QFN DESIGN CONSIDERATIONS TO IMPROVE CLEANING
A FOLLOW ON STUDY

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ABSTRACT:

The data findings from the QFN Design Considerations to Improve Cleaning presented at SMTAI 2013 found that the level of flux residue is less and cleaning improves from open spaces under the bottom termination, higher component clearance, and the ability for air to flow and exhaust during reflow. The data conclusively found that when flux volatiles outgas and escape from under the component during reflow, flux residue volatile ingredients exhaust with the remaining residue forming around the solder joints. This opens up flow channels to allow the cleaning fluid to penetrate, wet and dissolve remaining residues.

The 2013 research paper studied different ground pad designs with the addition of via holes within the ground pad penetrating to the back side of the board. The via holes allowed flux volatile ingredients to outgas and escape during reflow and for some of the flux residue to drain to the back side of the board. The level of flux residue under the bottom termination reduced upwards to 80% less residue within the streets and around pads.

The purpose of the follow on research is to place non-plated via holes within the QFN streets four quadrants. Learning from the 2013 research data findings, the research hypothesis for this study predicts that the non-plated via holes will allow to air to penetrate and exhaust during reflow resulting in less residue under the bottom termination. The major benefit is that less residue prevents flux bridging. With an open flow channel under the component, cleaning fluids penetrate at a faster rate, which allows for reduced cleaning time and more consistent cleaning.

KEY WORDS

QFN, MLF, LPCC, QLP, HVQFN, LCC, Electronic Assembly Cleaning, Flux Residue, Electrochemical Migration

INTRODUCTION

Electronic devices are the backbone for new innovations that enable market disruption and change the way we do things today. Packaging that enables these devices are continuing to miniaturize. Components that are joined with surface mount continue to improve functionality while challenging assembly operations. As bump diameters reduce, bump pitch also has to reduce. Component pitches of 0.3-0.5 mm are now common place. As bump pitch narrows, package height reduces. Standoff gaps continue to narrow as well, with less than 2 mils of clearance space from many small leadless / bottom termination components and packages.

Components with extremely tight gap heights can create assembly challenges. Solder spheres are combined with a flux composition to make solder paste. The flux component is extremely important to enable high yield on many processes. The first process is stencil printing. Assemblies with miniature components have a much smaller process window.[1] During stencil printing, particle size, rheology, slump and viscosity must enable aperture fill and release.

The second process is reflowing and joining the component to the substrate. The flux component is extremely important in removing surface oxides, protecting the alloy from oxidation during the reflow process, while also reducing paste slumping, spattering and voiding.[2] During the soldering process, some of the flux ingredients are designed to outgas with the remaining residue crosslinking into an inert residue. As gaps reduce, active flux ingredients can become entrapped under the bottom termination. Flux entrapment increases the level of residues post soldering and potential for electrochemical migration.

Design for manufacturability (DfM) requires closer, earlier and more proactive coordination across the supply chain, including OEM, ODM, EMS and the supply companies.[3] Sharing best practices ensures that decisions made early in the design process overcome assembly challenges with the net result of reliable products that perform to expectations. The goal of the research reported in this paper is to increase the body of knowledge with regards to bottom termination soldering effects during reflow. Better understanding leads to better designs, which opens process windows.

LEADLESS / BOTTOM TERMINATED COMPONENTS

The continued miniaturization trend can lead to excessive residue that bridges and climbs up the side of the component during reflow (Figure 2). For example, the physical size of passive components continues to decrease, which also reduces solder deposit thickness (Figure 1). In addition, printed circuit board finishes are moving away from non-planar finishes (i.e. – HASL) and to planar finishes (ENIG, ImAg, OSP, ENEPIG & ImAg, etc). Planar board finishes with typical copper thicknesses are flush with the solder mask, which also leads to tighter gap heights. Each of these trends reduces Z-Axis, which results in more flux residue under the component.

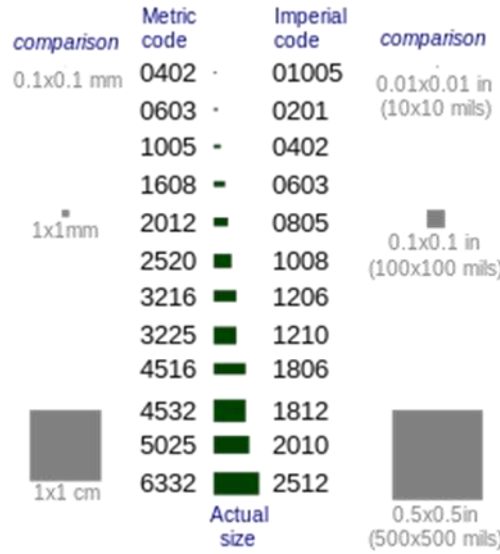

Figure 1: Passive Component Miniaturization

Figure 2: Passive Component Standoff Gap Example

The QFN micro lead frame component is popular as an IC package because it is a small, near chip scale package size, and can provide improved heat transfer to keep the IC cooler. The I/O and power and ground connections are typically arranged in one or two rows around the four edges of the device although the pattern can vary significantly from device to device.[4]

QFN's are more manufacturing friendly than other components because they are easier to handle and less prone to damage than alternative packages with leads or solder balls attached. The "Dual Flat No-lead" DFN is a cousin of the QFN having SMT leadless interconnects only on two sides of the package.

