Wafer-Level Packaging Symposium

FLUXLESS SOLDERING IN AN ACTIVATED HYDROGEN ATMOSPHERE

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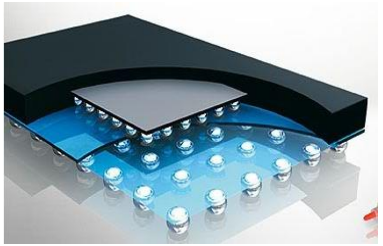
Outline/Agenda

Wafer-Level Packaging Symposium

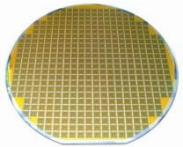
- ❑ Introduction
- ❑ System Overview
- ❑ Mechanical Sample Results
- ❑ Electrical Sample Results
- ❑ Solder Ball Drop Experiments and Data
- ❑ Conclusions

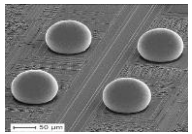
Wafer Bump Reflow

- Packaging technology for electronics devices has advanced rapidly in recent years driven by
  - Feature size reduction
  - New materials development
  - Increased device functionality/reliability
  - Cost reduction
  - Environmental considerations

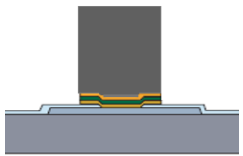


- The most fundamental among the advanced packaging technology is the use of wafer bumping and wafer-level chip-scale packaging

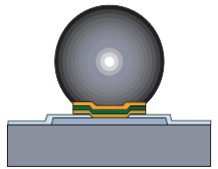




Solder bumps are formed over an entire wafer



Electroplated bump



Reflowed bump

Key Requirement: Surface Oxide Removal

- The bumped and reflowed wafer is cut into individual chips, which then go through subsequent packaging processes
- In the packaged devices, the formed bumps serve as electrical, mechanical, and mounting connections
- One of the keys for successful wafer bump reflow is to ensure an oxide-free molten solder surface
  - Any oxide layer acts as a solid skin to constrain molten solder's flow, thus affecting bump appearance and shape conversion
  - The oxide elimination is more critical and difficult as the bump size shrinks

Conventional Flux-based Oxide Removal

- Common approach for eliminating solder oxides is by coating wafers with a flux and then reflow in N_2
  - Flux volatiles and Residues
    - Form voids in solder bumps, thus degrading solder joint properties
    - Condense on furnace wall, thus causing frequent down time cleanup
    - Unhealthy exposure to the volatiles
    - Contamination on wafer surface that requires post reflow cleaning
    - Challenges for post cleaning of fine pitch and high-aspect ratio bumps
    - Hazardous wastes and increase in water usage
- ***For smaller geometries, Flux-free process is strongly preferred***

Flux-free Methods to Remove Metal Oxide

- Known flux-free technologies have limitations
  - Formic acid vapor
    - Is not completely residue free
    - Must be operated in a sealed system and vacuum atmosphere
  - H_2 or forming gas
    - Requires temperatures ≥ 350˚C for thermal activation of H_2 molecules
    - Requires flammable H_2 concentrations (≥ 5 vol%) to hasten the oxide reduction
  - Plasma-activated H_2
    - Is not effective at atmospheric pressure
    - Needs to be operated in vacuum, resulting in a batch process

Atmospheric plasma (DBD)

Novel Flux-free Technology with Electron Attachment (EA)

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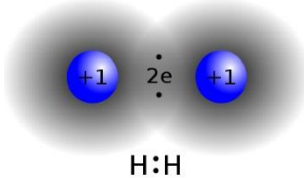
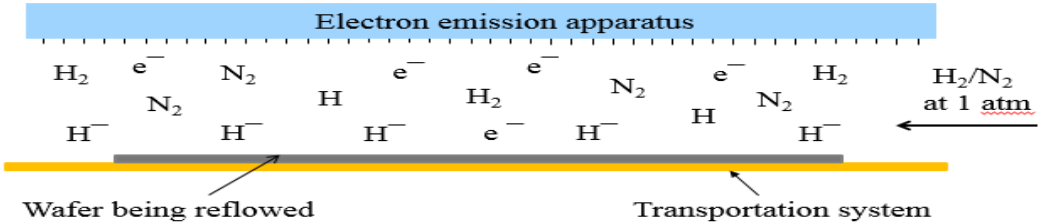
- Principle of Electron Attachment (EA) for hydrogen activation
  - Dissociation of H_2 molecules to form hydrogen anions
  - Our patented technology
  - Operable at ambient pressure and normal solder reflow temperatures using nonflammable mixtures of H_2 and N_2 (<5% H_2 in N_2)
  - Completely residue free and environmentally benign





Novel Flux-free Technology with EA (cont.)

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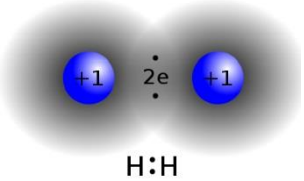
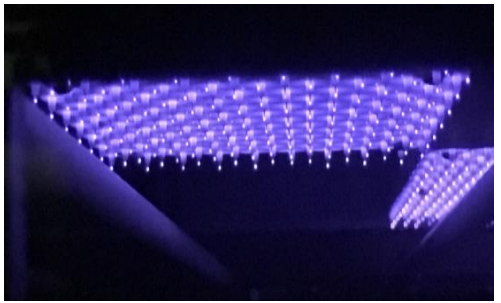
- When low-energy electrons (< 10 eV) collide with H_2 molecules, some are captured by H_2 molecules, producing atomic anions and neutral atoms
  - Dissociative attachment: $H_2 + e^- \rightarrow H_2^{-*} \rightarrow H^- + H$
  - Direct attachment: $H + e^- \rightarrow H^{-*}$



- The formed atomic hydrogen anions can be directed to the soldering surfaces for oxide reduction
  - Surface de-oxidation: $2H^- + SnO \rightarrow Sn + H_2O + 2e^-$



EA in operation

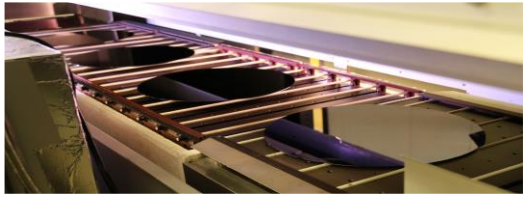
Advantages of EA Based Reflow

- Atomic hydrogen anion (H^-) formed under EA is a strong reducing agent
  - Free of chemical bond
  - Good electron donor
- EA environment is singly negative, thus extending the lifetime of H^-
  - Ambient pressure is more favorable than vacuum for forming H^- by EA
- H^- automatically moves to the soldering surface driven by an electrical field
- N_2 is inert to EA and can assist in the formation of H^-
- Capture the free electrons on the wafer surface
- EA flux-free process is completely residue free

