Impact of Process Control in Pb-Free to SnPb Reballing Techniques

Part 1: Control of Thermal Exposure

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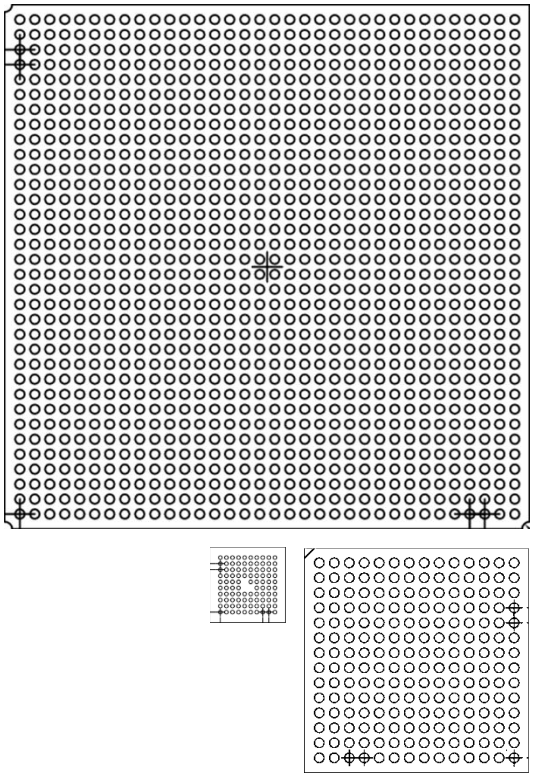
SMTA ISCR 2014

Reballing Process Controls

- Five reballers employing distinct techniques were audited during reballing of ball grid arrays
  - Reballers identified as A, B, C, D, & E
- This presentation compares observed differences in
  - Reballing techniques
  - Process control of thermal exposure
  - Resulting solder joints, including appearance of intermetallic compound (IMC)

Test Vehicle Selection

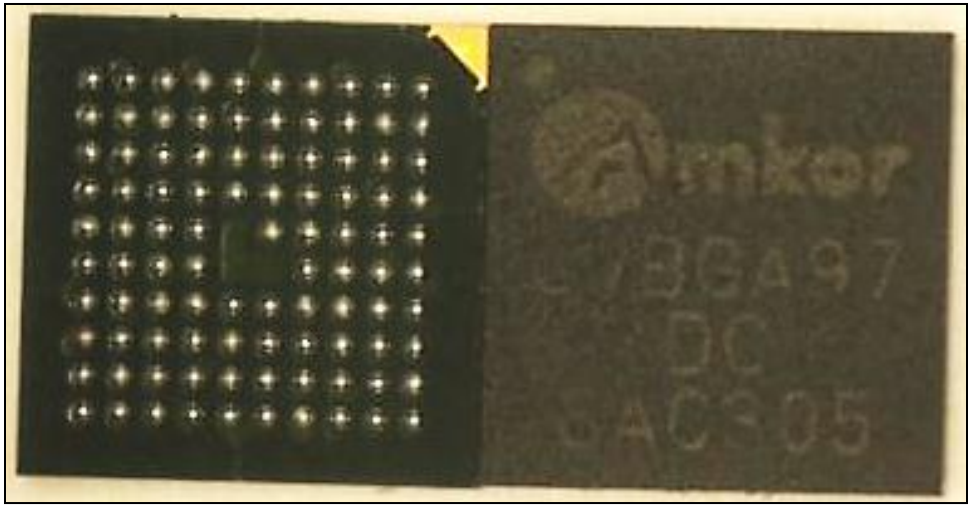
- Two devices which each presented a unique challenge to reballers
  - Fine pitch, low mass
  - Large plastic package



- Third component to study the impact of reballing stresses on 1st level interconnects[1]
  - Flip chip

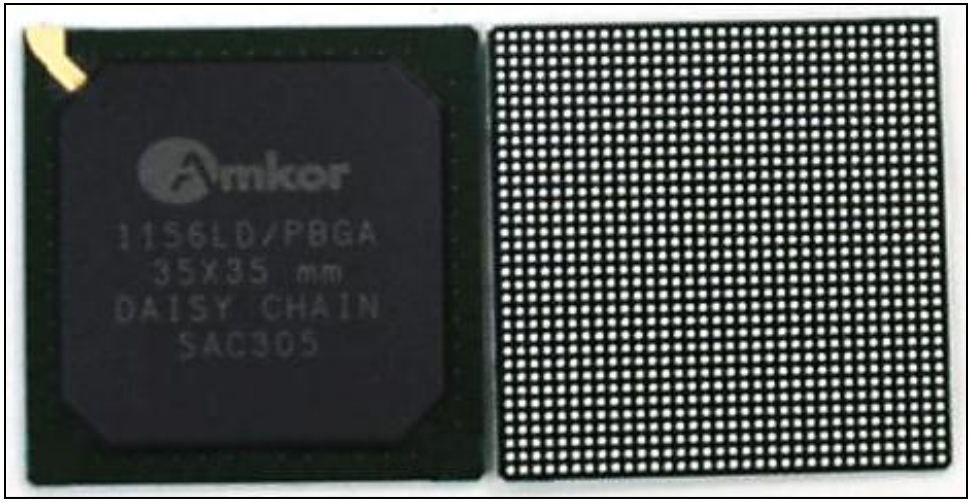
[1]J. Arnold et al, “Impact of Reprocessing Technique on First Level Interconnects of Pb-Free to SnPb Reballed Area Array Flip Chip Devices,” *iMAPs Device Packaging Conference*, 2014.

Test Vehicle: Dummy CSP



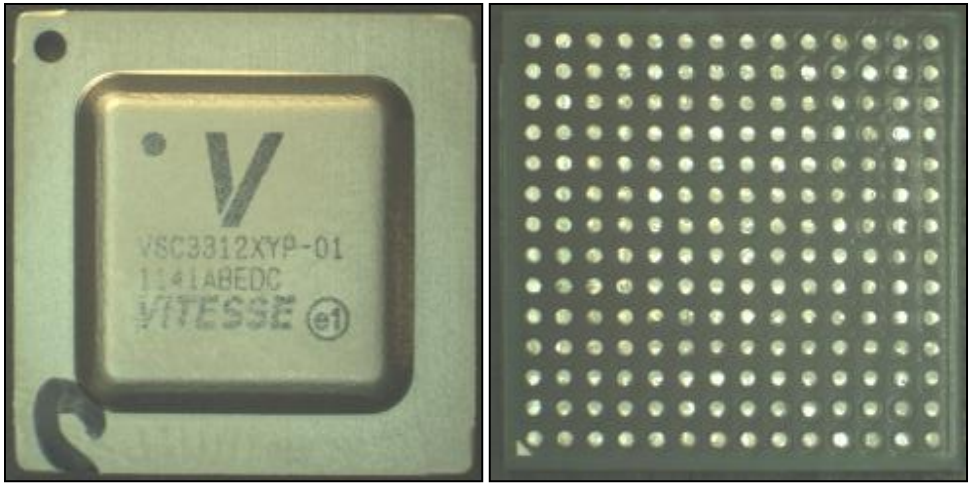
- Fine pitch, low mass CSP
  - 97 I/O, 0.4mm pitch
  - 5mm square package, 3.2mm die
- Demands precise tooling
- Requires care in handling

Test Vehicle: Dummy BGA



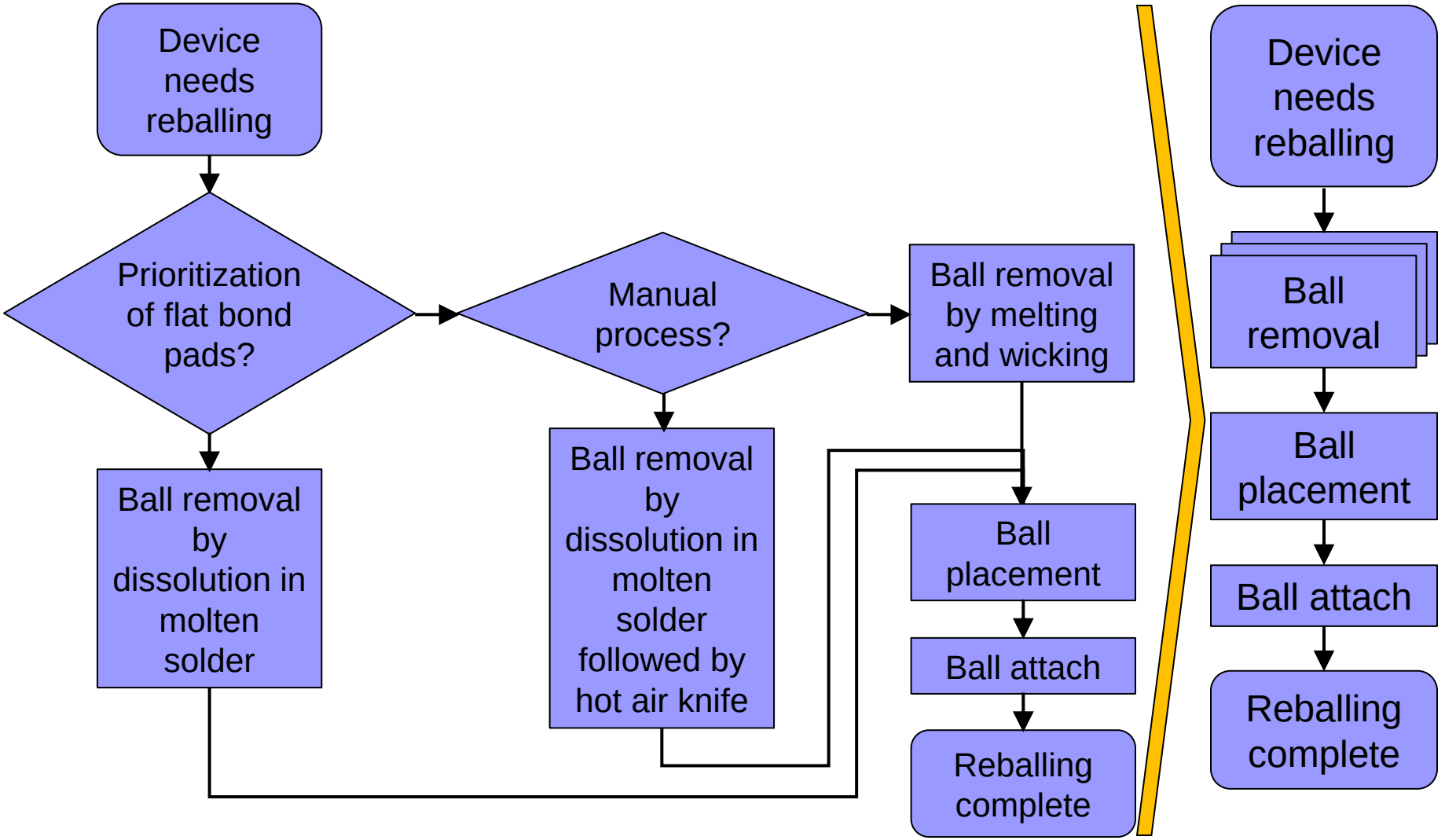
- Large plastic BGA
  - 1156 I/O, 1.0mm pitch
  - 35mm square package, 15.2mm die
- Susceptible to warpage

