

Material Selection and Parameter Optimization for Reliable TMV Pop Assembly

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ABSTRACT

The successful integration of package-on-package (PoP) stacking utilizing through mold via (TMV) technology hinges on a robust assembly process. In this study, seven dip materials were investigated for high quality TMV PoP assembly by optimizing machine settings to achieve proper material transfer. Film thickness was varied for each material to transfer enough material (target of 50% ball coverage) while preventing parts from sticking within the film. Assemblies were reflowed in both air and N₂ atmospheres and yields were quantified. It was determined that flux dipping provides for better TMV assemblies in air reflow due to the flux's ability to wet to and subsequently protect the TMV solder ball during reflow. All paste dipped materials experienced significant fallout in air reflow due to a non-coalescing of the TMV solder joint. All materials provided 100% assembly yields in N₂ reflow.

Keywords: 3-D packaging, package stacking, Package-on-package, PoP, through mold via, TMV

INTRODUCTION

Consumers continually drive electronics packaging engineers to design for portability, higher functionality, and smaller form factors, all while maintaining low manufacturing cost. This translates to managing smaller component geometries that are mounted to the board in higher densities, which generally requires more accurate processes with tighter tolerances to satisfy end of line surface mount yield targets. Package-on-package (PoP) technology offers several advantages by increasing silicon density for higher multimedia functionality while minimizing printed circuit board assembly footprints. Newer PoP devices now in manufacturing include through-molded-via (TMV) technology which is designed to minimize the extent of package warpage, (a major concern in the robust assembly of stacked devices) while enabling pitch reductions in the stacked interface.

Successful integration of these devices into a robust electronics assembly requires careful consideration over various aspects of the product design and assembly process. Paste printing, including materials, stencil design and machine setup will have the greatest effect on the bottom package to PCB interconnect formation. Top packages must be dipped into a flux or solder paste for soldering to the bottom package, so again material selection and machine setup will affect the solder joints at this stacked level. Finally reflow profile, including ramp rates; temperatures and atmosphere have a general effect on all solder joints.

The work presented here investigates selected aspects of the above mentioned processes to better understand the critical factors associated with successful TMV PoP assembly.

BACKGROUND

Warpage control and overall PoP density advantages for TMV technology were well summarized in a joint paper between Amkor and Sony Ericsson at SMTAI 2008¹. Here surface mount and board level reliability studies, compared a 14x14mm TMV PoP test vehicle with 620 pin bottom BGAs at 0.4mm pitch and a 200 pin top side stacking interface at 0.5mm pitch; to control samples with a bare die flip chip package structure. The TMV technology enabled use of a substantially thinner (90um reduction) four layer substrate for the bottom package vs. the bare die FC control package, while also providing a 2x improvement in warpage control. In addition, this paper reported the TMV technology, provided improvements in board level solder joint reliability (temp. cycle, drop and cyclic bend) vs. the bare die package structure.

What was not reported in this initial TMV PoP paper was the impact the TMV solder column interconnect structure had on the PoP surface mount stacking process and dip material sets. Thus, a second joint project was reported at SMTAI 2009 between Amkor and Celestica to study the impact stacking process conditions and dip materials have with the TMV interconnect structure². Here slight modifications were made to the 14mm 620 / 200 TMV PoP multi-net daisy chain test vehicle (reported in 2008).

The thirty-two 01005 passives surface mounted around the flip chip die were eliminated, enabling use of a thinner bottom package mold cap for an improved TMV solder column structure and lower overall PoP stacked height. Both flux and paste dipping were studied for PoP stacking with the use of nitrogen reflow atmosphere. One failure out of 120 flux dipped packages was reported and one failure out of 330 paste dipped packages was reported in this study through electrical testing.

These studies on TMV PoP validated the application of this technology to emerging high density package stacking requirements. This background work provided a basis for additional public³ and private qualification projects for the commercialization of TMV PoP technology.

TEST MATERIALS

The 14mm TMV PoP test devices include a 620 I/O bottom device at 0.4mm pitch (TMVPS 620) and a 200 I/O top device at 0.5mm pitch (SCSP 200). The TMVPS 620 devices utilize through-molded vias through which the SCSP 200 devices attach. The TMVPS 620 devices are balled with SAC125Ni alloy while the SCSP 200 devices are balled with SAC105 alloy. The TMV PoP test devices are shown in Figure 1.