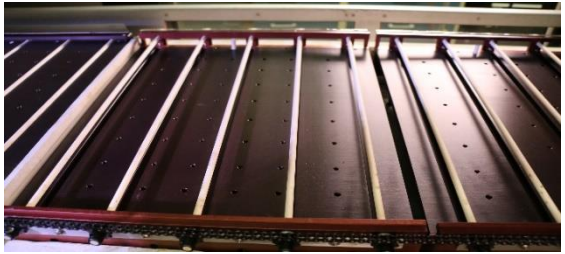
EA System Overview

- EA UP 1200 reflow system
  - Modified to accommodate activated hydrogen system
- Roller system for wafer transportation (60 wafers/hour)
- Capable of handling wafers up to 300 mm in size
- Non-contact heating in combination with forced convection ($\Delta T \leq 2^{\circ}C$) over 300 mm wafer
- Reflow zone operable temperature up to 400˚C
- Fully computer-controlled furnace operation
- Footprint: 192” X 47” (488 cm X 119 cm)

EA UP 1200 furnace



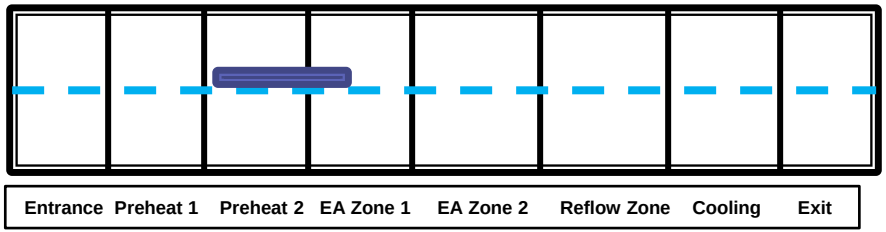
Wafer moving on ceramic rollers

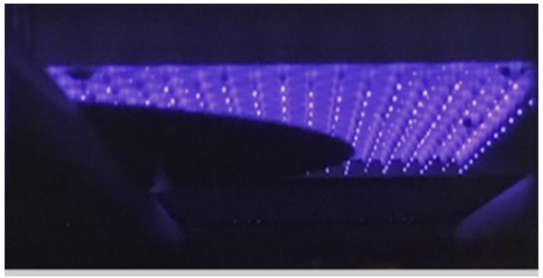


Non-contact heating

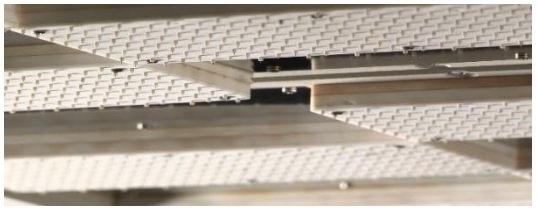
EA System Overview (Cont.)

- <5% H_2 in N_2 atmosphere in Preheat 2, EA and reflow zones and 100% N_2 for other sections
- Reachable O_2 level as low as < 5 ppm
- For each EA zone, an electron emission apparatus is mounted on the top side
- Before entering reflow zone, wafers are exposed to EA environment for oxide removal





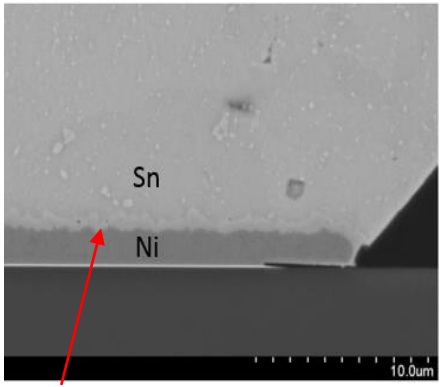
Wafer movement through EA zone



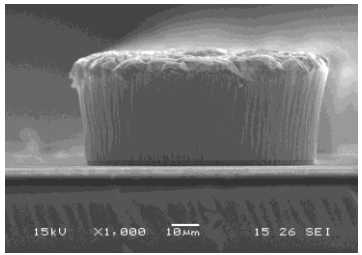
Electron emission apparatus

Individual Bump Reflow

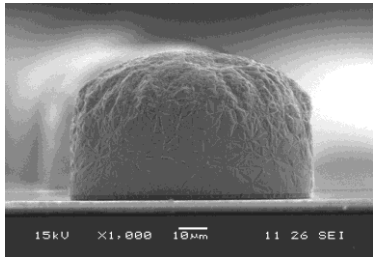
- Bump reflow quality by EA reflow
  - Acceptable IMC layer achieved
  - Full bump shape conversion
    - Without EA, the reflowed bumps have a rough surface and uncompleted shape change
    - With EA, the reflowed bumps are smooth and spherical, even better than that of flux-reflowed bumps



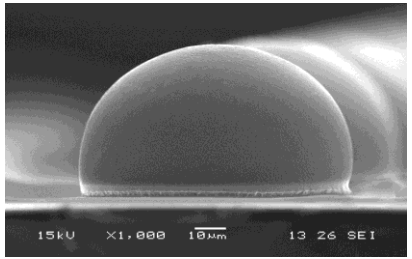
IMC layer of tin-based lead-free solder bump after reflow with EA



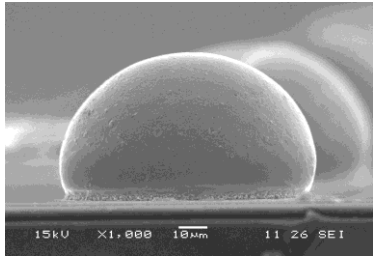
Before reflow



Reflow without EA



Reflow with EA



Reflow with flux

Array Bump Reflow

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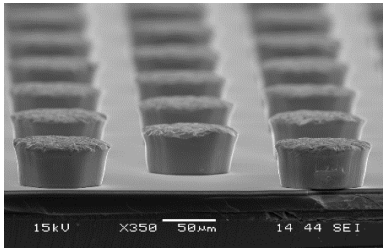
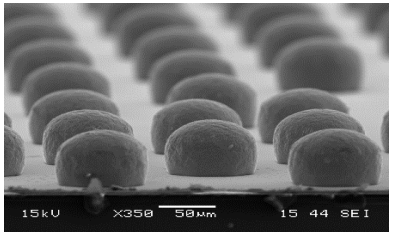
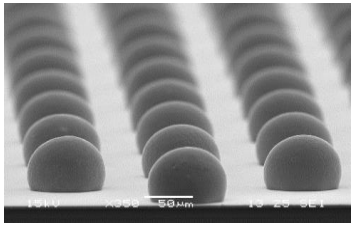
- Bump reflow quality by EA reflow
  - Without EA, the reflowed bumps have surface collapses and non uniform shape
  - With EA, solder bumps are completely reflowed with uniform bump height