Test Vehicle: Active Flip Chip

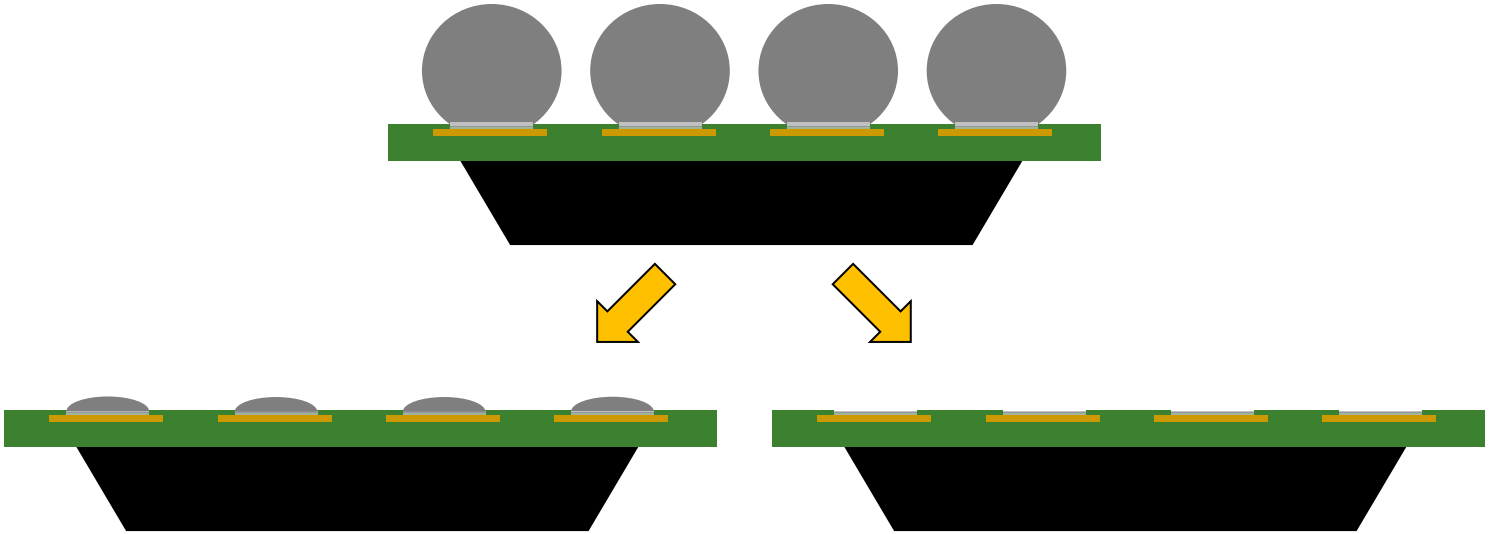


- Vitesse VSC3312 crosspoint switch
  - 196 I/O, 1.0mm pitch
  - 15mm square package, 3mm die
- Appearance of bond pads following ball removal

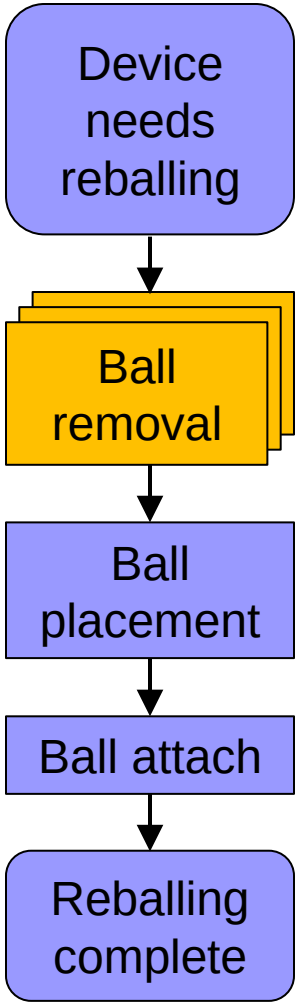
Reballing Process Flow



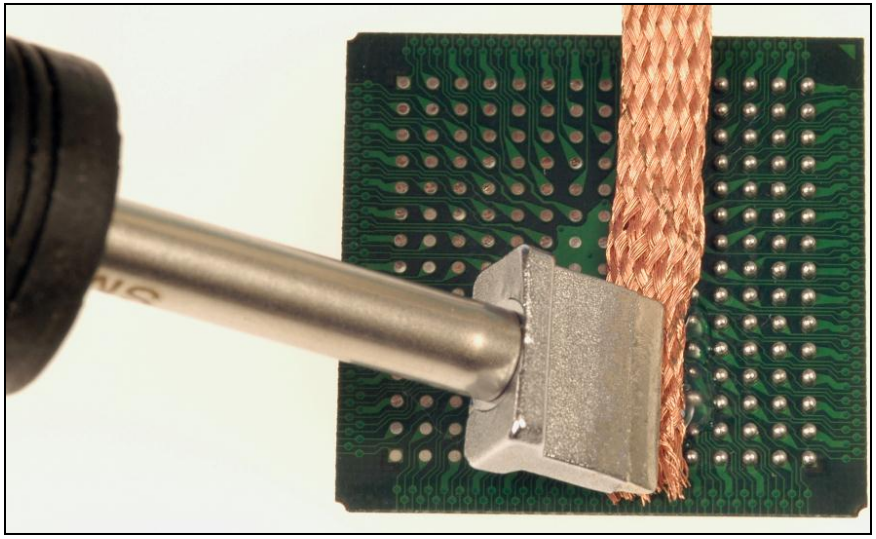
Ball Removal and Bond Pads



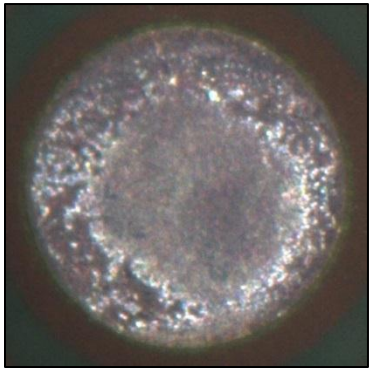
- Solder pads with domed solder coating
  - Reballers C & E
- Solder pads dressed flat
  - Reballers A, B, & D



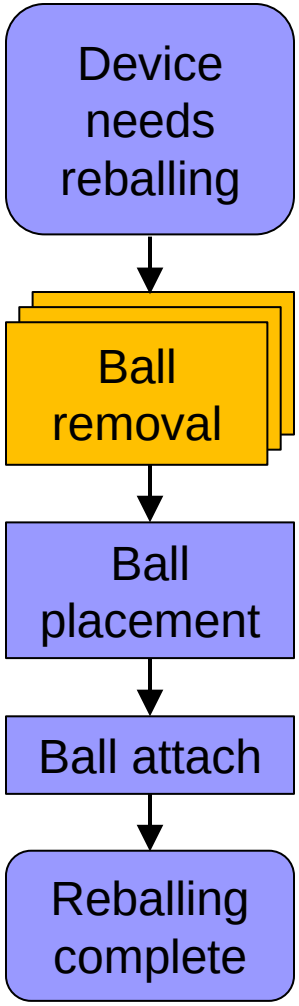
Ball Removal Techniques: Melting and Wicking



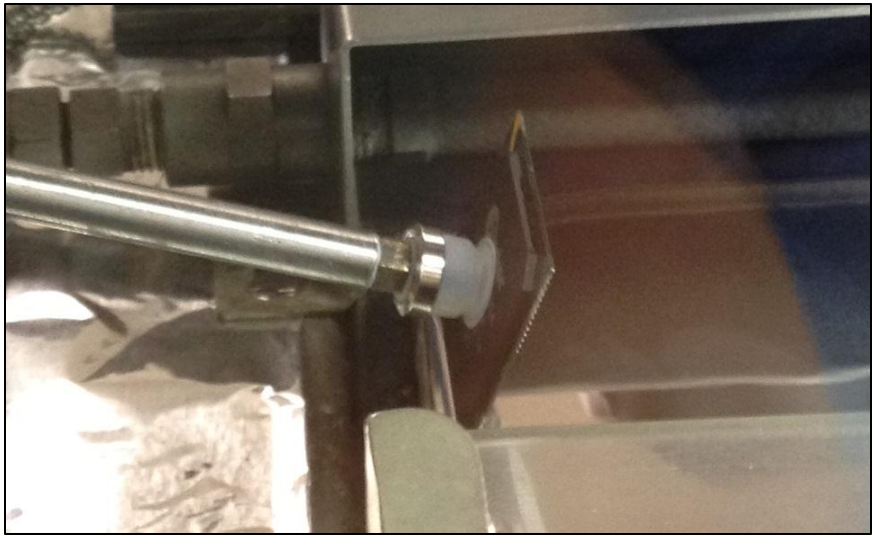
- Manual procedure
  - Balls melted with an iron
  - Liquid solder absorbed with fluxed wick