The down sides to using the QFN package are cleaning, rework and voiding. The large ground pad and low gap height result in significant flux contamination. Since there is no flow pattern, cleaning is a real challenge. Rework requires a lot of heat to melt the solder connecting heat transfer pads to the board via structure. This increases the thermal stress to the board and can limit the rework yield and number of rework cycles. During reflow, large voids within the ground pad can occur due to the inability of the flux to outgas.

The cleaning challenge is exacerbated by three points of the QFN design.[4] One, there is a lot of flux to deal with compared to other packages. Two, the spacing under the bottom termination is very tight, just a couple of mils. And last, the fluid flow channels that normally form and facilitate rapid cleaning are blocked by the heat sink pad.

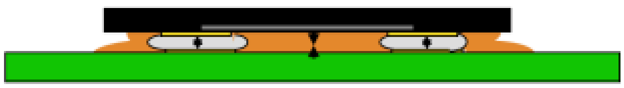

Figure 3: Flux residue fills open gaps in QFN structures

Solder paste typically contains approximately 10% flux by weight, but by volume the flux comprises nearly 50%. When QFN's are reflowed, most of the non-volatile flux residue expelled from the molten solder from the heat sink accumulates around the I/O pad structures in sufficient volume to seal gaps between component and board with solid flux residue. Flux residue can be trapped within the ground pad, which leads to increased voiding.

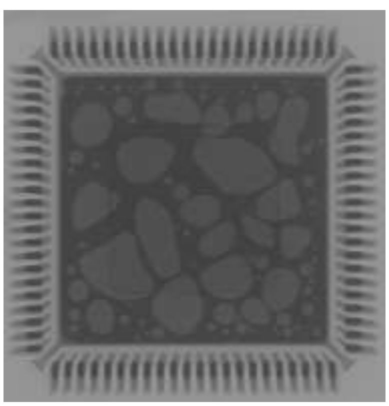

Figure 4: Large Voids due to Restricted Channels for Flux Volatiles to Outgas

DESIGN FOR CLEANING

Electronic assemblies are designed based on the form factor, contractual requirements, end use and cost.[3] Design for Manufacturing is contingent on component size, density and performance. Design rules must account for smaller solder connections, solder paste volume and reductions in the Z-Axis.

Prior research finds that flux residue under the bottom termination is a function of attractive and repulsive capillary forces.[4] When the Z-Axis is less than 2 mils, flux residue capillary forces attract during reflow. As flux accumulates, channels for outgassing become blocked. When this occurs, the bottom side of the component is underfilled with flux residue. The problem with this phenomenon is that unreacted flux activators can be left under the component. With flux residues bridging components, electrochemical migration can take place in short order.

Figure 5: Flux Bridging Conductors can lead to ECM

From a design perspective, the key is developing channels for the flux to outgas during reflow. Designs for cleaning strategies that allow flux to exhaust during reflow reduce the level of flux under the bottom termination by as high as 80% reduction. Flux residues tend to form next to the solder connection and are very manageable from a cleaning perspective.

Figure 6: Channels that allow Flux to Outgas reduce Flux Residues

Solder mask definition strategies create channels for flux to outgas. Removal of the solder mask next to the component creates a trough that effectively breaks the vacuum effect from the solder pad to the solder mask. The channel around the solder pad provides roughly one mil of Z-Axis. These non-solder mask define pads reduce flux flowing away from the solder pad and provide a channel for flux to outgas.

Removal of all solder mask under the bottom termination is another effective strategy for increase the Z-Axis and providing a channel for flux to exhaust.[5] Unlike Non Solder Mask Defined pads, No Solder Mask allows some flux to flow away from the pad. This limitation is mostly mitigated by the air channels that can flow during reflow. Solder Mask Defined pads are the least preferred strategy for bottom termination components.

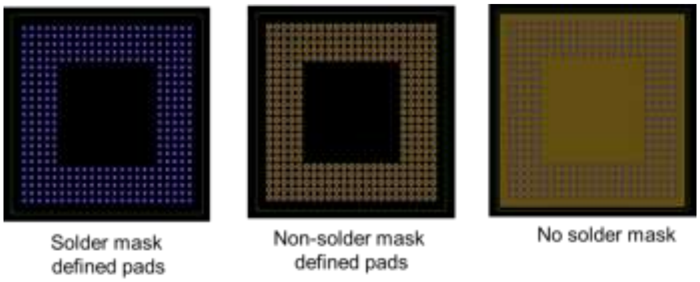

Figure 7: Solder Mask Definition Strategies

Inserting preforms is another strategy that can be used to increase gap height. Preforms are placed at the four corners of the ground pad. The preform increases gap height by 1-2 mils. The added gap height allows flux to outgas during reflow. Similar to Non Solder Mask Defined pads, this strategy decreases flux residue under the bottom termination and is easier to clean.

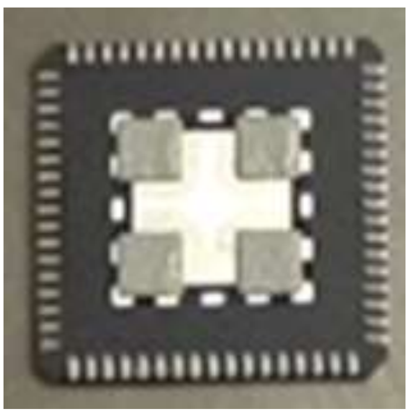

Figure 8: Preforms at the Corners of the Ground Pad

The initial research paper presented at SMTAI last year placed plated via holes within the ground pad.[4] The objective of the plated via holes was to provide a channel for flux to exhaust and drain to the back side of the board The strategy worked but there were some complications. The first complication was the ability of the solder to flow into the plated through hole and form a bump on the bottom side of the board. The second complication with this strategy came from rework. The solder that ran into the plated vias reinforced the strength and permanency of the component. It was challenging to remove the component without destroying the pad terminations.