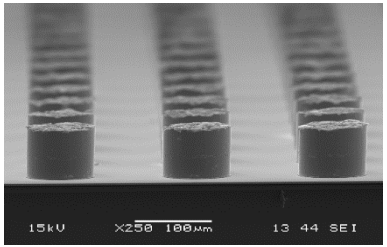
Sample #1

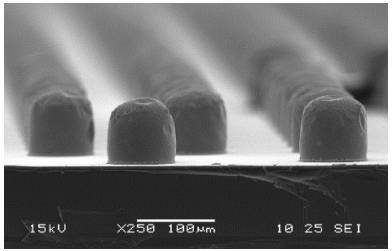


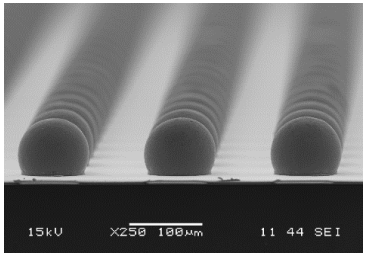




Sample #2







Before reflow | Reflow without EA | Reflow with EA

Bump Reflow Across 12" Width (300 mm)

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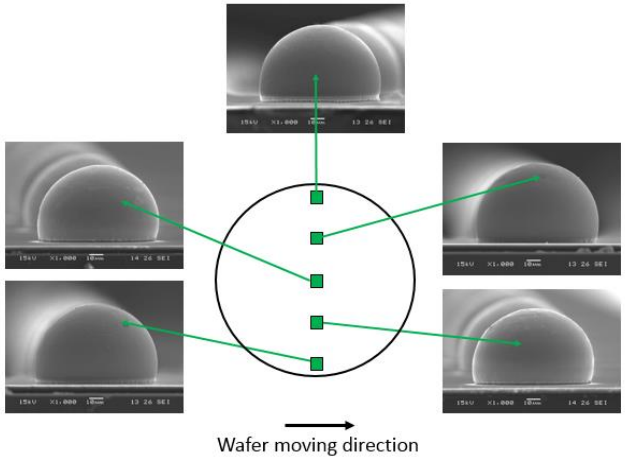
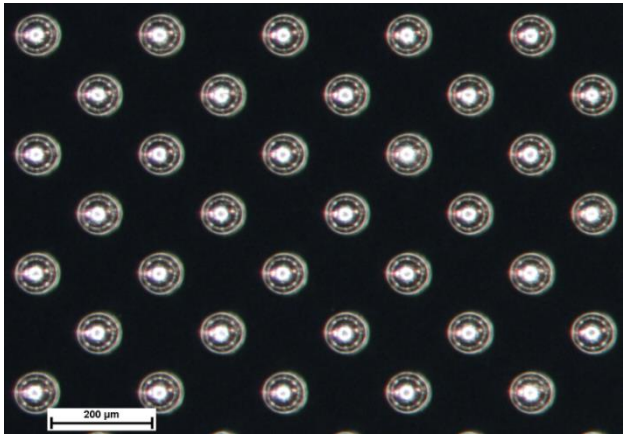
- Bump reflow quality by EA reflow
  - Good bump uniformity across the width of a 12” (300 mm) wafer moving through the EA reflow furnace
- Free of extraneous solder and foreign materials on wafer surface

Uniform bump shape by reflow with EA



Clean wafer surface after reflow with EA



Full 8“ (200 mm) Wafer Reflow Test

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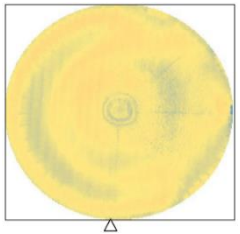
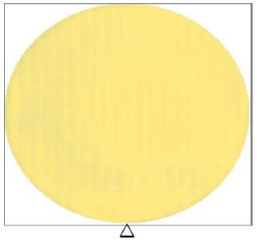
- Leading OSAT standard quality inspections of full wafers with EA reflow
  - AOI (Automatic Optical Inspection) shows that bump height and bump diameter across an 8” full wafer are within specifications
  - All shear failures are within solder bumps and shear strengths well exceed their criterion

Spec	62 ± 15 um
AVG BH	59.1um
Max BH	62.8um
Min BH	48.7um
BH Sigma	1.42um

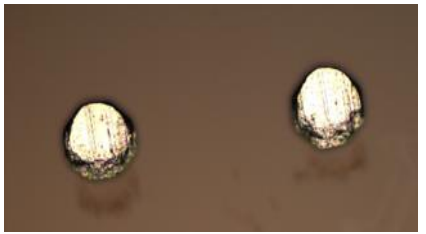


Bump height distribution map and data

Spec	88 um +20%/-10%
AVG BD	90.2um
Max BD	91.9um
Min BD	88.0um
BD Sigma	0.47um



Bump diameter distribution map and data



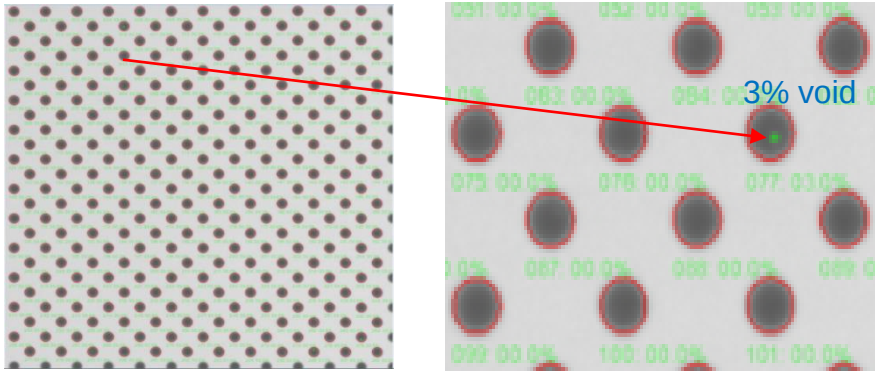
AVG	Max	Min
3.70	4.11	3.34

Spec>2 g/mil2

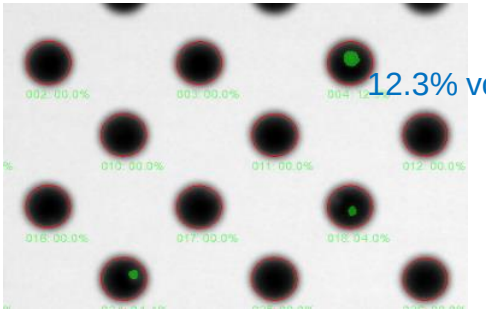
Bump shear failure and data

Full 8“ (200 mm) Wafer Reflow Test (Cont.)