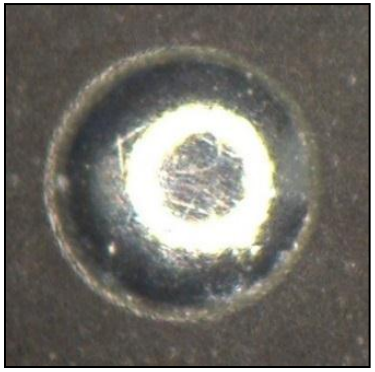
- 1 or 2 passes with the iron
- Results in a flat pad
- Used by Reballers B & D



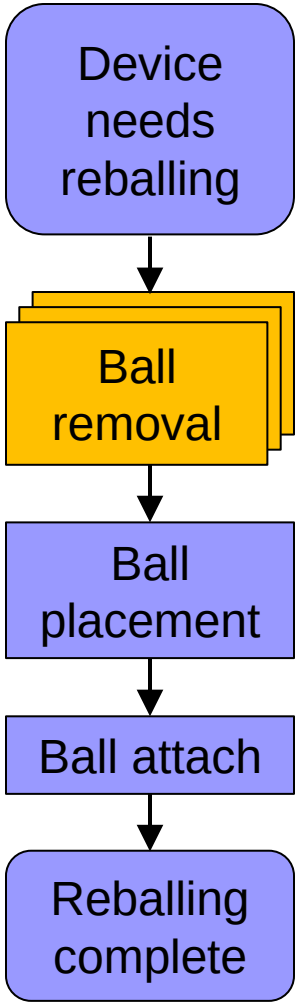
Ball Removal Techniques: Dissolution in Molten Solder



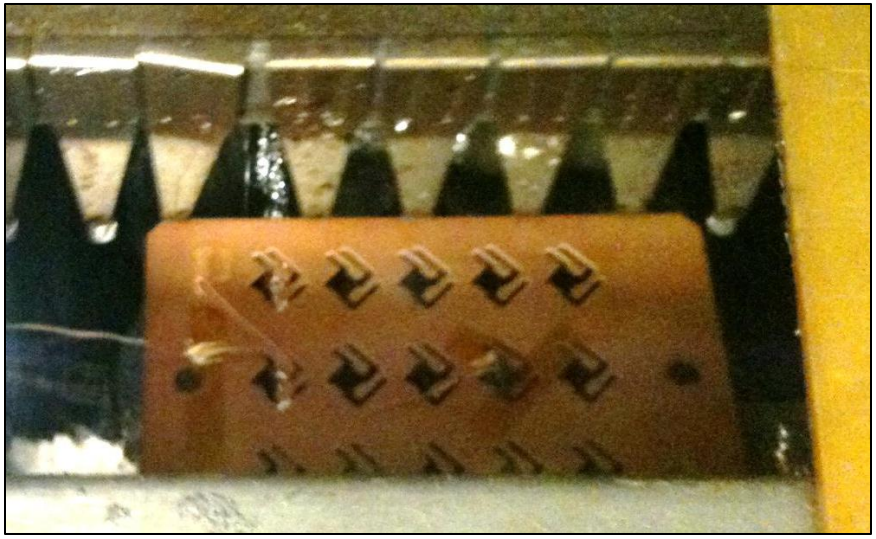
- Automated procedure
  - SAC305 balls melted off package by contact with SnPb fountain



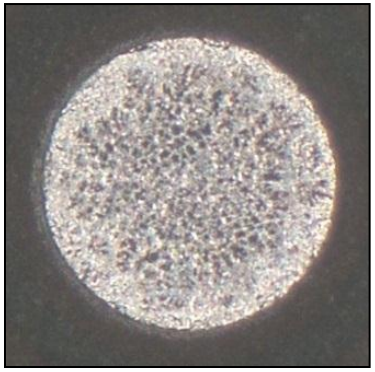
- Component contacts molten solder at least twice
- Results in a domed pad
- Used by Reballers C & E



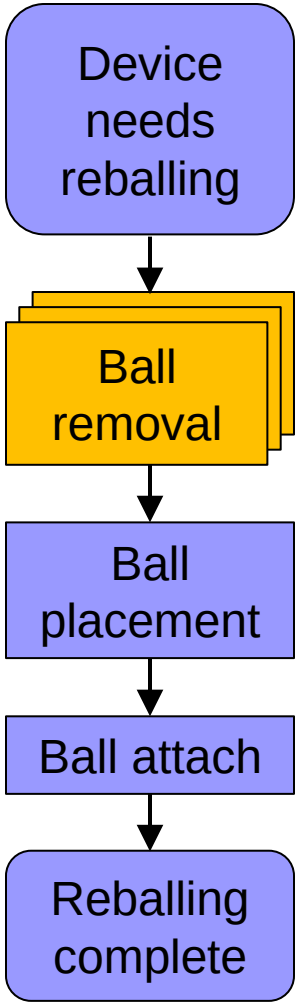
Ball Removal Techniques: Dissolution in Molten Solder'



- Automated procedure
  - SAC305 balls melted off package by contact with SnPb wave

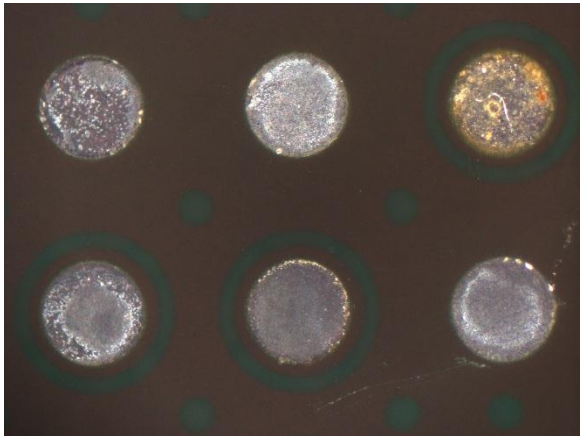


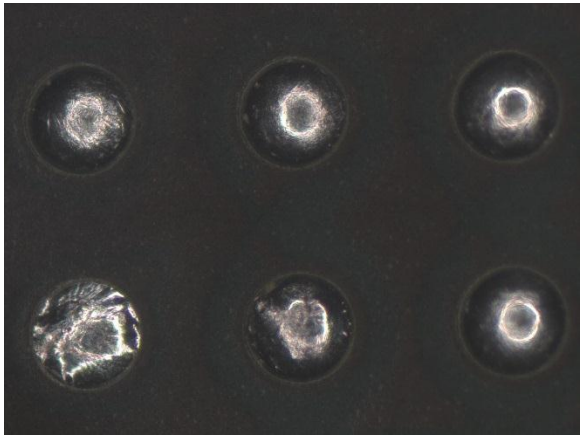
- Additional thermal excursion
  - Hot air knife
- Results in a flat pad
- Reballer A



Pad Appearance

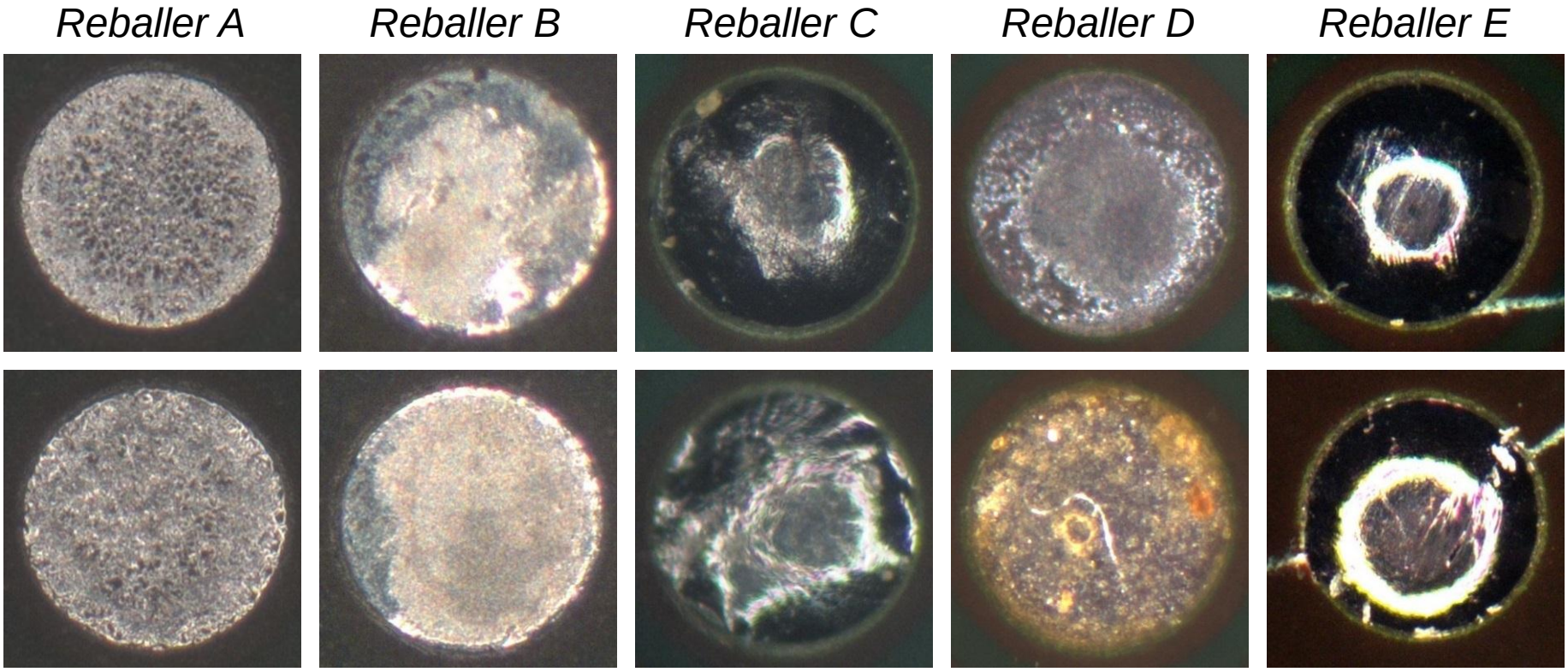
- Flip chips had balls removed
  - Reflowed to simulate ball attach
  - No new spheres placed
- Allowed for inspection of prepared pads
  - Flat vs domed
  - Residual solder
  - Symmetry and regularity
  - Contamination (flux residue)
  - Damage to package





