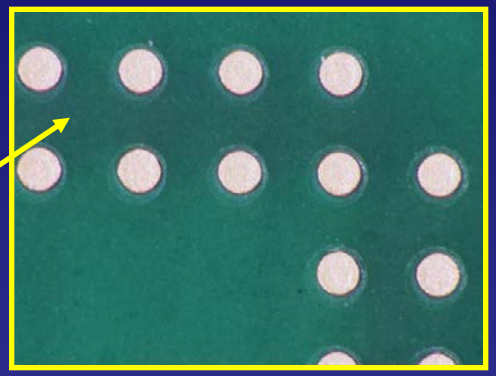
DOE: Influences of various soldering parameter & materials

Test procedure & tested factor

Step-3

SMT

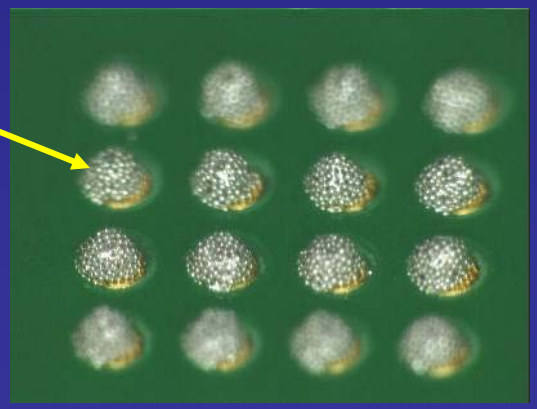


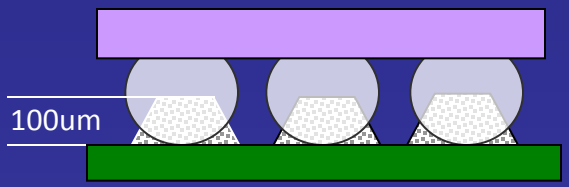


PCB
- FR-4 0.6mmt
- Finish: CU+OSP

Printing condition
- Stencil thickness: 100um
- Aperture: 240um
- Squeegee: Metal 60deg
- Speed: 30mm/s
- Pressure: 0.2N/mm

SMT paste
- Standard (STD)
- HIP Improved model (HIP)
- HIP improved HF model (HIP-HF)



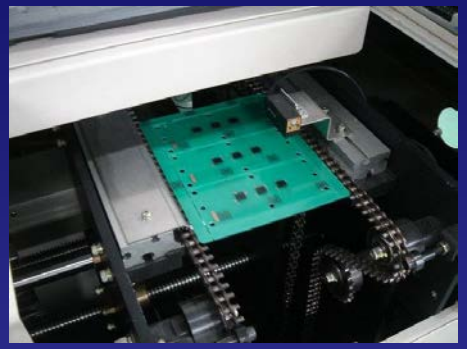


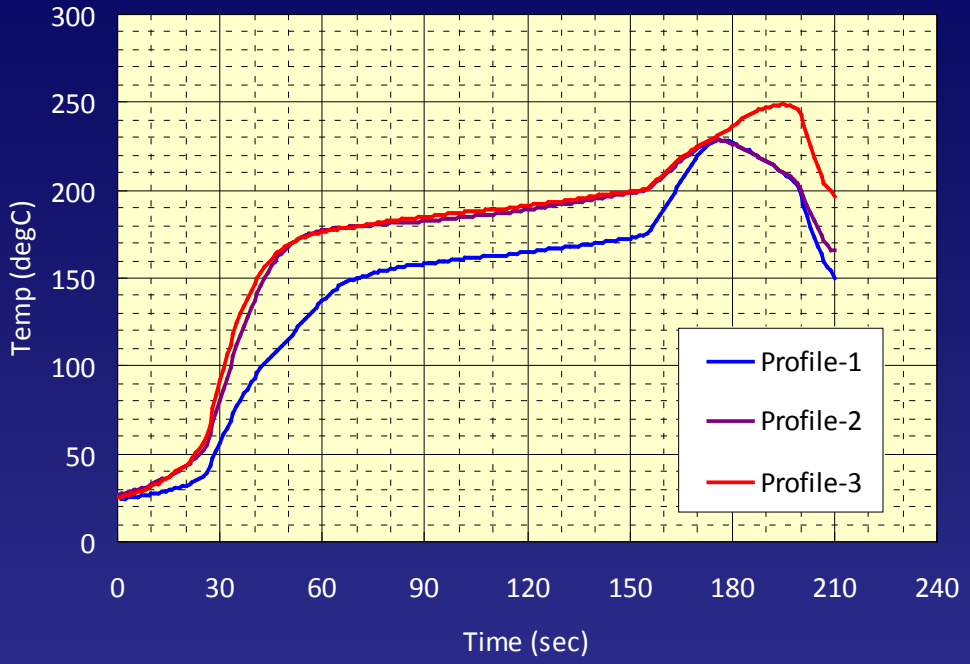
DOE: Influences of various soldering parameter & materials

- Test procedure & tested factor

Step-3

SMT





SMT Reflow Profile:

Profile		Model	Soak zone		Reflow zone	
			Temp (C)	Time (s)	Peak temp (C)	Time (s)
●	Profile 1	Soak: Low & Short / Peak: Low & Short	155 ~ 175	88	234	18
●	Profile 2	Soak: High & Long / Peak: Low & Short	180 ~ 200	98	234	21
●	Profile 3	Soak: High & Long / Peak: High & Long	180 ~ 200	96	244	43

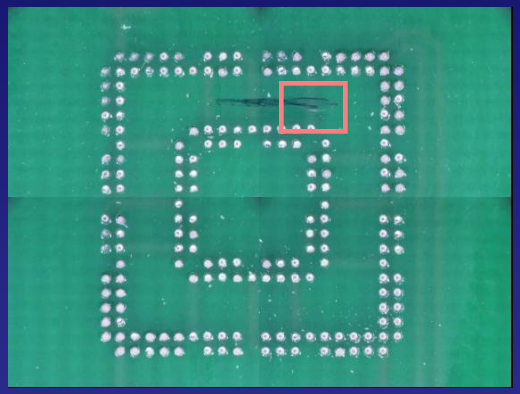
DOE: Influences of various soldering parameter & materials

- Test procedure & tested factor

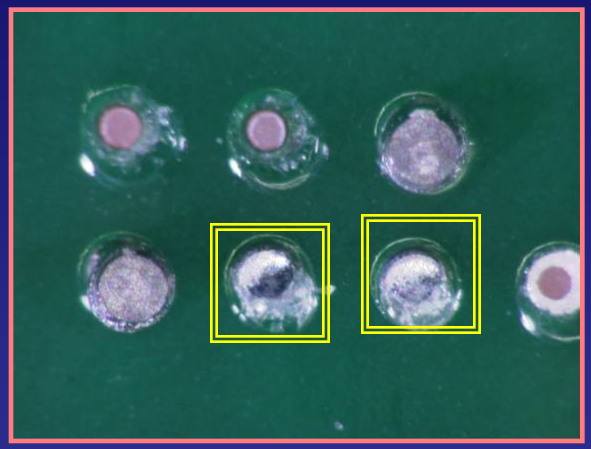
Step-4

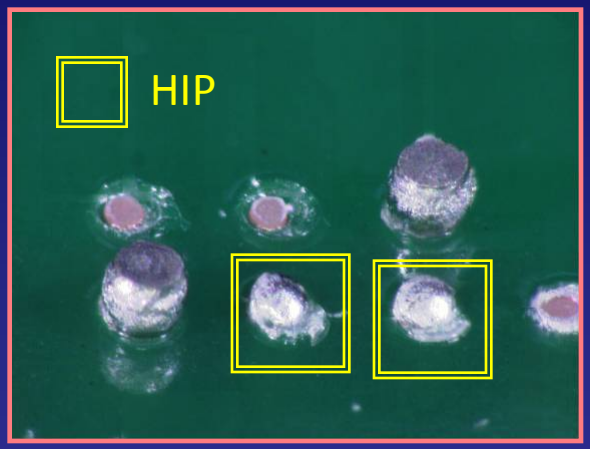
Inspection

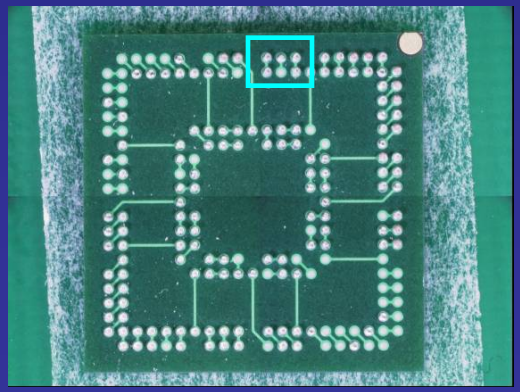
Pry BGA package off after reflow & Inspect visually for HIP



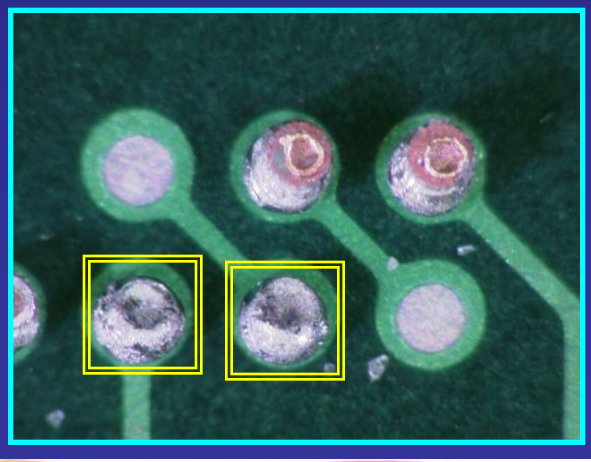
PCB side





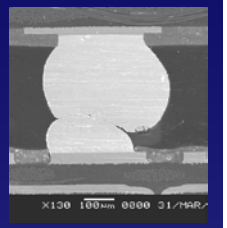


BGA side

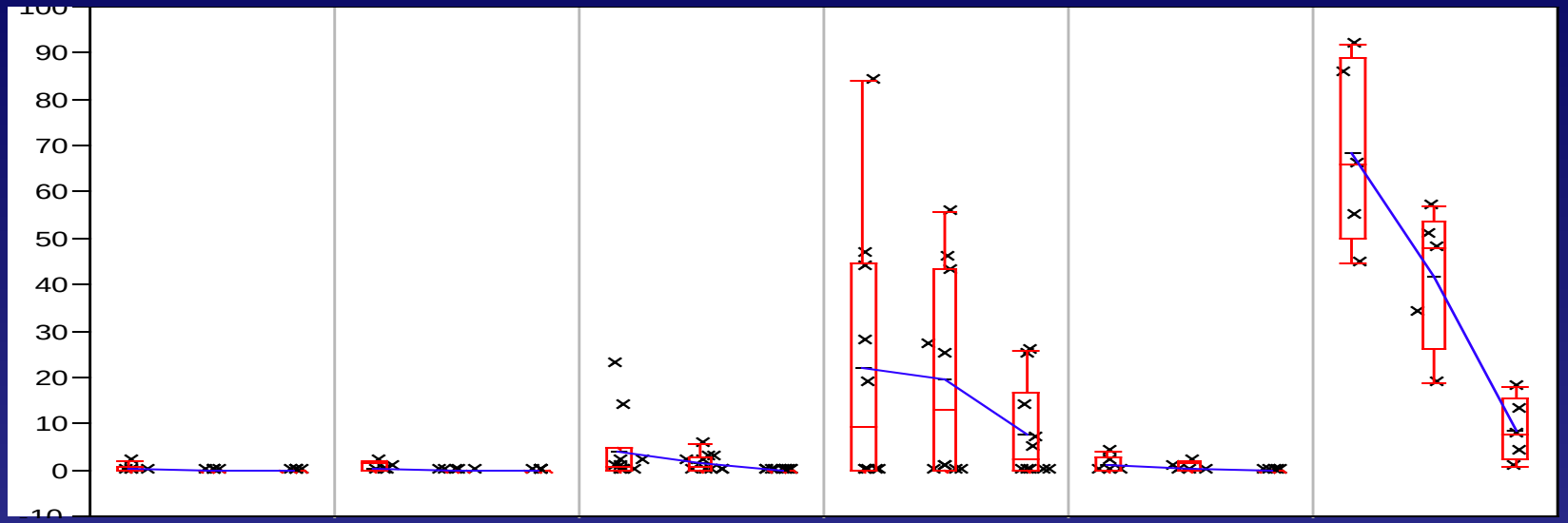


DOE: Influences of various soldering parameter & materials

Test results



HIP count
In each BGA



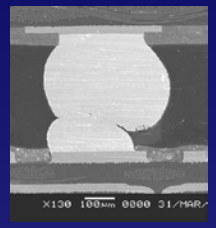
SMT paste	STD	HIP	HIP -HF	STD	HIP	HIP -HF	STD	HIP	HIP -HF	STD	HIP	HIP -HF	STD	HIP	HIP -HF	STD	HIP	HIP -HF
BA material	NC paste			WS flux			NC paste			WS flux			NC paste			WS flux		
Reflow profile	Profile-1						Profile-2						Profile-3					

