Process Considerations for Defluxing Ultra-Fine Pitch Die on CoWs

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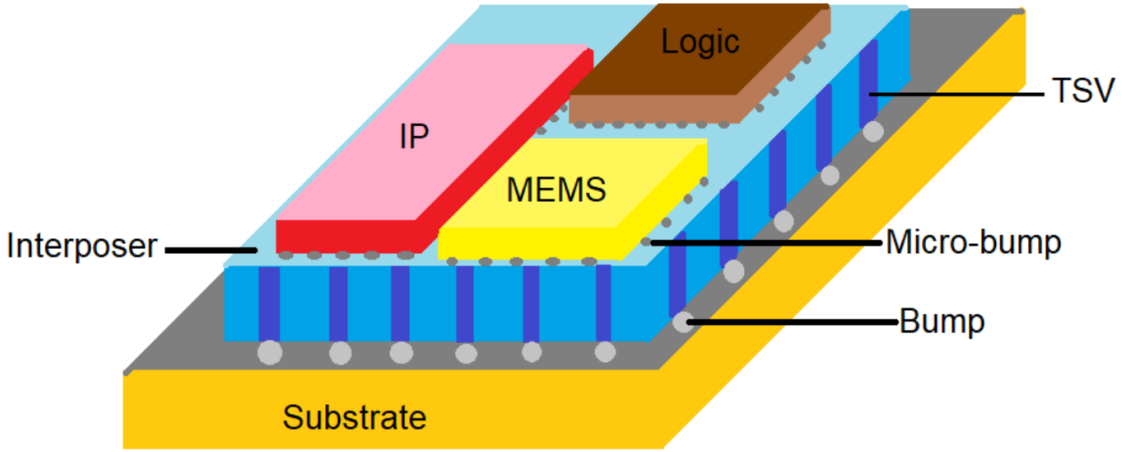
Outline

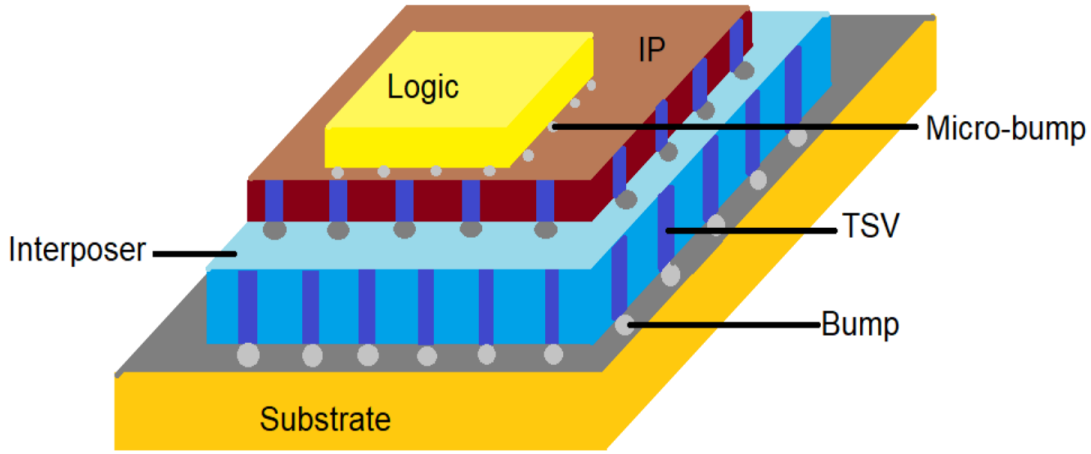
- Introduction
- Background
- Case Study
  - Current POR
  - CoW & Flux Specifications
  - Cleaning Agent Used
- Test Plan
- Results
- Conclusions
- Acknowledgements

Introduction

- Advanced packaging: Crucial for moving beyond Moore's Law.



2.5D Package



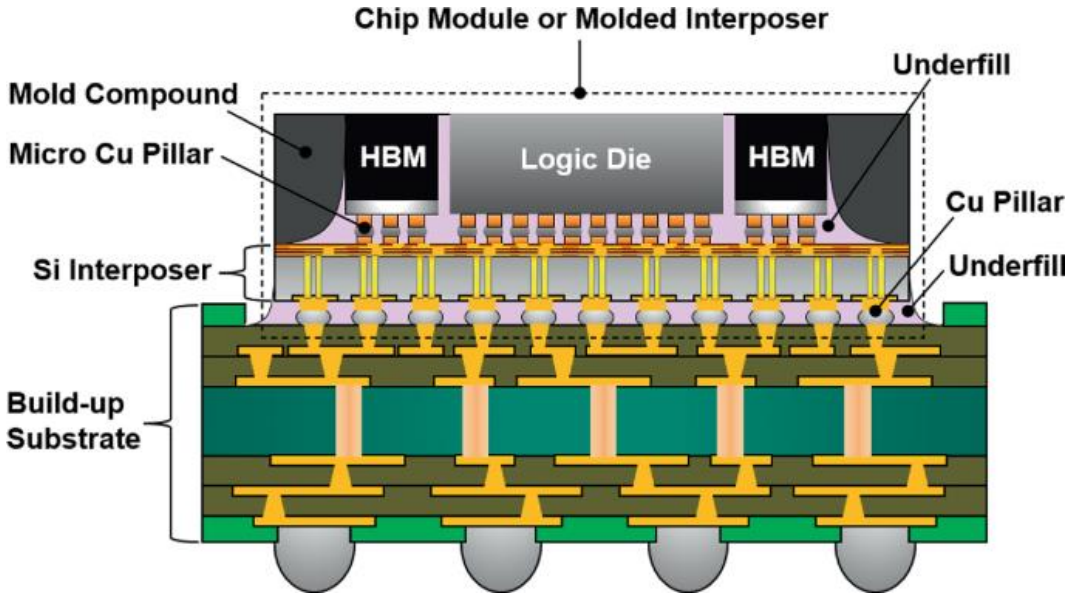
3D Package

- Packaging technologies such as 2.XD, 3D, and chiplets have skyrocketed in demand, solidifying their status as prized assets within the semiconductor industry.

Introduction

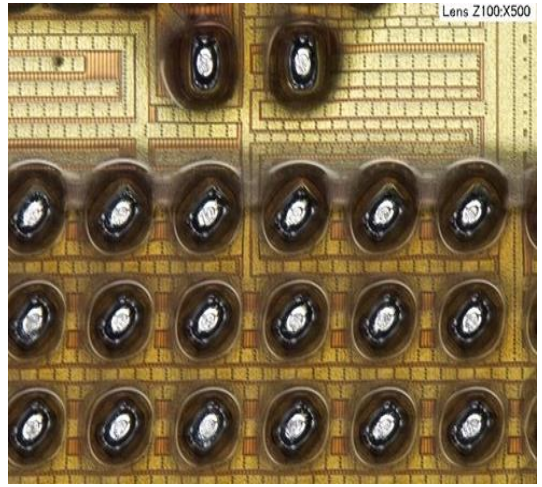
- The copper pillar interconnect represents a pivotal enabling technology and the subsequent logical progression.

- It offers several benefits:
  - Superior electromigration resistance
  - Improved electrical and thermal conductivity
  - Simplified under bump metallization (UBM)
  - Higher I/O density
  - Smaller (Finer) Pitch

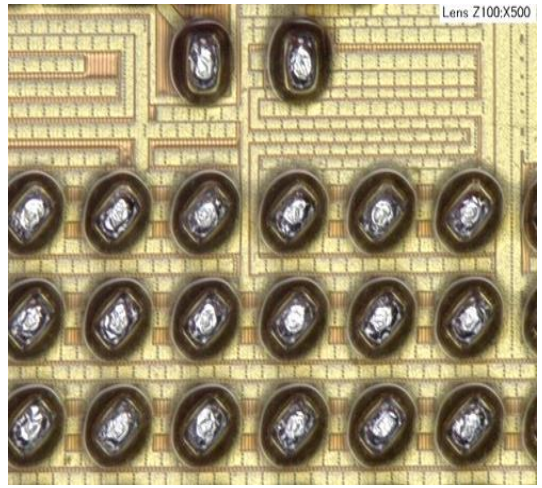


Introduction

- Latest advanced packages are trending towards a lower gap
  - between the stacking chip and include new soldering material
  - to create reliable solder joints
- Flux residues left around the bumps are difficult to remove



Space between bumps completely filled with flux

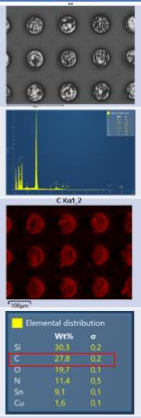
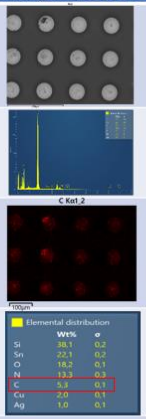
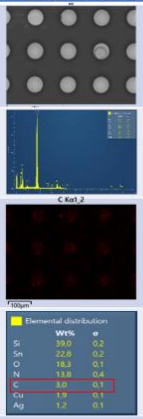


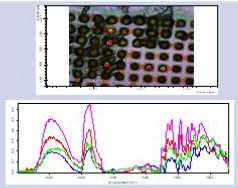
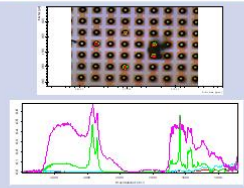
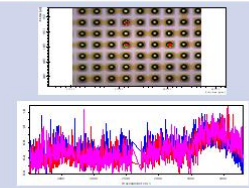
Isolated flux residues around bumps

Background

- At IMAPS Device Packaging Conference 2023, a Phase I study titled *"Defluxing of Copper Pillar Bumped Flip Chips"* was presented
- The study confirmed that compared to low concentration alkaline cleaning agents, the deionized water inline cleaning system is challenged to consistently and effectively clean flux residues underneath low standoff Cu-pillar packages with 150µm pitch and 30µm pillar height
- This follow-up study is continuation of earlier effort but focuses on next level of ultra-fine pitch CoW devices *down to 10µm bump pitch and bump counts in excess of 200K*
  - Focuses on different spray technologies, impact of wash temperatures and chemical exposure time
  - In collaboration with an Global OSAT (Outsourced Semiconductor And Test) company

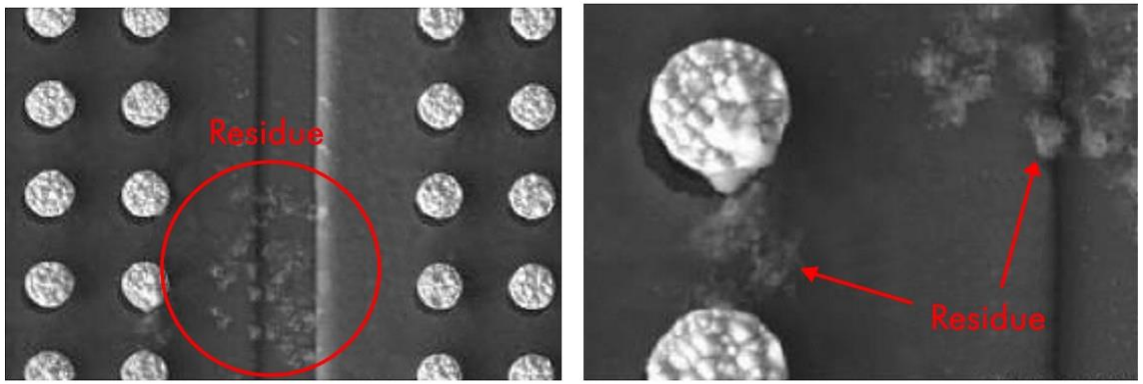
Excerpt results from Phase I study

	Un-clean	De-ionized water at 2.0 fpm	Cleaning Agent at 3.0 fpm
Chip backside (BSE & EDS detector)			
	High amount of carbon contamination, most likely flux is visible on chip backside.	Low to minimal amount of carbon contamination, most likely flux is visible on chip backside.	Very low (trace levels) of carbon contamination visible on chip backside.

	Un-clean	De-ionized water at 2.0 fpm	Cleaning Agent at 3.0 fpm
Chip backside (bumps)			
Au-pad (mapping)			
Results	Significant amount of carbon/flux signals visible on bumps and Au-pad.	Carbon/flux signals visible around bumps and Au-pad	No detectable carbon/flux signals visible on bumps and very minor residues visible in upper right corner on Au-pad

Case Study

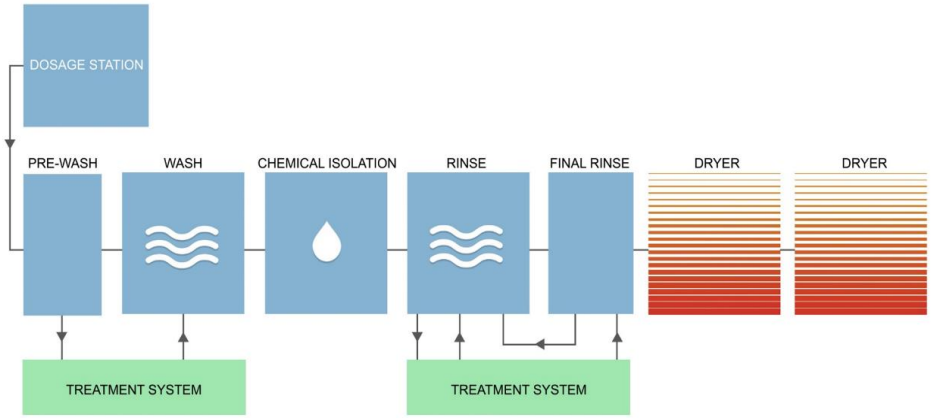
- Global OSAT company has been utilizing pH-alkaline cleaning agent at low concentration (< 5%) for removing water-soluble flux residues from ultra-fine pitch CoW packages without success
  - Continue to observe flux residues on their packages despite subjecting to multiple wash passes as well as varying the cleaning parameters



Flux residues visible underneath the chip after cleaning process

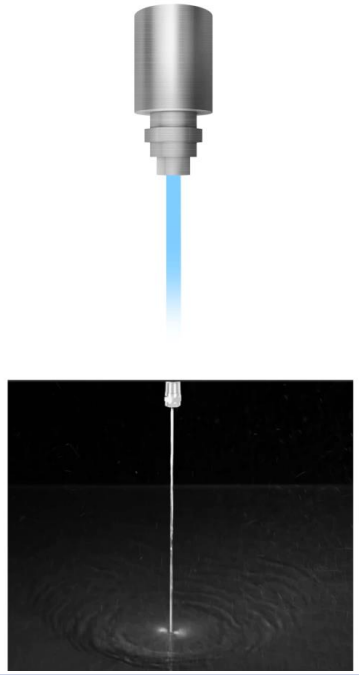
Current POR (Process of Record)