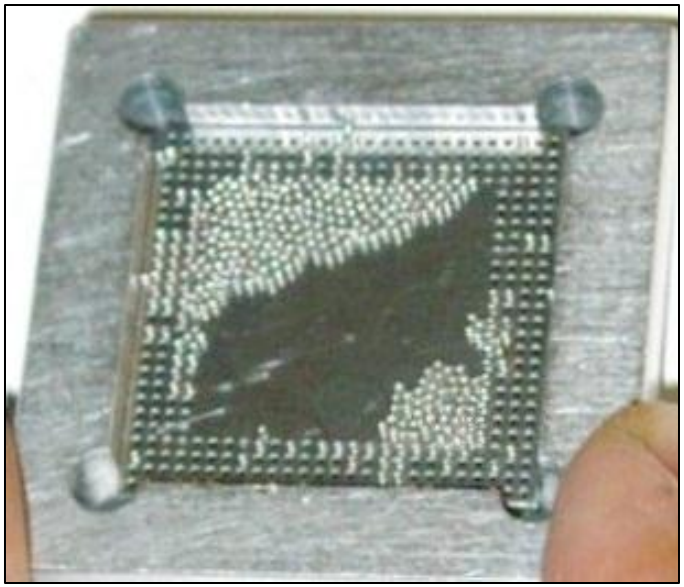
Pad Appearance

- Reballer A produces the most uniform pads

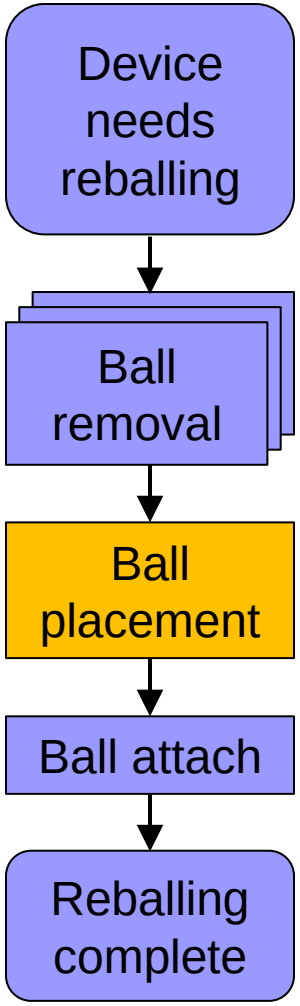


Ball Placement and Attachment

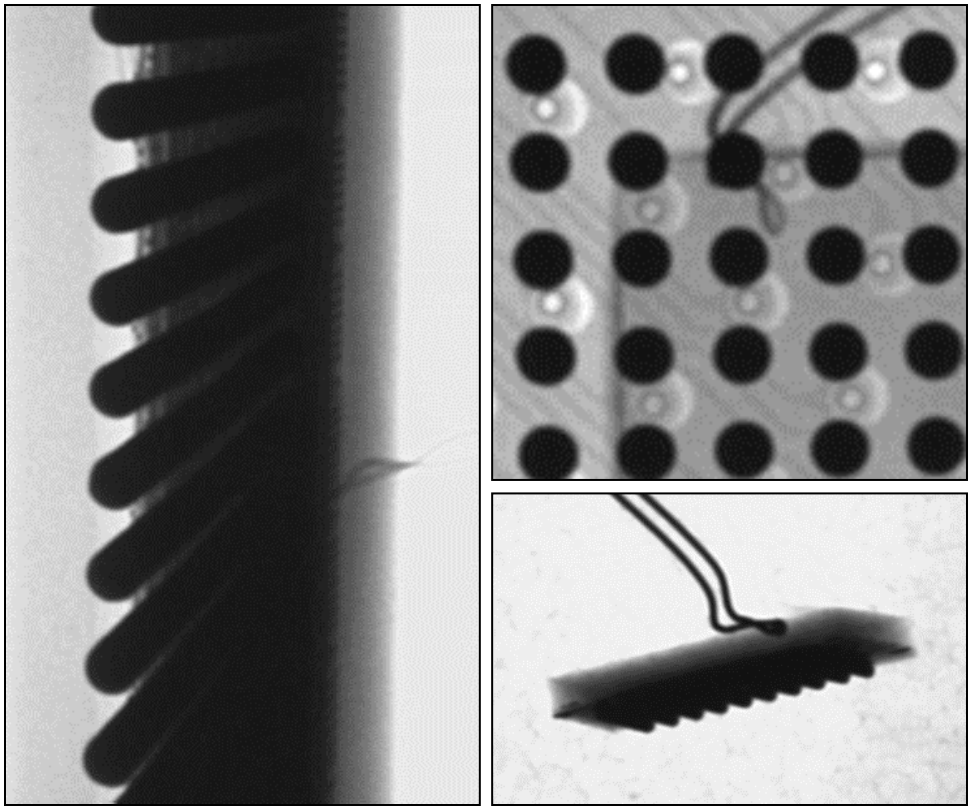
- Ball placement techniques and tooling are widely considered trade secrets
- All reballers surveyed employed stencils to align new solder spheres with dressed pads



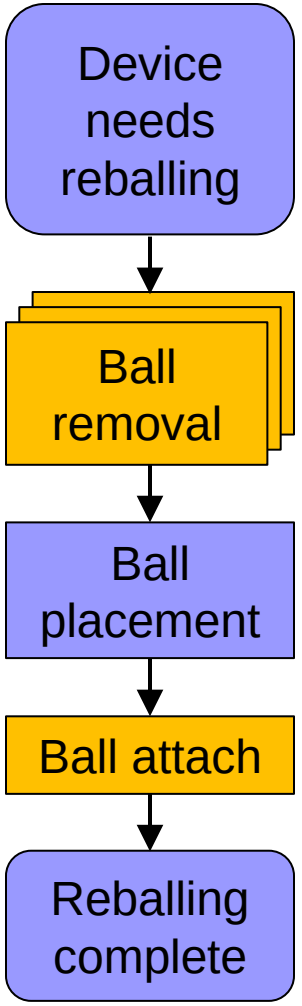
Generic stencil and fixture



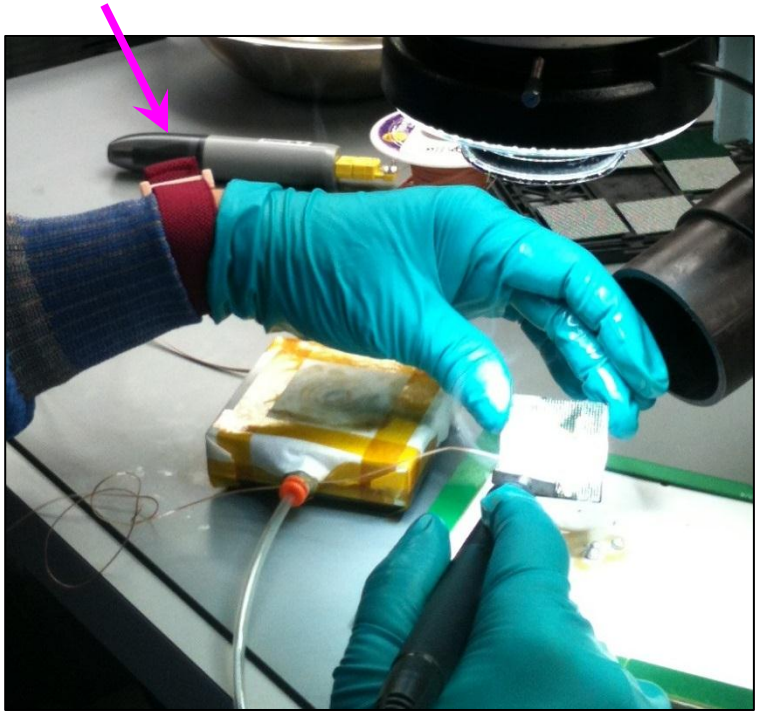
Thermal Monitoring

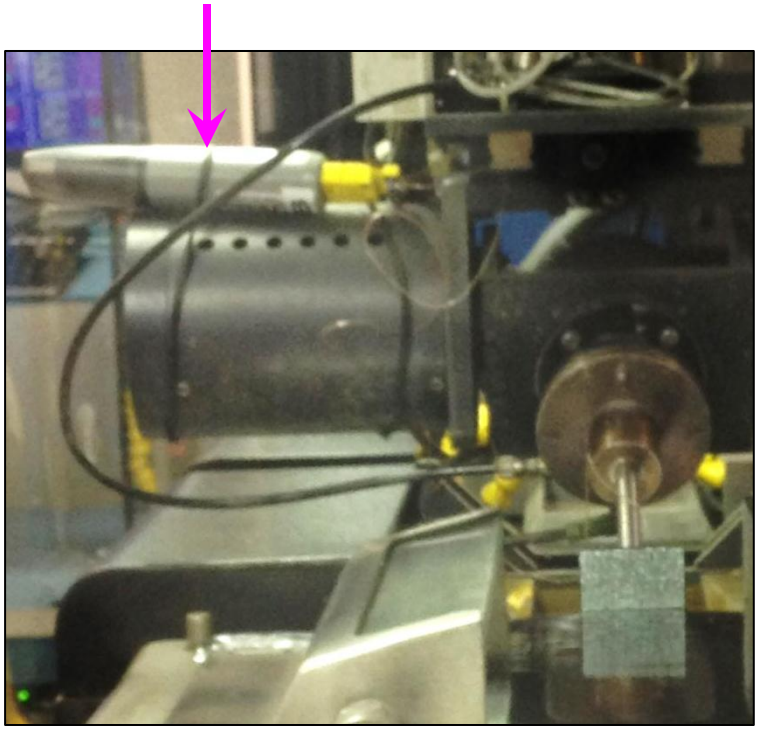


- Thermal monitoring during reballing processes
  - Thermo-couples epoxied on die