Highlight

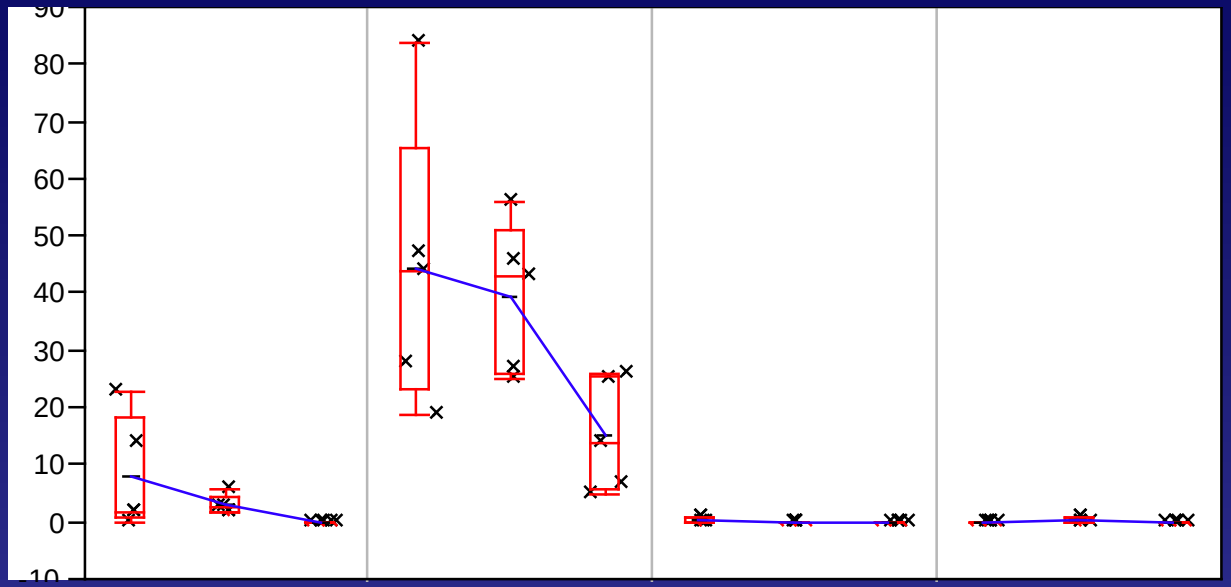
- Reflow profile: Lower soak temperature & shorter time is better than Higher & Longer.
  Higher & Longer peak temperature doesn't work to improve HIP.
- Ball Attach materials: In the BA process, NC paste appears to lower HIP risk.
- SMT paste: Improved SMT paste can lower HIP risk compared to earlier versions.

DOE: Influences of various soldering parameter & materials

Test results



HIP count
In each BGA

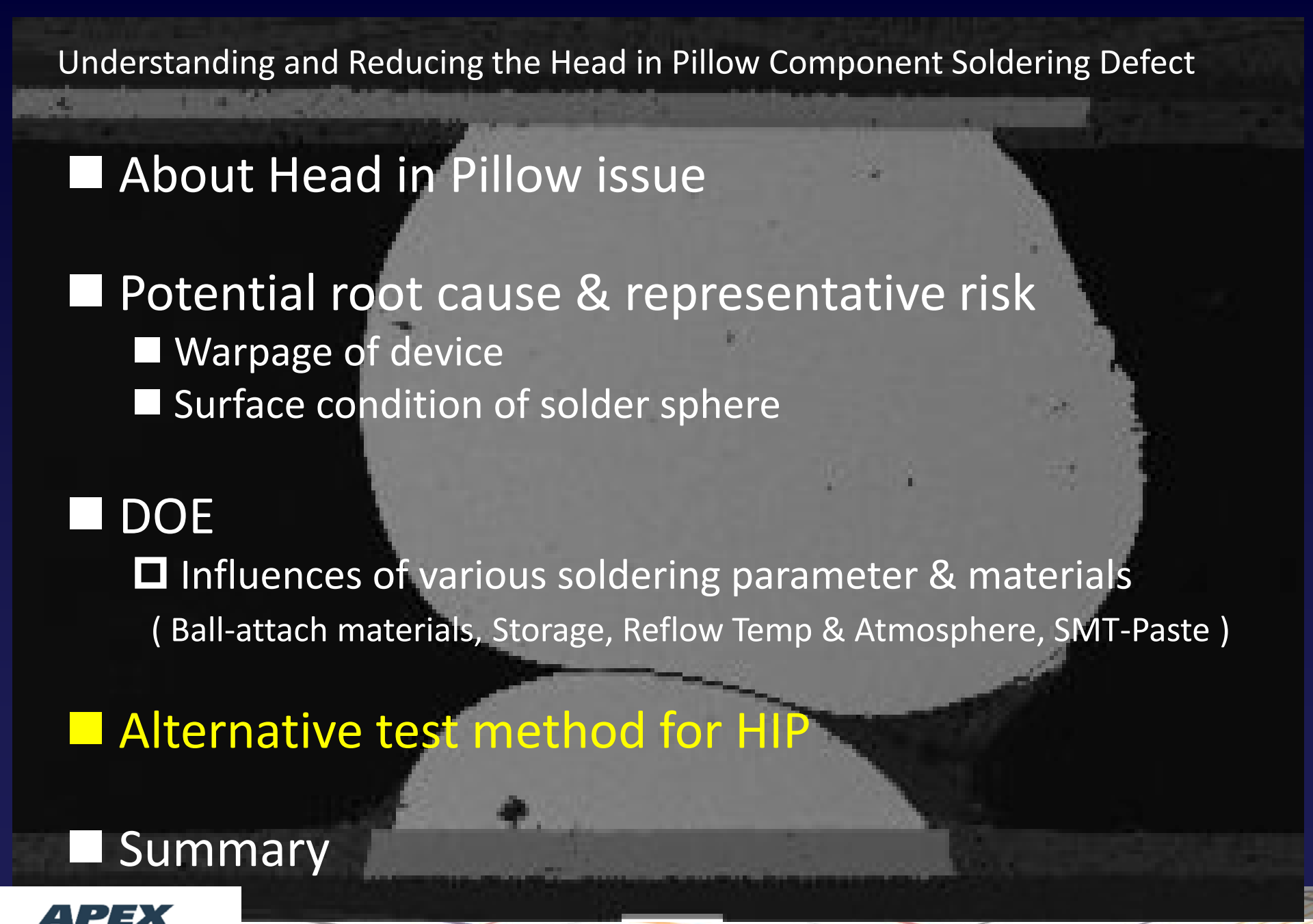


SMT paste	STD	HIP	HIP -HF	STD	HIP	HIP -HF	STD	HIP	HIP -HF	STD	HIP	HIP -HF
BA material	NC paste			WS flux			NC paste			WS flux		
Reflow profile	Profile-2											
Atmosphere	AIR						N2					

Highlight

- Reflow atmosphere:

Nitrogen reflow effective in preventing HIP compared with AIR reflow.



- About Head in Pillow issue
- Potential root cause & representative risk
  - Warpage of device
  - Surface condition of solder sphere
- DOE
  - Influences of various soldering parameter & materials

    (Ball-attach materials, Storage, Reflow Temp & Atmosphere, SMT-Paste)
- Alternative test method for HIP
- Summary

Alternative test method for HIP: Wetting Balance test

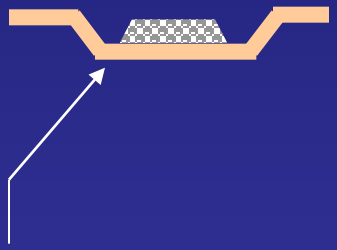
Test procedure & tested factor

Step-1 → Printing SMT paste on Cu plate

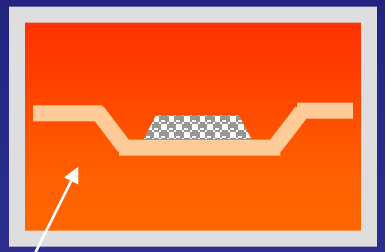
Step-2 → Preheating in heat chamber

Step-3 → Attach sphere onto sensor tool

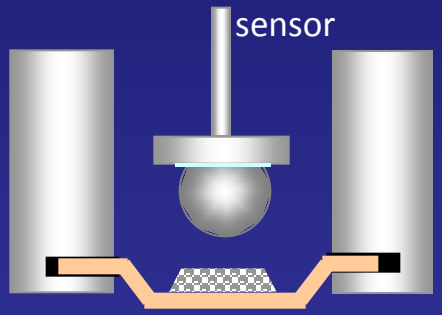
Step-4 → Heating Cu plate with solder bath



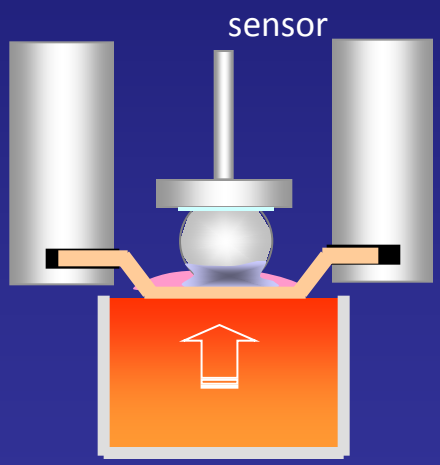
SMT paste
- LF Standard
- Improved model for HIP
- Improved HF model for HIP



Preheat condition
- 125deg C / 10min
- 150deg C / 5min
- 160deg C / 4.5min
- 170deg C / 4min
- 180deg C / 3.75min
- 190deg C / 3.5min



Solder sphere
SAC305



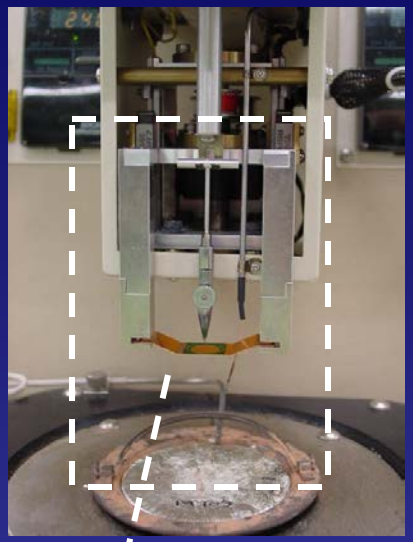
Solder bath
Temp: 240°C

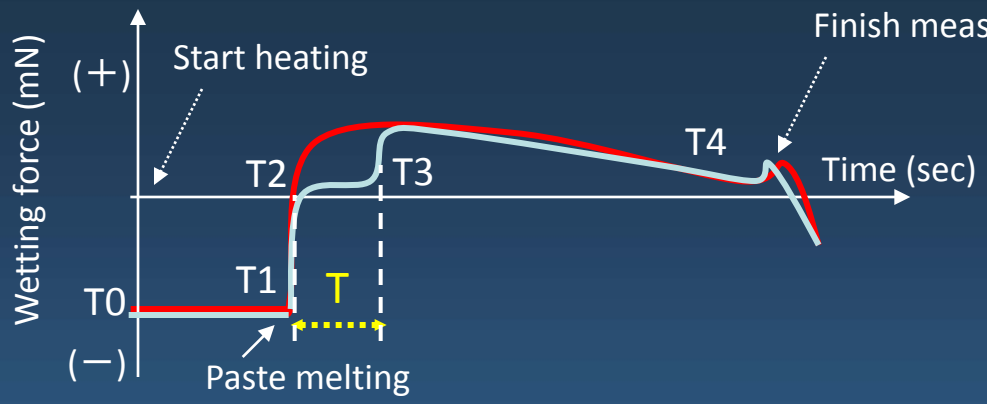
Process Video (Quicktime)

Close Up of Wetting Moment

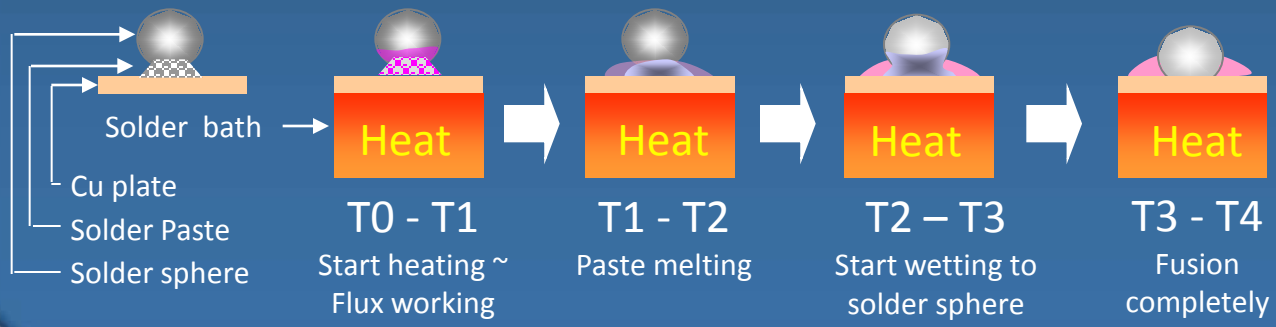
Alternative test method for HIP: Wetting Balance test

Test procedure & tested factor





T (Paste melting – Occurrence of wetting force) = T3 – T2
Occurrence of wetting force is same as paste melting: T= 0
Occurrence of Delay : T = T3-T2



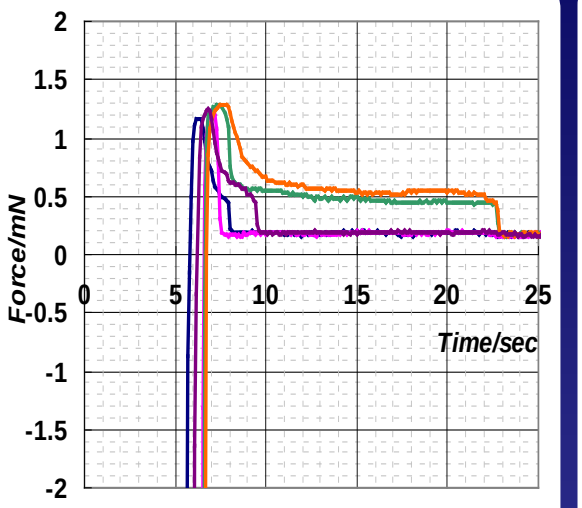
Alternative test method for HIP: Wetting Balance test