Figure 9: Plated Via Holes in Ground Pad

Each of the strategies had one common purpose of providing a channel for flux to exhaust during reflow. Air channels reduce flux residue under the bottom termination and reduce ground pad voiding.

RESEARCH PURPOSE

The purpose of the follow on research is to place non-plated via holes within the QFN streets four quadrants. Learning from the 2013 research data findings, increasing gap height and providing a channel for flux to exhaust is the key factor for reducing flux under bottom terminations. Non plated vias were strategically placed in the streets and corners.

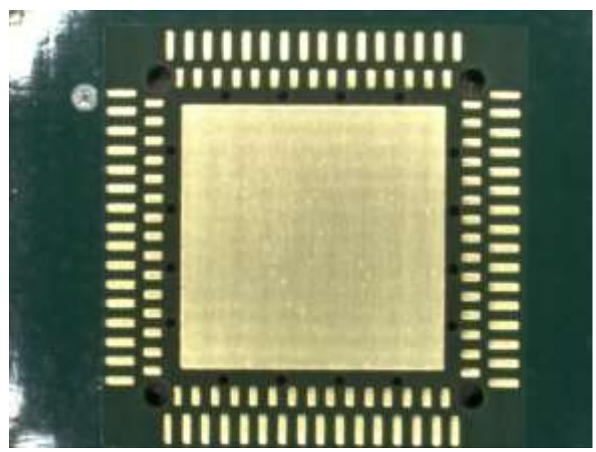

Figure 10: Non Plated Via Design in Streets and Corners

Research Hypothesis #1: Removal of solder mask from both the pads and streets will increase gap height and allow flux residues to outgas.

Research Hypothesis #2: Plated via holes in the ground pad will allow flux residues to outgas and reduce voiding.

Research Hypothesis #3: Non-plated via holes in the streets will allow flux residues to outgas during reflow resulting in less residue under the bottom termination.

EXPERIMENTAL

The test vehicle designed for this research was similar to the original design used for the 2013 study. Two differences were built into the test vehicle design. The test vehicle used for the original 2013 study had immersion silver as the pad finish. For this study, ENIG planar finish was used. The second change was the addition of non-plated via holes in the streets on components with solid ground pads (Figure 10 & 11).

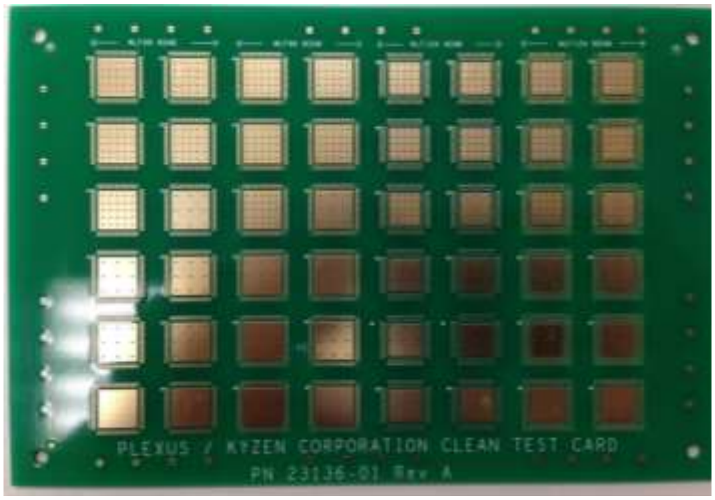

Figure 11: Test Vehicle used for this Research Study

Four lead free Type V solder pastes were evaluated in this study

1. Lead-Free No-Clean #1
2. Lead-Free No-Clean #2
3. Lead-Free No-Clean #3
4. Lead-Free Water Soluble

The board finish was ENIG. The test vehicle was designed to evaluate voiding relative to solder mask and via hole combinations as listed below:

- 25 Via Holes in Ground Pad
  - MLF88 Single Row NSMD
  - MLF88 Single Row NoSM
  - MLF124 Dual Row NSMD
  - MLF124 Dual Row NoSM
- 9 Via Holes in Ground Pad
  - MLF88 Single Row NSMD
  - MLF88 Single Row NoSM
  - MLF124 Dual Row NSMD
  - MLF124 Dual Row NoSM
- No Via Holes in Ground Pad
  - 10 holes on each of four quadrants streets
    - MLF88 Single Row NSMD
    - MLF88 Single Row NoSM
    - MLF124 Dual Row NSMD
    - MLF124 Dual Row NoSM
  - 5 holes on each of four quadrants streets with holes in corners
    - MLF88 Single Row NSMD
    - MLF88 Single Row NoSM
    - MLF124 Dual Row NSMD
    - MLF124 Dual Row NoSM

Boards were processed at TriQuint Semiconductor using gloves and were not cleaned after SMT processing.

Methodology

The test vehicles were delivered to the TriQuint Semiconductor's Advanced Microwave Module Assembly facility (AMMA) in Richardson, TX. The components were delivered in feeder tubes, which were then transferred to a tape and reel format for compatibility with the placement equipment.

The Design of Experiment called for a combination of four lead free solder pastes, which would be used for the board fabrication. The solder paste stencil was fabricated from 0.004 inch thick nano-coated laser cut stencil (see Figure XX below). The stencil was cleaned between each print by the screen printer automated dry wipe, and washed between each paste type used to prevent print contamination.