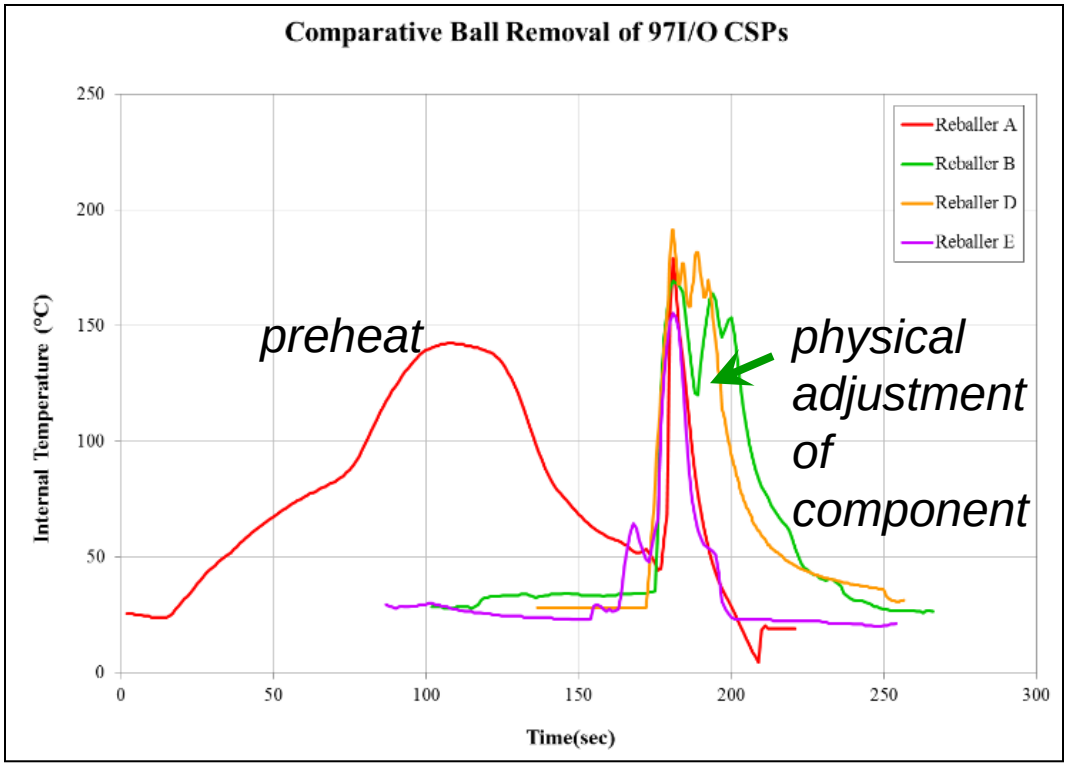
Thermal Monitoring



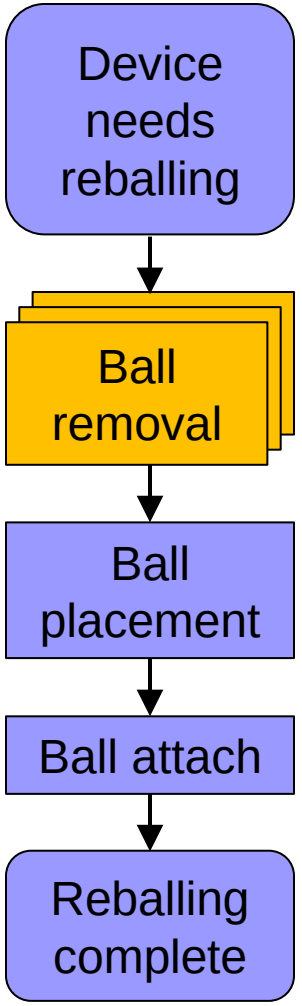


- Battery powered dataloggers
  - Monitoring compatible with most techniques

Thermal Exposure During Ball Removal



- Procedural differences visible in thermal exposure during ball removal

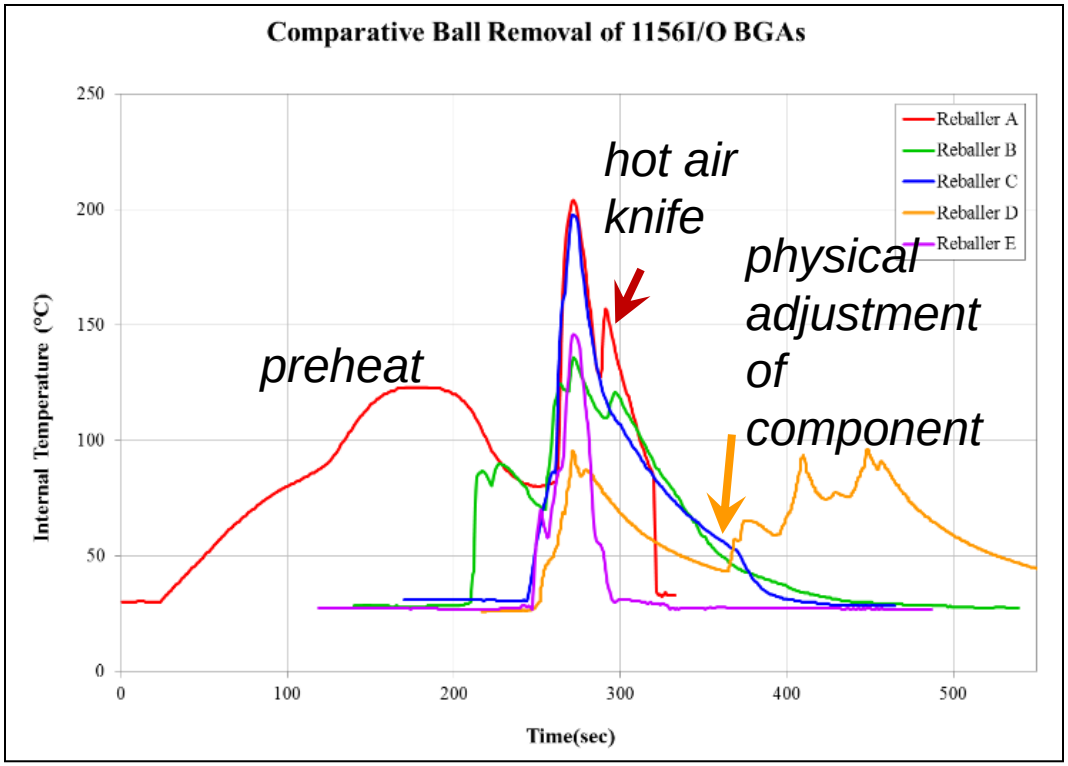


Thermal Exposure During Ball Removal (CSPs)

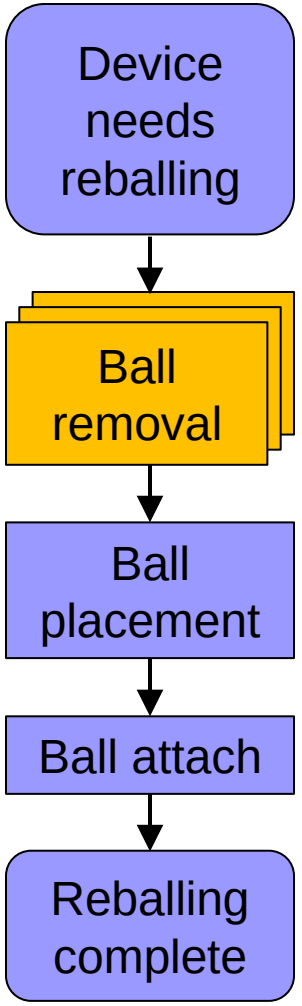
	Peak Temperature (°C)	Time above 80% T_L (sec)	Highest Ramp Rate (°C/sec)
Reballer A	179	3	33.5
Reballer B	170	17	22.3
Reballer C	N/A		
Reballer D	191	17	18.6
Reballer E	156	4	15.7

- Ball removal exposes small packages to thermal shock (>15°C/min or 0.25°C/sec)

Thermal Exposure During Ball Removal



- Procedural differences visible in thermal exposure during removal

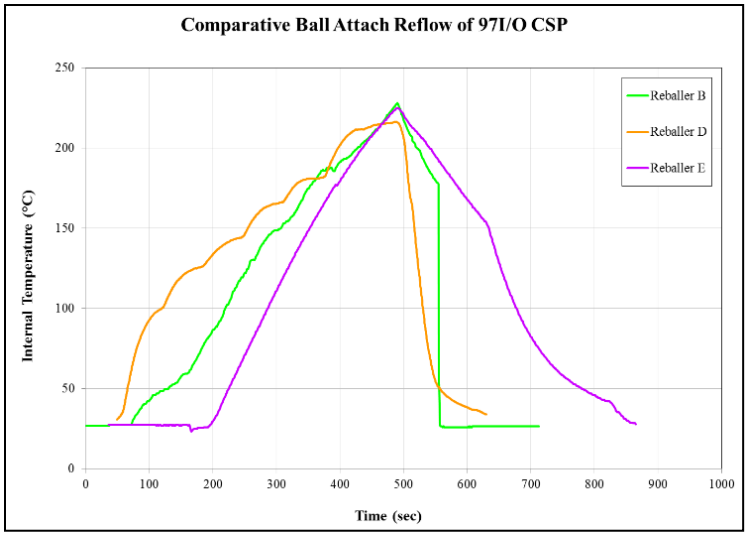


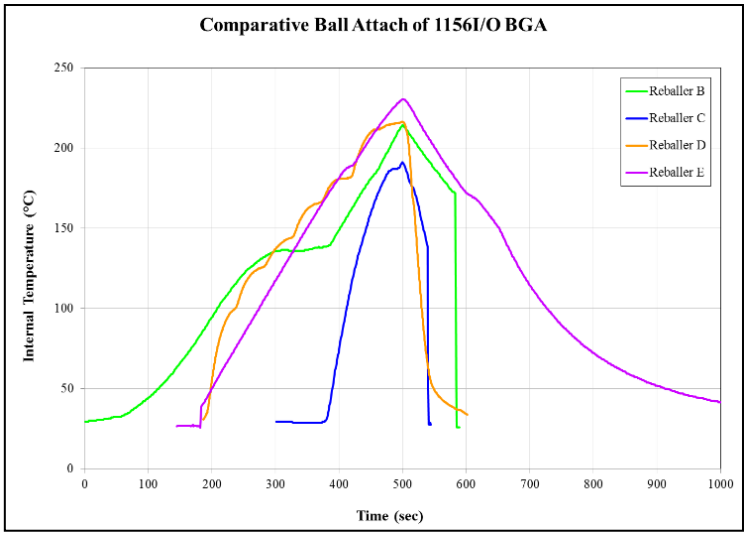
Thermal Exposure During Ball Removal (BGAs)