Test results

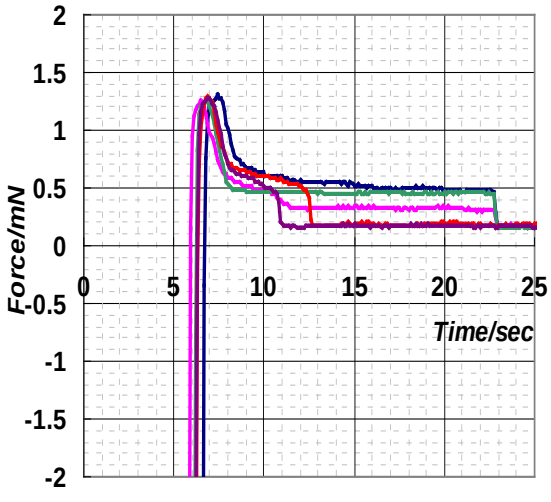
Solder paste: STD

Delay of wetting

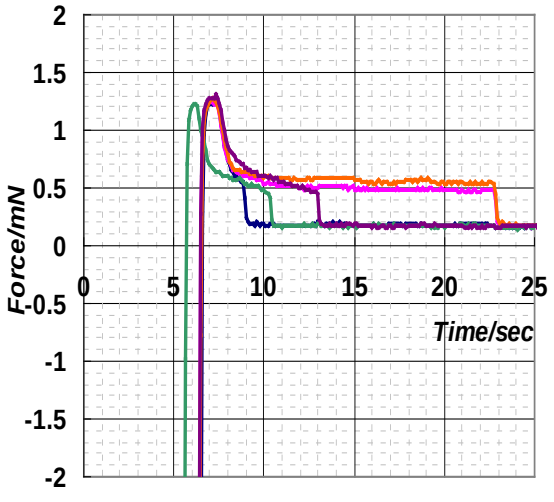
Non wetting



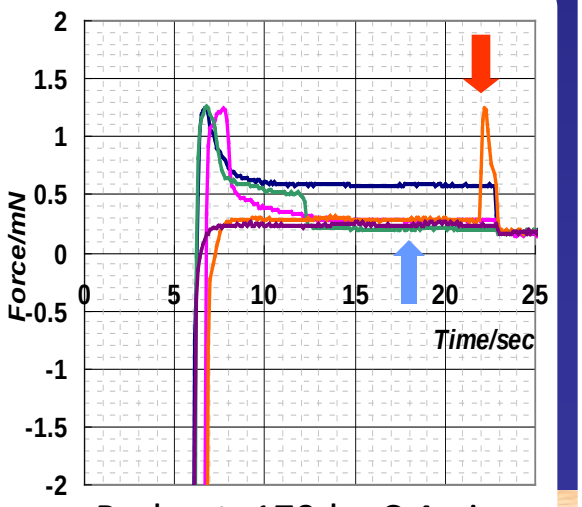
Preheat: 125degC 10min



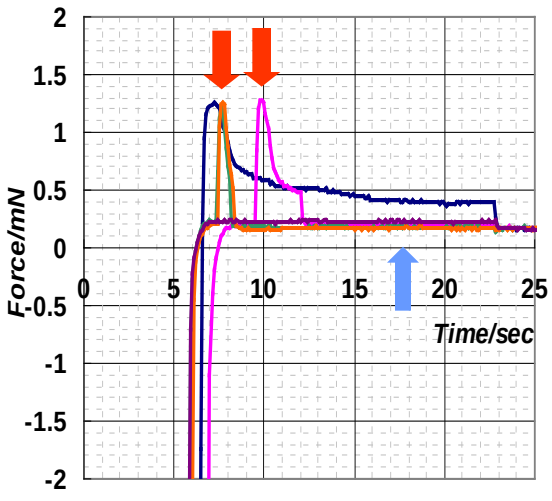
Preheat: 150degC 5min



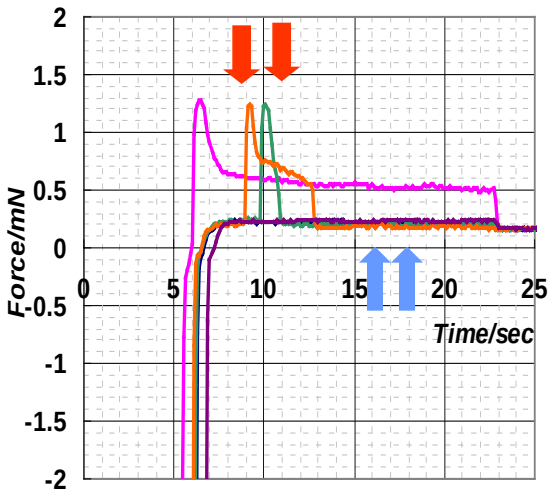
Preheat: 160C 4.5min



Preheat: 170degC 4min



Preheat: 180C 3.75min



Preheat: 190C 3.5min

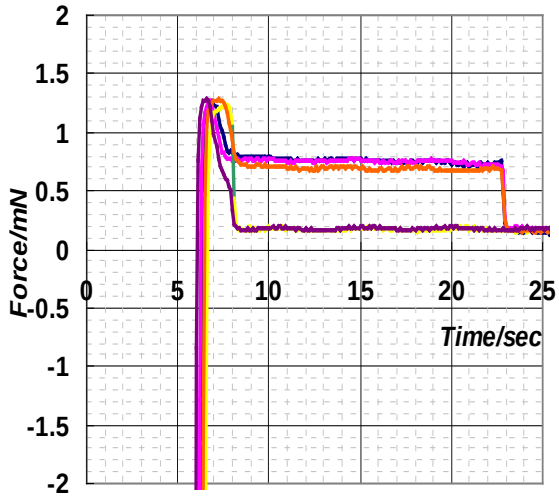
Alternative test method for HIP: Wetting Balance test

Test results

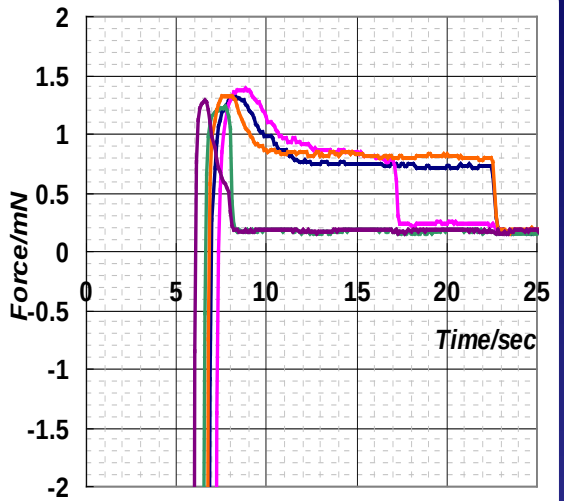
Solder paste: HIP

Delay of wetting

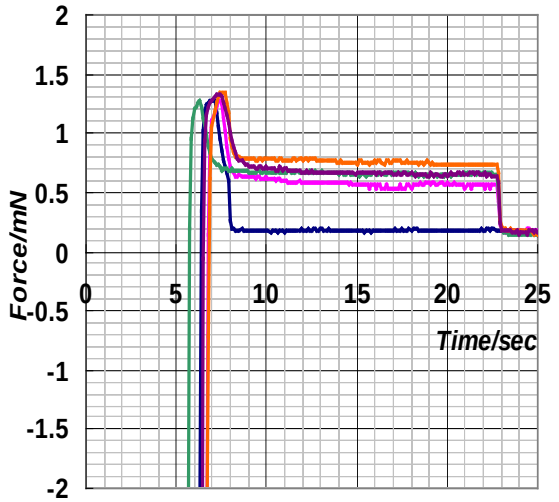
Non wetting



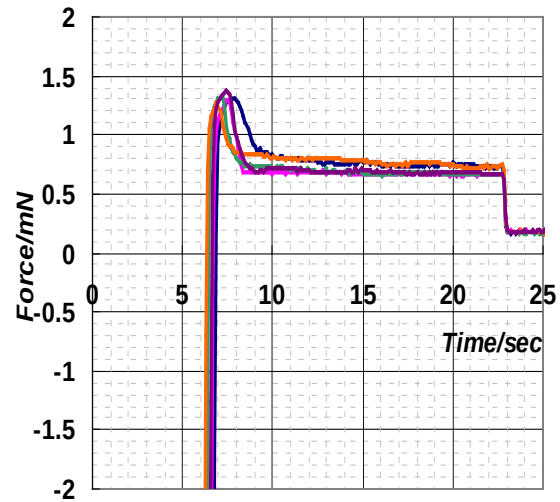
Preheat: 125degC 10min



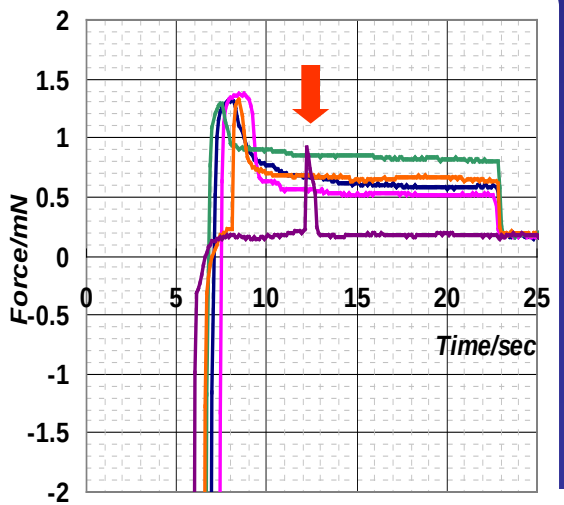
Preheat: 150degC 5min



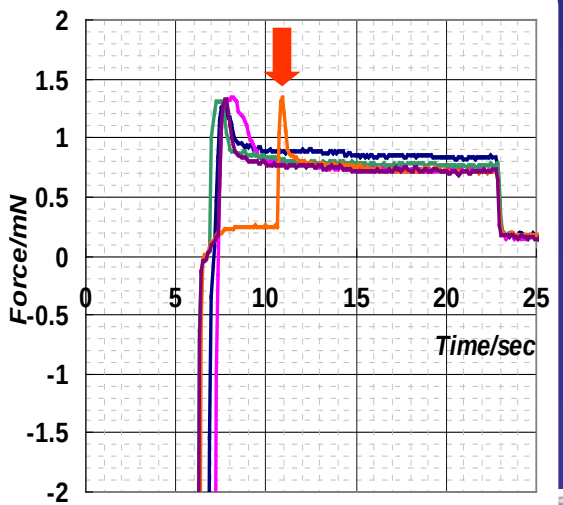
Preheat: 160C 4.5min



Preheat: 170degC 4min



Preheat: 180C 3.75min



Preheat: 190C 3.5min

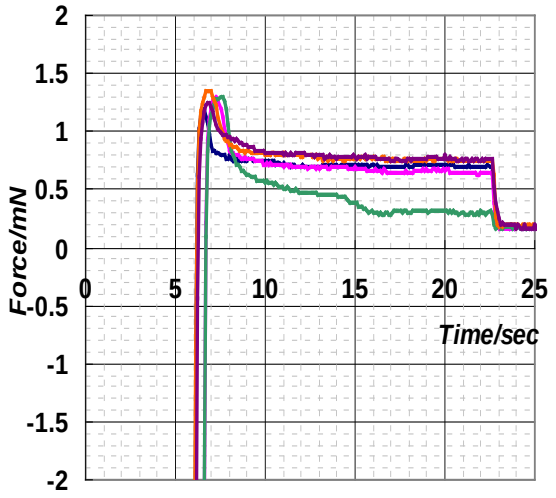
Alternative test method for HIP: Wetting Balance test