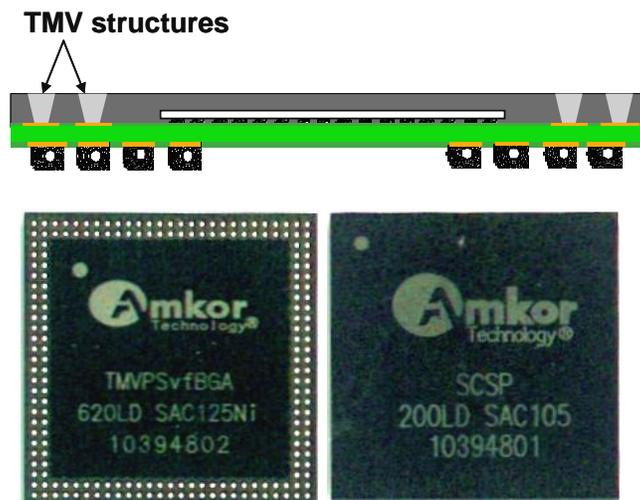


Figure 1. TMV PoP Test devices. Bottom pkg on left.

The benefit of the TMV design is that better warpage control can be realized, which has a direct effect on both the assembly quality as well as ultimate reliability. Both bottom and top packages were analyzed for thermal warpage through a simulated reflow cycle up to 245 °C. The results plotted in Figure 2 show maximum warpage of approximately 40 μm for either device. There is excellent matching of the warpage behavior of the two devices which is critical for stacked package applications.

The test board design is based on the JEDEC JESD22-B111 drop test method⁴. Modifications included reducing layer count from 8 layers (1+6+1 stackup) to 4 layers, and reducing board thickness to 0.8mm from the required 1mm. These changes reduce cost and better reflect current PCB designs in handheld devices. The board finish is OSP over Cu pads. An image of the unpopulated test board is shown in Figure 3.

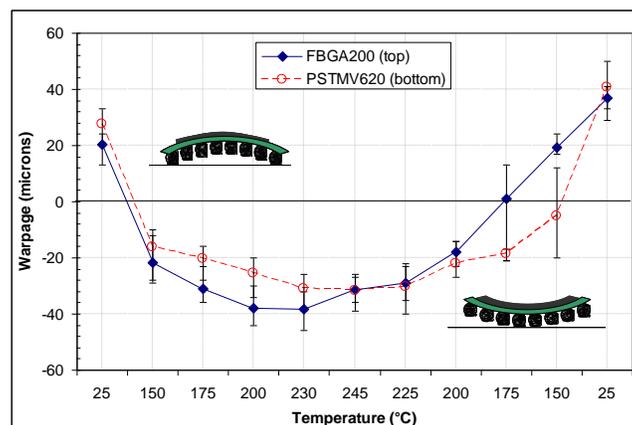


Figure 2. Warpage behavior of test packages during reflow. Values are the average of 3 package measurements.

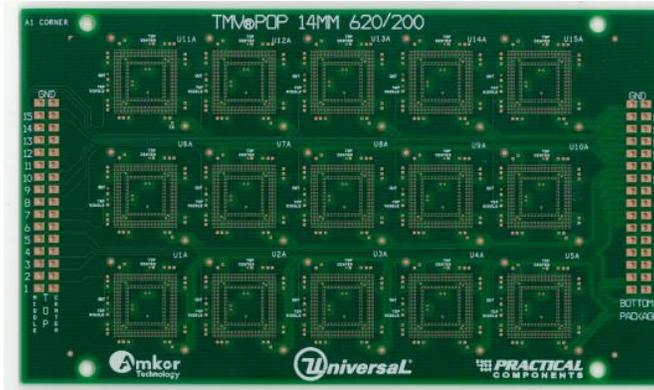


Figure 3. Unassembled test board.

Seven dip materials were acquired and investigated for dip performance and assembly yields. These materials included both tacky flux and solder paste from different manufacturers. The materials are listed in Table 1. All materials are no-clean formulations.

ID	Material Type	Alloy	Powder Size	Metal Content
A	Flux, Non-HF	--	--	0%
B	Flux, HF	--	--	0%
C	Paste, HF	SAC305	Type 5	80%
D	Paste, HF	SAC305	Type 5	80%
E	Paste, HF	SAC305	Type 5	79%
F	Paste, HF	SAC305	Type 6	79%
G	Paste, HF	SAC105	Type 5	79%

Table 1. Listing of materials used in this investigation.