	Chemical Concentration	Wash Temperature	Rinse Temperature	Dryer Temperature	Cleaning Agent Exposure Time	No. of Wash Passes	Overall Results
POR	<5%	65-70 ºC	65-70 ºC	65-70 ºC	~ 4.5 minutes	2	Residues visible

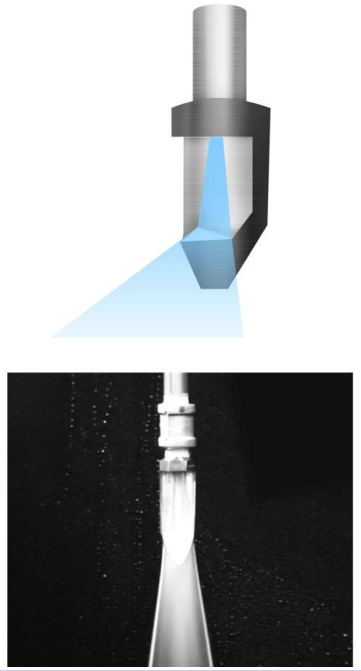


Schematic of the inline cleaning system

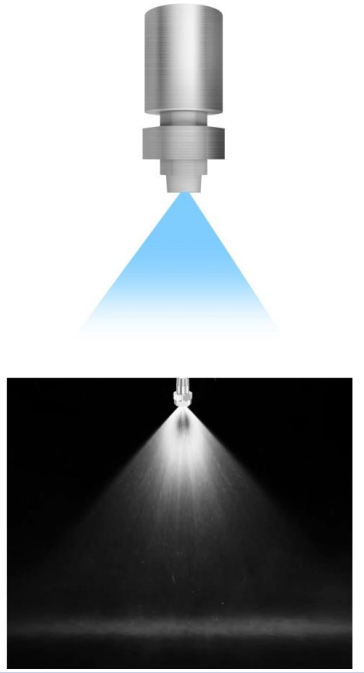
Solid Stream Spray Pattern



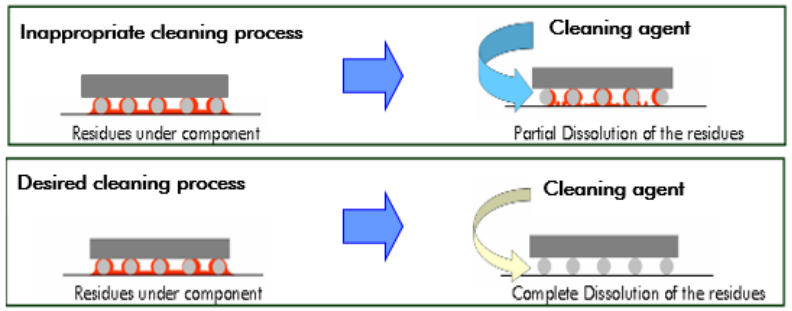
Flat Non-Tapered Spray Pattern



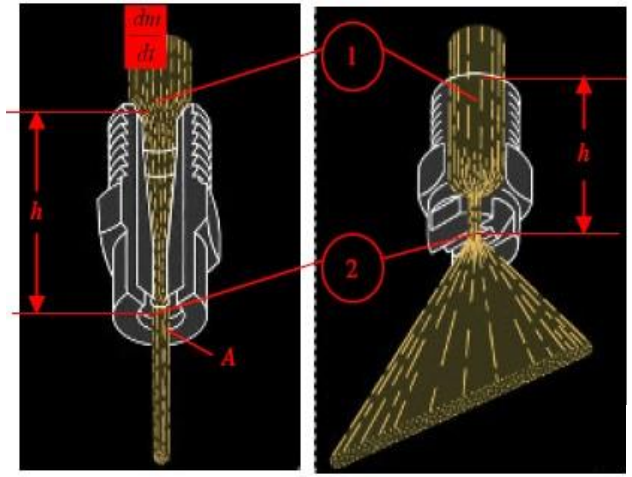
Flat Spray Pattern



Cleaning Process Parameter – Key Factors and Optimization

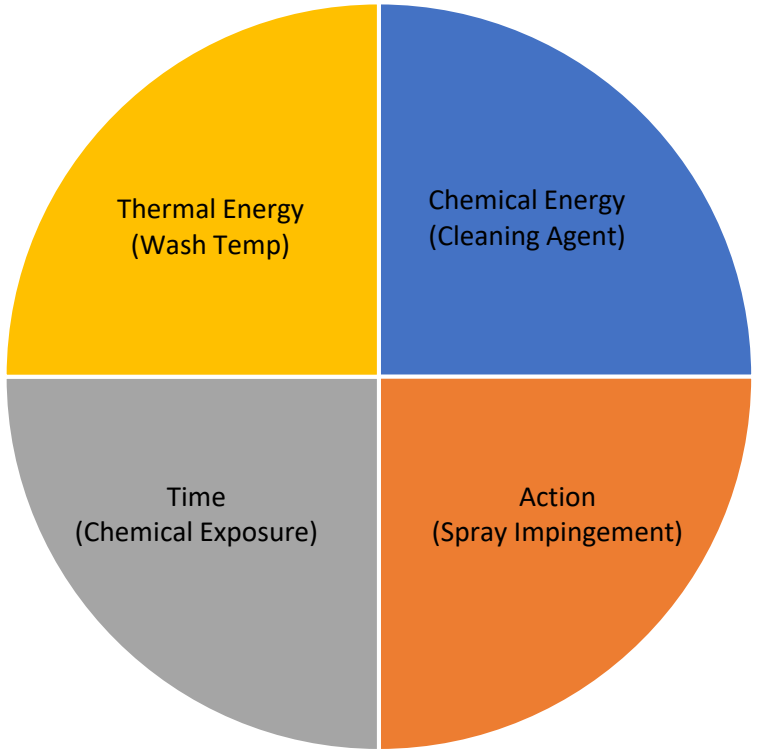


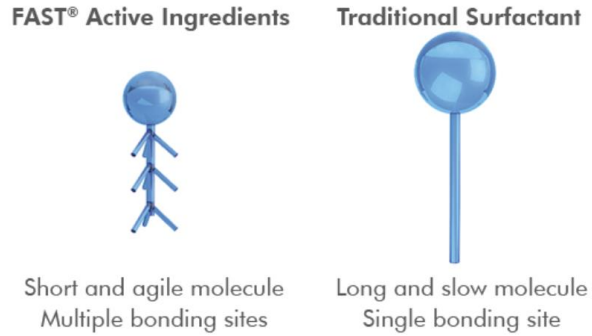
Time and Temperature



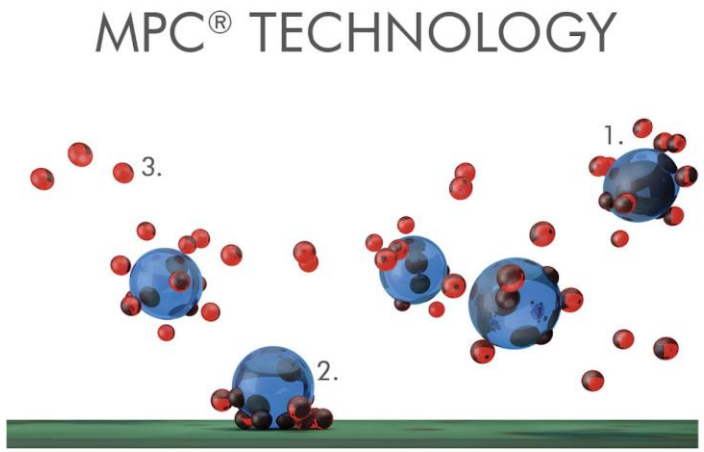
Equipment / Agitation

T.A.C.T. Principle



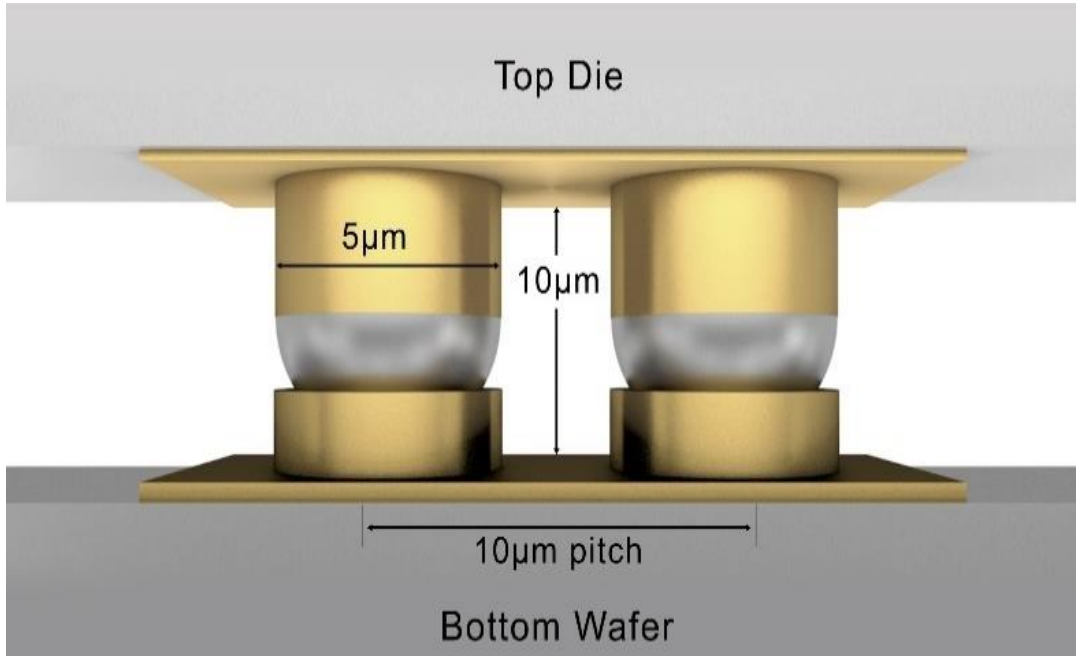


Chemical / Cleaning Agent



CoW Specification

- 8mm x 8mm die placed on a silicon wafer with 10µm fine pitch
- Gap height between the top die and bottom wafer is 10µm
- Total number of bumps > 200K



Flux Specification

- Identical to the one evaluated in Phase I Study presented at IMAPS Device Packaging Conference 2023
- Lead-free water-soluble tacky flux
- Commonly used materials in semiconductor packaging, including copper pillar bump applications

Cleaning Agent Used

- Aqueous-based for removal of lead-free water-soluble fluxes
- Excellent compatibility with variety of metals (Sn, Ag, Cu, Ni, Al, etc.)
  - Lack of corrosion inhibitors can easily attack these metals causing galvanic corrosion reactions
- Specifically developed focusing on stacked copper pillar packages, 2.XD/3D TSV stacks, BGAs and SiP packages having interposers
- Recommended for use in spray-in-air cleaning processes

Test Plan

- OSAT company provided 60 CoW packages for first round of testing
- Mutually agreed on the experimental plan prior to initiating the trials
- Four (4) CoW packages were utilized for each of these cleaning trials

Trial #	Concentration (%)	Wash Temp (°C)	Conveyor Belt Speed (m/min)	No. of Passes
1*	Low	High	Faster	2X
2	Low	High	Faster	1X
3	Low	High	Slower	1X
4	Low	Low	Slower	1X
5	Low	Low	Faster	2X
6*	High	High	Faster	2X
7	High	High	Faster	1X
8	High	High	Slower	1X
9	High	Low	Slower	1X
10	High	Low	Faster	2X

NOTE: a) * represents current OSAT process settings in terms of temp, belt speed and no. of wash passes
b) Faster belt speed corresponds to ~ 4.5 minutes of chemical exposure time
c) Slower belt speed corresponds to ~ 9.0 minutes of chemical exposure time

Test Plan

- Working closely with the equipment supplier in procuring specific spray manifolds and nozzles (replicating OSAT's machine set-up)

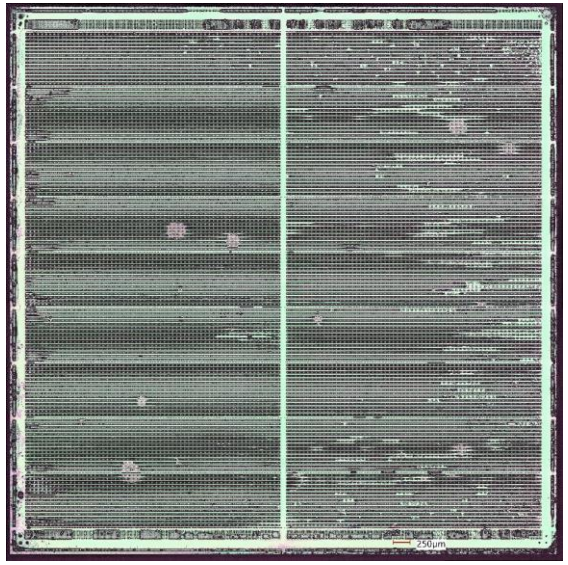
Wash Stage	
Cleaning Agent (Concentration)	Refer to earlier slide for settings
Conveyor Belt Speed	
Cleaning Temperature	
Wash Spray Configuration	Customized spray manifolds with combination of different nozzle types
Wash Pressure	25-45 PSI
Chemical Isolation Pressure	25 PSI

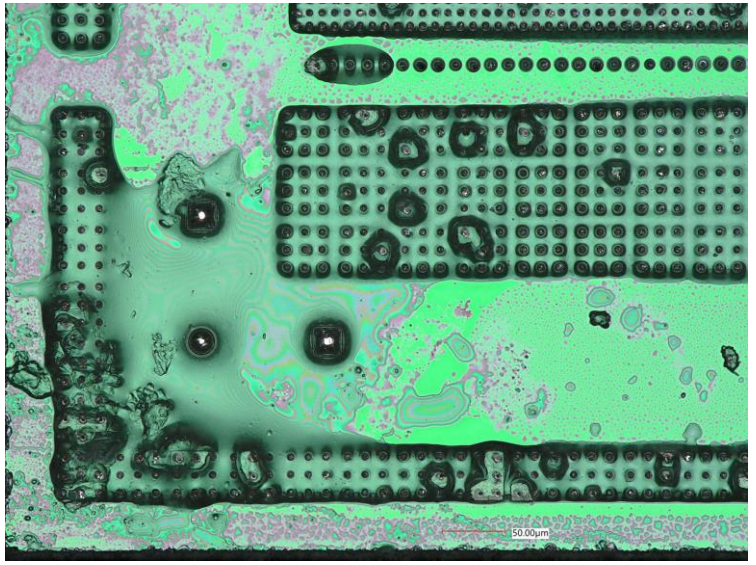
Rinsing Stage	
Rinsing Agent	DI-water
Rinse Spray Configuration	Customized spray manifolds with combination of different nozzle types
Rinse Pressure	30-45 PSI
Rinse Temperature	70°C
Final Rinse Pressure	25 PSI
Final Rinse Temperature	Room Temperature
Drying Stage	
Drying Temperature	65-80°C