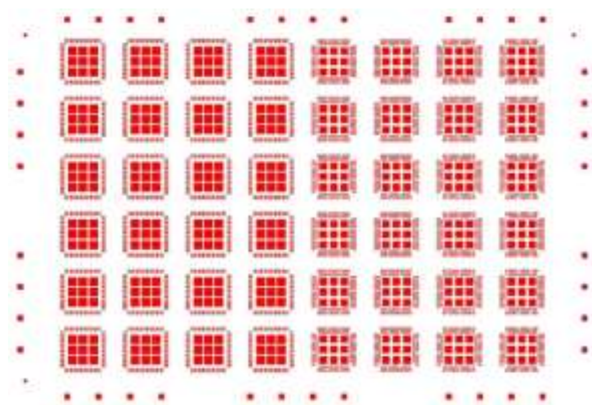

Figure 12: Standard Stencil Pattern

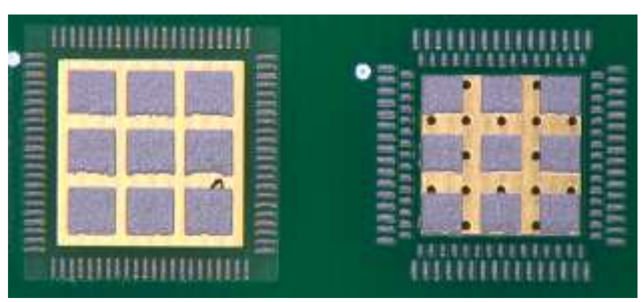

Figure 13: Solder Paste Print

The solder pastes used were a Type V solder paste mesh, for the fine stencil apertures. The solder paste application used a DEK Horizon 03iX screen printer using the solder pastes specified in the matrix. The vendor recommended solder paste print parameters (e.g. print speed, print pressure, etc.) were followed. The test vehicles were transferred to the Juki CX-1 high speed pick and place machine for placement of the components.

The test vehicles were generally fully populated per the DOE Matrix. In a few cases, the matrix defined unpopulated boards without components as control boards to determine the residues remaining from each paste used and the overall print quality. The test vehicles were immediately reflowed using the Heller 1936MK5 convection reflow oven. This oven had twelve temperature zones for solder reflow, and the conveyor was set at 25 IPM. The reflow profile used was a ramp-to-spike profile with a peak temperature target of 235°C. The reflow profile was identical for all paste types.

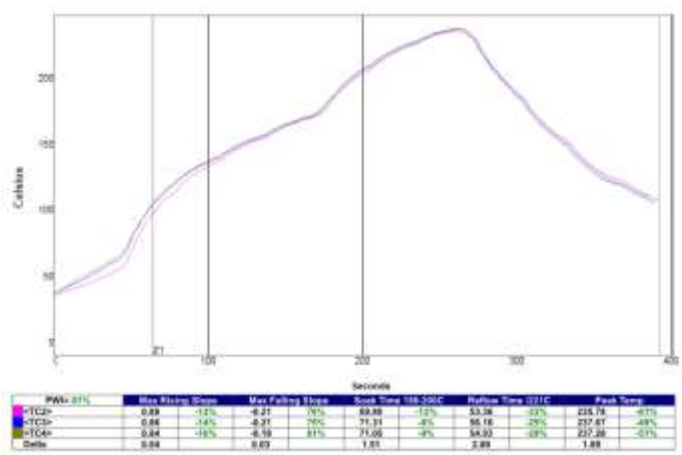

Figure 14: Ramp to Spike Reflow Profile

No touch-up was performed on these assemblies. After reflow, the boards were inspected by X-Ray to determine voiding from the manufacturing process and the stencil/board combinations.

Following assembly, an XD7600NT Transmissive X-Ray Laminography system from Nordson-Dage (Ruby series) was used to evaluate solder voiding under the components.

The boards were sent from TriQuint to Kyzen Corporation for removal of components and collection of data.

Response Variables

The response variables from this study include:

1. Gap Height
2. Flux Residue Levels
    a. Streets
    b. Pads
3. Voiding
    a. Transmissive X-Ray Laminography

DATA FINDINGS

The standoff gap from the board to the bottom side of the component is critical for flux residue volatiles to outgas. When gap heights are less than 2 mils, flux residue volatiles become entrapped under the bottom termination. This results in heavy flux residues next to pads and streets. Some of the flux volatiles can still be active and susceptible to leakage when biased. Cleaning QFN components that are totally underfilled with flux residues is highly challenging and problematic.

The test vehicles within the 2013 research study average 2-6 mils standoff gap. Parts with higher gap heights resulted in less flux residue under the bottom termination. The level of residues in both the street and pad areas from that study was low. The gap heights for this study were measured for the Single and Dual non solder mask defined (NSMD) and no solder mask components (NoSM). Similar to the 2013 research study, higher gap heights resulted in less flux residue under bottom terminations.

The via holes in the ground pads and within the streets provide a path for flux residue volatiles to outgas during reflow. The insertion of via holes resulted in smaller and fewer voids. On pads with 25 via holes in the ground pads, voiding was minimal and the size of the voids was small in diameter. When the via holes were placed in the streets and not the ground pad, the voids were larger and slightly higher in the ground pad area. The insertion of via holes in both the ground pads and streets showed a positive correlation for flux residue volatiles having a path to outgas.