ASSEMBLY PROCESS

The purpose of this study is to document the various aspects of successful TMV PoP assembly including paste printing, component dipping and reflow. Each portion of the assembly process is described in detail below. Component yields and general solder joint formation were used as metrics to define a robust process.

Printing Process

Thorough process development was carried out for each phase of this investigation. Stencil printing for 0.4mm pitch is relatively common, yet stencil designs can be optimized for best assembly and reliability. For this investigation both a 101.6- μm (4-mil) and 127- μm (5-mil) thick stencils were considered. Each stencil thickness incorporated 3 aperture designs, as shown in Table 2. Square apertures were selected over round to maximize the amount of material printed onto the PCB. As a general rule, an area ratio greater than 0.66 is desired for best transfer efficiency. However tighter pitch designs sometimes require lower area ratios to allow the use of thicker stencils and also to prevent solder paste bridging between closely spaced apertures.

Stencil Thickness		Sq. Aperature Size		Area Ratio	Aspect Ratio
microns	Mils	microns	mils		
101.6	4	225	8.9	0.554	2.2
101.6	4	254	10.0	0.625	2.5
101.6	4	280	11.0	0.689	2.8
127	5	225	8.9	0.443	1.8
127	5	254	10.0	0.500	2.0
127	5	280	11.0	0.551	2.2

Table 2. Six stencil designs evaluated.

Three pastes were used to investigate the stencil configurations, including SAC305 Type 4, SAC305 Type 5 and SAC105 Type 4. The data shown in Figure 4 summarizes the printing trials in terms of volume transfer for the SAC105 Type 4 paste. Each stencil configuration includes ten print trials, with each trial representing the volume of material printed onto 9300 pads.

Process stability was achieved after 3-5 prints, which were required to fully lubricate the aperture walls. The 127- μm (5 mil) stencil did not provide good process control as indicated by the wide scatter for any given print trial. It should be noted that the greatest area ratio for this stencil thickness was 0.55, well below the target limit of 0.66. The 101.6- μm (4 mil) stencil provides much tighter volume distribution for any given print trial. The 280- μm apertures achieve the greatest volume transfer and desired area ratio (0.69) however certain cases showed signs of potential bridging defects so the 254 μm apertures were selected for final assembly. Examples of the print deposits are shown in Figure 5.

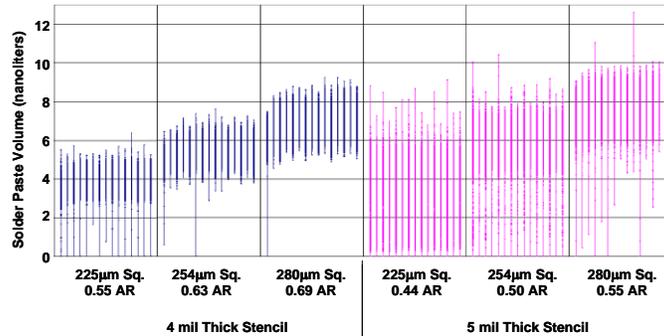


Figure 4. Printed Paste volume for various stencil designs using SAC105 type 4 paste.

Dipping Procedure

There are several factors to consider when developing a robust flux or paste dipping process including both dip material properties and equipment settings. The film thickness, dip speed (both insertion and extraction), dip force, dwell time in the film and finally nozzle design can all contribute to a successful dip process. Table 3 outlines the risk for selected machine settings. For simplicity and to best simulate production tempo while minimizing cycle time, only the film thickness was varied in this investigation to arrive at the optimum settings for assembly. All dipping was performed on a linear thin film applicator (LTFA) that was integrated into the placement machine.