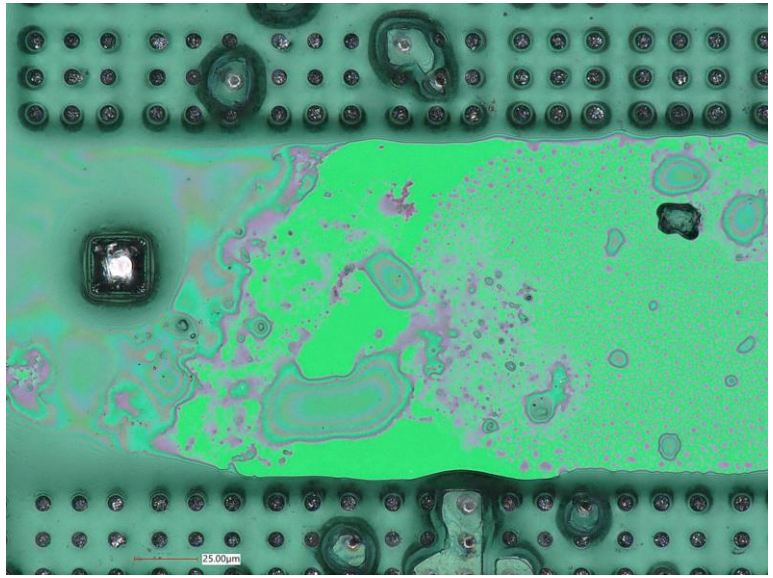
- Post-cleaning, all the CoWs were sent to independent third-party lab for cleanliness analysis (Visual, SEM/EDX & FTIR)
- Upon identifying the best process settings, the OSAT company provided additional CoW packages for 2nd round of testing and requested to be returned for reliability testing

Test Plan – Visual Inspection

- Prior to cleaning, one (1) die was removed from an uncleaned package to identify the residue distribution. Inspection of both die and substrate were performed



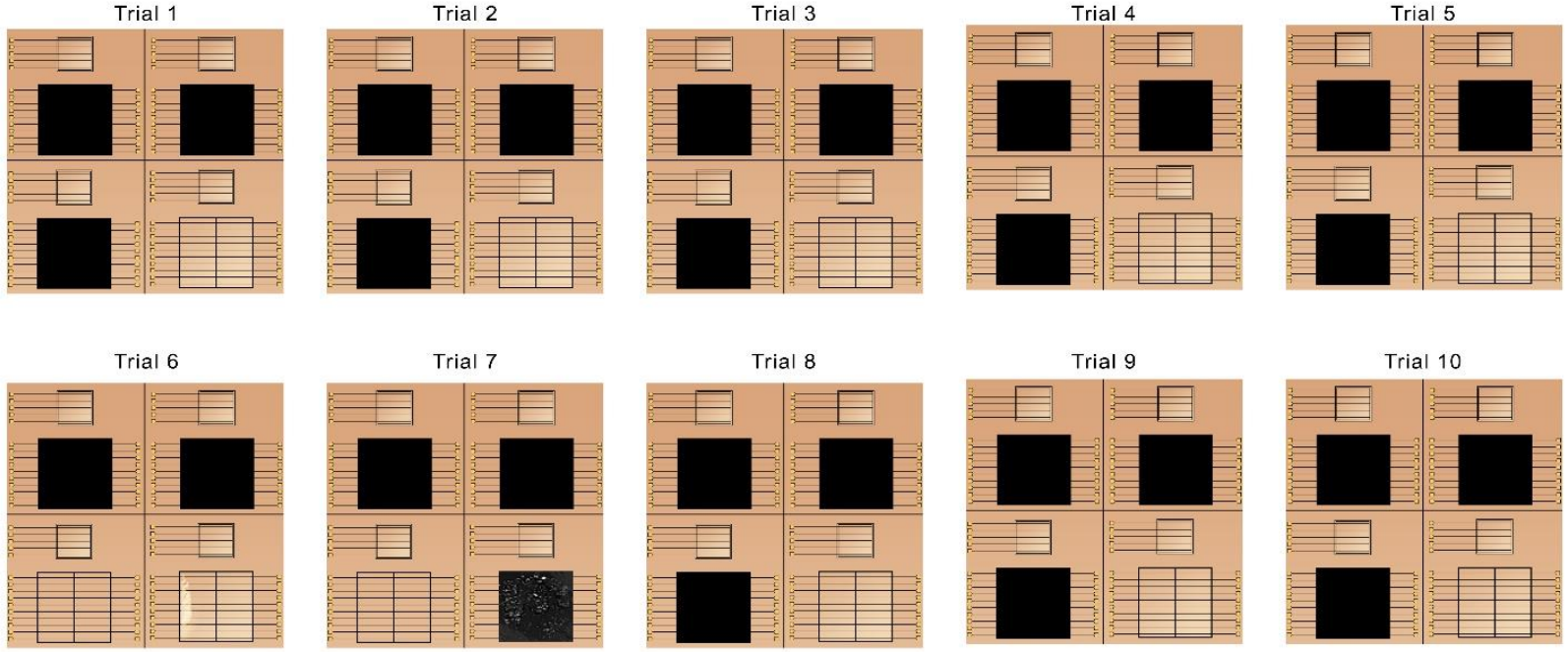




Visual Inspection – presence of flux residues around bumps

Test Plan – Visual Inspection

- One (1) die was removed from the cleaned substrate and goal was to shear the die from same location for each trial sample

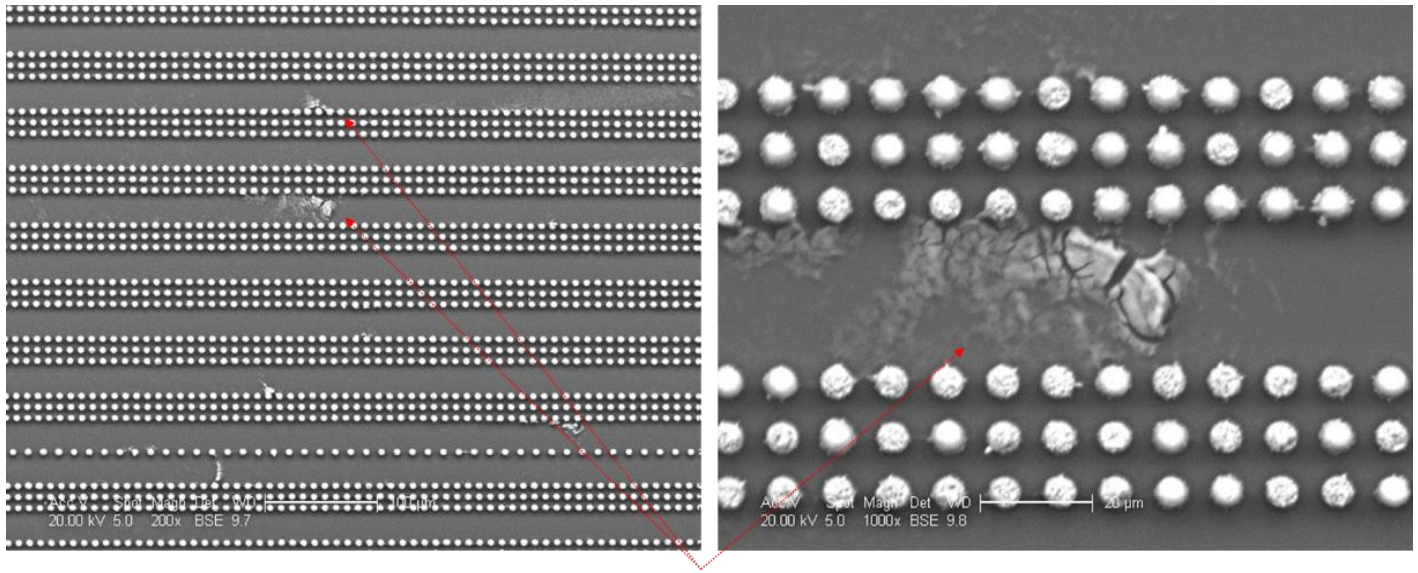


Location of die removed from the substrate for each cleaning trial

NOTE: A different die location was used on Trials #6 and #7 due to issue with die removal

Test Plan – SEM/EDX Analysis

- Entire surface scanned at 100-1000X magnification and BSE detector at 20kV used in this study

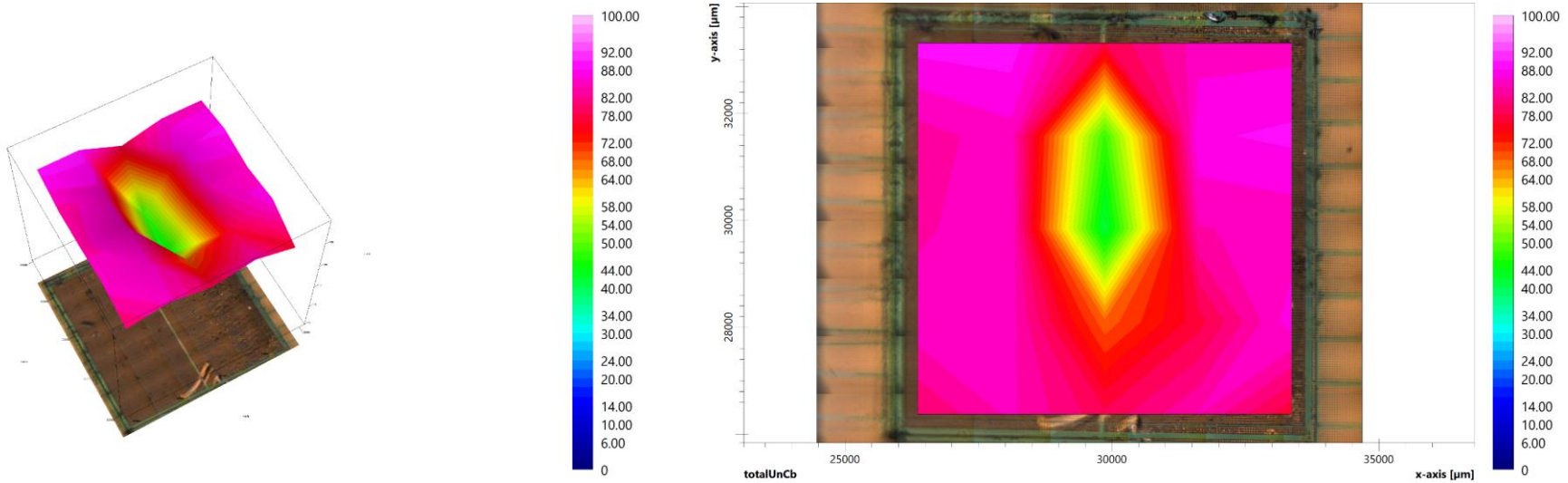


SEM Imaging (1000X magn.) indicating the presence of residues after pulling the die from the substrate

- Post-cleaning, the die was removed from the substrates (for each trial run) and analyzed

Test Plan – FTIR Analysis

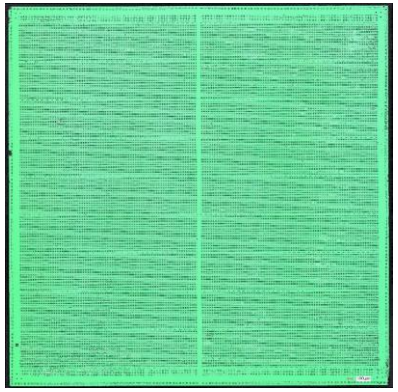
- Performed using Bruker LUMOS™ equipment with liquid-nitrogen cooled detector
- FTIR heat map indicates the intensity of carbon/flux residue signal.



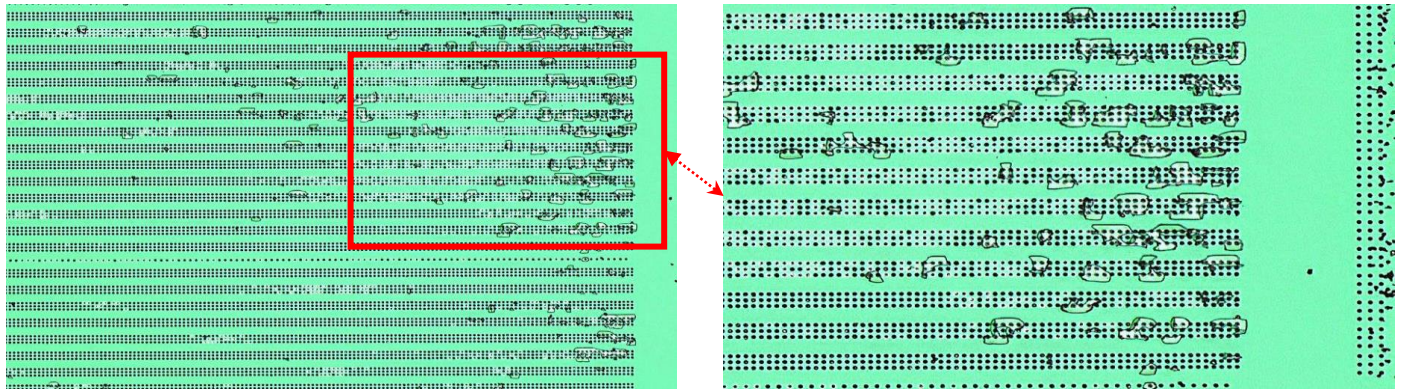
FTIR color mapping shows the residue distribution on uncleaned substrate: 3D plot (left) and 2D plot (right)

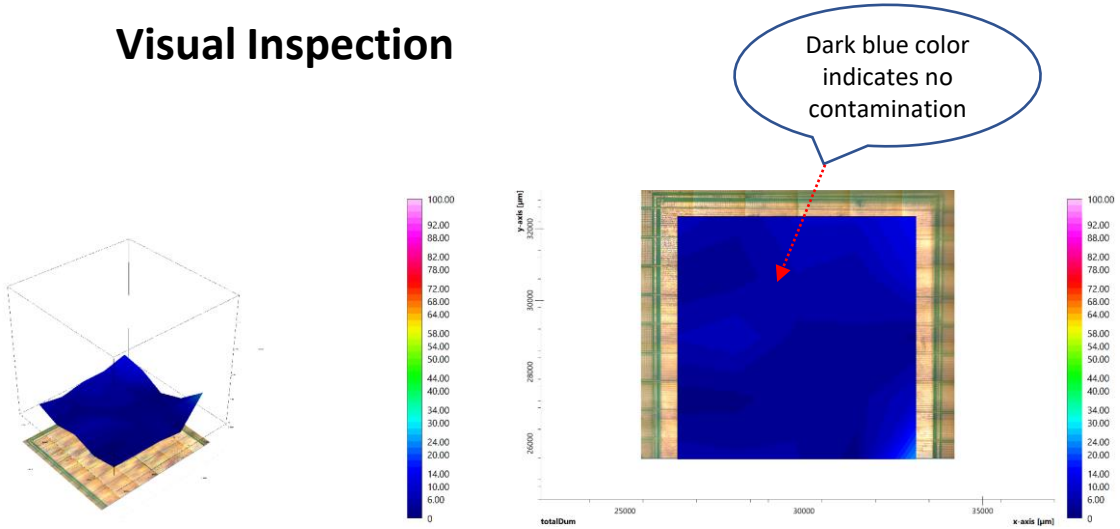
- Total of 100 locations were analyzed and number obtained via integration of FTIR signal which was correlated to the color obtained for each of those locations.