Test results

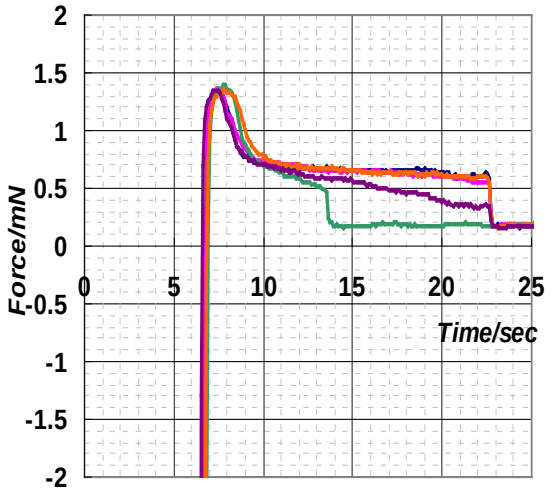
Solder paste: HIP-HF

Delay of wetting

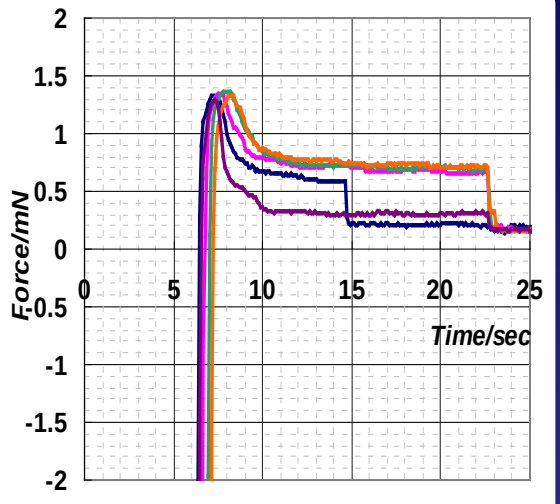
Non wetting



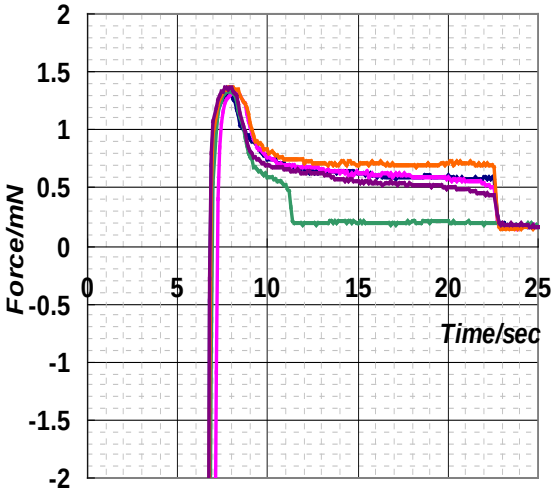
Preheat: 125degC 10min



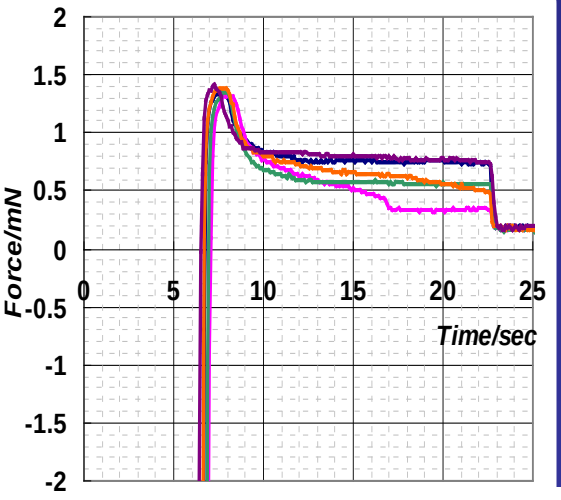
Preheat: 150degC 5min



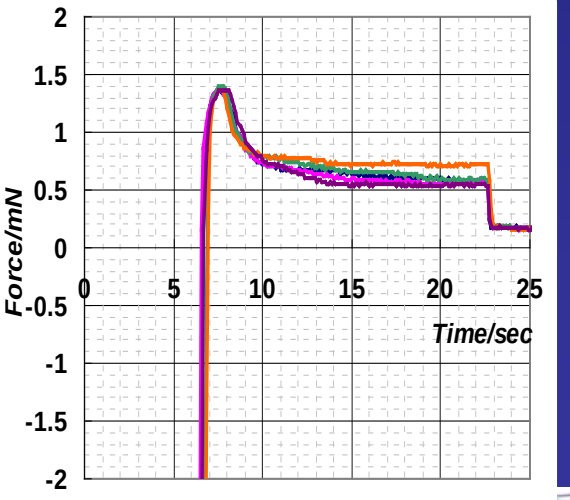
Preheat: 160C 4.5min



Preheat: 170degC 4min



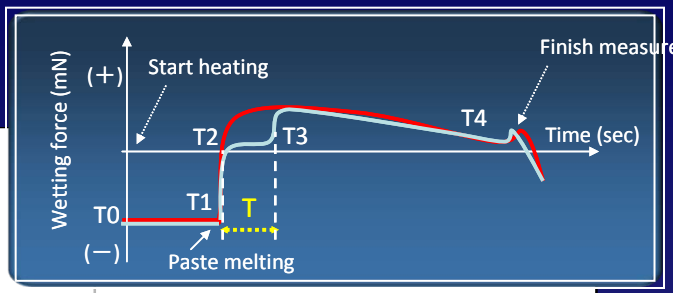
Preheat: 180C 3.75min



Preheat: 190C 3.5min

Alternative test method for HIP: Wetting Balance test

Test results



Highlight

- Preheat condition: Higher soak temp prevents continued oxidation reduction and may delay or prevent adequate wetting.
- SMT paste: Improved models can assist wetting or non wet v. previous one.

This wetting balance test reflects well the results of HIP test with BGA.

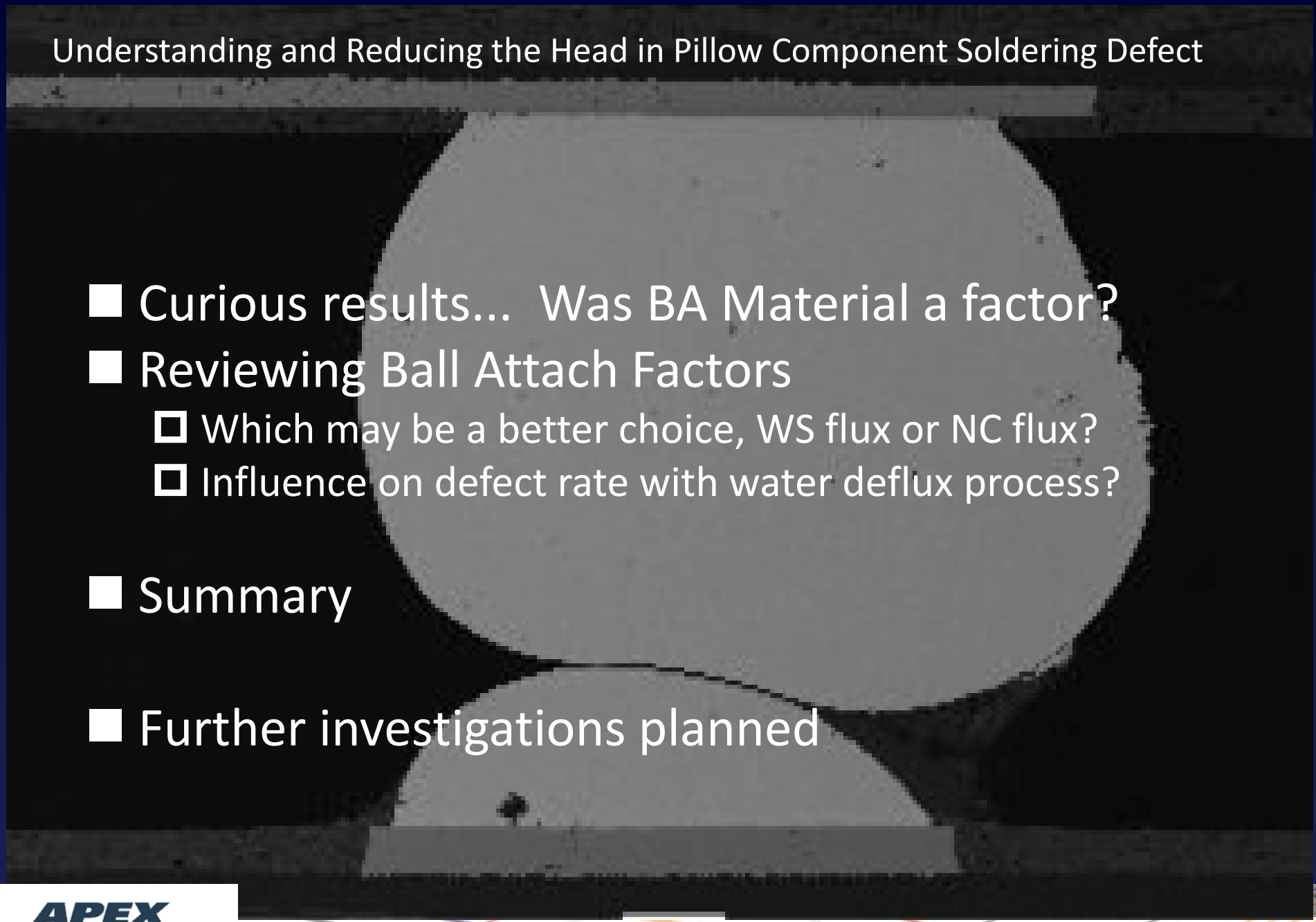
Initial Testing Summary

Head in pillow occurrence is dependent upon cumulative risks such as device warp or oxidation on sphere surface along with the site's SMT process capability (solder paste, reflow profile and atmosphere etc.)

In this evaluation, we verified their influences and found some tendencies.

- BGA mfg process: No Clean Ball Attach materials can decrease the risk of oxidation or corrosion on Sn surfaces.
- Reflow profile: Soak zone optimization is important to prolong SMT paste activity allowing solder to fuse completely in reflow. Nitrogen reflow is also highly effective.
- SMT solder paste: Should select high performance model against HIP.

We continue to search for alternative methods to assess the performance of solder pastes. Results show that a modified wetting balance test using actual solder spheres is a valid method to evaluate HIP risks quantitatively and has the ability to meet preferred reproducibility goals.



- Curious results... Was BA Material a factor?
- Reviewing Ball Attach Factors
  - Which may be a better choice, WS flux or NC flux?
  - Influence on defect rate with water deflux process?
- Summary
- Further investigations planned

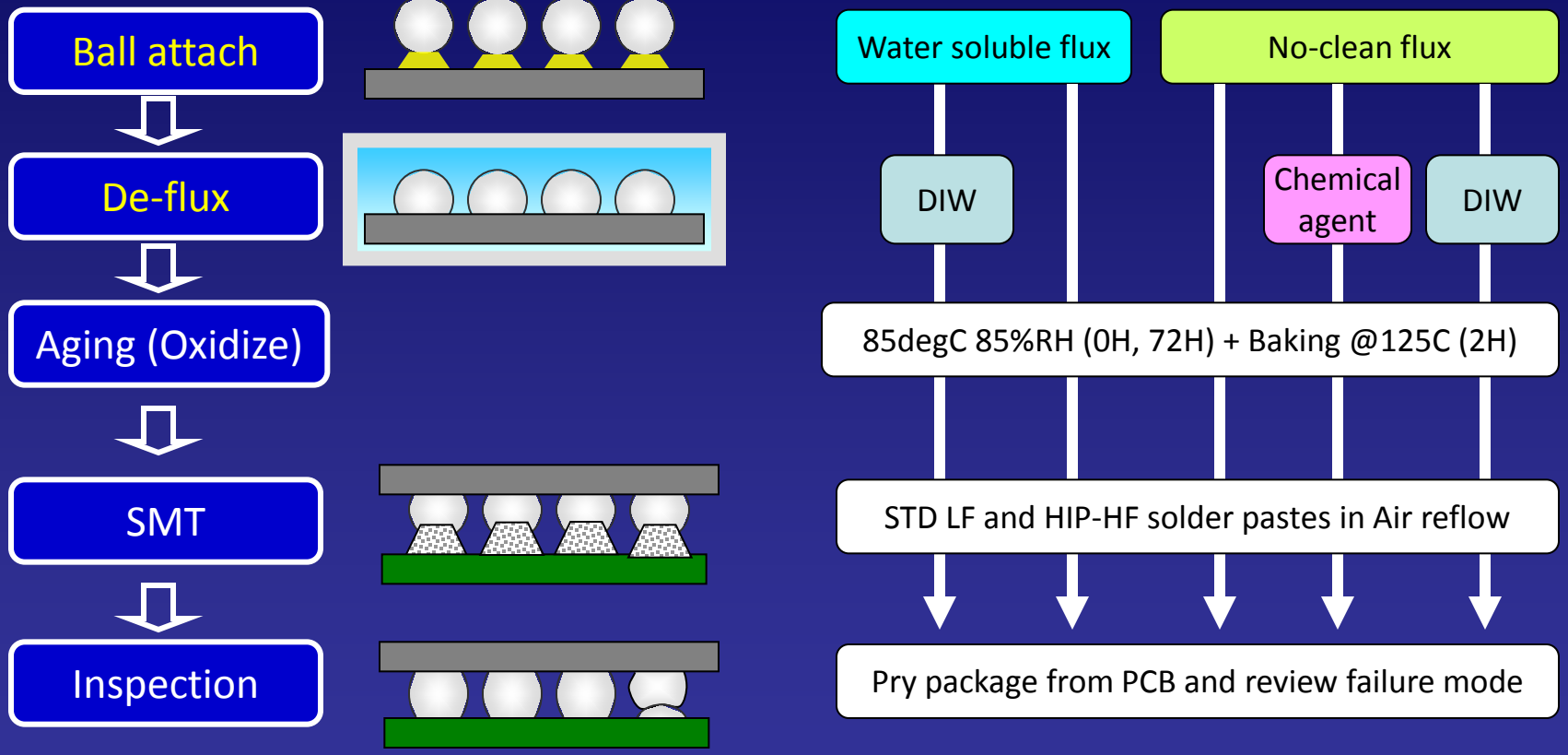
DOE: Influences of BA material & De-flux process

Ball attach materials	De-flux process	Aging (Oxidation) for BGA*	Solder paste for SMT	Test method
Water soluble flux	By DIW	85degC 85% RH Initial, 72hours*	● Standard LF (Halogenated)	● SMT assembly with dummy BGA
	Non de-flux			
No-clean flux	Non de-flux	Baking at 125deg C, 2 hours*	● HiP improved model (Halogen free)	● Wetting balance test
	By Chemical agent			
	By DIW			

*Conditioning on BGA device completed in order to create a more difficult wetting condition. In previous test experiences, non conditioned parts created defect rates similar to those seen in the field. I.e. it would take too many builds to generate defects.