25 via holes in Ground Pad

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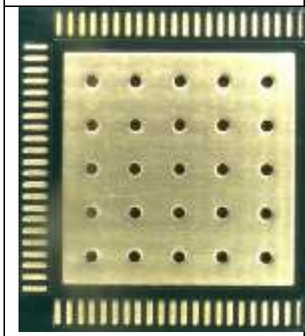
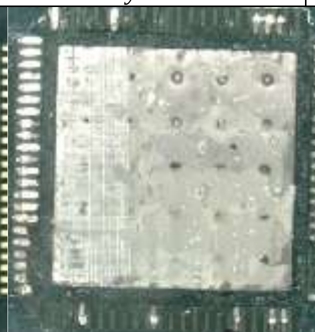
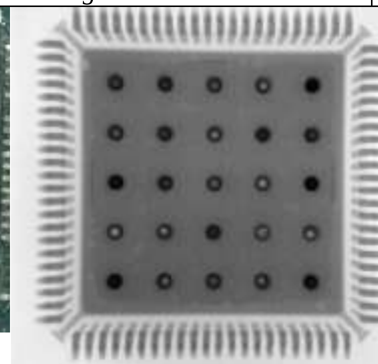
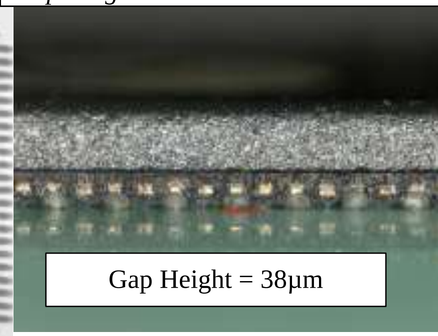
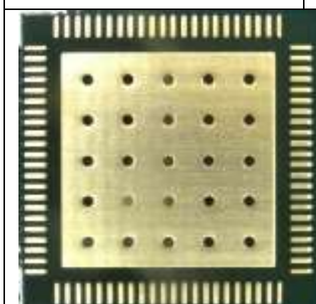
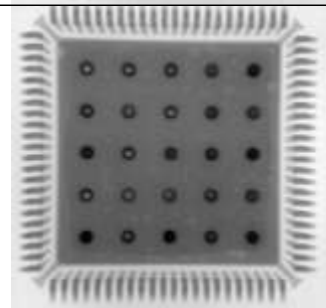
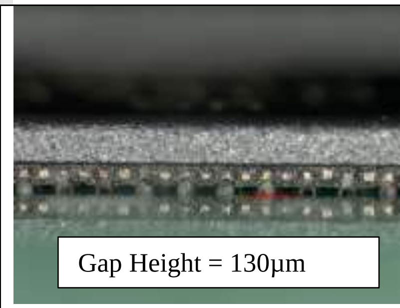
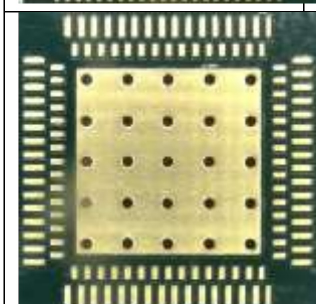
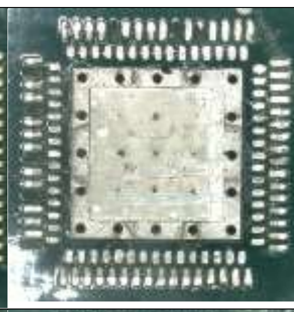
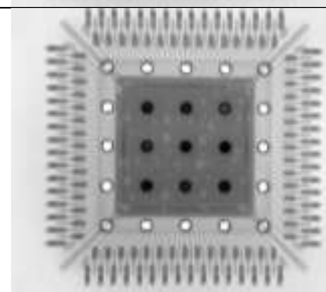
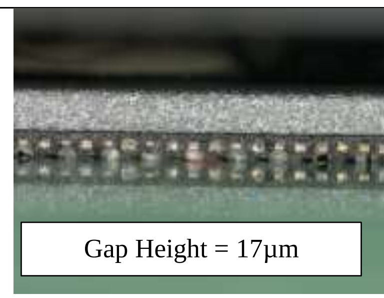
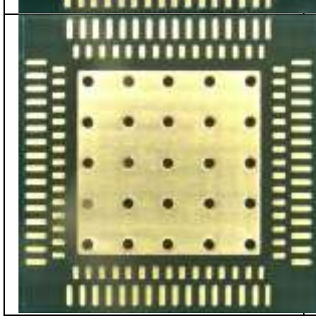
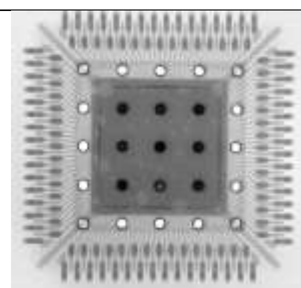
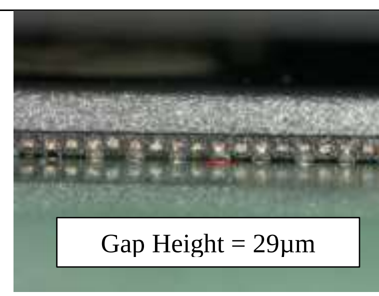