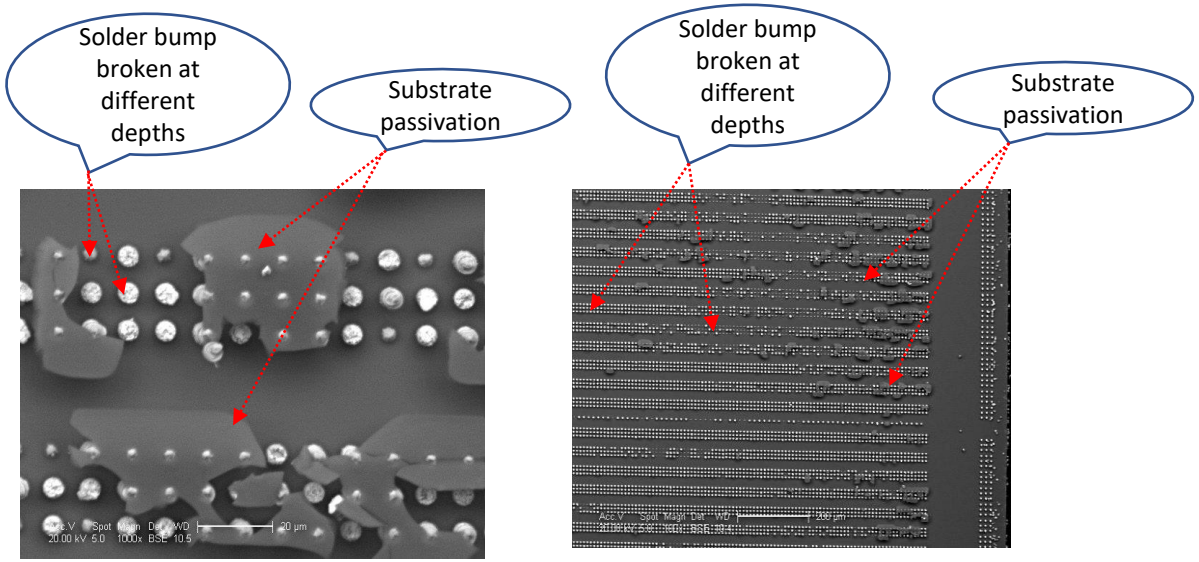
Results – Trial 1 (Current OSAT process settings)



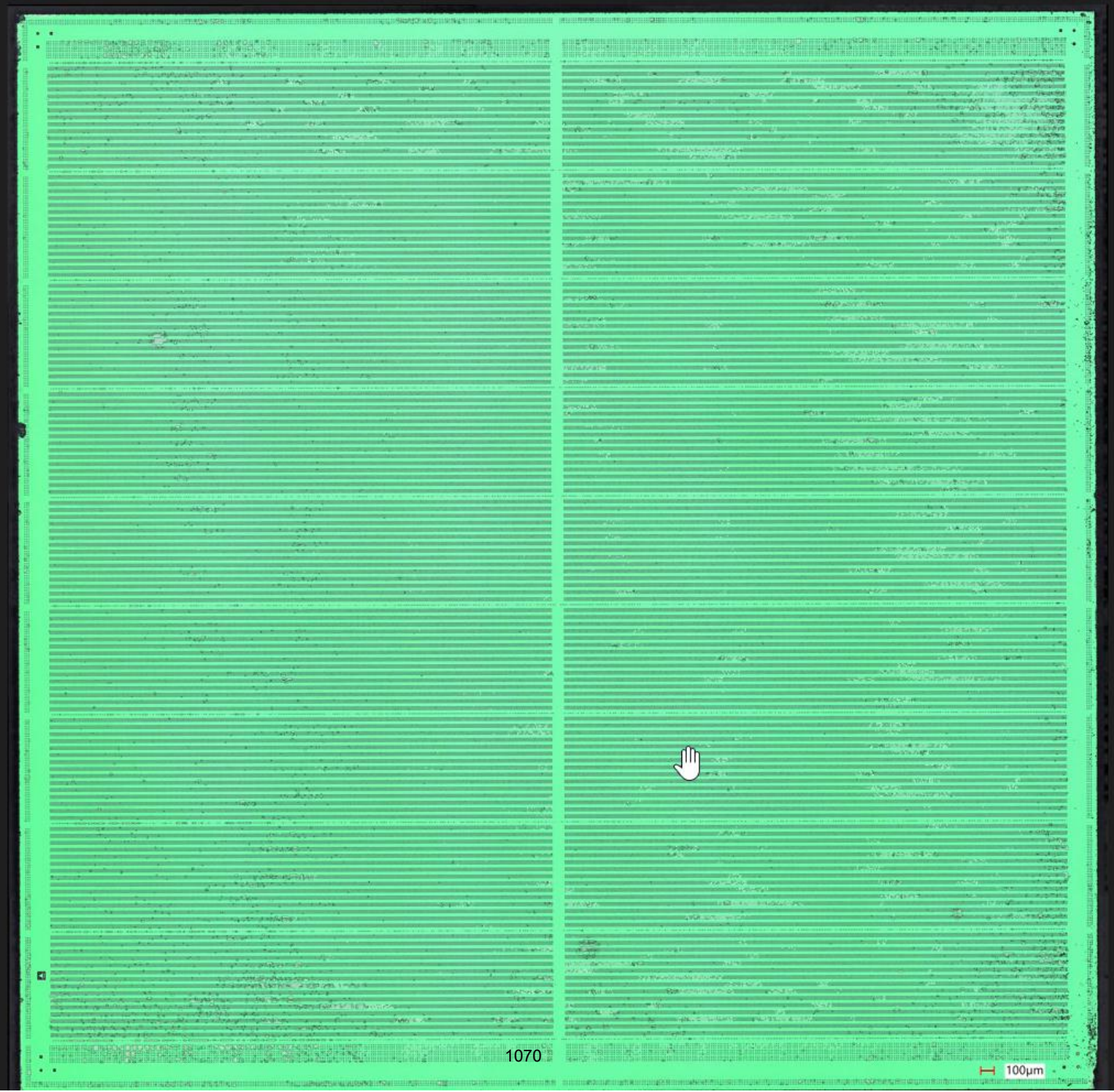
Visual Inspection







FTIR color mapping shows the residue fully removed: 3D plot (left) and 2D plot (right)

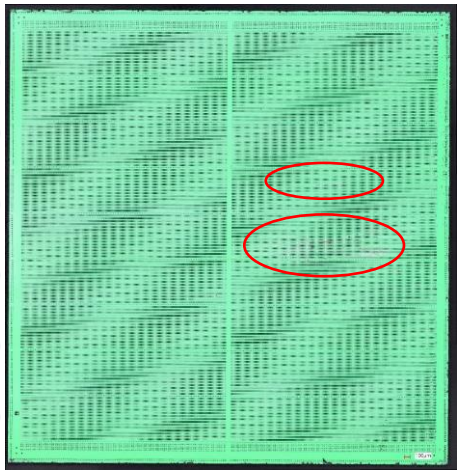

1070
100µm

Results – Trial 1 (Current OSAT process settings)

KEY POINTS:

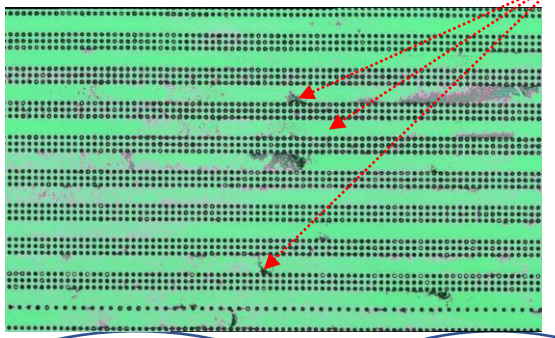
- **Flux residues fully removed around the solder bumps**
- **Solder bumps observed to fail at different depths**
- **Some Si-oxide passivation transferred during the chip removal process**

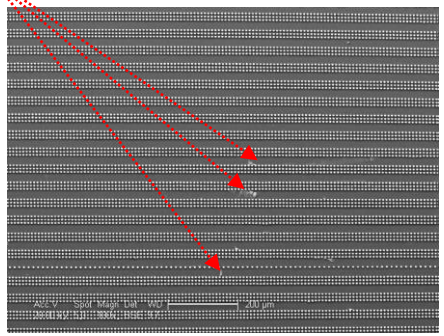
Results – Trial 2 (Low Conc., High Temp., Faster belt speed, 1X wash pass)

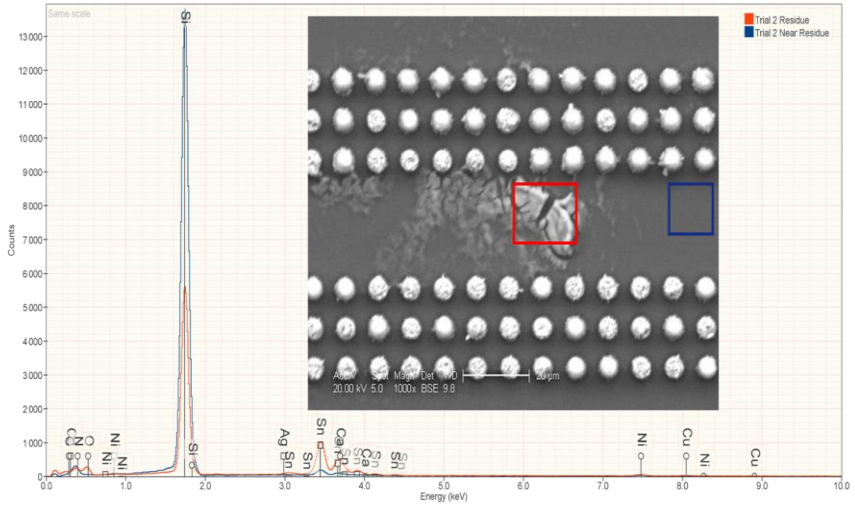


Visual Inspection

Residue observed

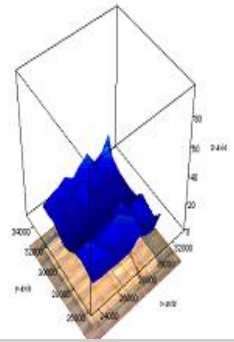


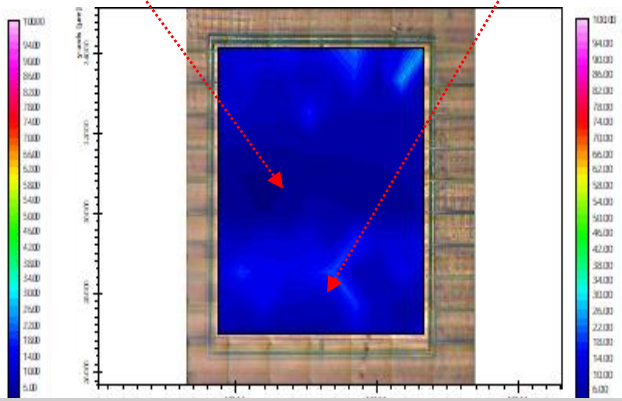




Dark blue color indicates no contamination

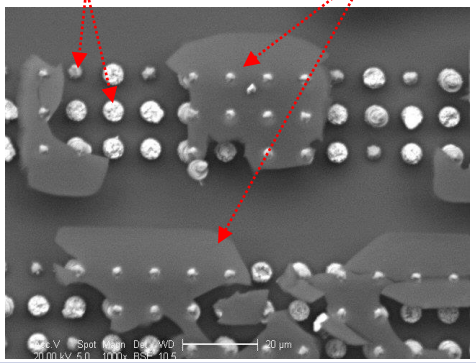
Lighter blue shade indicates slight presence of contamination