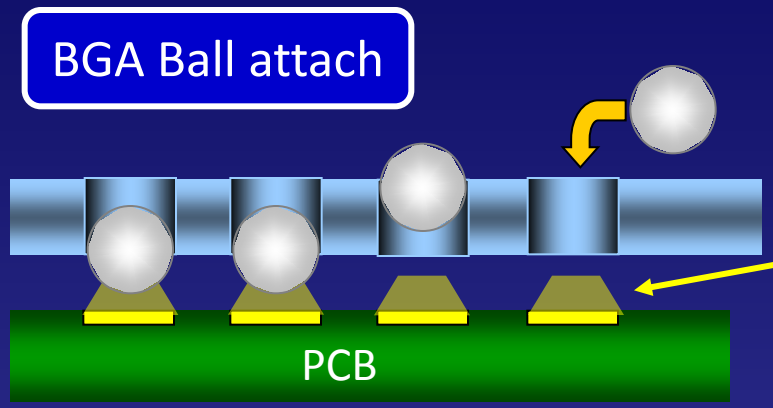
DOE: Influences of BA Material & Cleaning Process on HIP

Test procedure



DOE: Influences of BA Material & De-flux Process

Mock BGA Device Preparation

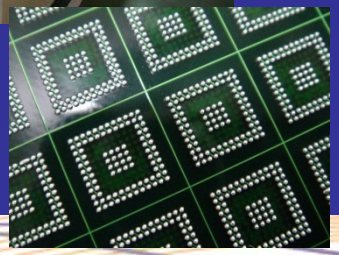


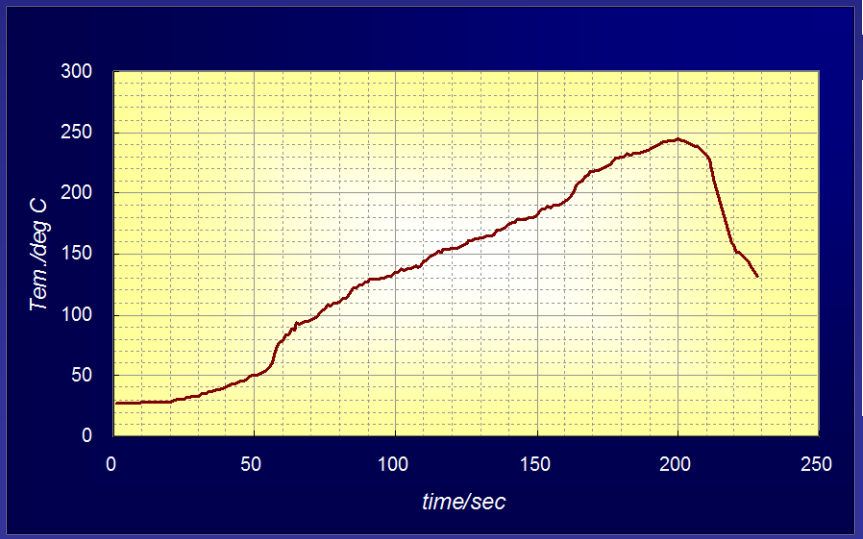
Material for Ball attach
- Water soluble flux (WS)
- No-clean flux (NC)

Mock BGA Package
- Form size: 23*23mm
- Pad pitch: 1.27mm Pitch
- Pad size: 0.6mm
- Plating: Cu-OSP

Flux printing condition
- Thickness: 150um

Sphere
- Size: 760um





Ball attach reflow profile
- Oven: SNR615
- Peak temp: 244degC
- TAL: 40sec
- Ramp rate: 1.07deg C/s
- Time to Peak: 200sec
- O2 conc.: <100ppm

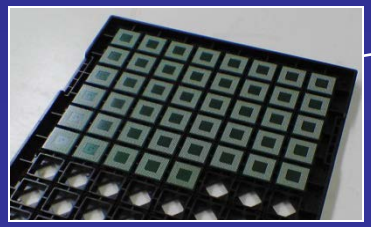
DOE: Influences of BA material & de-flux process

Residue Removal and Oxidation

De-flux

De-flux condition
- DI water (temp: 60C)
- Semi-aqueous based agent (temp:60C)
- No-clean; residues NOT cleaned

Aging

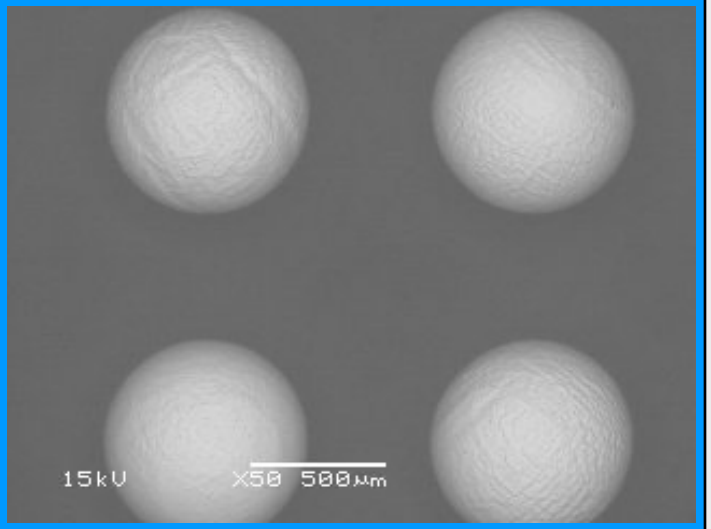
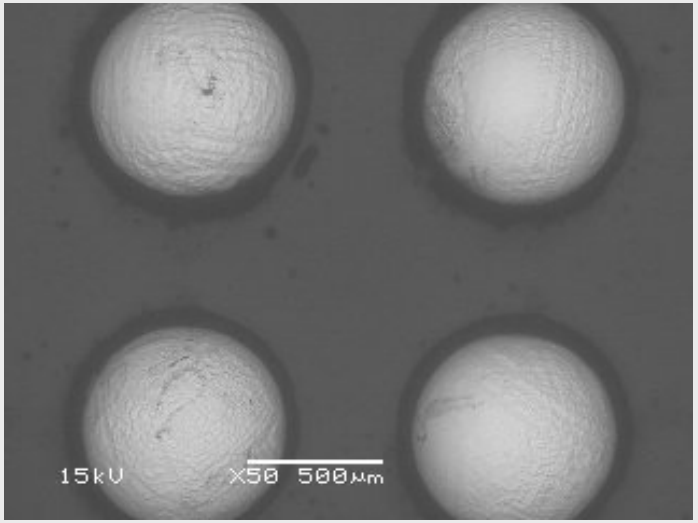
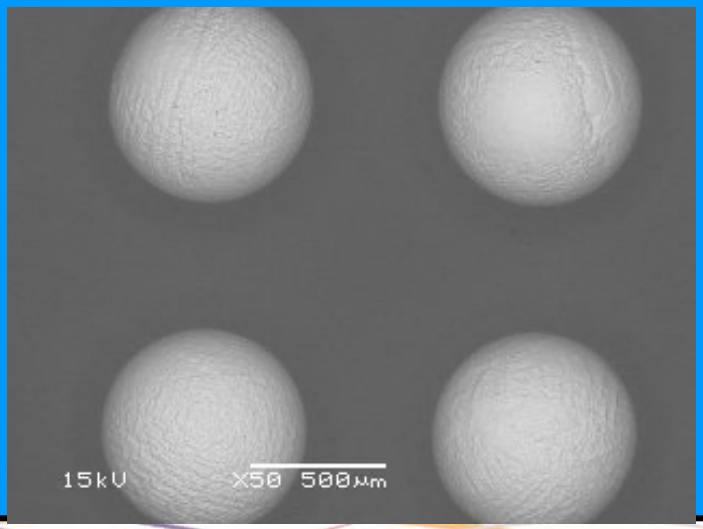
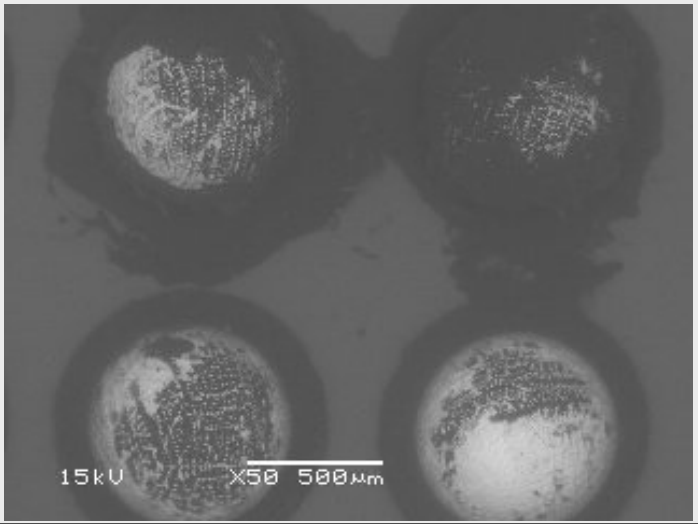


Oxidize in humidity chamber
85degC 85% x 72H

Baking in heat chamber
125degC x 2H

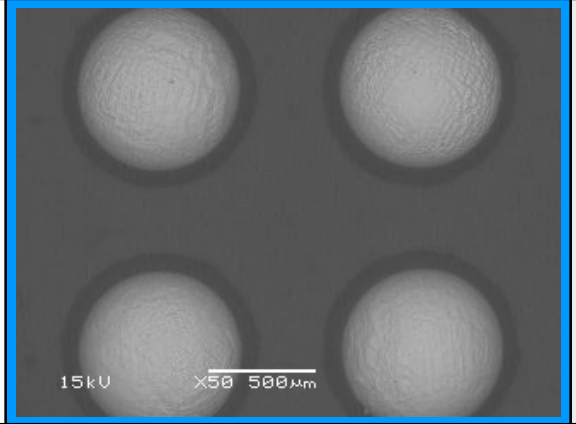
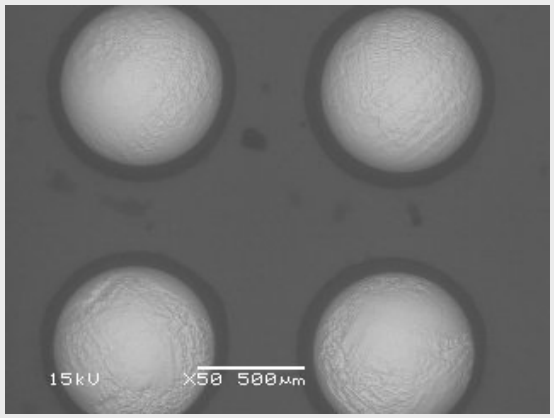
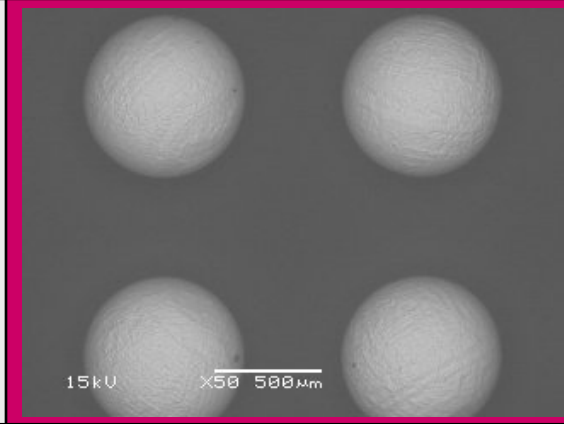
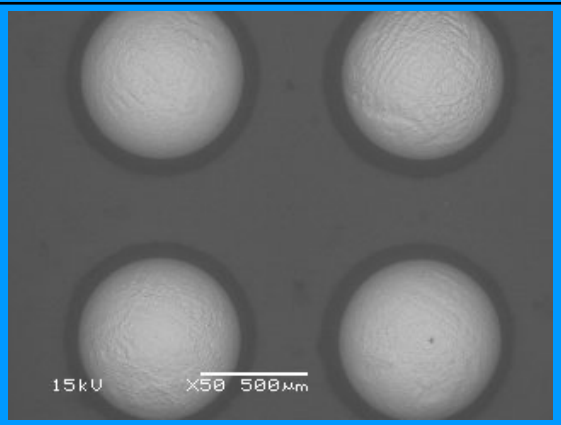
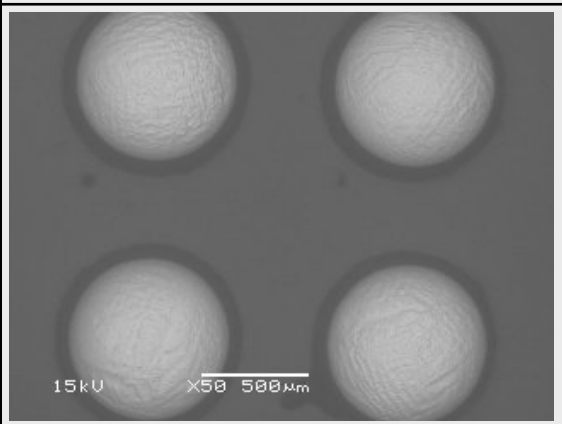
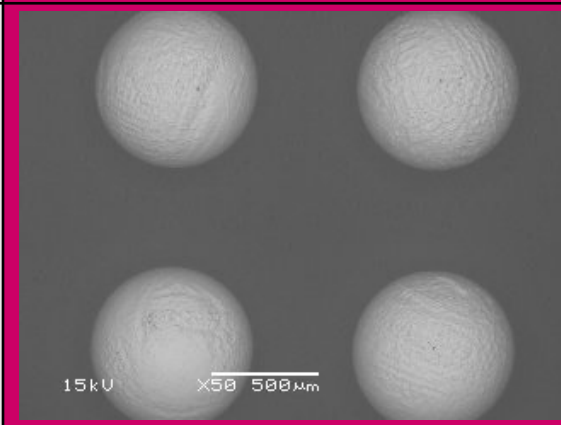
SEM observation of surface condition of solder sphere after BA