- Bump void X-ray inspection passes criterion (< 8% of bump area)
  - Low number of bump voids
  - Small void size (~3% of bump area)
- Comparison
  - Larger void number and size were found in the same type wafer reflowed with flux



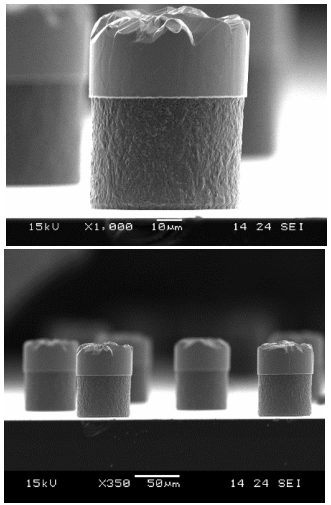
X-ray image for reflow with EA



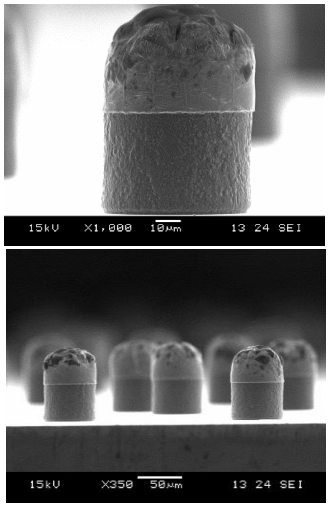
X-ray image for reflow with flux

Mechanical Wafer “A” EA Reflow Test

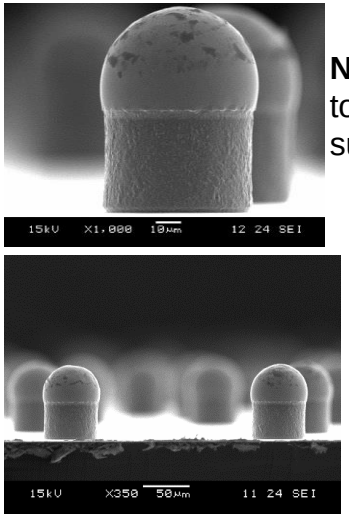
- Lead-free copper pillar bumps with 70 µm in diameter
- Completed bump shape conversion by EA-based reflow, equivalent to flux-based reflow



Before reflow



Reflow without EA



Reflow with EA

Note: Black spots on bump surface due to plating chemical issues per wafer supplier

Mechanical Wafer “B” EA Reflow Test

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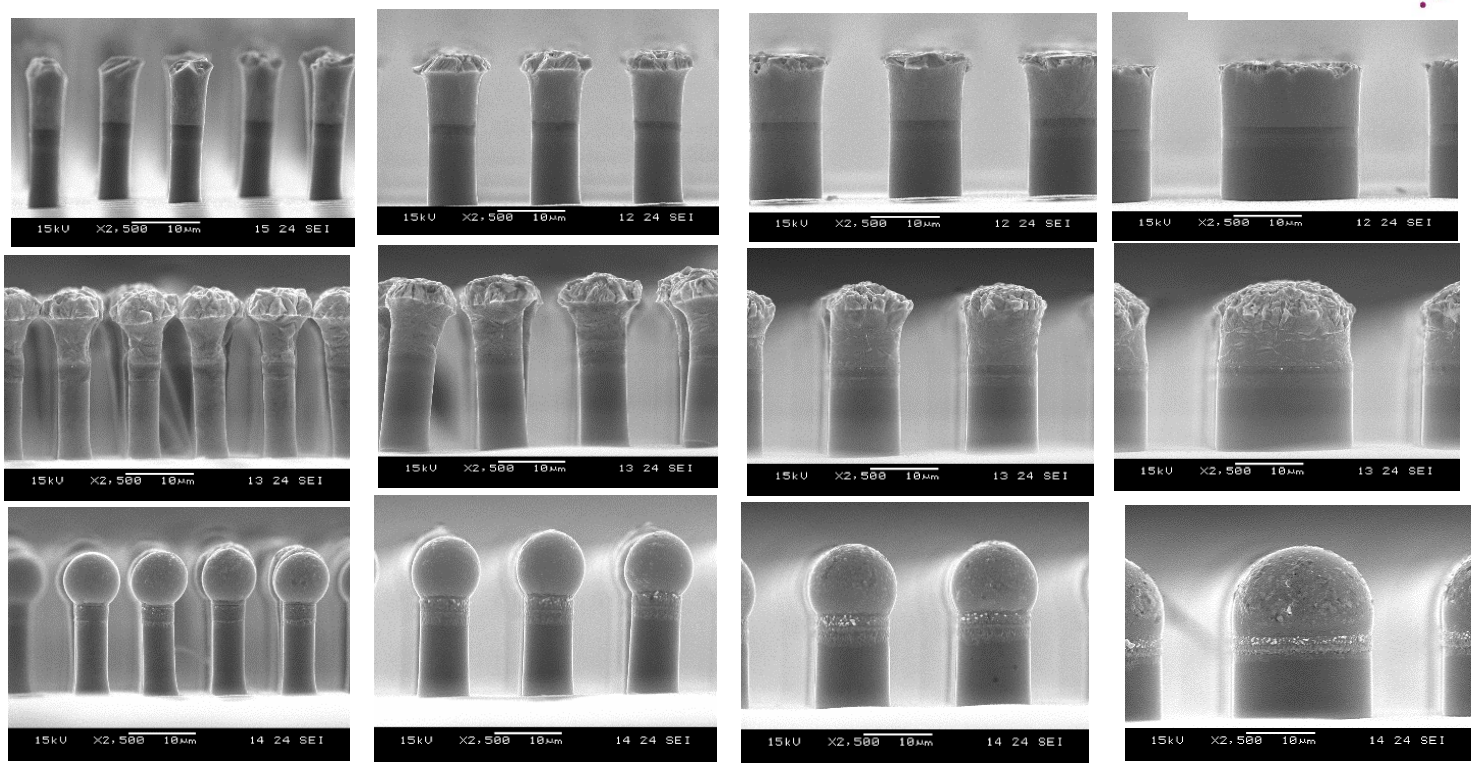
Before reflow