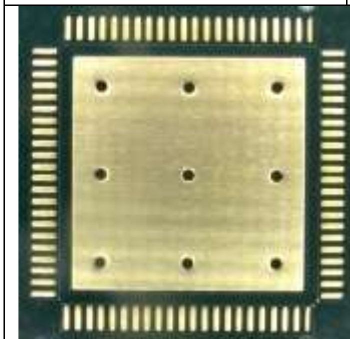
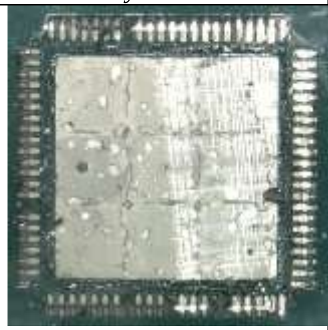
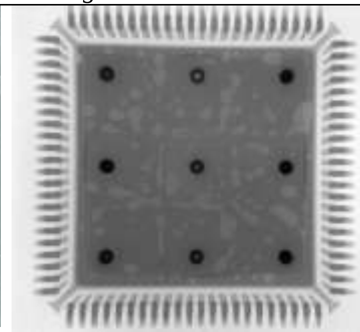
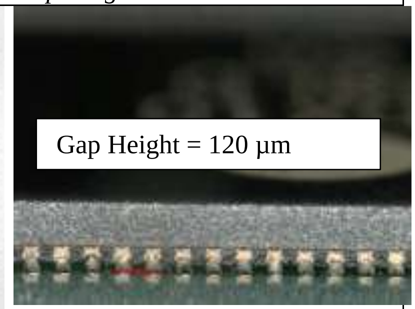
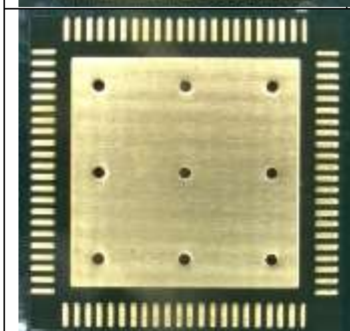
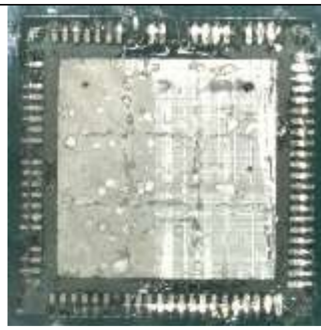
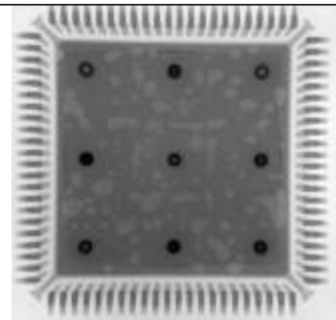
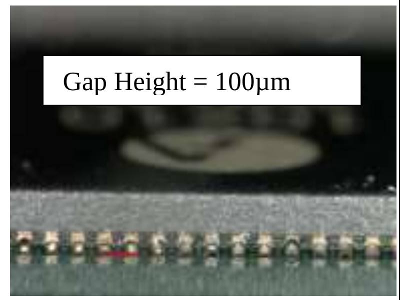
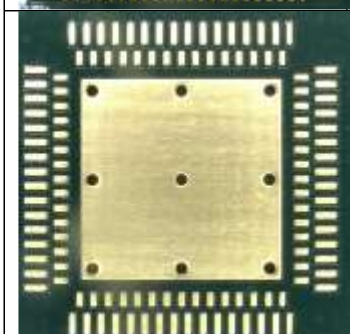
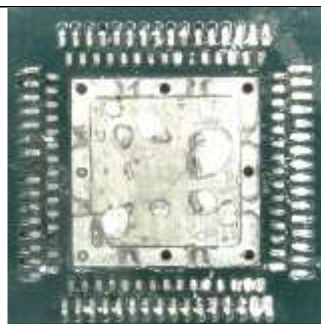
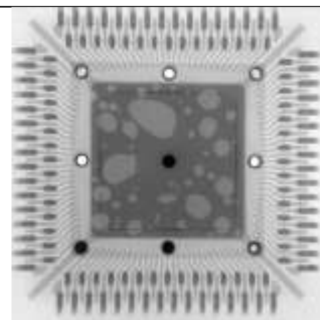
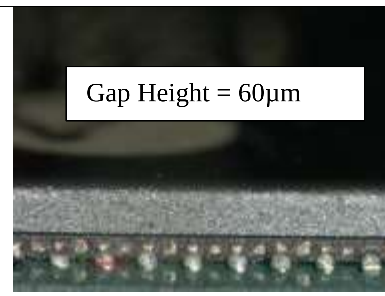
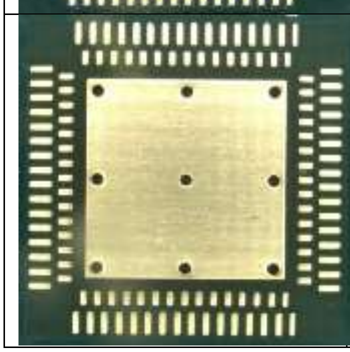
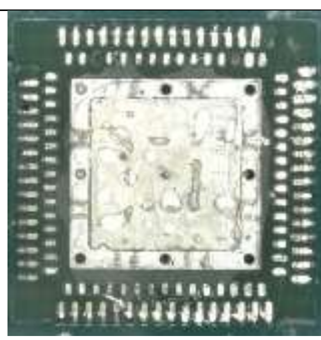
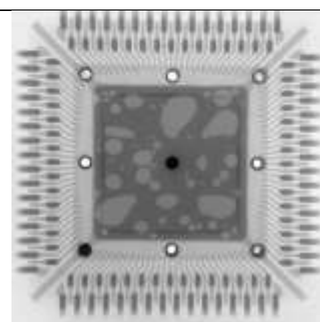
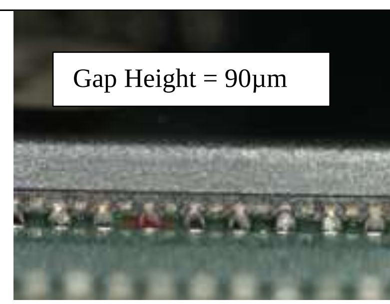
			