BA flux: Water soluble flux

	WS flux + DIW deflux	WS flux + Uncleaned
Initial		
After Aging 85C85%RH for 72H		

SEM observation of surface condition of solder sphere after BA

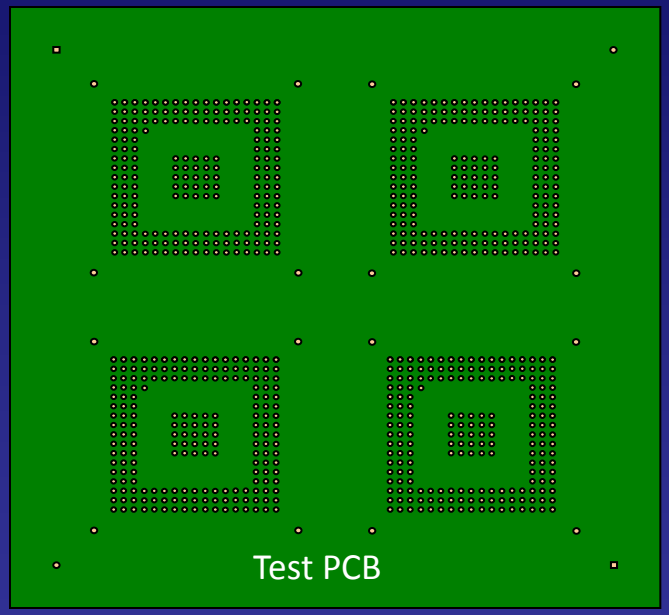
BA flux: No-Clean flux

	NC flux + DIW deflux	NC flux + Uncleaned	NC flux + Semi-Aqueous
Initial			
After Aging 85C85%RH for 72h			

DOE: Influences of BA material & De-Flux process

PCB Test Vehicle and Paste Process

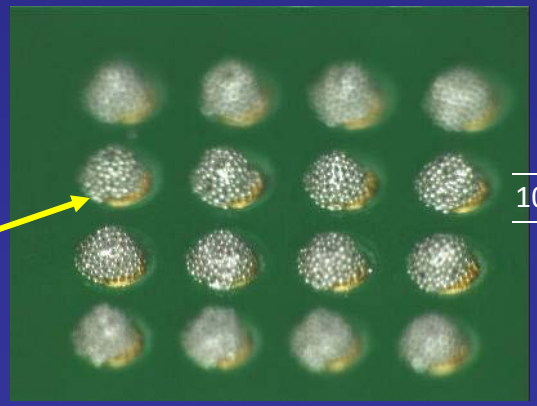
SMT print & placement

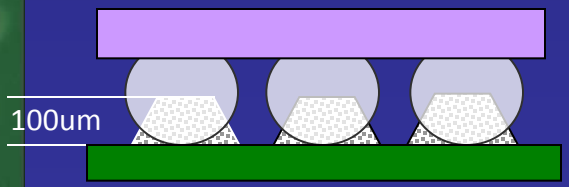


PCB
- FR-4 1.0mmt
- Finish: CU+OSP

Printing condition
- Stencil thickness: 100um
- Aperture: 600um
- Squeegee: Metal 60deg
- Speed: 30mm/s
- Pressure: 0.2N/mm

SMT paste (SAC305 Alloy)
- Standard LF (Halogen)
- HIP – HF (Halogen Free)

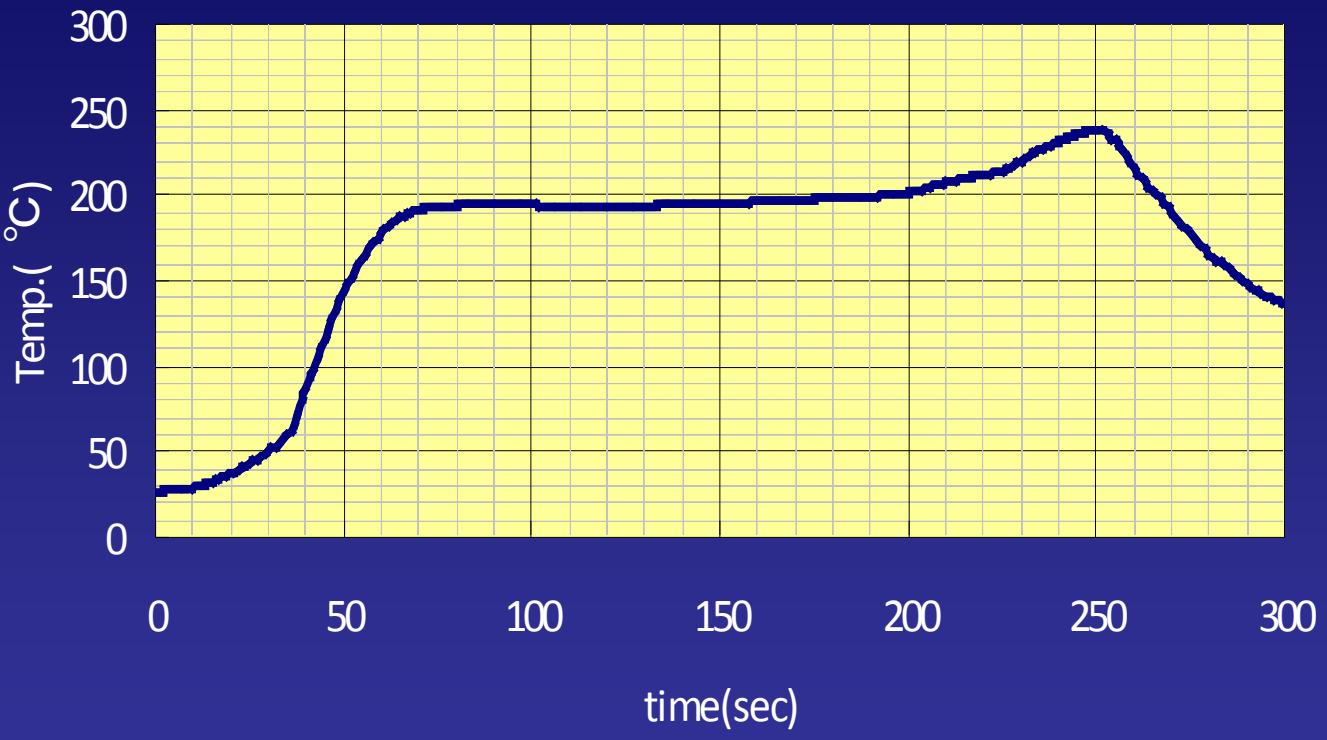




DOE: Influences of BA Material & De-Flux process

PCBA Profile

SMT reflow



SMT Profile	Soak zone		Reflow zone	
	Temp (C)	Time (s)	Peak temp (C)	220C over time (s)
	190 ~ 205	130	236	30

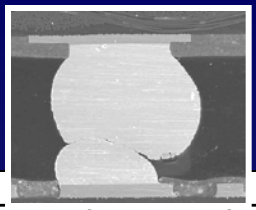
DOE: Influences of BA material & de-flux process

Test procedure & tested factor

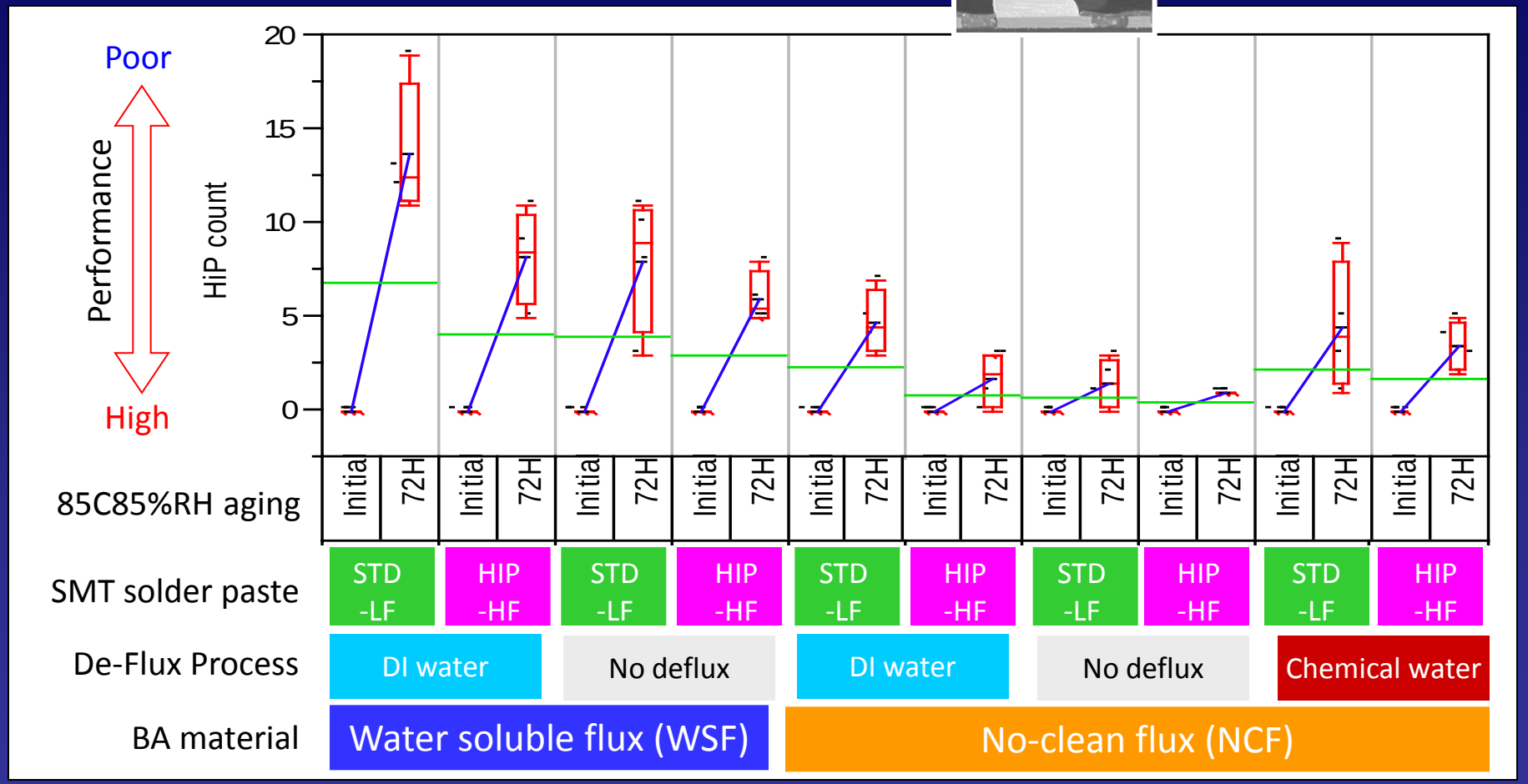
Test condition & materials			
BGA	Sphere	Alloy composition	SAC305
		Size(diameter)	0.76mm
	BGA package	Material	FR-4
		Pitch	1.27mm
		Pad size	0.6mm
		Surface finish	Cu+OSP
		Solder resist	SMD
	Ball attach material	Flux	Water soluble &
	Stencil for flux printing	Aperture	0.6mmΦ
		Thickness	0.2mm
	Ball attach reflow	Profile	See figure
		Atmosphere	N2 (Oxygen conc:<100ppm)
	De-Flux	Condition	60degC DI water 15min
	Humidify	Condition	85C85%RH 36～72h
	Baking	Condition	125degC-1hour (with vacuum)
SMT Assemble	Test Board	Material	FR-4
		Pad size	0.6mmΦ
		Surface finish	Cu+OSP
		Solder resist	SMD
	Stencil for paste printin	Aperture	0.6mmΦ
		Thickness	0.10mm
	SMT reflow	Profile	See figure
		Atmosphere	AIR

DOE: Influences of BA material & de-flux process

☐ Test results for PCBA HiP test



HiP count
After SMT



Highlight

- BA flux: Water soluble flux has higher HiP risk than NC flux, in other words higher oxidation risk.
- Deflux: The wash process using water may make HiP risk higher than leaving flux residue.
- SMT paste: HIP-HF improved model has better performance compared to a standard LF paste.