Reflow without EA

Reflow with EA



6 µm | 9 µm | 11 µm | 20 µm

Comparison Processing

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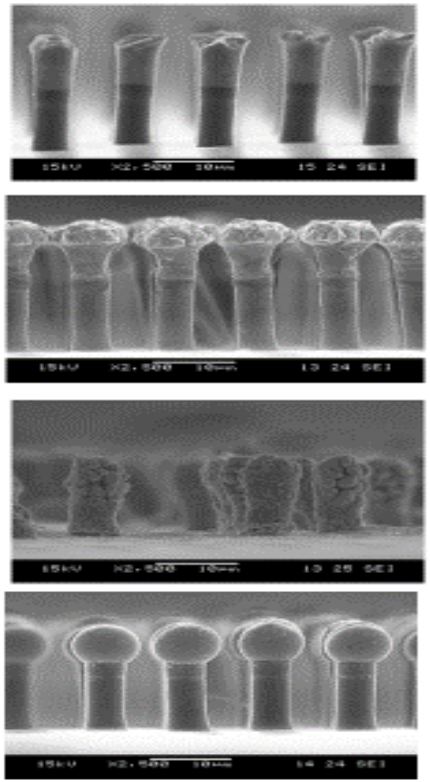
Before reflow

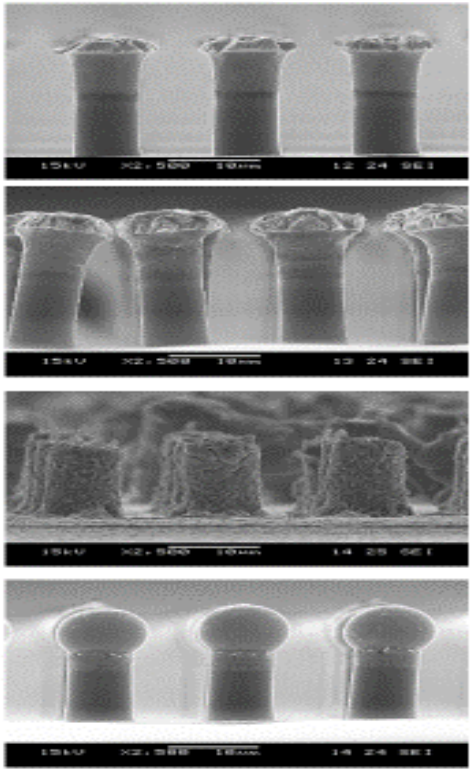
Reflow without EA

Reflow with Flux/Post Clean

Reflow with EA



6µm diameter
10µm pitch



9µm diameter
15µm pitch

Electrical Test
Transistor Level (SRAM at Contact Level)

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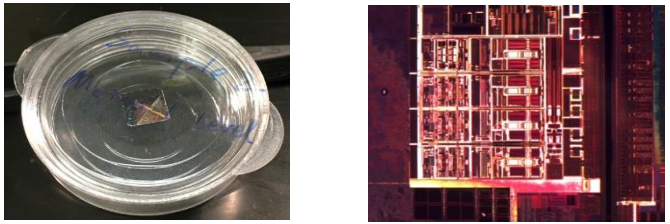
- SRAM chips from a real product wafer at 28nm node
  - Worse-case test (using almost naked transistors) to evaluate effect of EA process on functional devices
  - Passed functional dies through EA-enabled reflow furnace
  - Measured 12 SRAM transistors (2 bits) before and after EA reflow by nanoprobe testing

Die #1 Contact level



Die #2 Metal 1 level

Electrical Test

Transistor Level (SRAM at Contact Level) (Cont.)

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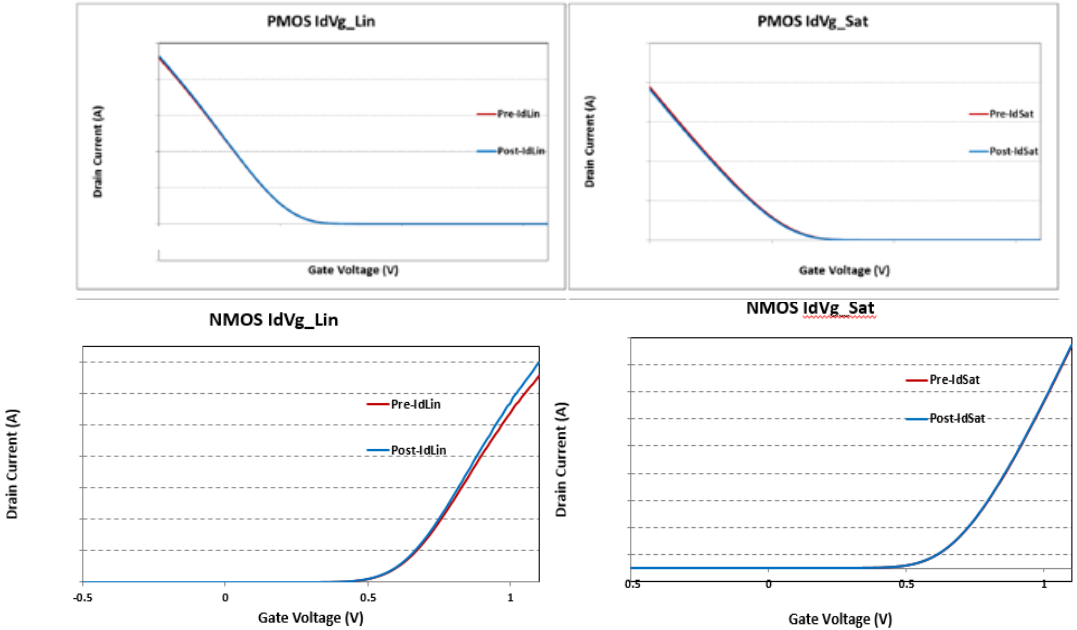
- IV curves (Id-Vg) overlay very well between pre- and post-EA exposures
- For both PMOS and NMOS, average change in Id-lin, Id-sat, Vt-lin, Vt-sat parameters are within 5% for all transistors (acceptable results).



Electrical Test

Wafer Level – Functional Probed Wafer Testing

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- Functional probed solder bumped CMOS wafers were provided by a Major Semiconductor Company
- Two probed wafers were processed in the EA activated hydrogen reflow system
- Post EA processed probe testing showed insignificant changes to the device characteristics as compared to the pre-EA process data
- Pre and post probe wafer testing was completed by the major semiconductor company
- EA activated hydrogen process had no effect on the electrical characteristics or functionality of the devices on the wafers.