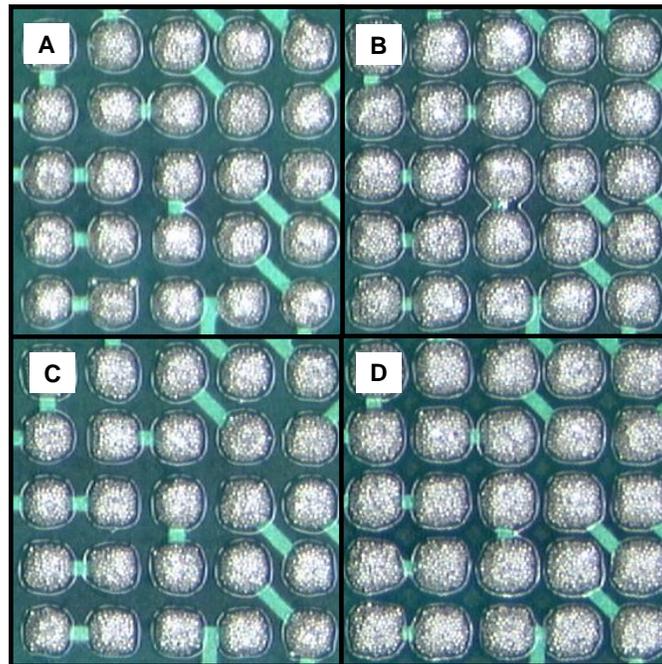


Figure 5. Print deposits using SAC305 Type 5 paste. A) 127- μm stencil/254 μm apertures, B) 127- μm stencil/280 μm apertures, C) 101- μm stencil/254 μm apertures, D) 101- μm stencil/280 μm apertures.

Machine Setting	Risk
Film Thickness	Too Low: Inadequate material transfer Too High: Bridging, or parts stick in dip film
Dwell Time	Too Low: Inadequate material transfer Too High: Bridging, parts stick in film, lower throughput
Dip Force	Too Low: Inadequate material transfer Too High: Bump Coining
Extraction Speed	Too Low: Reduced throughput Too High: Parts stick in film
Nozzle Design	Too small nozzle or weak vacuum and parts may not be extracted from dip film.

Table 3. Selected machine settings and potential consequences.

The optimum film thickness of each material was determined by trial runs on several applicator plate thicknesses. The initial target was to achieve 50% material coverage on the solder balls of the SCSP 200 device while at the same time preventing any devices from sticking within the film. Bumps heights were measured to be approximately 300 μm , so a nominal dip thickness of 150 μm was desired. It should be noted that actual film thickness may not correlate to material transfer thickness due to material factors such as tack and elasticity. In many cases a thicker film is required to transfer an adequate amount of material. Visual inspection and weight measurement were used as indicators of the stability of the process. Figure 6 shows the average weight transfer for each material using the optimized film thickness. The data shown is the average of 5-8 measurements. Notably, the flux materials (A & B) results in much less weight transfer due to the absence of metal. Figure 7 shows examples of the material transfer onto the SCSP 200 device. Figure 8 shows an example of a film that was too thick. In this last case paste material came into contact with the package substrate creating a potential for bridging defects during assembly.

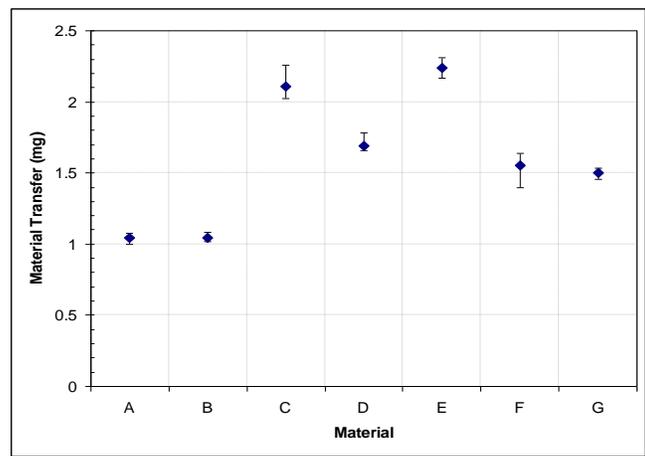


Figure 6. Material transfer by weight for optimized dip thickness for each material.