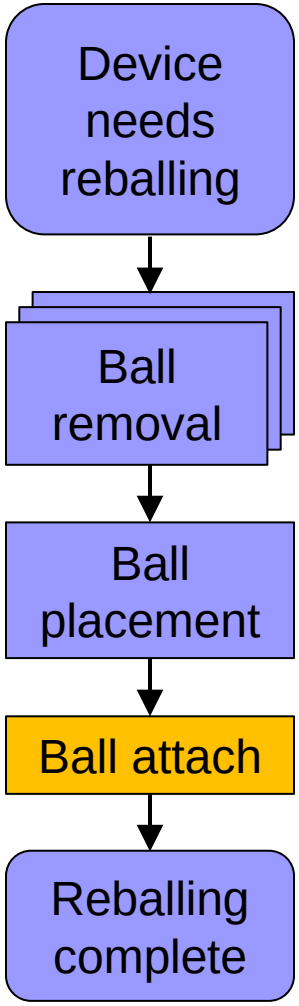
	Peak Temperature (°C)	Time above 80% T_L (sec)	Highest Ramp Rate (°C/sec)
Reballer A	204	24	13.4
Reballer B	136	0	11.2
Reballer C	198	19	18.1
Reballer D	96	0	5.4
Reballer E	146	1	8.4

- Ball removal exposes large packages to high ramp rates, but not as extreme as for small packages (15°C/sec - 35°C/sec)

Thermal Exposure During Ball Attach







- Ball attach is a reflow process
  - Reflow is a mature process with standardized profiles and best practices

Thermal Exposure During Ball Attach (CSPs)

	Peak Temperature (°C)	Time above 80% T_L (sec)	Highest Ramp Rate (°C/sec)
Reballer A	N/A		
Reballer B	228	330*	0.7
Reballer C	N/A		
Reballer D	216	268	0.6
Reballer E	225	290	0.7

- Ball attach exposes CSPs to higher temperatures and longer durations than ball removal

Thermal Exposure During Ball Attach (BGAs)

	Peak Temperature (°C)	Time above 80% T_L (sec)	Highest Ramp Rate (°C/sec)
Reballer A	N/A		
Reballer B	219	255*	0.7
Reballer C	191	95	1.6
Reballer D	216	192	0.5
Reballer E	231	314	0.8

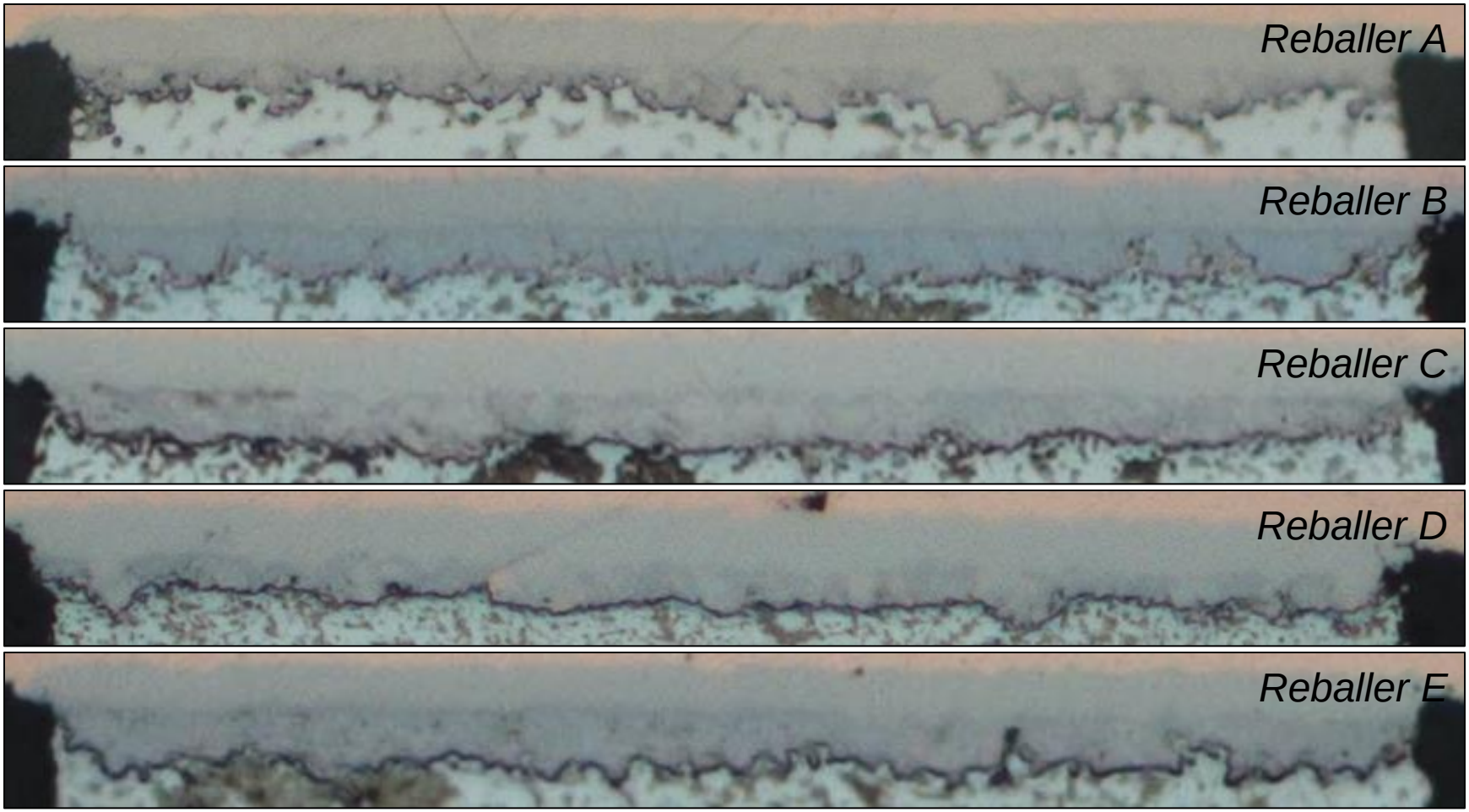
- Ball attach exposes BGAs to higher temperatures and longer durations than ball removal

Thermal Exposure

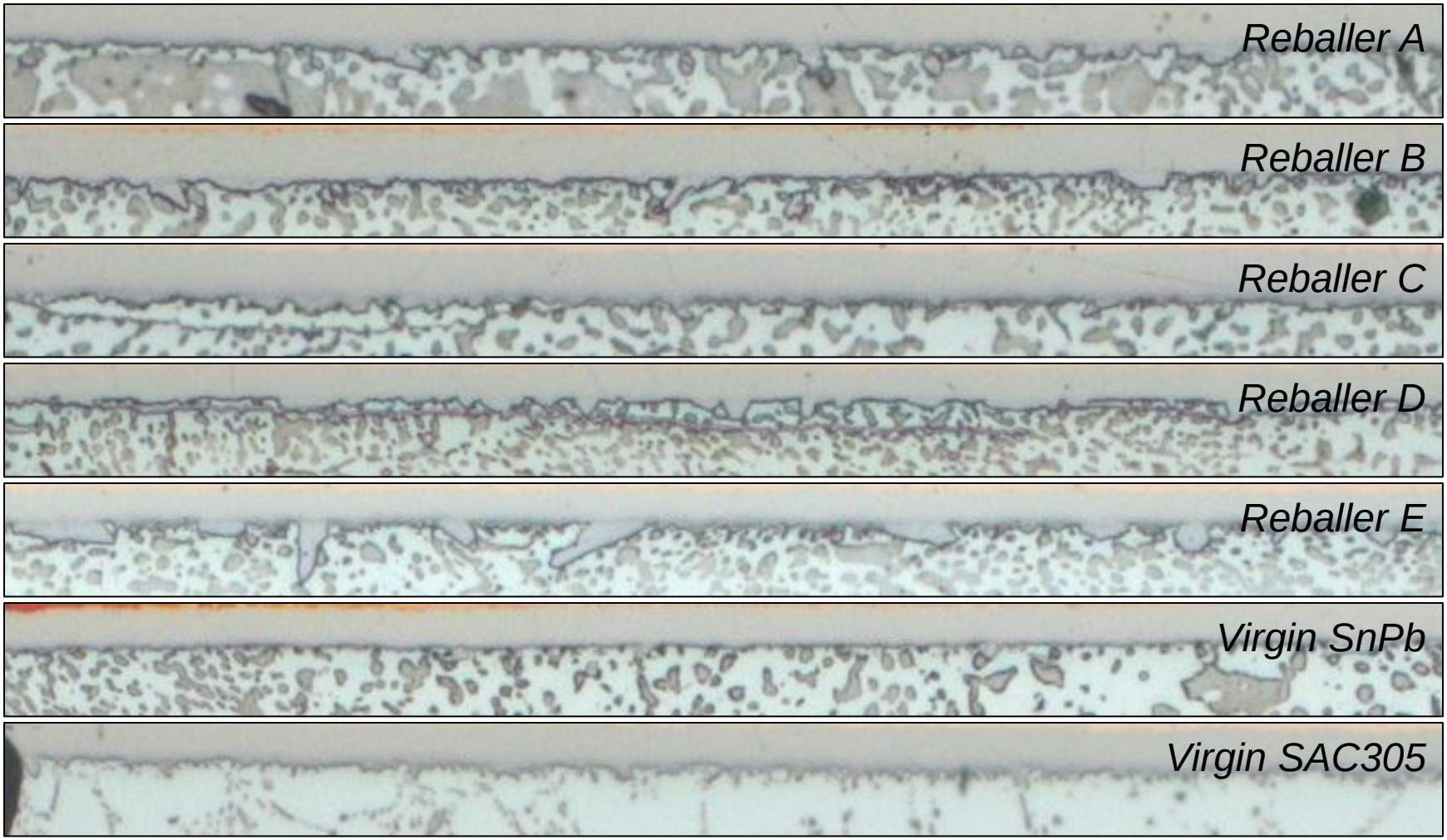
- Thermal exposure was greatest for Reballers B and E
  - Ball attach reflow profile greatest contributor to peak temperatures and durations