			
			
			

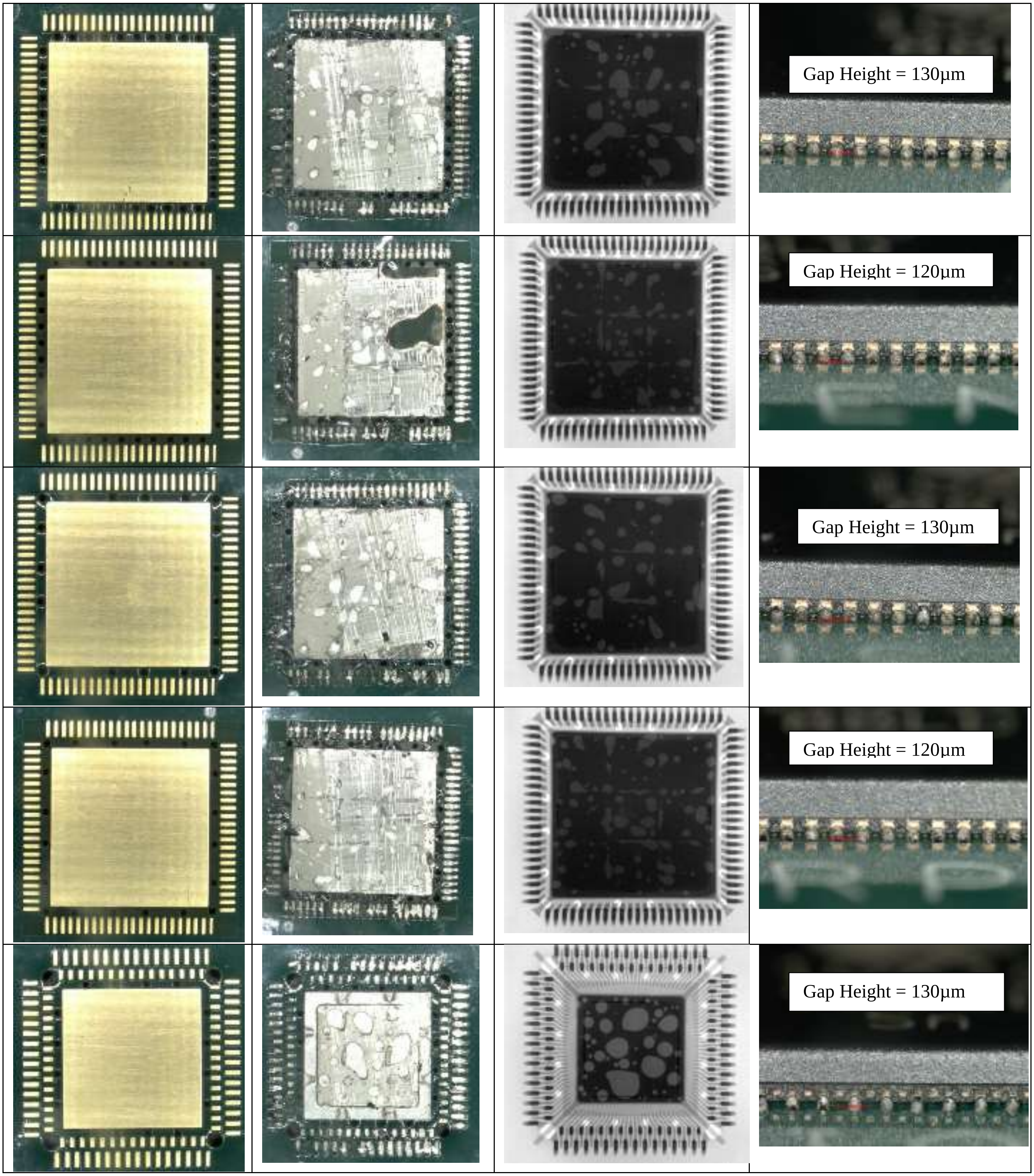
- MLF88 Single Row / 25 Plated Via Holes / NSMD
  - 80% Flux Residue in Streets
  - 60% Flux Residue next to Pads
  - 10% Voiding
- MLF88 Single Row / 25 Plated Via Holes / NoSM
  - 30% Flux Residue in Streets
  - 50% Flux Residue next to Pads
  - 10% Voiding
- MLF124 Dual Row / 25 Plated Via Holes / NSMD
  - 25% Flux Residue in Streets
  - 30% Flux Residue next to Pads
  - 15% Voiding
- MLF124 Dual Row / 25 Plated Via Holes / NoSM
  - 15% Flux Residue in Streets
  - 20% Flux Residue next to Pads
  - 15% Voiding