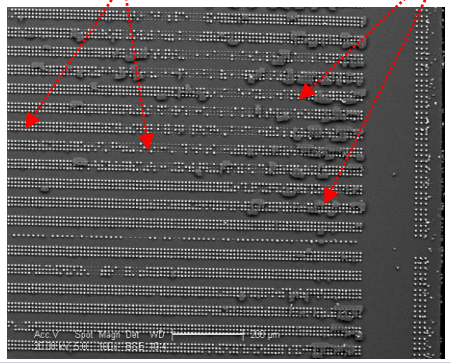
Solder bump broken at different depths

Substrate passivation



Solder bump broken at different depths

Substrate passivation



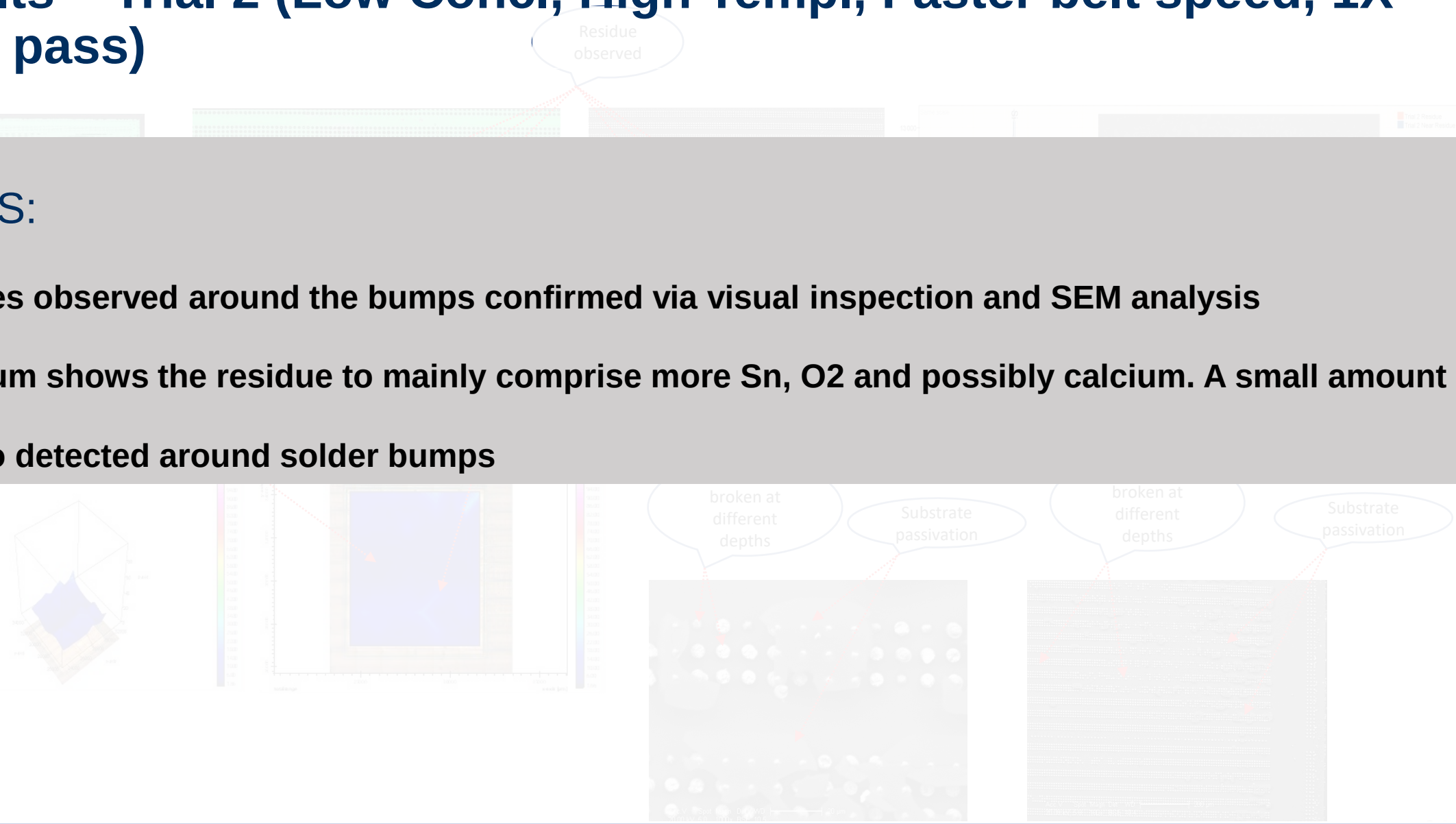
FTIR color mapping shows the presence of contamination: 3D plot (left) and 2D plot (right)


50.00µm

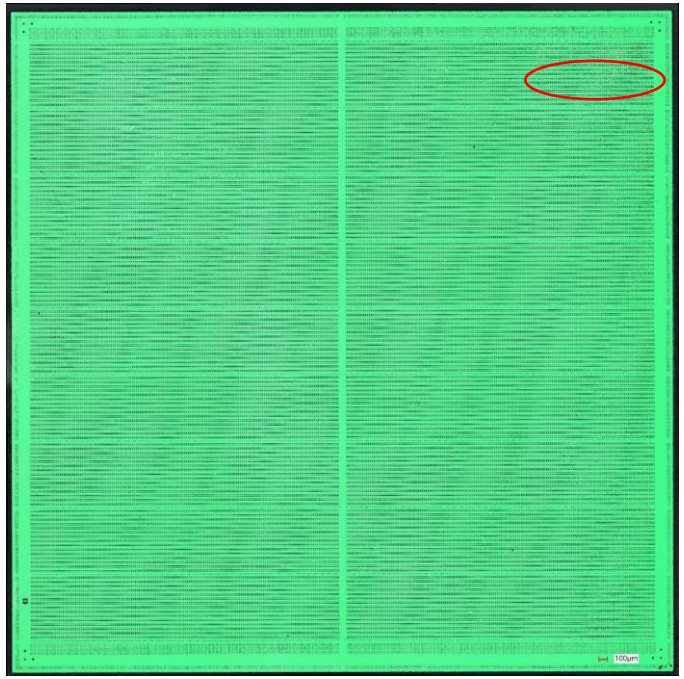
Results – Trial 2 (Low Conc., High Temp., Faster belt speed, 1X wash pass)

KEY POINTS:

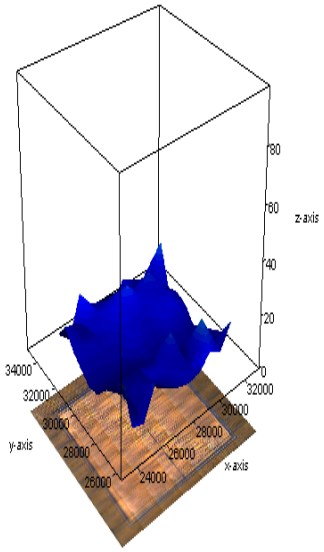
- **Flux residues observed around the bumps confirmed via visual inspection and SEM analysis**
- **EDS spectrum shows the residue to mainly comprise more Sn, O2 and possibly calcium. A small amount of Ni & Cu also detected around solder bumps**

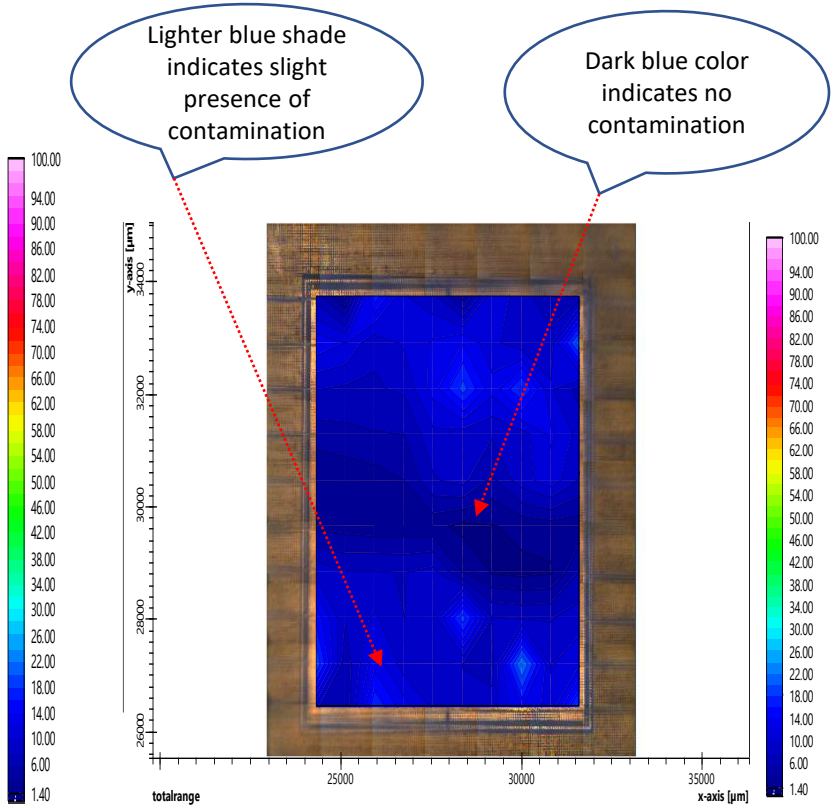


Results – Trial 3 (Low Conc., High Temp., Slower belt speed, 1X wash pass)



Visual Inspection



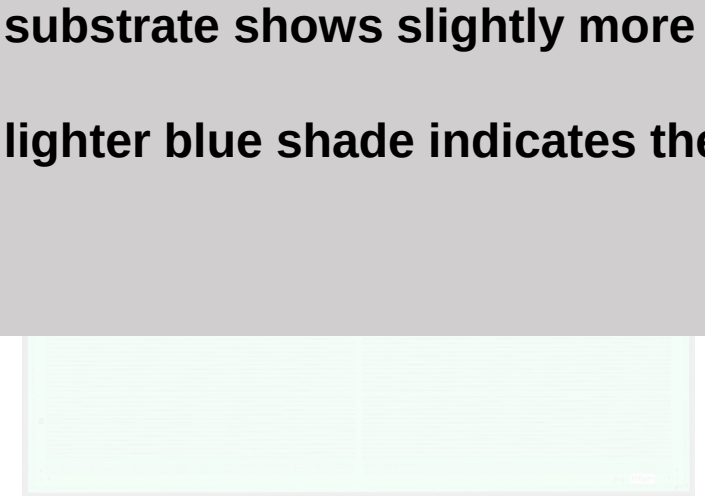


FTIR color mapping shows the slight presence of contamination: 3D plot (left) and 2D plot (right)

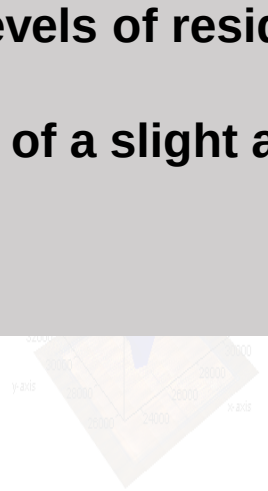
Results – Trial 3 (Low Conc., High Temp., Slower belt speed, 1X wash pass)

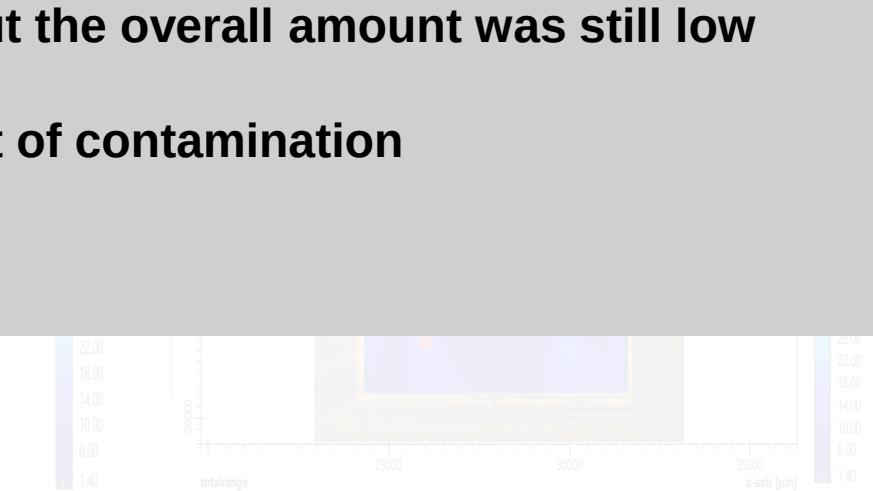
KEY POINTS:

- **The substrate shows slightly more elevated levels of residue, but the overall amount was still low**
- **The lighter blue shade indicates the presence of a slight amount of contamination**

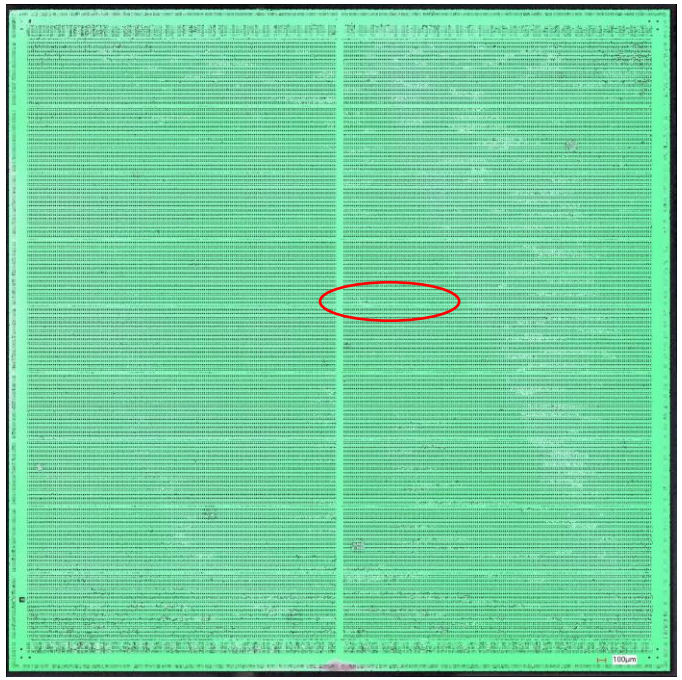


Visual Inspection

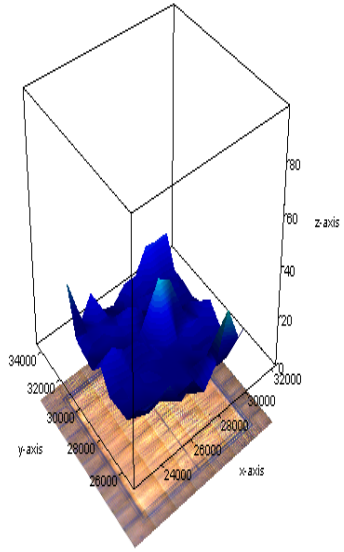


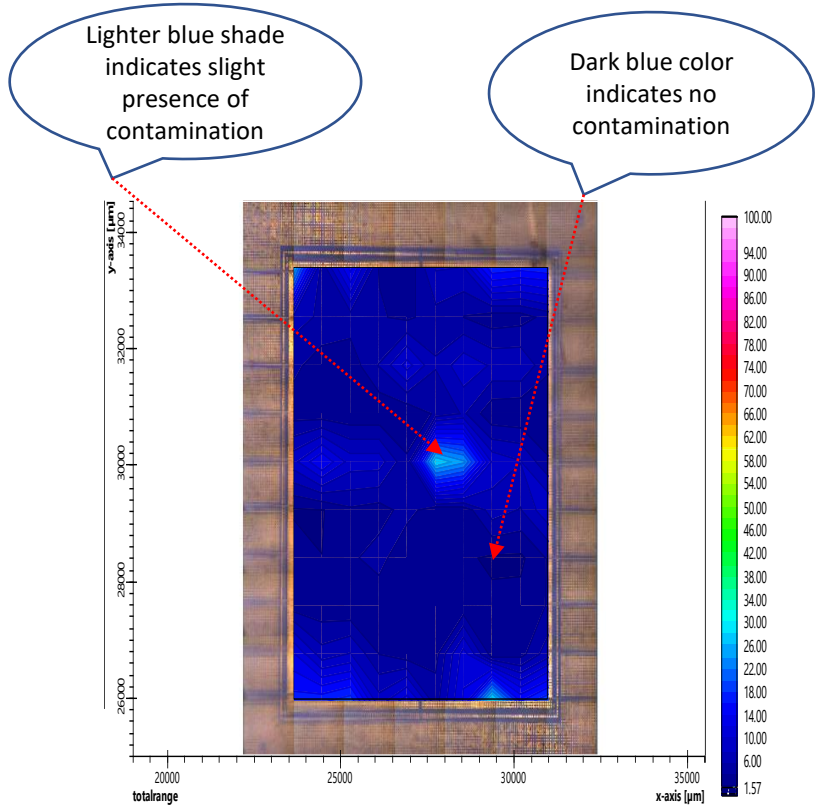


Results – Trial 4 (Low Conc., Low Temp., Slower belt speed, 1X wash pass)