	CSP		BGA	
	Time above 80% T_L (sec) – Ball Removal	Time above 80% T_L (sec) – Ball Attach	Time above 80% T_L (sec) – Ball Removal	Time above 80% T_L (sec) – Ball Attach
Reballer A	3	N/A	24	N/A
Reballer B	17	330*	0	255*
Reballer C	N/A	N/A	19	95
Reballer D	17	268	0	192
Reballer E	4	290	1	314

Intermetallic Compound (CSPs)



Intermetallic Compound (BGAs)



IMC Thickness

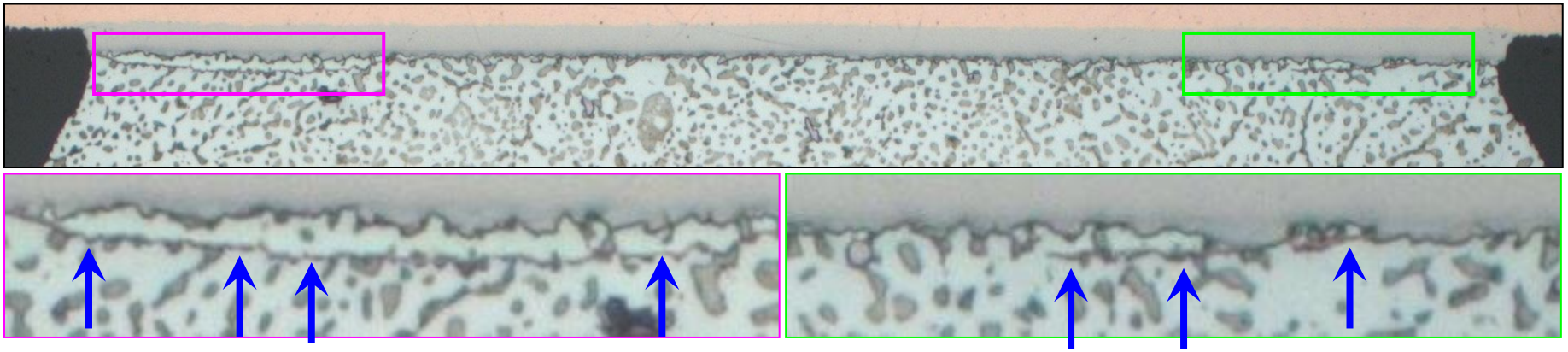
	CSP		BGA	
	Package IMC Thickness (µm)	Standard Deviation (µm)	Package IMC Thickness (µm)	Standard Deviation (µm)
Reballer A	3.1	1.0	2.2	1.0
Reballer B	3.4	1.2	2.9	2.0
Reballer C	2.2	0.7	1.7	0.6
Reballer D	2.9	0.9	1.8	1.4
Reballer E	1.6	0.3	1.4	0.8
Virgin SnPb	N/A		1.3	0.4
Virgin SAC305	N/A		1.4	0.4

Intermetallic Compound Growth

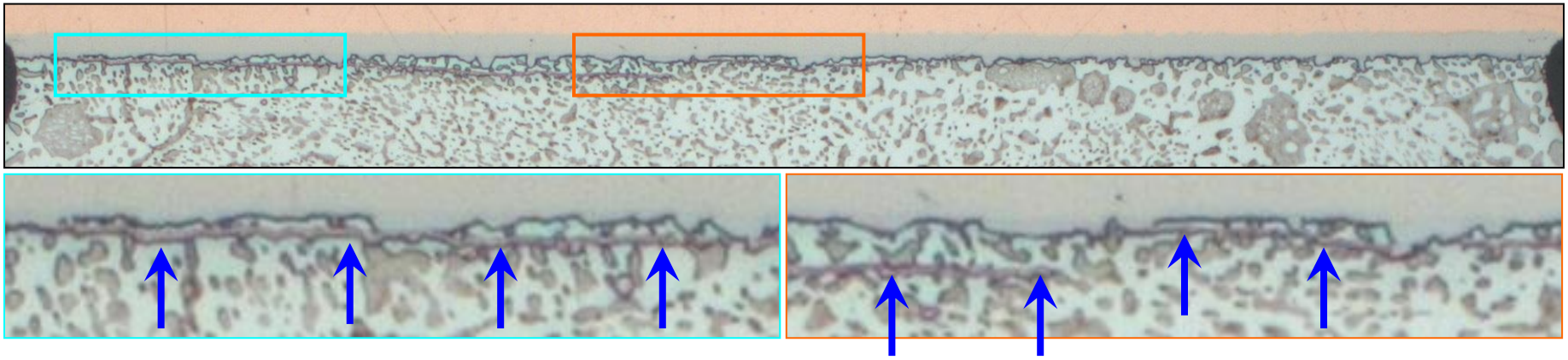
- Reballers who prioritize flat pad dressing exhibit greatest IMC growth
- Thermal exposure alone does not determine thickness of IMC for reballed joints
  - Reballers B and E exposed components to highest temperatures for longest durations
  - Reballer B has thickest IMC
  - Reballer E has thinnest IMC