SOLDER BALL DROP STUDY TECHNOLOGY

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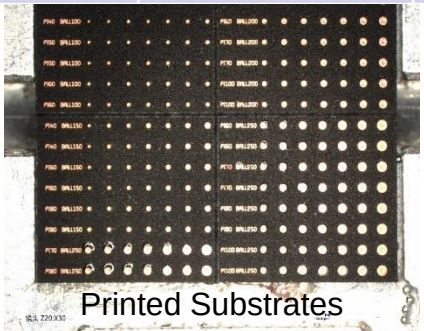
- Objective
  - To evaluate the capability of Indium NC 702 Near-Zero Residue Tacky Agent for ball drop with Sikama EA fluxless activated reflow process
- Test Plan

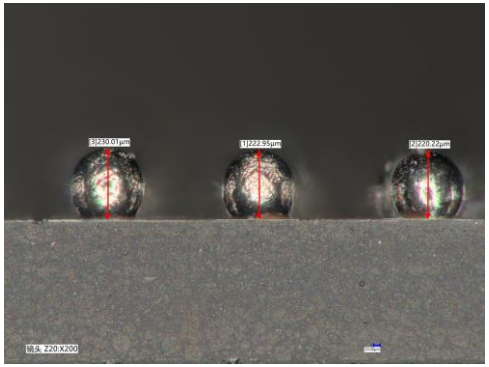
Solder ball alloy compositions	Substrates	EA and reflow temperature profiles	Throughput	Characterizations
SnAg2.6Cu0.6	Copper substrate with and without EA precleaning	EA 216 for SnAg2.6Cu0.6, Reflow at 255 C	60/40/20 wph	Optical microscopy SEM morphology Cross section (IMC layer) TGA analysis

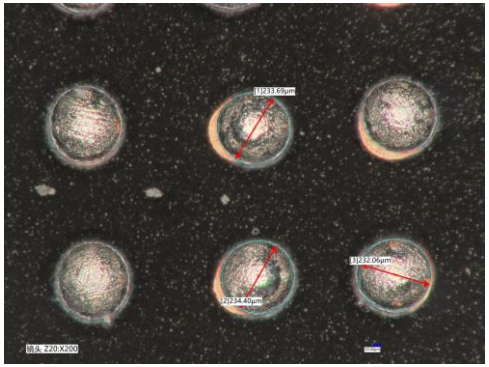


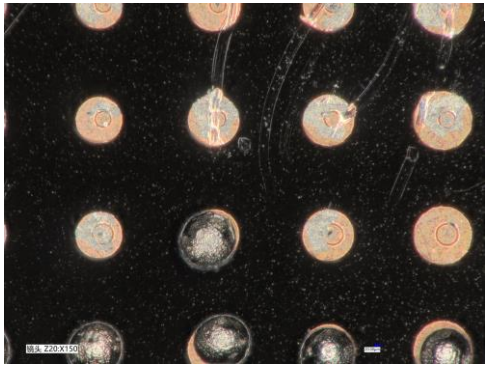
Printed Substrates

Balls Mounted

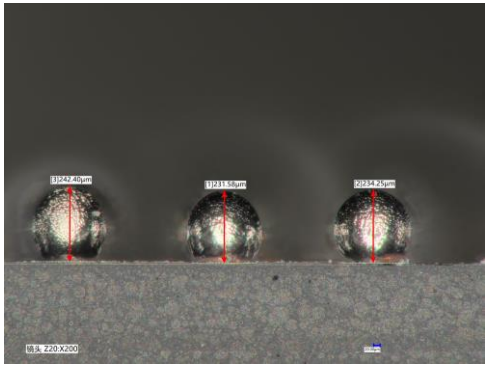
Without Precleaning, 60 wph EA + Reflow

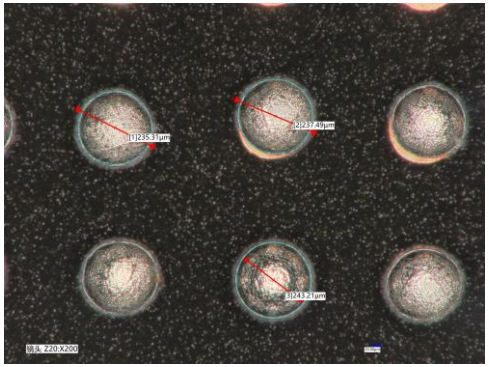


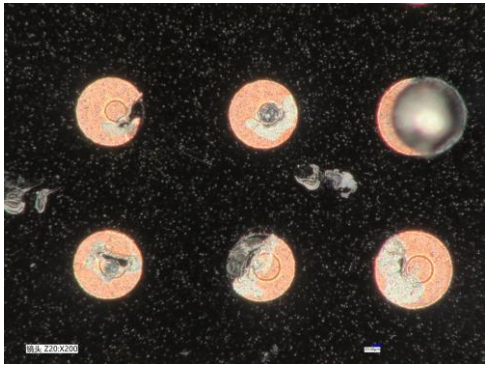




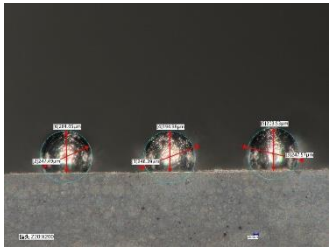
Without Precleaning, 20 wph EA + Reflow

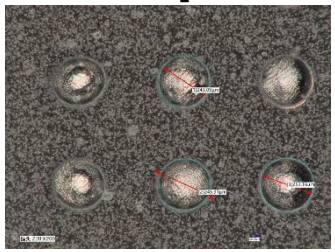


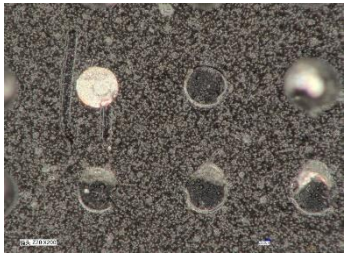




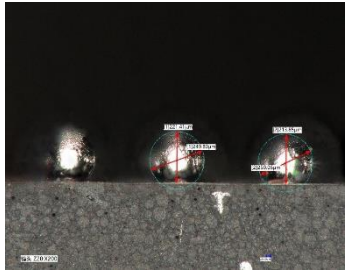
With Precleaning, 60 wph EA + Reflow

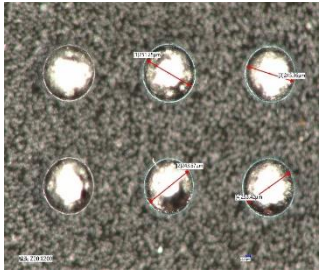


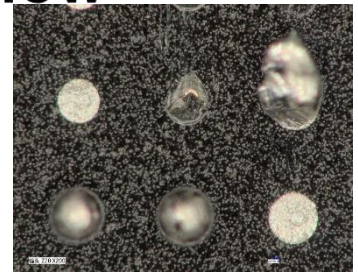




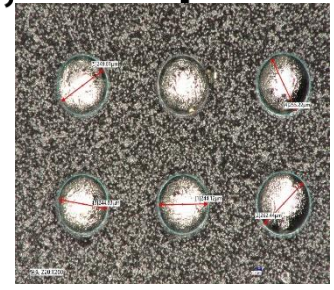
With Precleaning, 40 wph EA + Reflow







With Precleaning, 20 wph EA + Reflow



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SEM Morphology and Cross Section