Visual Inspection





FTIR color mapping shows the slight presence of contamination: 3D plot (left) and 2D plot (right)

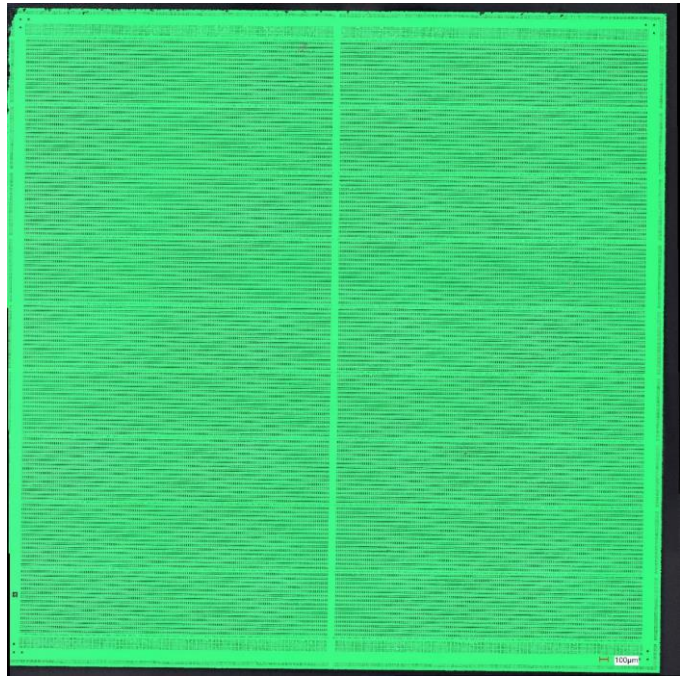
Results – Trial 4 (Low Conc., Low Temp., Slower belt speed, 1X wash pass)

KEY POINTS:

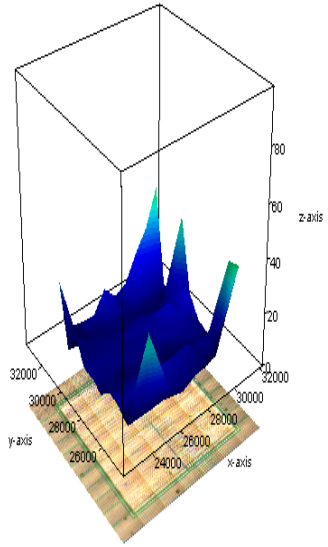
- **The substrate showed one area of more elevated amount of residues towards the center, indicated by light blue shade**
- **Overall, very minor amount of residues observed around the bumps**

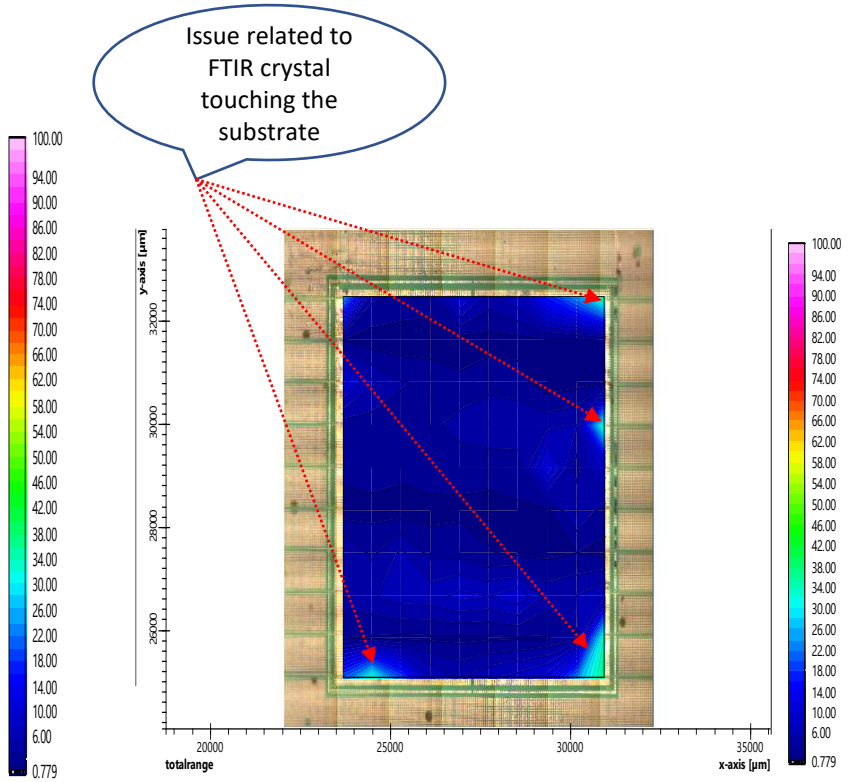
Visual Inspection

Results – Trial 5 (Low Conc., Low Temp., Faster belt speed, 2X wash pass)

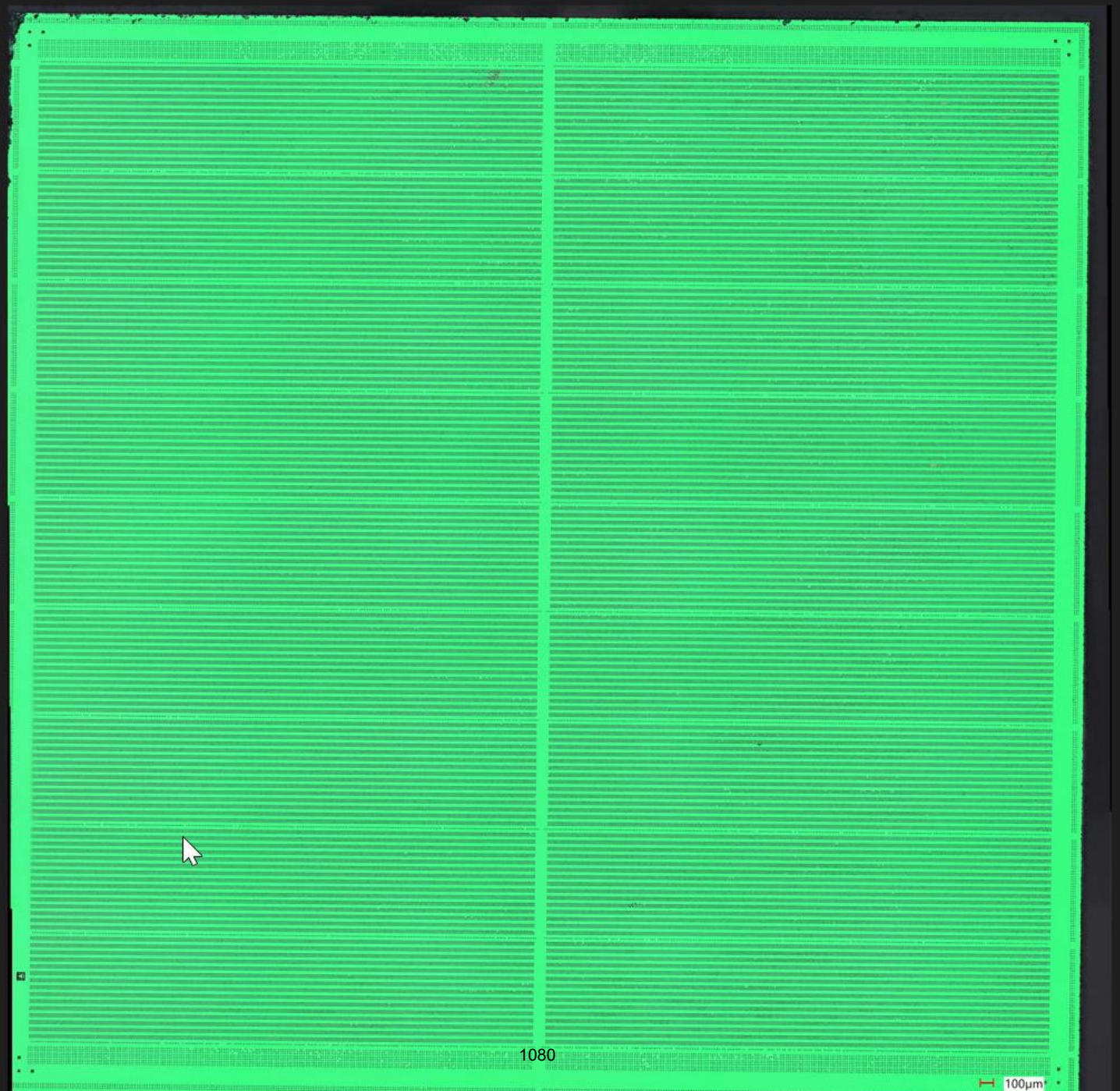


Visual Inspection





FTIR color mapping shows the residue to be fully removed: 3D plot (left) and 2D plot (right)


1080
100µm

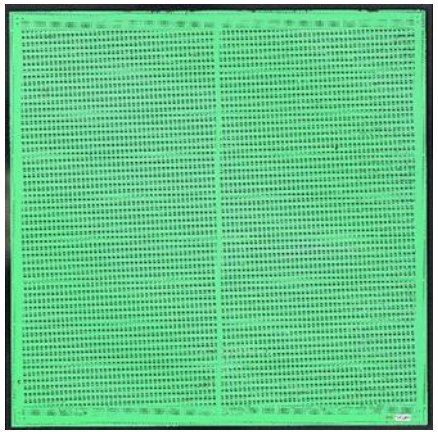
Results – Trial 5 (Low Conc., Low Temp., Faster belt speed, 2X wash pass)

KEY POINTS:

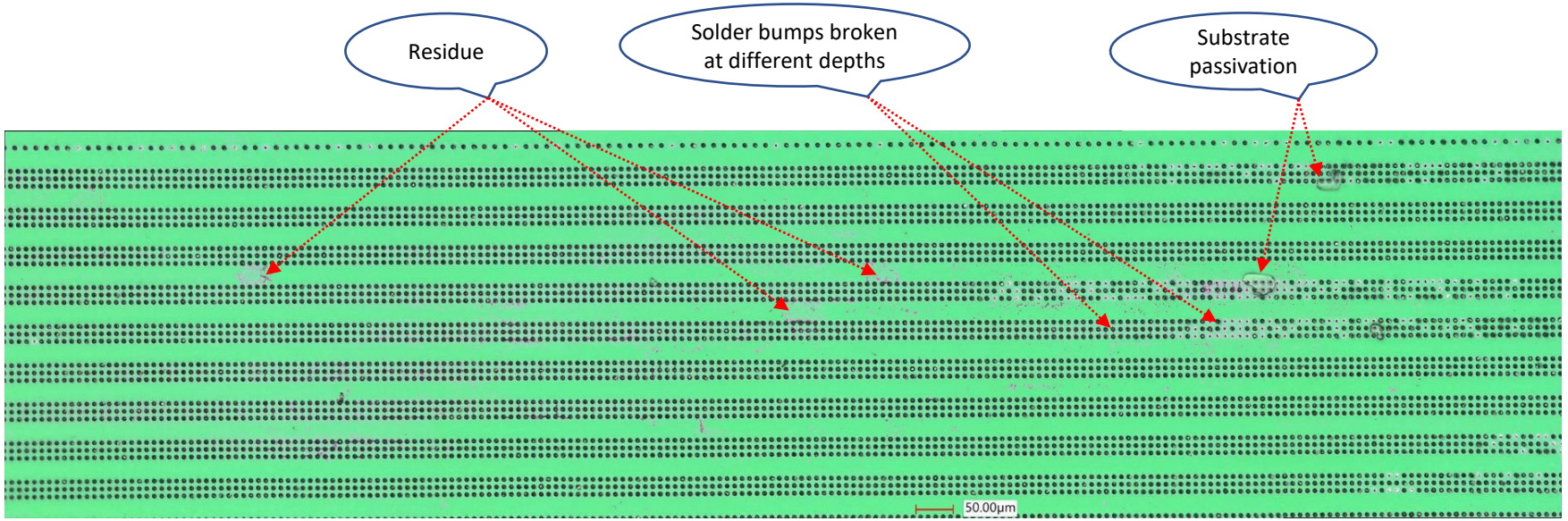
- **The cleaned substrate indicated presence of residues at the outer edges. On further analysis, it was found to be not flux but an issue related to FTIR crystals touching the substrate outside the area of interest**
  - **The green outer edges produce a different signal as compared to the area under focus**
- **The flux residues are fully removed around the solder bumps**

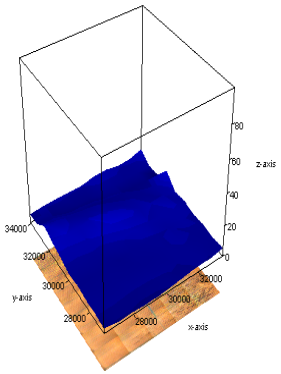
Visual Inspection

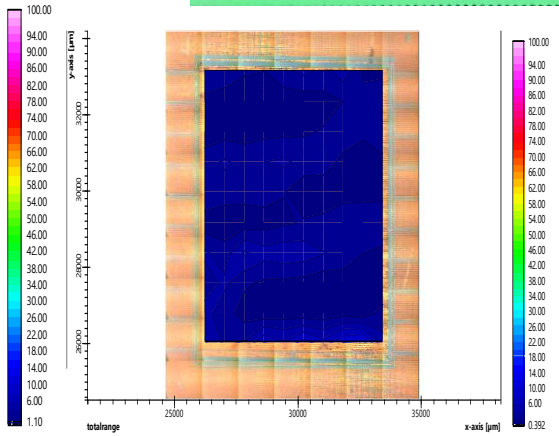
Results – Trial 6 (Current OSAT process settings, High Conc.)