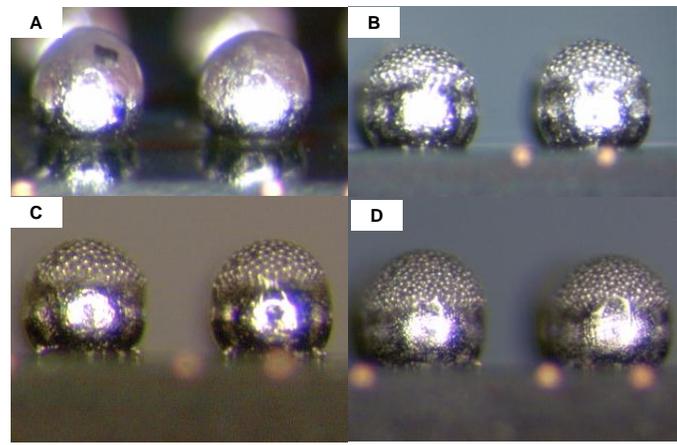


Figure 7. Material transfer for various conditions. A) Flux A using a 127-150 μm thick film; B) Paste C using a 127-150 μm thick film; C) Paste D using a 150-178 μm thick film; E) Paste F with a 178-203 μm thick film.

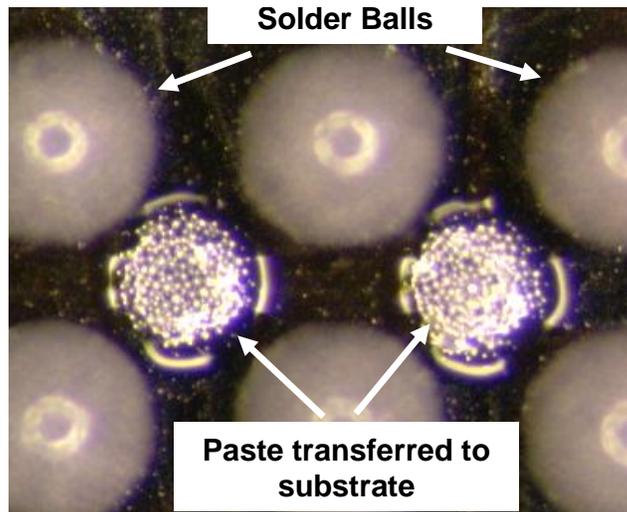


Figure 8. High film thickness with 12-mil plate resulted in material also being transferred to substrate using Material F (SAC305 Type 6).

Dip flux materials easily achieved the target 50% ball height and none of the flux dipped trials resulted in the packages not being extracted from the film. Dip paste materials required a better balance between film thickness and the ability to extract the SCSP 200 package from the paste film. Paste material C (HF, SAC305 Type 5) required a lower film thickness than desired due to many parts “sticking” in the paste film. Alternatively, paste material E required a higher film thickness to achieve the target material coverage. Even at the increased film depth, this particular material did not result in packages sticking in the film during extraction. These two examples illustrate the balance between material transfer and component extraction from the dip material. Table 4 outlines the optimized settings that were determined during extensive characterization trials. All film thickness measurements were made using a wet film thickness gauge.

Material ID	Measured Film Thickness μm (mils)	Avg. Weight Transfer mg	Approx. Material Depth (% of ball height)
A	127-150 (5-6)	1.05	40%-50%
B	127-150 (5-6)	1.04	40%-50%
C	127-150 (5-6)	2.11	30%-40%
D	150-178 (6-7)	1.69	30%-40%
E	178-203 (7-8)	2.24	40%-50%
F	150-178 (6-7)	1.56	40%-50%
G	150-178 (6-7)	1.50	40%-50%

Table 4. Film thickness and material transfer amount for each material.

Assembly Results

All boards were printed with the same SAC305 Type 5 solder paste using a 101.8- μm (4 mil) stencil and 254 μm apertures as determined from the printing process development. Assembly was performed in a 10-zone convection reflow oven with a peak temperature of 239-243 $^{\circ}\text{C}$ and 80 seconds above reference temperature (217 $^{\circ}\text{C}$), as measured on a populated setup board. Both air and nitrogen reflow atmospheres were evaluated for assembly yields. Nitrogen reflow was defined by less than 50 ppm O_2 in the full tunnel.

Thirty devices were assembled for each dip material and reflow atmosphere. After assembly each device was measured for electrical continuity. Table 5 and Table 6 show the assembly yields for both air and nitrogen reflow atmospheres. For the sake of simplicity all TMVPS 620 packages were grouped together for each reflow atmosphere since the dip material does not affect the bottom package soldering.