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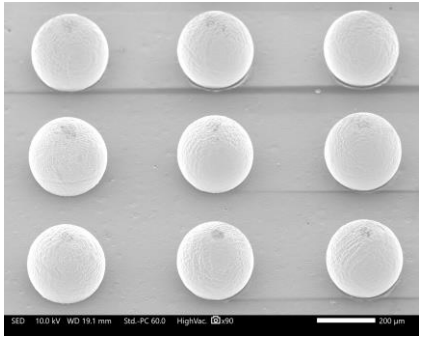
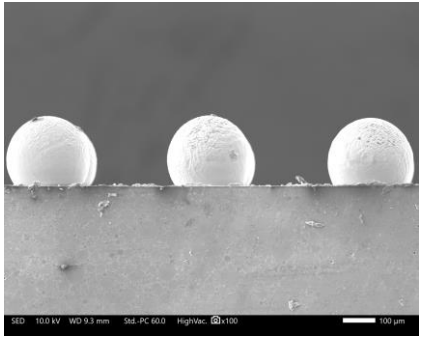
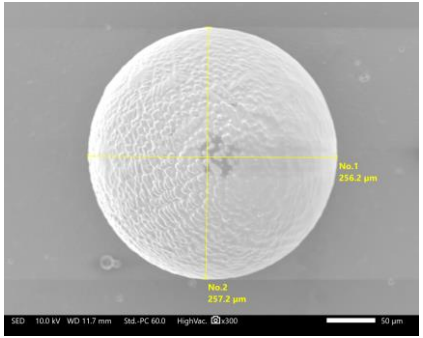
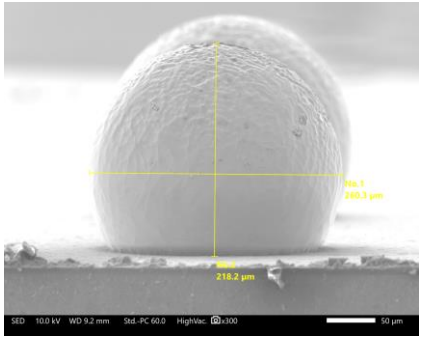
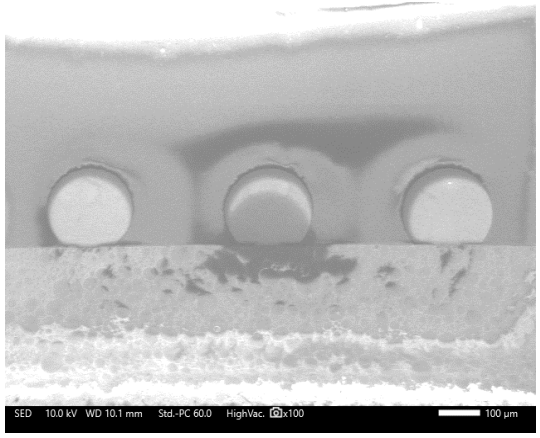
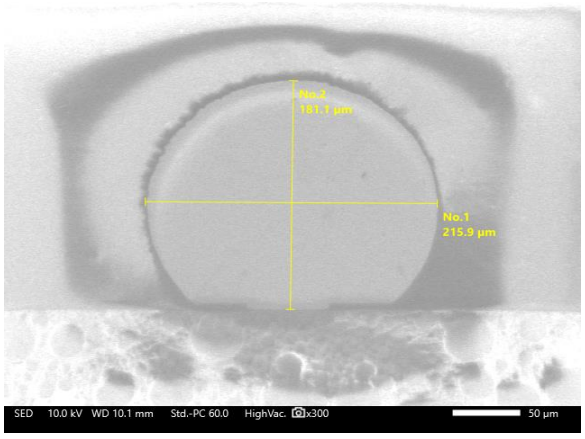