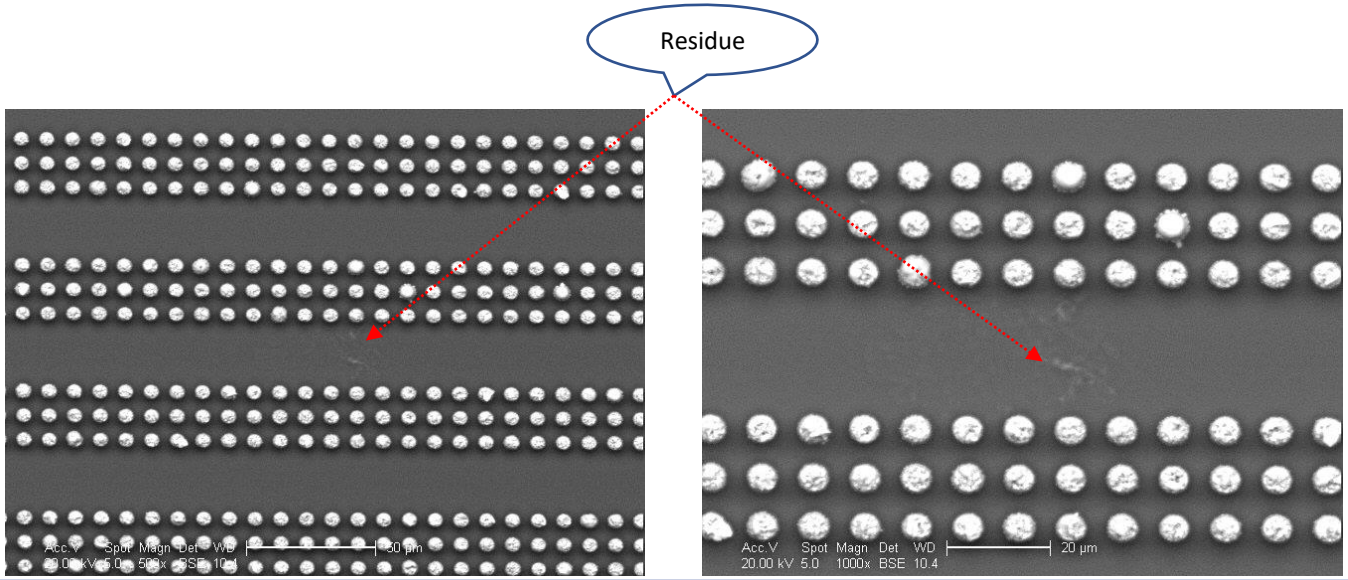


Visual Inspection

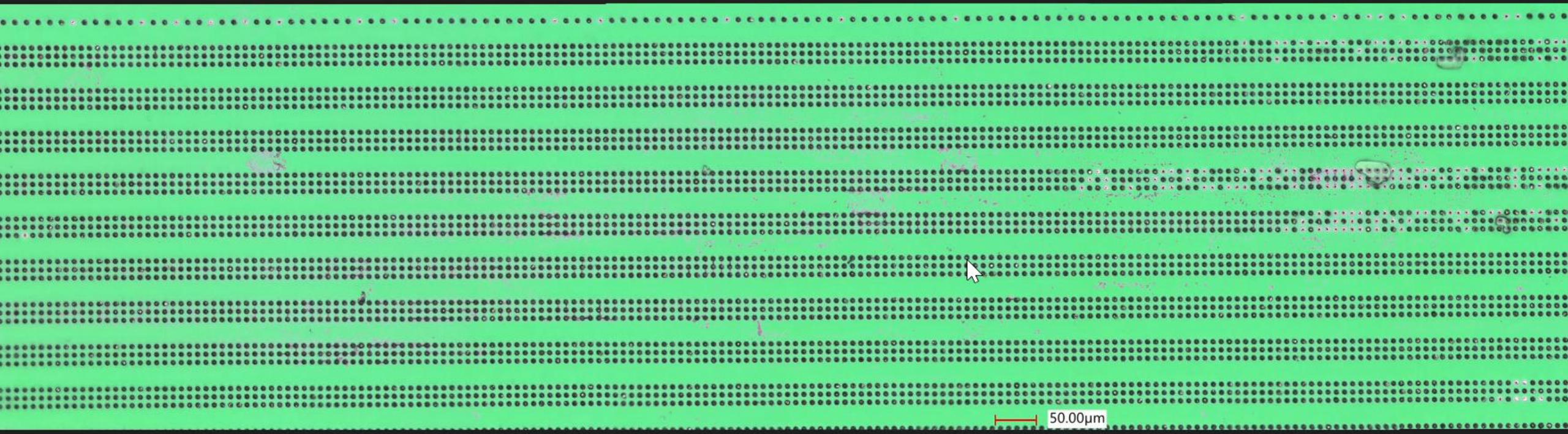








FTIR color mapping shows bulk residue to be fully removed: 3D plot (left) and 2D plot (right)

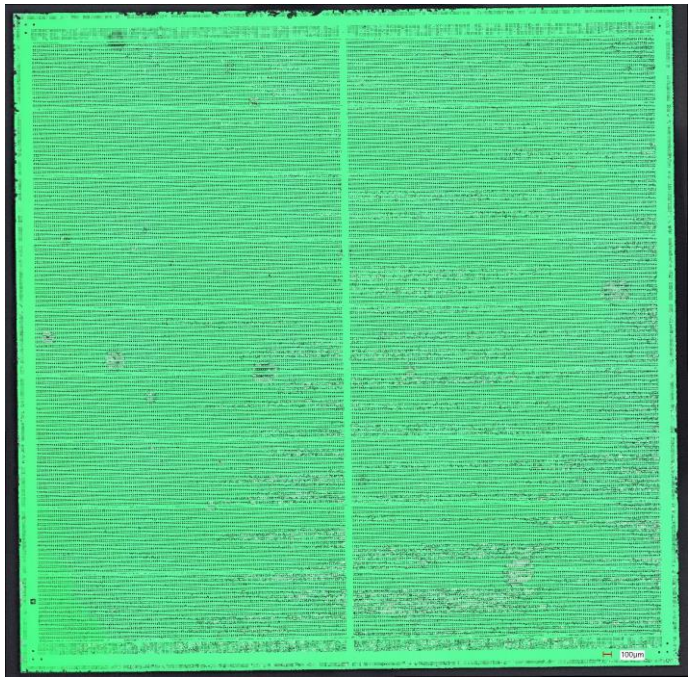

50.00µm

Results – Trial 6 (Current OSAT process settings, High Conc.)

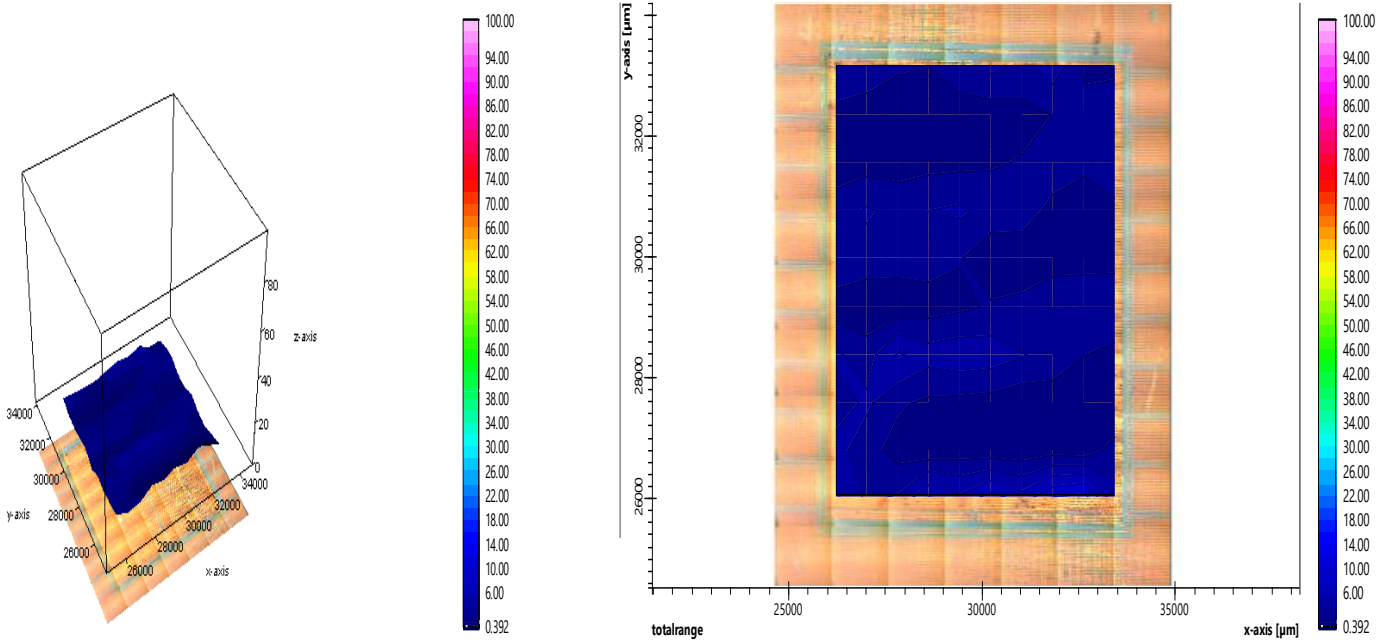
KEY POINTS:

- **Majority of flux residues removed around the solder bumps**
- **Trace level of residues visible on the substrate but was found to be too thin for analysis**

Results – Trial 7 (High Conc., High Temp., Faster belt speed, 1X wash pass)

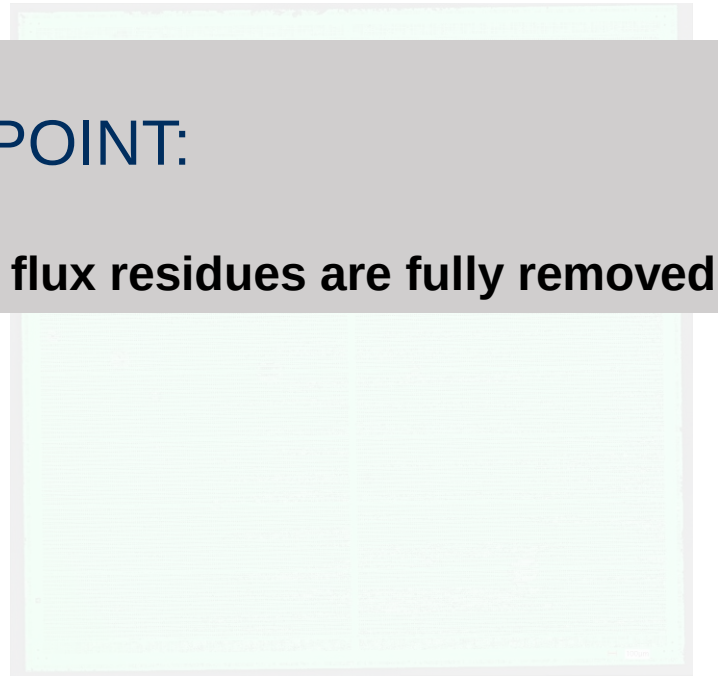


Visual Inspection

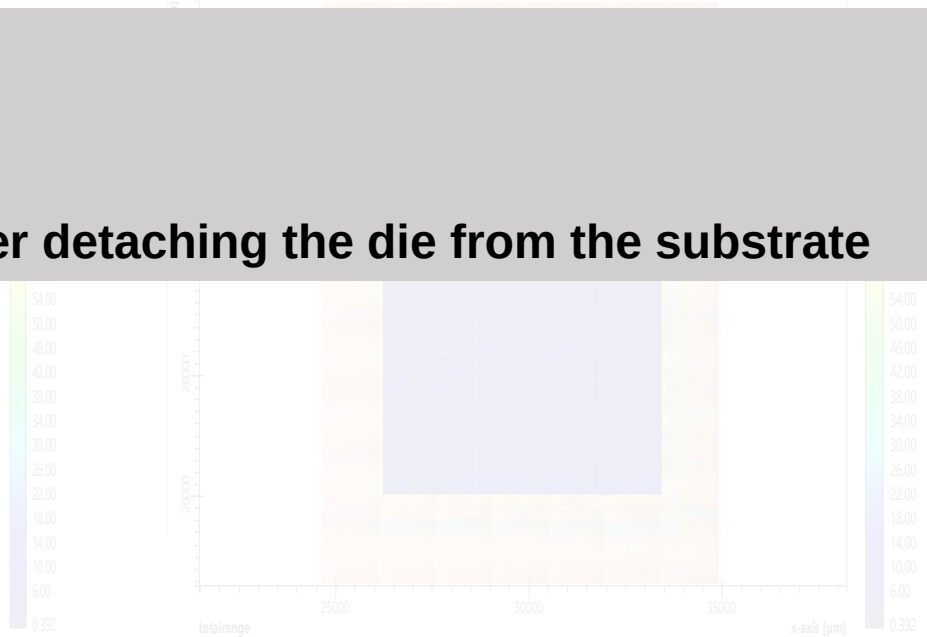


FTIR color mapping shows the residue to be fully removed: 3D plot (left) and 2D plot (right)

Results – Trial 7 (High Conc., High Temp., Faster belt speed, 1X wash pass)



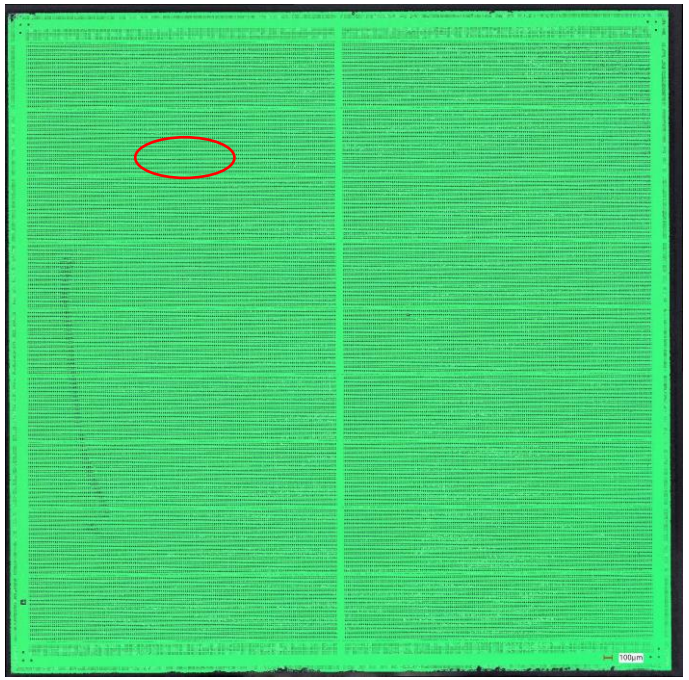
Visual Inspection



KEY POINT:

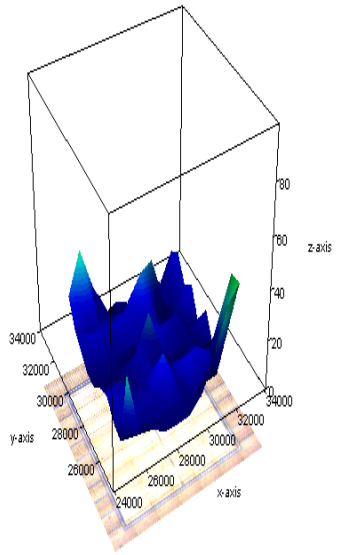
- **The flux residues are fully removed around the solder bumps after detaching the die from the substrate**