Air Reflow Atmosphere				
Device	Dip Material ID	Number of Devices Assembled	Number of Devices Open	Yield
FPBGA	A	30	0	100%
	B	30	0	100%
	C	30	12	60%
	D	30	14	53%
	E	30	25	17%
	F	30	25	17%
	G	30	17	43%
PSTMV620	All	210	4	98%

Table 5. Assembly yields for Air Reflow

Nitrogen Reflow Atmosphere				
Device	Dip Material ID	Number of Devices Assembled	Number of Devices Open	Yield
FPBGA	A	30	0	100%
	B	30	0	100%
	C	30	0	100%
	D	30	0	100%
	E	30	0	100%
	F	30	0	100%
	G	30	0	100%
PSTMV620	All	210	0	100%

Table 6. Assembly yields for Air Reflow

DISCUSSION

The air reflow atmosphere clearly shows a preference for flux dipping over paste dipping. This suggests that the oxides which may be present before assembly or form during reflow cannot be adequately removed by the limited flux provided by solder paste dipping. Therefore poor wetting occurs, and solder joints do not properly form. Figure 9 and Figure 10 show the X-Ray and cross-sectional images respectively, of the solder joint formation of Material C (SAC305 Type 5 paste) in air reflow. There is clear non-coalescing of the SCSP and TMV solder balls, creating a failure mode similar to head-in-pillow. Figure 9 shows that all joints along the outer edge exhibit similar formation, suggesting that package warpage is not an issue. The X-ray image in Figure 11 shows the formation of the solder joints using a flux dip (Material A) in air reflow. In this case the TMV solder joints coalesce and form the expected column shape.

A nitrogen reflow environment produces better yields because oxides do not readily form on the unprotected TMV solder balls during reflow. This allows better wetting and coalescing of the solder during reflow, producing better solder joints. The results show that all dip materials achieved the same assembly yields; in this case 100% of the devices that were assembled were functional. Figure 12 and Figure 13 show the N₂ reflow counterpart to Figure 9 and Figure 10. The desired columnar TMV joint formation is achieved with N₂ reflow

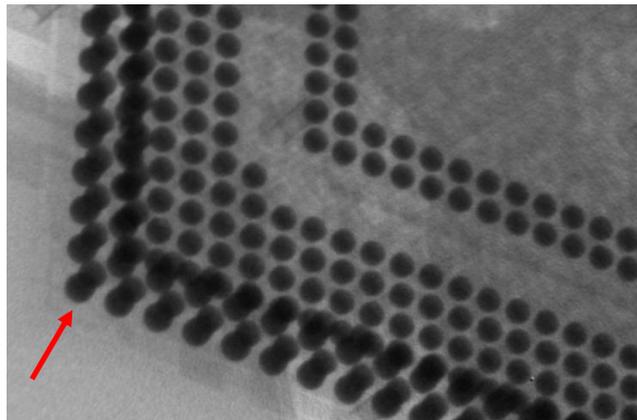


Figure 9. X-Ray image of TMV solder joints showing non-coalescing solder balls. Dip Material C (SAC305 Type 5 Paste), Air Reflow.

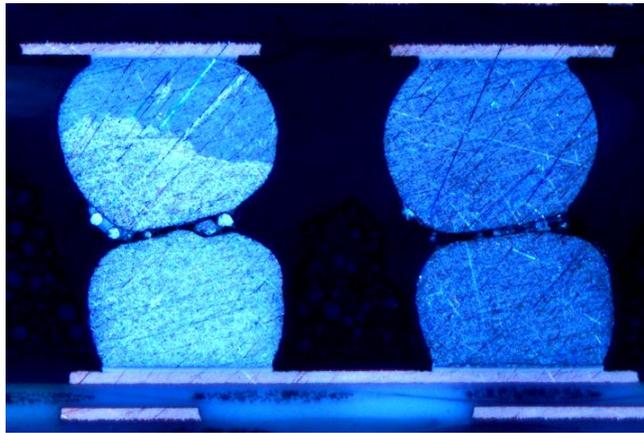


Figure 10. TMV solder joints formed using Material C (SAC305 Type 5 Paste) in Air reflow.