Residual IMC Anomaly

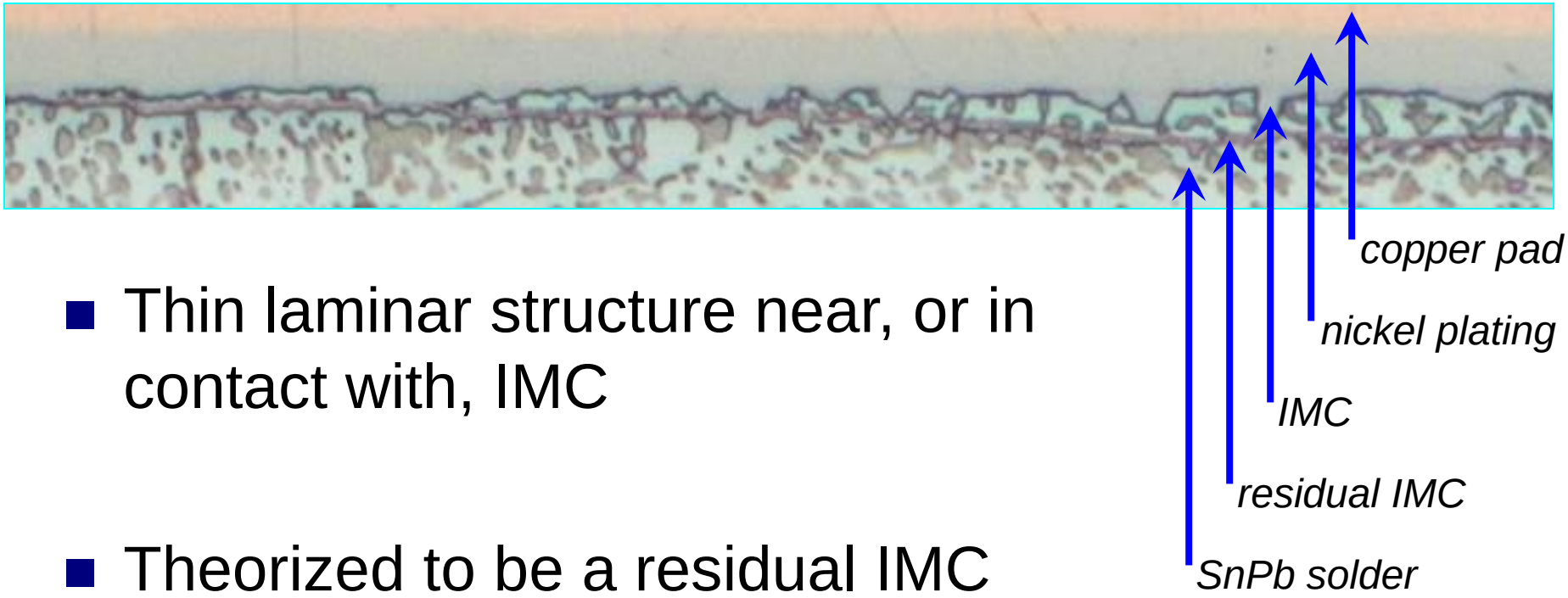
Reballer C



Reballer D



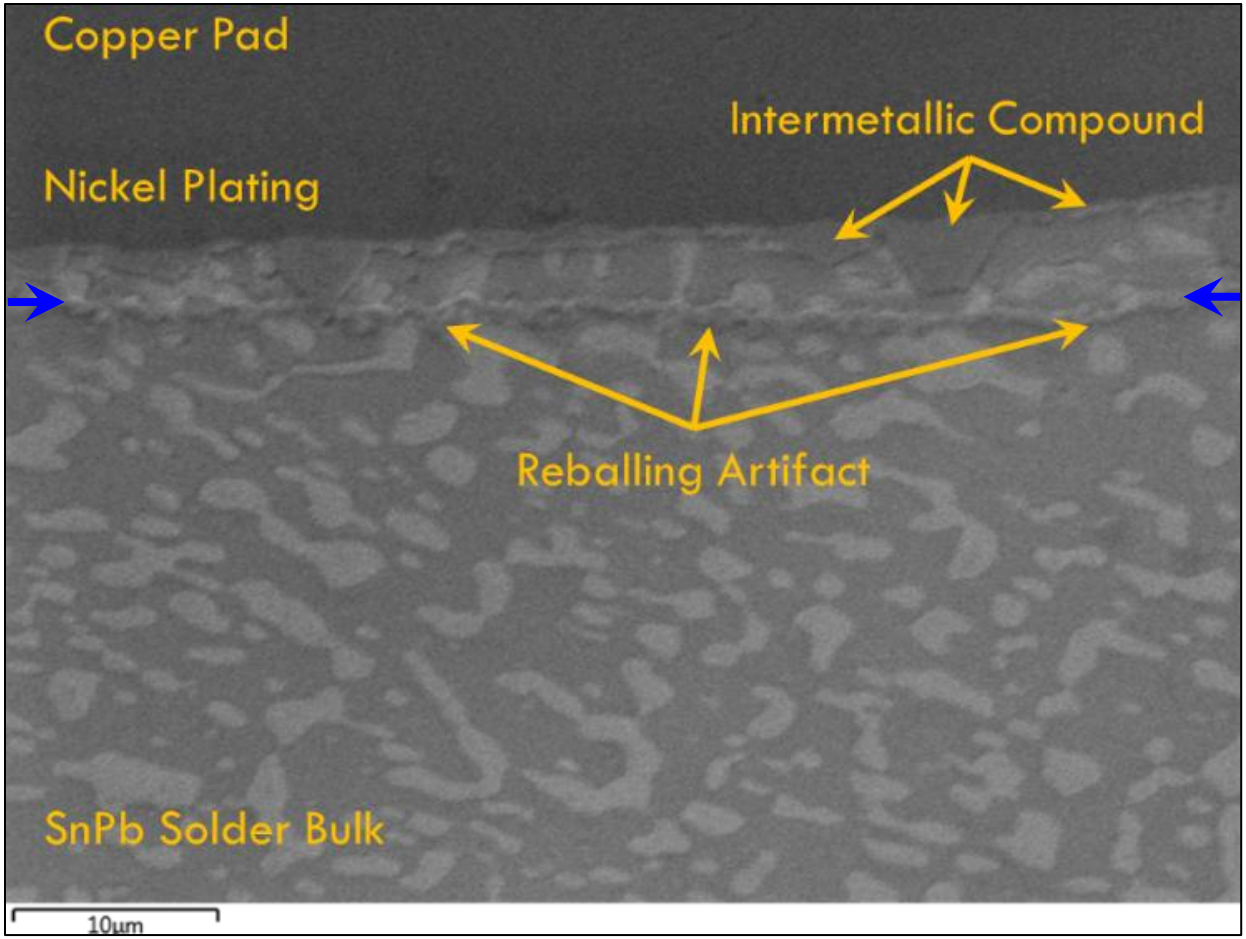
Residual IMC Anomaly

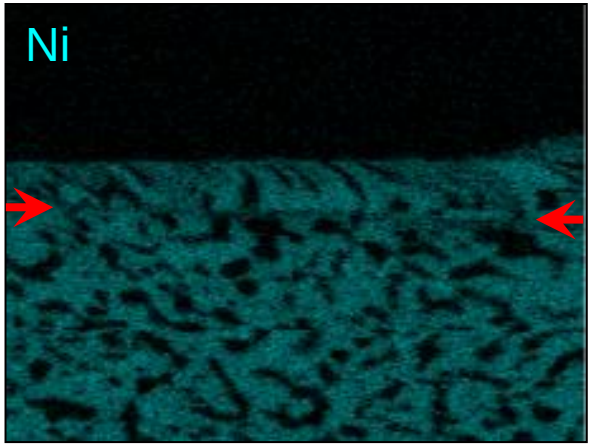


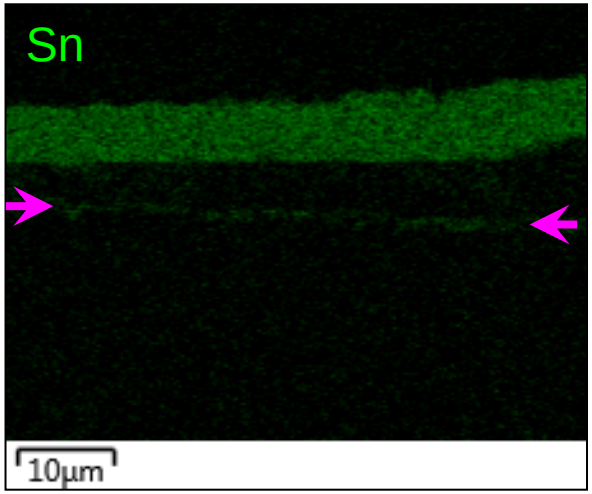
- Thin laminar structure near, or in contact with, IMC
- Theorized to be a residual IMC
  - IMC “scab” from original solder ball bond
  - Partially detached during ball removal
  - Enveloped by new solder ball

Residual IMC Anomaly

- EDS identifies as containing Ni and Sn







Findings: Ball Removal Techniques

- Two types of ball removal processes exist
  - Melting and wicking
  - Dissolution in molten solder

- Two priorities among reballers
  - Dress pads to a flat profile
  - Disturb the IMC as little as possible, results in domed pads

Findings: Technique and Thermal Exposure

- Thermal exposure is minimal for all ball removal techniques
- Greatest contribution to thermal exposure is ball attach reflow profile

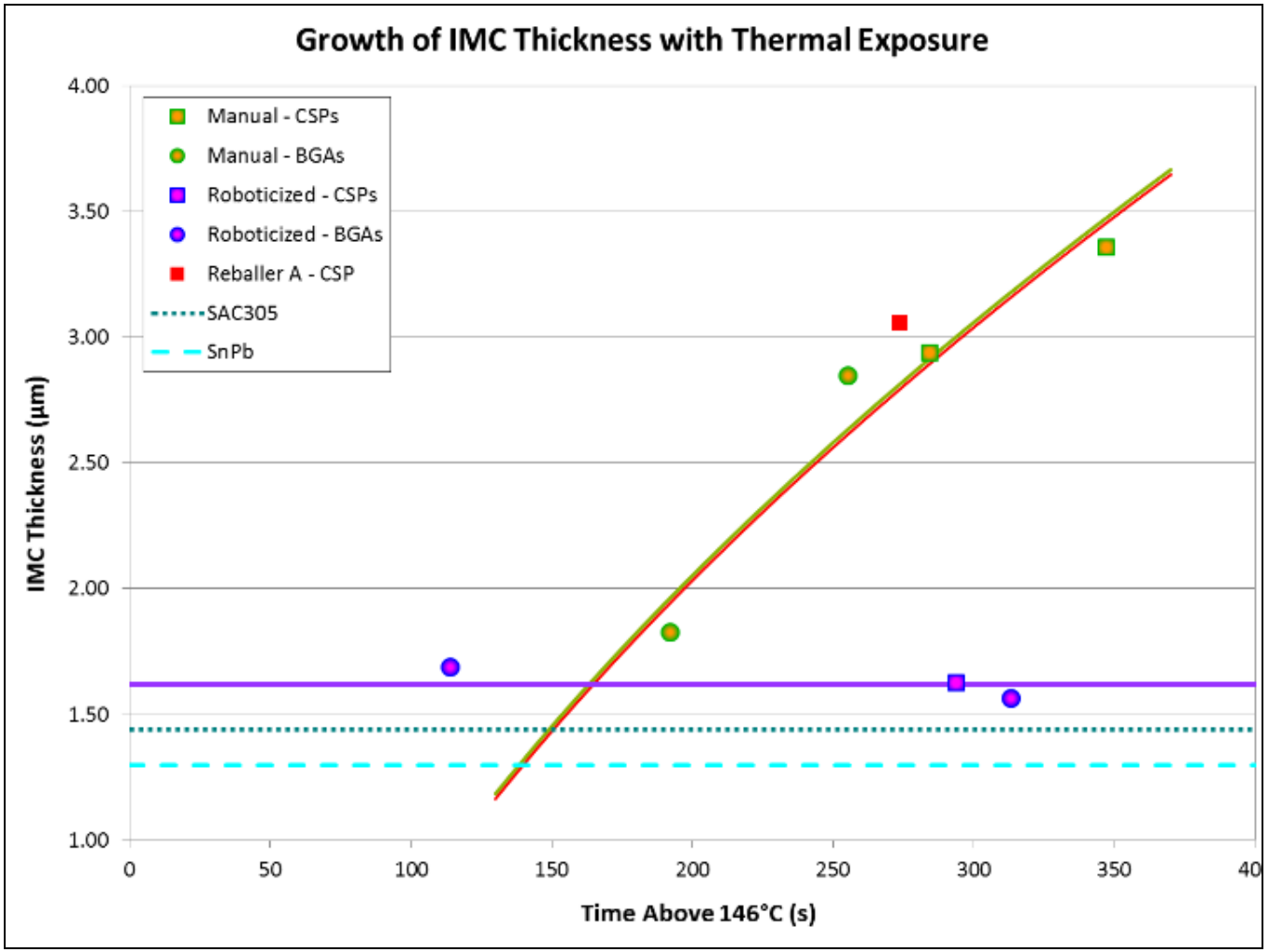
Findings: Appearance of Intermetallic Compound

- IMC thickness is greater than that of non-reballed components
- IMC thickness does not correlate well with thermal exposure
- A free-floating IMC was observed on some components

Discussion: IMC Growth

- The most IMC growth was observed for reballers who prioritized a flat pad appearance
  - Does this stimulate growth of the IMC?
- Exposure of the IMC and physical abrasion to the crystal boundaries provides high energy sites for nucleation following reflow

Intermetallic Compound Growth



- Grouped by approach to reballing and test vehicle
  - Robo-ticized = domed

Discussion: Residual IMC

- The free-floating IMC was observed on components with solder domes on pads or dressed flat
  - Fractures due to thermal cycling, mechanical shock, and vibration testing were not observed to propagate along such an artifact

Conclusions

- Flat pad dressing increases IMC thickness
  - Intermetallic compound exhibits brittle fracture behavior
  - Excessive growth of IMC should be avoided for high stress applications
- Pre-existing IMC should be disturbed as little as possible
  - Dressing pads to a domed appearance is recommended for applications where shock may be a concern

Acknowledgements

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The author also wishes to thank the participating reballers for their warm welcome and insight into the reballing process.

Questions?

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