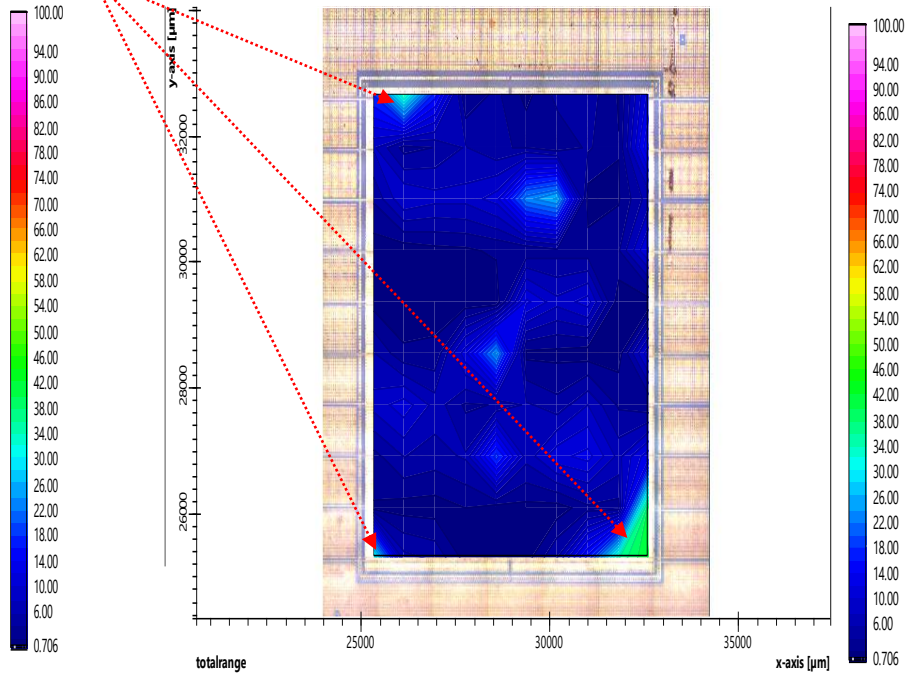
Results – Trial 8 (High Conc., High Temp., Slower belt speed, 1X wash pass)



Visual Inspection

Issue related to FTIR crystal touching the substrate





FTIR color mapping shows very minimal presence of residues: 3D plot (left) and 2D plot (right)

Results – Trial 8 (High Conc., High Temp., Slower belt speed, 1X wash pass)

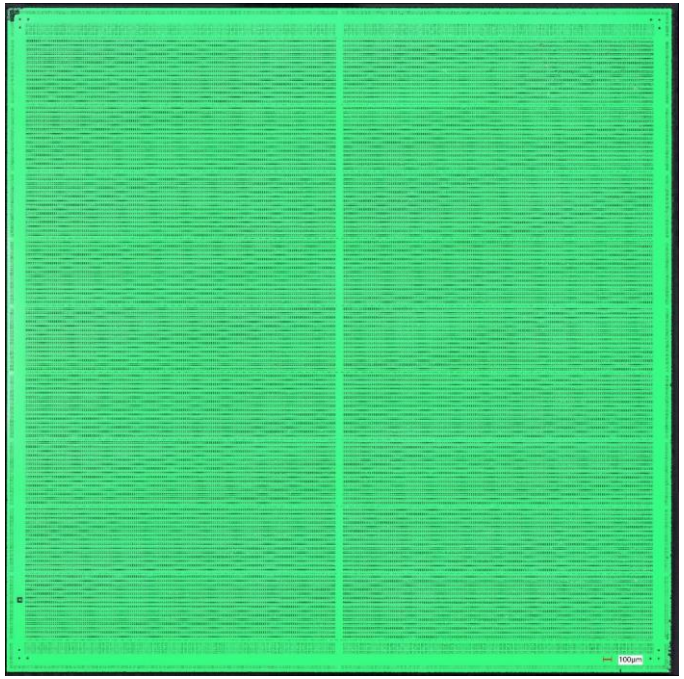
Issue related to FTIR crystal touching the

KEY POINTS:

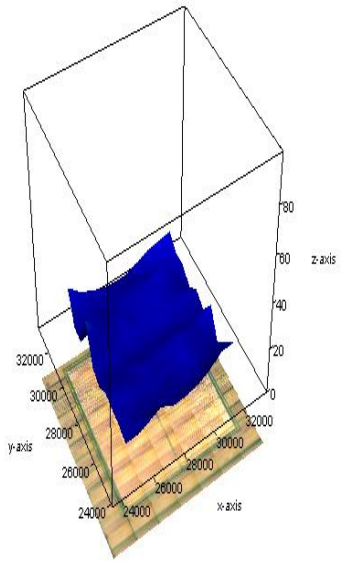
- **The cleaned substrate showed similar pattern to seen in Trial #5 with higher levels at the edges. These signals are not flux related**
- **Majority of flux residues were fully removed around the bumps after detaching the die off the substrate**

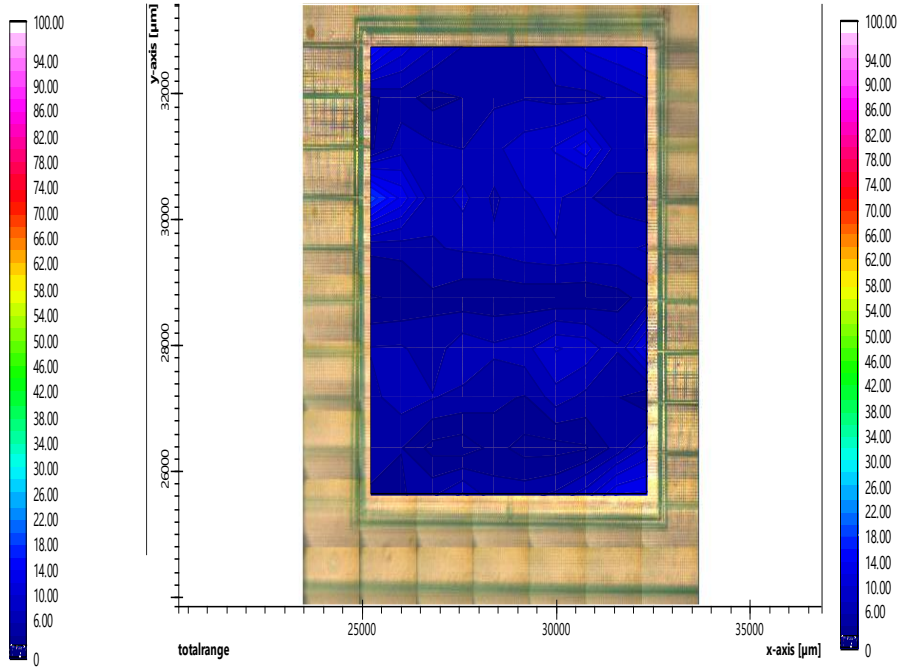
Visual Inspection

Results – Trial 9 (High Conc., Low Temp., Slower belt speed, 1X wash pass)



Visual Inspection





FTIR color mapping shows very low level of contamination: 3D plot (left) and 2D plot (right)

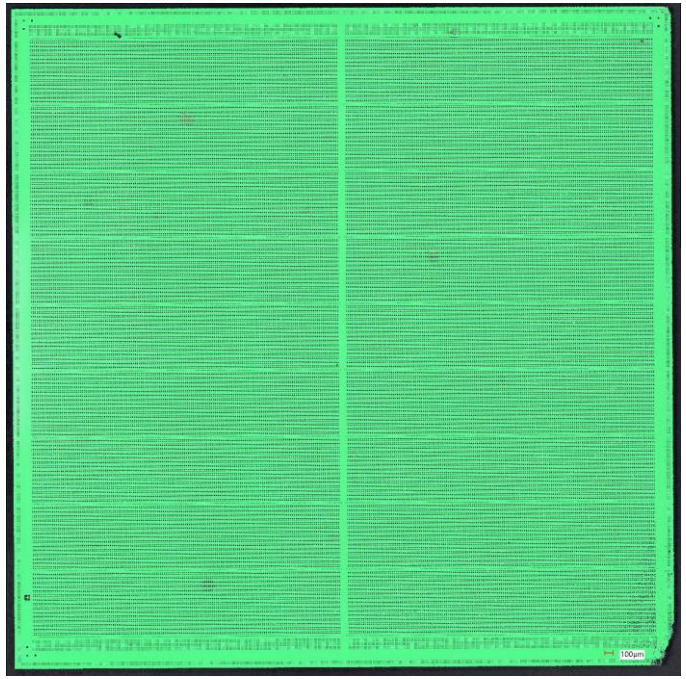
Results – Trial 9 (High Conc., Low Temp., Slower belt speed, 1X wash pass)

KEY POINT:

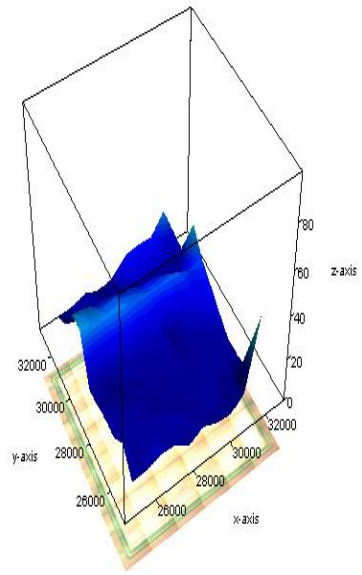
- **Flux residues were fully removed around the bumps after detaching the die from the substrate**

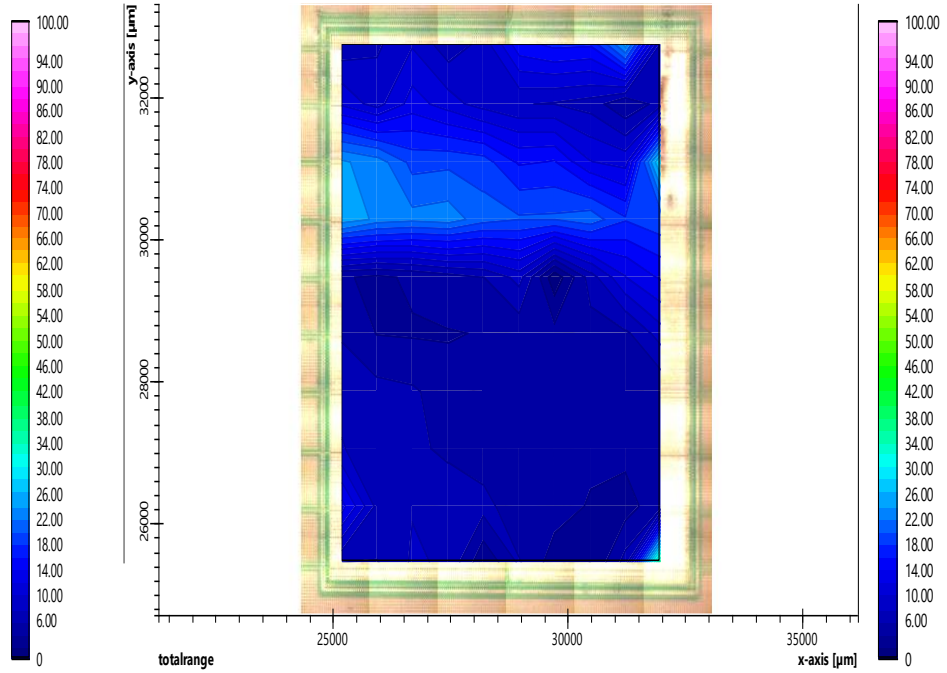
Visual Inspection

Results – Trial 10 (High Conc., Low Temp., Faster belt speed, 2X wash pass)



Visual Inspection





FTIR color mapping shows very low level of contamination: 3D plot (left) and 2D plot (right)

Results – Trial 10 (High Conc., Low Temp., Faster belt speed, 2X wash pass)

KEY POINT:

- **Very low level of residues visible around the bumps after detaching the die from the substrate**

Visual Inspection

FTIR Color Mapping Results (Via Integration Process)

- Total of 100 locations were analyzed and number obtained via integration of FTIR signal which was correlated to the color obtained for each of those locations.

Trial #	Average Rating	0-20 (Blue)	21-50 (Green)	51-70 (Yellow-	70+ (Red-pink)
Unclean	76.10117	0	4	8	88
1*	2.212134	96	4	0	0
2	8.376782	88	12	0	0
3	6.760311	94	6	0	0
4	8.034368	92	8	0	0
5	3.728978	98	2	0	0
6*	2.121061	98	2	0	0
7	2.782588	100	0	0	0
8	5.540677	94	6	0	0
9	7.886614	90	10	0	0
10	4.441255	95	5	0	0

NOTE: * represents current OSAT process settings

- Un-clean substrate showed high average (~ 76%) with 88/100 locations in 70+ region which represents red-colored region indicating increased contamination levels
- Trials #1 and #6 which represents current OSAT process settings had lower average (~ 2%) with 96-98/100 locations in 0-20 region which represents blue-colored region indicating very low contamination levels

Conclusions

- Mechanical, chemical, thermal energies and cleaning agent exposure time are significant factors when it comes to achieving a good cleaning process

- Significant challenges from cleaning perspective when it comes to advanced packaging especially when focusing on ultra-fine pitch devices (bump pitch down to 10µm & bump counts > 200K)

- Phase II study confirmed that low concentration aqueous cleaning agent was successfully able to remove lead-free water-soluble tacky flux residues from underneath ultra-fine pitch CoW packages.
  - Cleaning results significantly out-performed the current pH alkaline chemistry utilized at Global OSAT company

Conclusions

- Based on the cleaning trials performed, the best results were achieved using the settings shown in Trials #1, #5, #6, #7 and #10
  - At Low Concentration Levels:
    - Wash Temperature was not a factor
    - 2X wash passes required
  - At High Concentration Levels:
    - Wash Temperature was not a factor
    - 1X wash pass is possible (Trial #7)

Trial #	Concentration (%)	Wash Temp (°C)	Conveyor Belt Speed (m/min)	No. of Passes	Overall Remarks
1*	Low	High	Faster	2X	**No residues**
2	Low	High	Faster	1X	Residues visible
3	Low	High	Slower	1X	Slight residues visible
4	Low	Low	Slower	1X	Slight residues visible
5	Low	Low	Faster	2X	**No residues**
6*	High	High	Faster	2X	Trace level of residues
7	High	High	Faster	1X	**No residues**
8	High	High	Slower	1X	Slight residues visible
9	High	Low	Slower	1X	Slight residues visible
10	High	Low	Faster	2X	**No residues**

- Additional CoW packages were cleaned at OSAT facility and passed the reliability testing (HAST, uHAST & THB) as per JEDEC standards

Thank You!

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ZESTRON
High Precision Cleaning