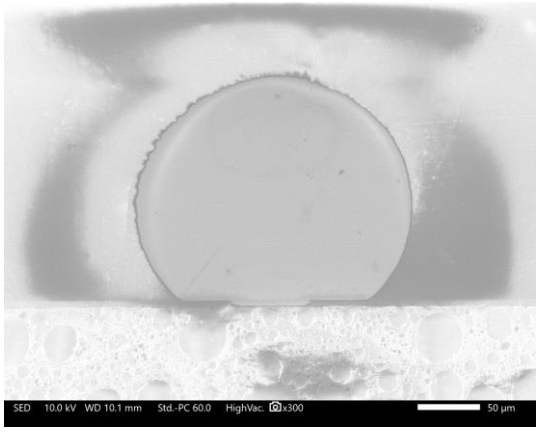




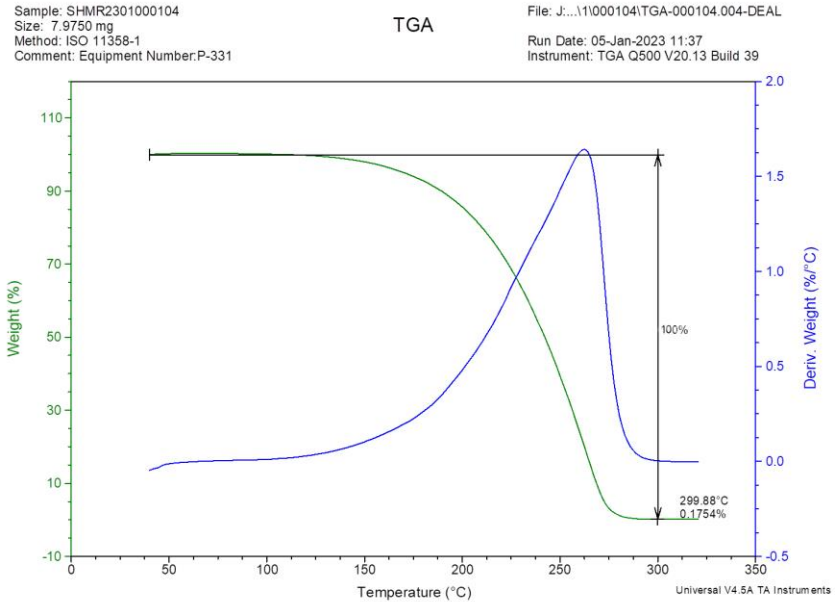


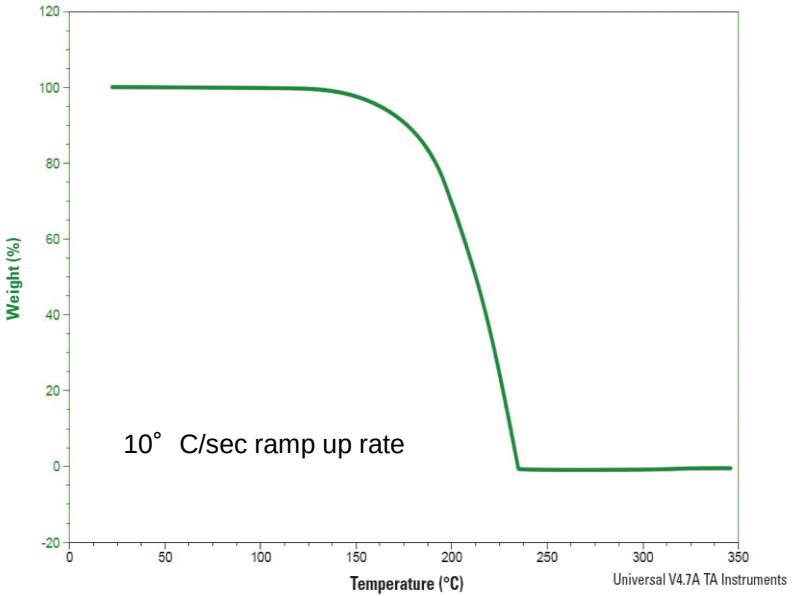






TGA Analysis – Indium NC-702 Near Zero Residue Material

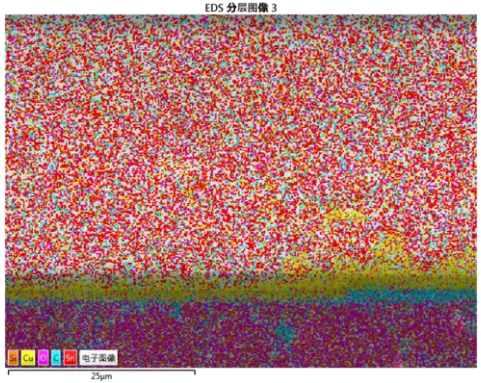


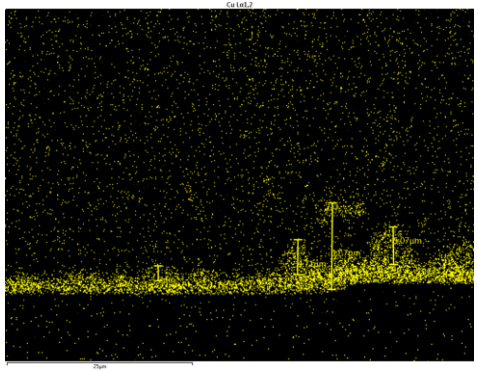


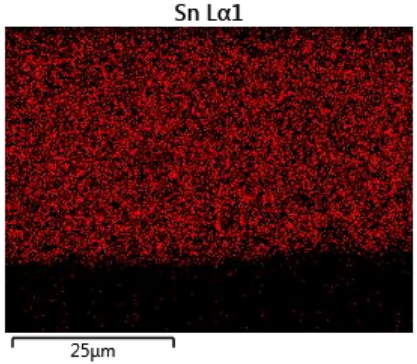
- Temp Ramp Up Rate
  - 50 °C/min
- 100% weight loss around 280 °C to ensure near-zero residue.

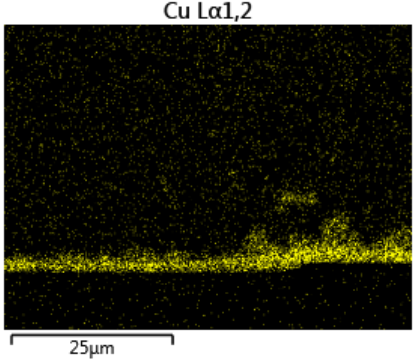
Courtesy of Indium Corporation

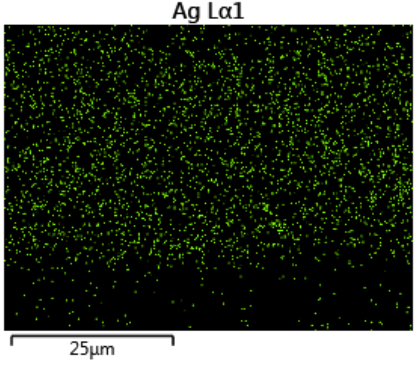
SEM EDS Mapping - Ball Drop Sample

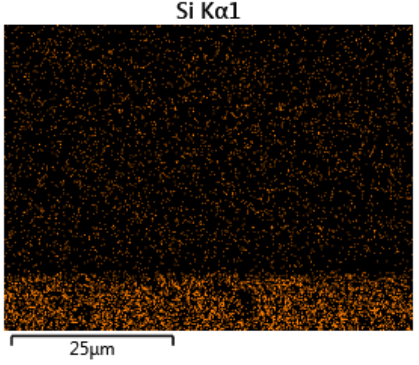












SEM: JEOL JSM - IT500

Conclusions on Solder Ball Drop Testing

- The preliminary results with Indium near zero material on chip substrate demonstrate residue free under OM after normal temperature
- The Indium near zero residue material have the capability to hold the solder balls in respective positions of chip substrates during EA treatment and thereafter reflow bumping

Conclusions on Solder Ball Drop Testing (Cont.)

- The substrates precleaned by EA show acceptable wetting, ball formation and bonding, even if the fastest conveyer speed (60wph) shows the promising results.
- The footprints/pads with precleaning after balls were removed indicate that the complete wetting & spread and good bonding could be achieved after appropriate EA precleaning, while the chip substrates without precleaning show insufficient wetting, ball formation and bonding.

Conclusions on EA Technology

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- Our team has completed in designing, building, testing, and qualifying the EA-based flux-free solder reflow system.
- The system can provide a production-ready process solution to IC packaging industry.
- System hardware tests and actual mechanical and electrical samples have met specifications.
- System can operate in a reliable and stable condition
- EA-based reflow is superior to flux-based reflow, especially for single digit μm bumps
- Electrical studies of functional devices after EA reflow showed negligible effects on device reliability.

Conclusions on EA Technology (Cont.)

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- EA technology offers the following benefits for wafer bump reflow:
  - Enhanced bump reflow quality (no flux-induced solder voids and wafer contaminations)
  - Improved productivity (in-line process, no need for post wafer cleaning and furnace down time cleaning)
  - Reduced cost of ownership (no need for cleaning equipment, solution, labor work, and flux)
  - Improved safety (no flux exposure, using a non-toxic and non-flammable gas mixture)
  - No environmental issues (no organic vapors, hazard residues, and CO_2 emission and eliminate water for cleaning)

Thank You!

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