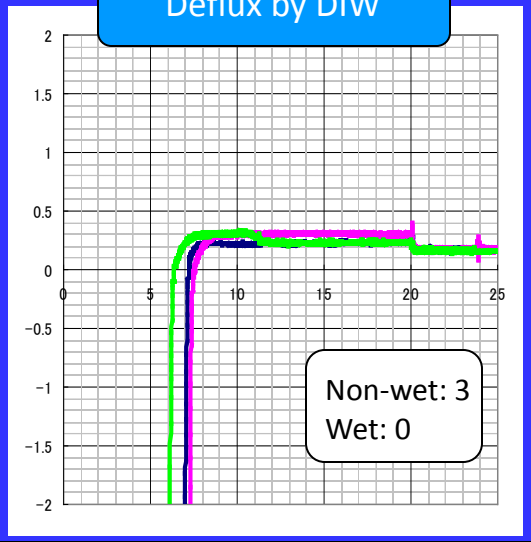
DOE: Influences of BA material & de-flux process

☐ Test results of wetting balance test

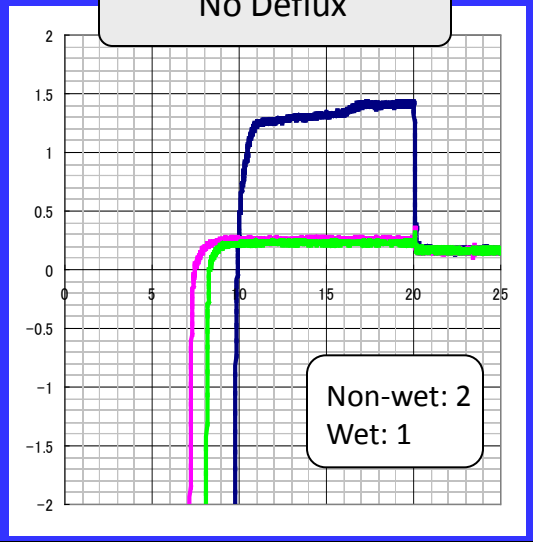
SMT Solder paste: STD

Water Soluble BA flux

Deflux by DIW

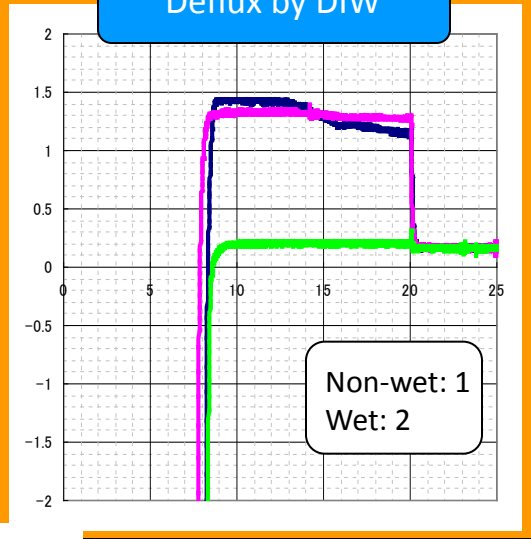


No Deflux

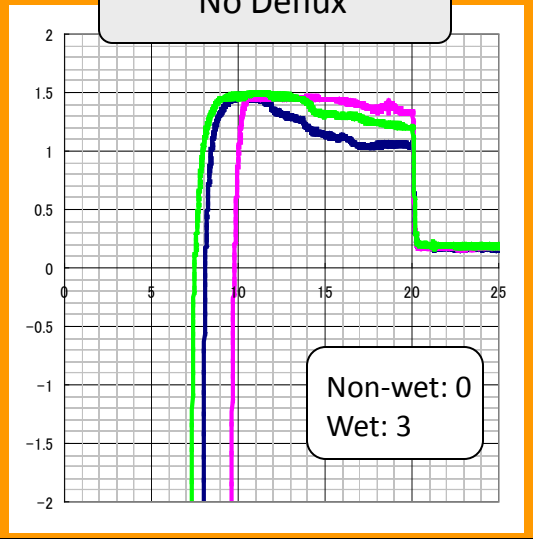


No-clean BA flux

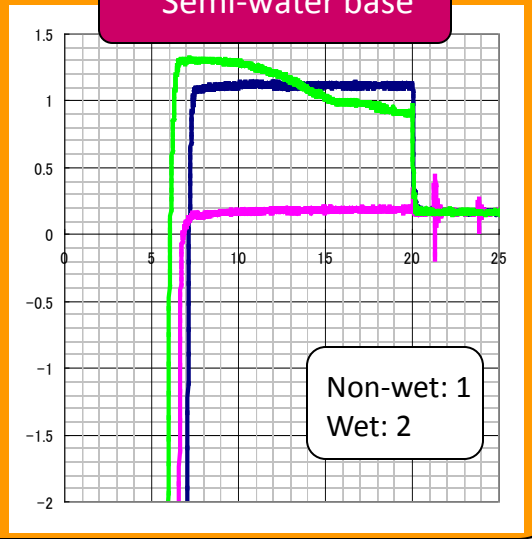
Deflux by DIW



No Deflux



Semi-water base



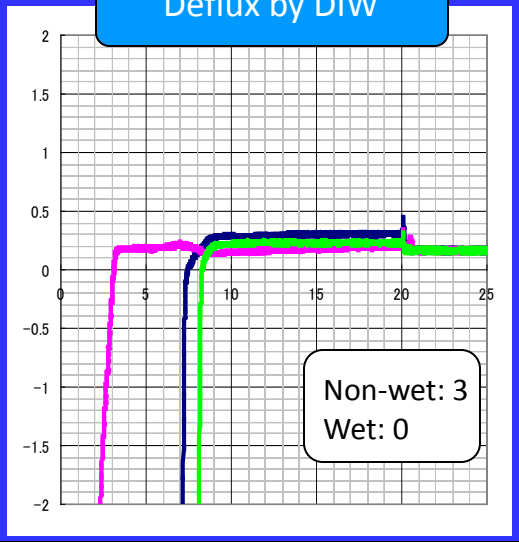
DOE: Influences of BA material & de-flux process

☐ Test results of wetting balance test

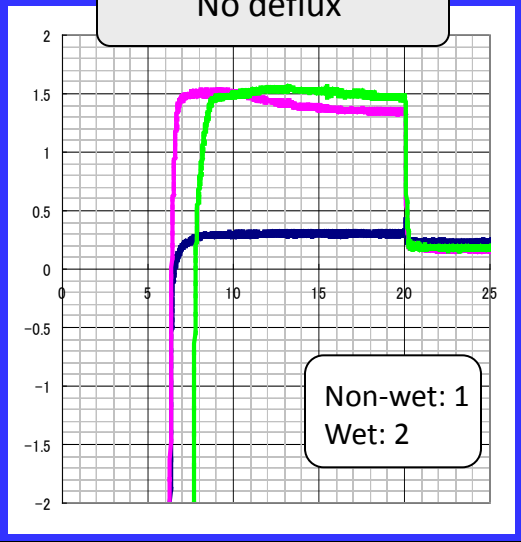
SMT Solder paste: HIP-HF

Water Soluble BA flux

Deflux by DIW

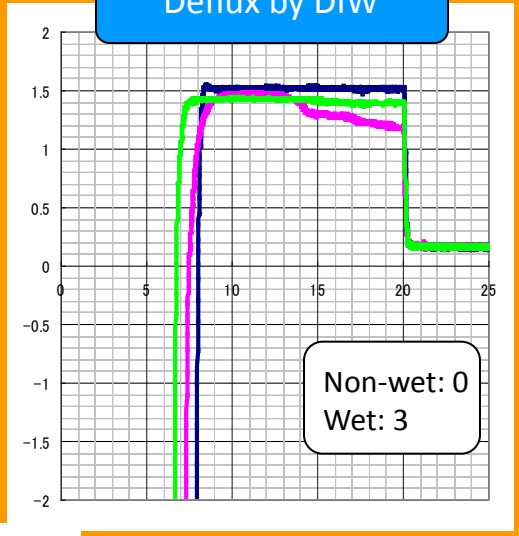


No deflux

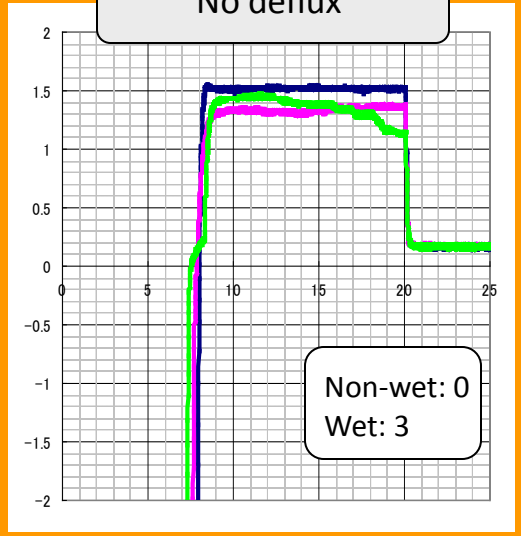


No-clean BA flux

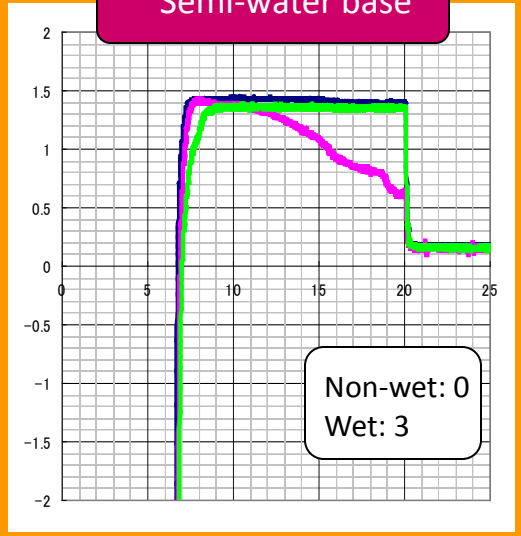
Deflux by DIW



No deflux

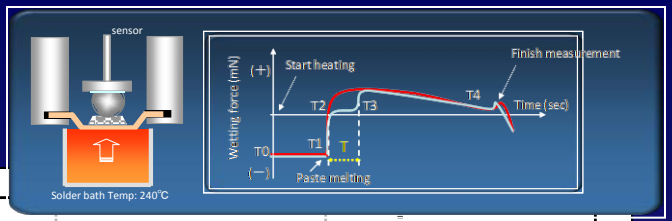


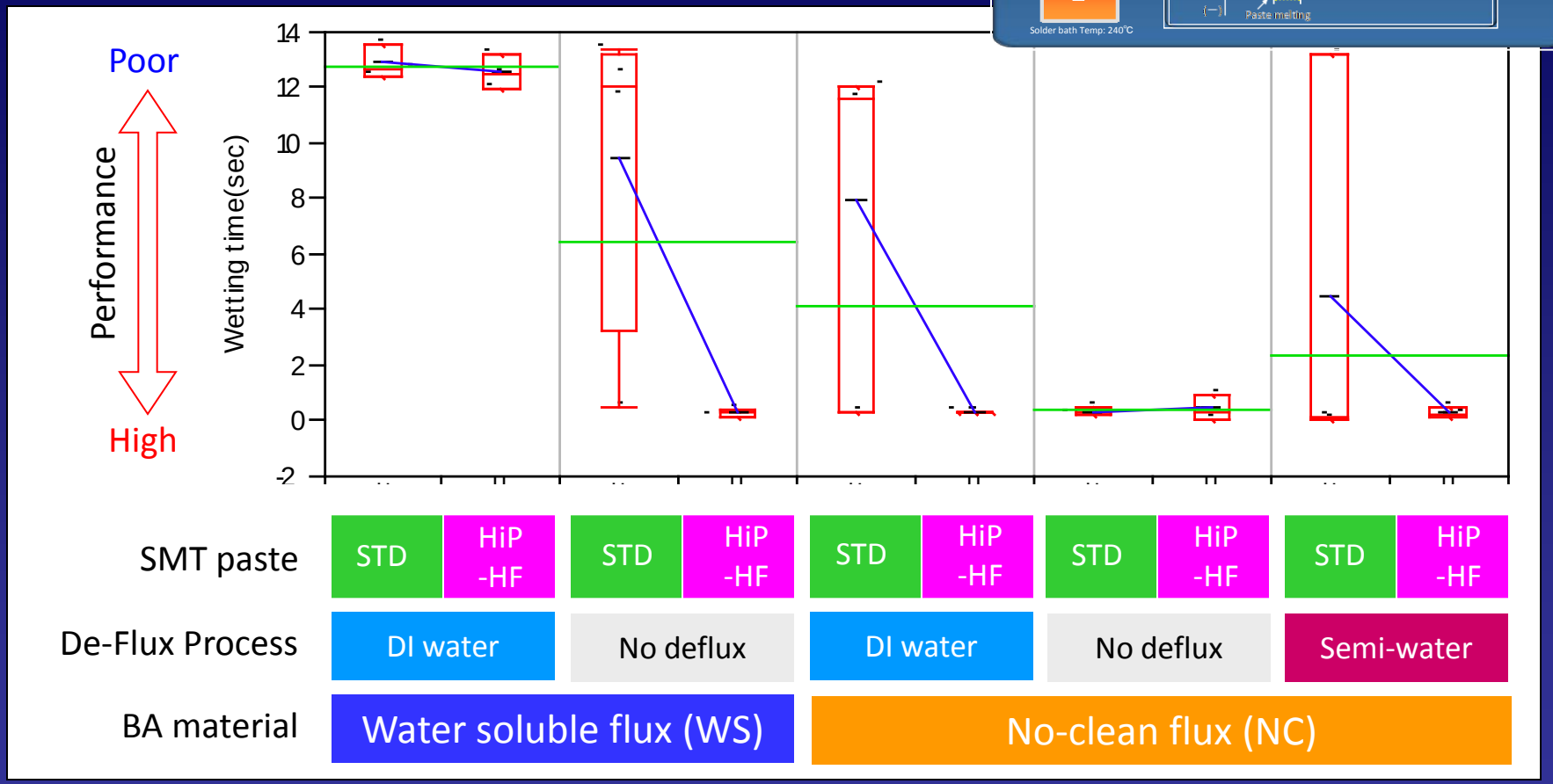
Semi-water base



DOE: Influences of BA material & de-flux process

☐ Test results of wetting balance test





Highlight

- BA flux: Water soluble flux had longer wetting delays than NC flux, hence a higher risk for HiP.
- Deflux: Washing process by DI water may delay wetting more than No De-flux condition.
- SMT paste: HIP improved model has higher performance than standard LF paste.