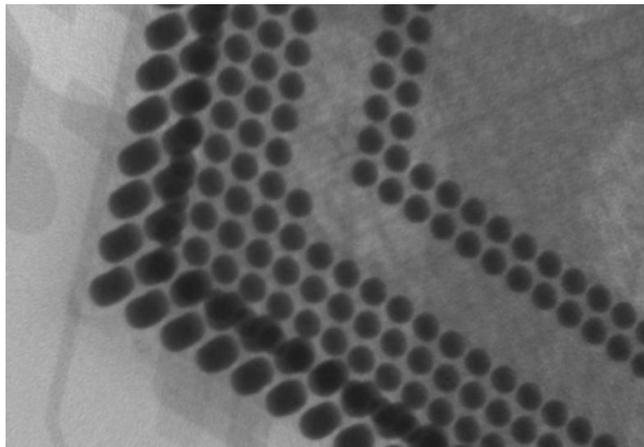


Figure 11. X-Ray image of TMV solder joints showing good coalescing. Dip Material A (Non-HF Flux), Air Reflow.

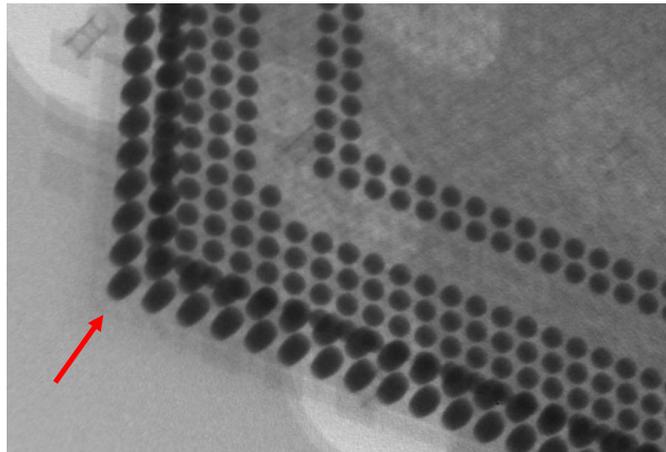


Figure 12. X-Ray image of TMV solder joints showing good columnar formation. Dip Material C(SAC305 Type 5 Paste), N₂ Reflow.

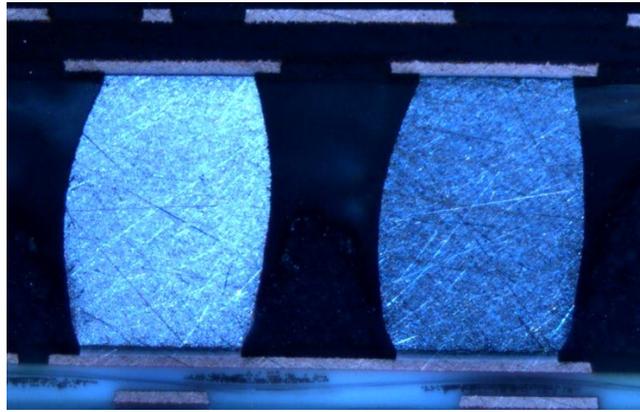


Figure 13. TMV solder joints formed using Material C (SAC305 Type 5 Paste) in N₂ reflow.

FUTURE WORK

Following the results of this study, selected samples will be placed into reliability test to better gauge the quality of the solder joints formed with different dipping materials. Both accelerated thermal cycling and drop/shock testing are planned. In addition, further process optimization is taking place to increase the yields on the air atmosphere reflow samples. The results of these efforts will be published at a later date.

CONCLUSIONS

The successful integration of PoP using TMV technology relies on careful attention to each aspect of the assembly process. Most of the attention is focused on soldering the top package to the bottom package because this relies on either a flux or paste dip process. Consideration over the material selection, film thickness and other machine variables is necessary to achieve best results.

Seven dipping materials, including two fluxes and five solder pastes, were investigated. Machine parameters were optimized for each material by setting a target of 50% ball coverage of the dip material, while preventing any parts from being stuck within the dip film. This exercise is necessary when evaluating new materials.

In this investigation, assembly yields were highly influenced by the reflow atmosphere. Nitrogen atmosphere produced 100% yields of both top and bottom packages for every material used in the study. Air reflow atmosphere resulted in non-coalescing TMV solder joints when the SCSP 200 package was dipped into solder paste. This is presumably due to oxide formation on the unprotected TMV solder ball which is not sufficiently removed with the minimal flux available in dipping solder paste. Five different dip pastes were used with varying degrees of success, while the flux dipped samples achieved excellent yields in air reflow. Additional efforts are taking place to enhance the assembly yields in air reflow, and ultimately quantify the reliability of these devices as a function of the assembly process and material selection.

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