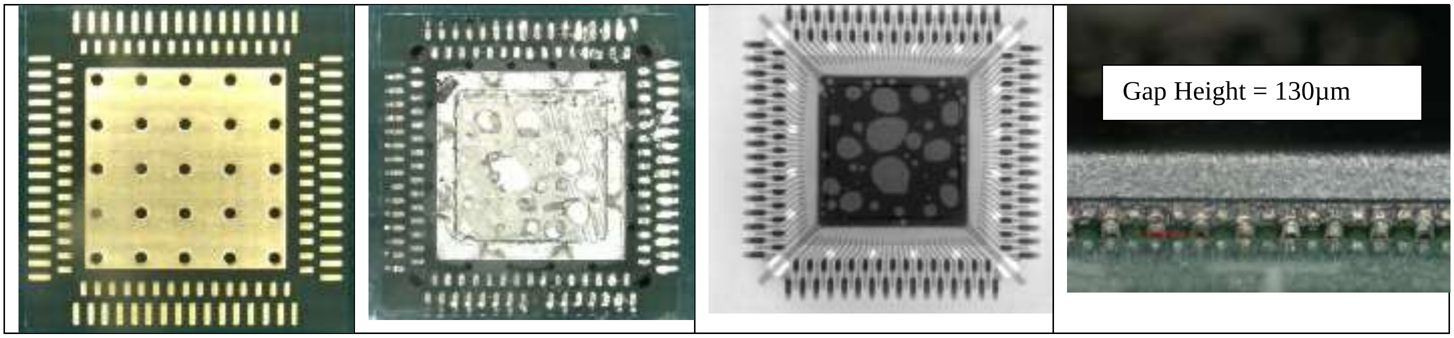
9 via holes in Ground Pad

Bare Board	*Removed by Chisel*	*Voiding*	*Gap Height*
			
			
			
			

- MLF88 Single Row / 9 Plated Via Holes / NSMD
  - 70% Flux Residue in Streets
  - 30% Flux Residue next to Pads
  - 20% Voiding
- MLF88 Single Row / 9 Plated Via Holes / NoSM
  - 30% Flux Residue in Streets
  - 25% Flux Residue next to Pads
  - 20% Voiding
- MLF124 Dual Row / 9 Plated Via Holes / NSMD
  - 30% Flux Residue in Streets
  - 40% Flux Residue next to Pads
  - 25% Voiding
- MLF124 Dual Row / 9 Plated Via Holes / NoSM
  - 15% Flux Residue in Streets
  - 20% Flux Residue next to Pads
  - 30% Voiding

Via Holes in Streets ~ No Via Holes in Ground Pad





- MLF88 Single Row / 10 Plated Via Holes in each street for a total of 40 Via Holes in Streets/ NSMD
  - 50% Flux Residue in Streets
  - 60% Flux Residue next to Pads
  - 25% Voiding
- MLF88 Single Row / 10 Plated Via Holes in each street for a total of 40 Via Holes in Streets / NoSM
  - 30% Flux Residue in Streets
  - 25% Flux Residue next to Pads
  - 15% Voiding
- MLF88 Single Row / 5 Plated Via Holes in each street for a total of 20 Via Holes in Streets/ NSMD
  - 50% Flux Residue in Streets
  - 60% Flux Residue next to Pads
  - 20% Voiding
- MLF88 Single Row / 5 Plated Via Holes in each street for a total of 20 Via Holes in Streets/ NoSM
  - 30% Flux Residue in Streets
  - 20% Flux Residue next to Pads
  - 20% Voiding
- MLF124 Dual Row / 9 Plated Via Holes / NSMD
  - 30% Flux Residue in Streets
  - 30% Flux Residue next to Pads
  - 30% Voiding
- MLF124 Dual Row / 9 Plated Via Holes / NoSM
  - 15% Flux Residue in Streets
  - 20% Flux Residue next to Pads
  - 30% Voiding

INFERENCES FROM THE DATA FINDINGS

Research Hypothesis #1: Removal of solder mask from both the pads and streets will increase gap height and allow flux residues to outgas.

The data findings reported in this paper accept the first research hypothesis that gap height is a critical factor for flux residues volatiles to outgas. The study finds that solder mask definition is one of the effective strategies for increasing gap height. Within this study, non-solder mask defined pads (NSMD) were not as effective as was no-solder mask under the bottom termination. Removal of the solder mask in both the pad and street areas resulted in less flux residue under the bottom termination.

Research Hypothesis #2: Plated via holes in the ground pad will allow flux residues to outgas and reduce voiding.

The data findings reported in this paper accept the second research hypothesis that plated via holes in the ground pad allow flux residues to outgas and reduce voiding. The insertion of via holes in the ground pad area reduced both voiding and flux residues under the bottom termination. For ground pads with 25 via holes, voids were reduced. The voids that were present were much smaller in diameter than voids on ground pads that do not have via holes.

Research Hypothesis #3: **N**on-plated via holes in the streets will allow flux residues to outgas during reflow resulting in less residue under the bottom termination.

The data findings in this paper accept the third hypothesis that non-plated via holes in the streets support flux outgassing during reflow. The non-plated via holes in the streets on the dual row MLF124 components provided a better path for flux residues to outgas. On the single row MLF88, the via holes were place with in the street area. On the MLF124, there was a large via hole place in the four corners. This large via hole in the corner resulted in less flux residue under the bottom termination. Additional study of the data findings is needed to make a conclusive observation.

CONCLUSION

With the trend toward higher density and miniaturization, the use of bottom termination components has increased. During reflow, flux residue volatiles will accumulate and underfill bottom terminations that have low standoff gaps. Developing a channel for flux residues to outgas significantly reduces flux residue under bottom terminations.

Designs for manufacturing strategies that allow flux residues to outgas during reflow have positive benefits. First, there is less flux residue under the bottom termination. Secondly, cleaning agents will be able to penetrate and flush residues at a much faster rate when the bottom terminations are not totally underfilled with flux residues. Third, flux volatiles that are not reacted leave an active residue that is prone to leakage currents and electrochemical migration. Fourth, voiding is reduced when flux residues have a channel to outgas.

Both the 2013 and 2014 research studies generated a significant amount of data that is difficult to report in totality. Additional data findings will be included in the presentation.

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