Summary

- BA flux: Water soluble BA flux has a higher HiP risk relative to NC BA flux, likely due to higher surface oxidation risks.
- Deflux: Washing process using water or DIW in combination with other solutions may make HiP risk higher when compared to leaving flux residue as received*.
- SMT paste: HIP improved models have higher performance than standard LF paste.

*NOTE: Allowing water soluble flux residue to remain on site without proper removal is *not recommend* as this will create reliability risks. Testing done for HIP comparative purposes only.

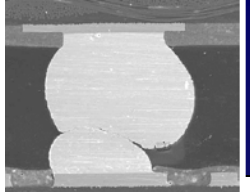
Continued Study

- Alloy Factors:
  - Will sphere alloys also play a role in HiP occurrence?
    - Low Temp v. High Temp, etc
  - Can sphere alloys also be optimized to improve the margin of defects.
  - Sphere surface coloration and affect on HiP?

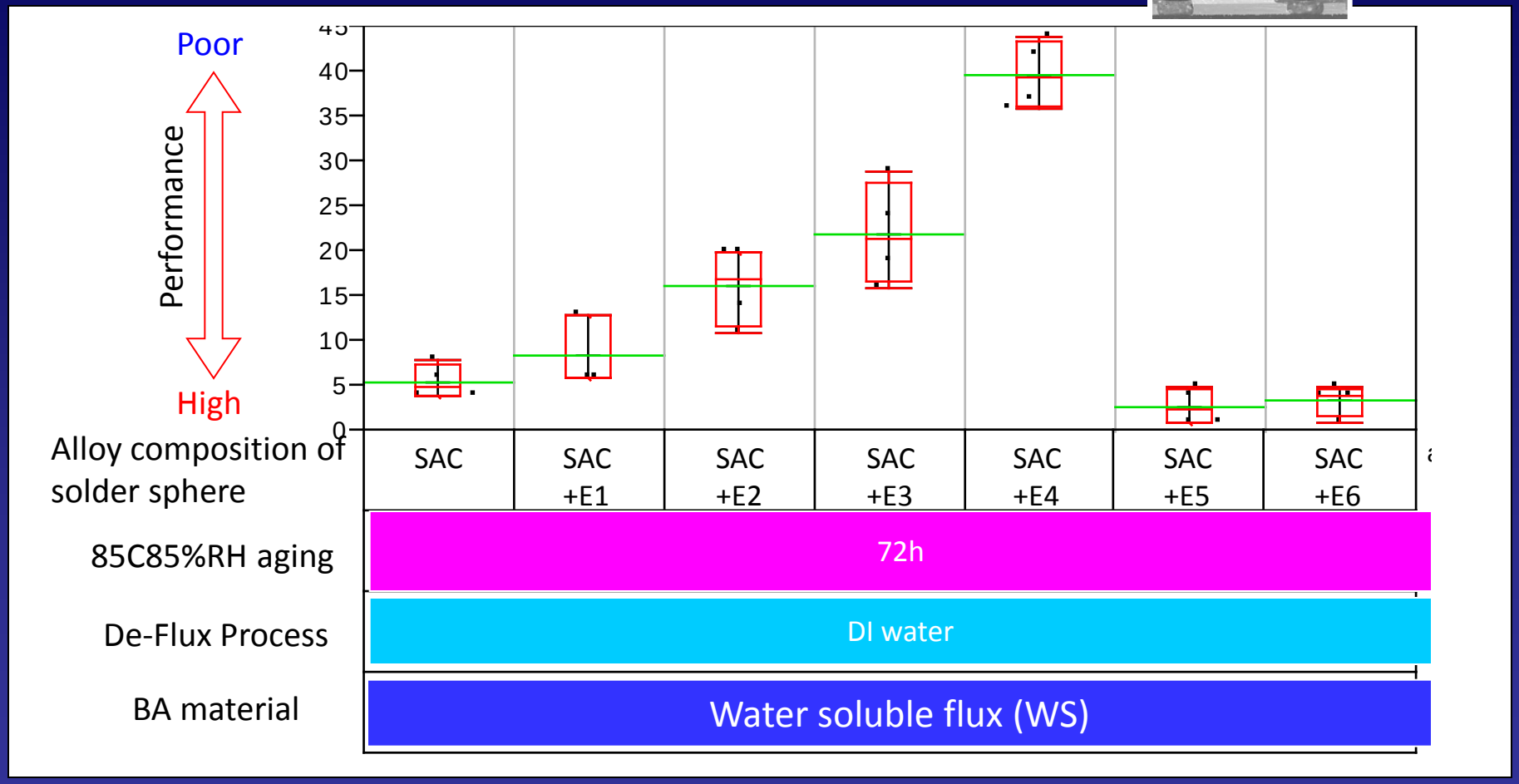
- Deflux Process Relationships:
  - Plans to measure the surface oxidation thickness of spheres as tested
  - Moisture content also to be reviewed.

Investigation to Further Restrain HIP

Test results of SMT HiP test

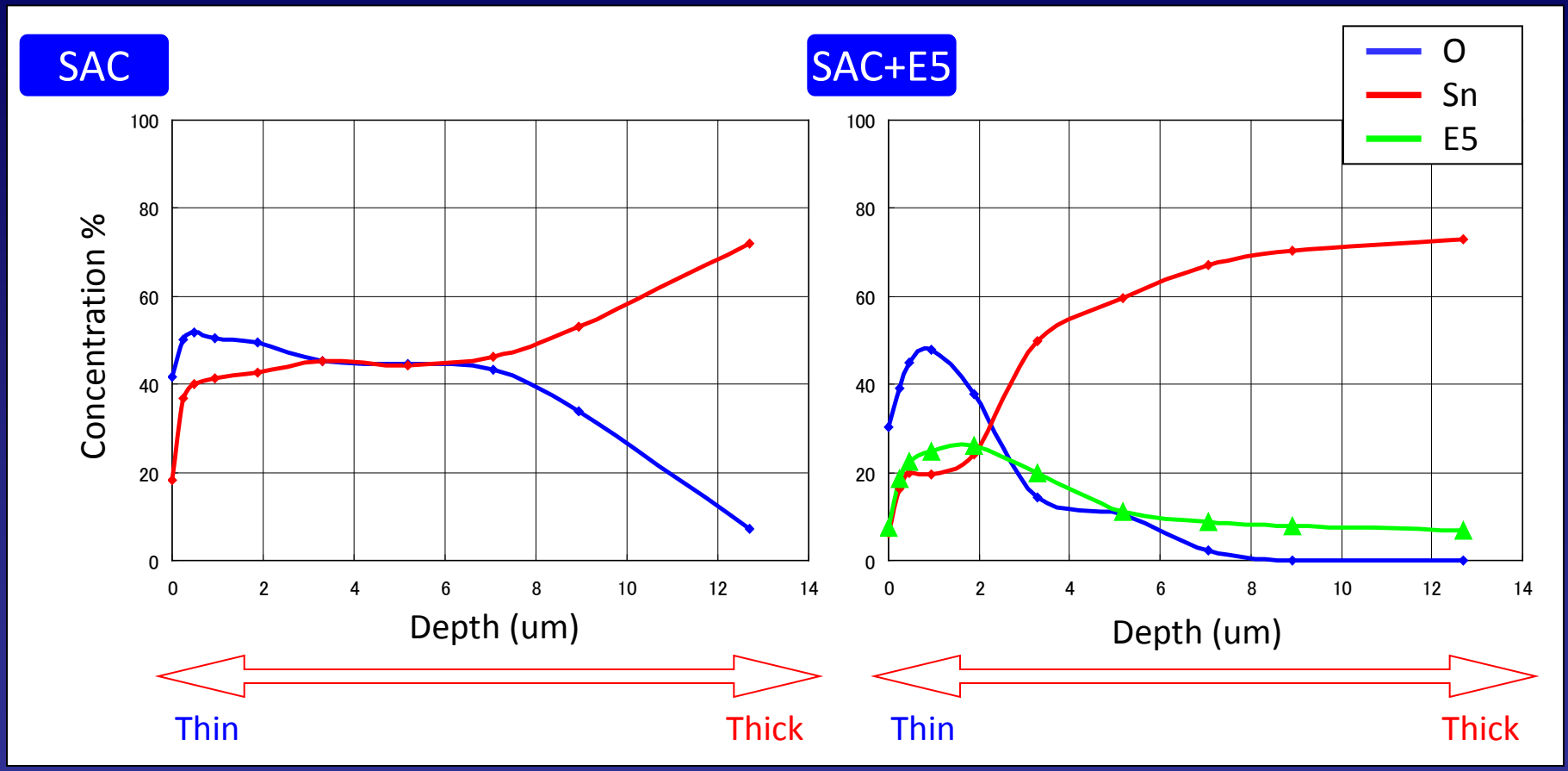


HiP count
After SMT



Highlight
HiP risk when using additional elements in solder sphere composition.

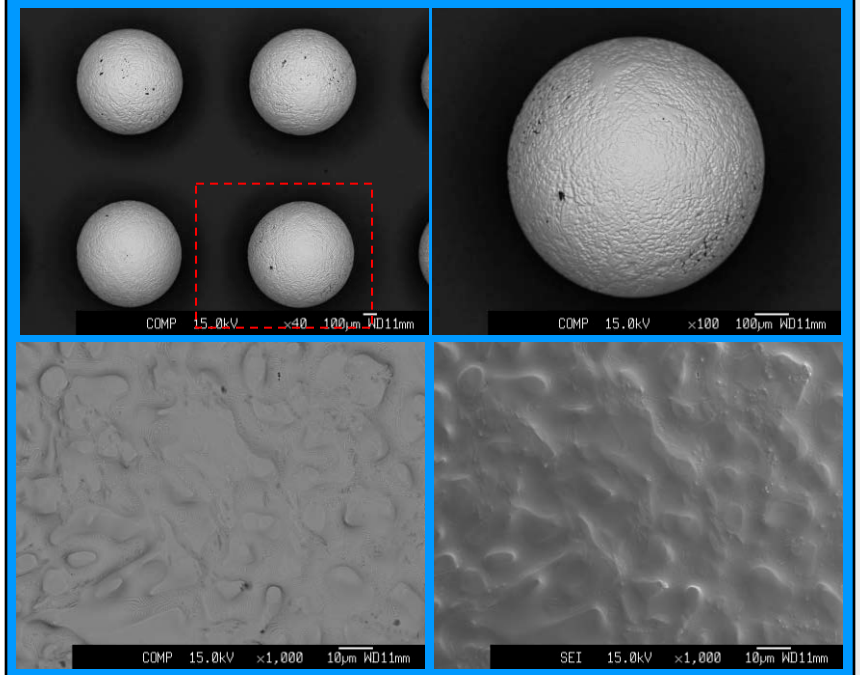
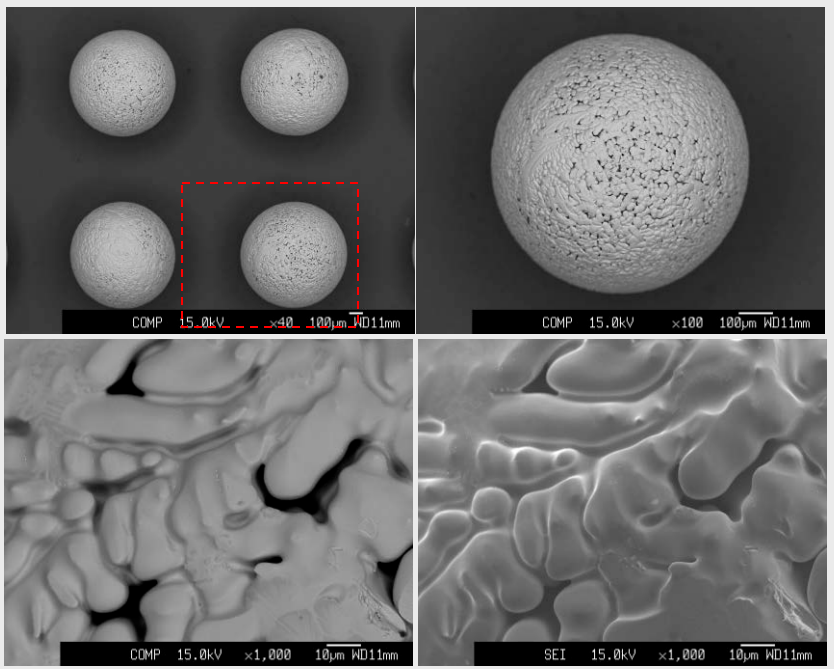
XPS observation of additional element thickness of solder sphere after aging



Highlight

- SAC : Typical Oxide Depth
- SAC+E5 : Reduction in Oxide Thickness due to E5 dopant.

SEM observation of surface condition of solder sphere after aging

	SAC	SAC+E2
After aging		

Highlight

- SAC : Typical SAC Surface
- SAC+E2 : SAC with E2 dopant showing additional surface grain.
  - Potential for additional moisture entrapment.

Understanding and Reducing the Head in Pillow Component Soldering Defect

BGA joint may or may not be happier with voids, smile for demonstration purposes only

Portions of this presentation excerpted from SMTA International Conference Proceedings, Oct.2009, San Diego CA and Oct.2010, Orlando FL.

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