3D and 2.5D Packaging Assembly with Highly Silica Filled One Step Chip Attach Materials for Both Thermal Compression Bonding and Mass Reflow Processes

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Abstract

One Step Chip Attach (OSCA) materials are chemically engineered organic fluids that function both as underfills and fluxes for flip chip assembly. These emerging materials chemically remove solder oxides and surface finishes to facilitate soldering during reflow while simultaneously curing to form a rigid reinforcing polymeric underfill that improve the reliability of the finished product. The key advantage of OSCA is a reduction in the number of steps in the assembly process, which naturally results in faster cycle times and more efficient flip chip assembly. With suitable chemistry, fillers and the correct filler loading, OSCA materials are dispensable and capable of achieving high yield and reliability. OSCA materials may be designed for use in thermo-compression bonding (OSCA-T) and in more standard mass or gang reflow (OSCA-R), the choice of process depending on the package functionality and design requirements.

This paper shares information on the properties and processing techniques of OSCA materials and explores the assembly data concerning control of solder wetting, over collapse, voiding, and HAST behavior. Data will be presented from testing at the material level and from testing of micro bumped lead free Silicon to Silicon vehicles designed to simulate chip to wafer or chip to chip bonding. Challenging loadings of up to 65% silica with distributions as low as 0.5 micron average particle size will be shown at both the assembled and material level.

1.0 Introduction

The need for continued increase in interconnect density in advanced microelectronics packaging, like mobile computing applications for example, is driving the need for new assembly process and materials. [1][2] **Traditional** flip chip assembly fluxes bumps and reflows ICs, which is then followed by a capillary underfill process [3] as shown schematically in Figure 1. However, demand for smaller and thinner ICs with reduced power consumption and greater functionality requires smaller bumps and chip standoff heights and finer bump pitches. With smaller bumps and standoffs and high bump density, getting enough flux onto bumps to ensure all bumps are soldered is important. However, overfluxing to ensure all bumps are fluxed can result in flux residues that interfere with the underfill flow and adhesion with no clean processes. With water soluble fluxes fine bump pitches and low standoff heights can make cleaning very difficult at best, increasing the cleaning process costs and/or cycle time and at worst it may be impossible to fully remove all of the flux residue prior to underfilling.

One Step Chip Attach Materials (OSCA) have been proposed as a solution to these issues by combining the functionality of a flux prior to curing and an underfill after curing. These materials have the advantage of combing two materials into one and removing the problems of flux interference or flux cleaning. The OSCA materials need to be tuned for the desired assembly process: the newer Thermo-Compression Bonding (TCB) or the more traditional mass reflow. The process flow of the OSCA materials is shown schematically in Figure 2 below. The OSCA-T path shows the process for TCB, while the OSCA-R path shows the process for mass reflow.

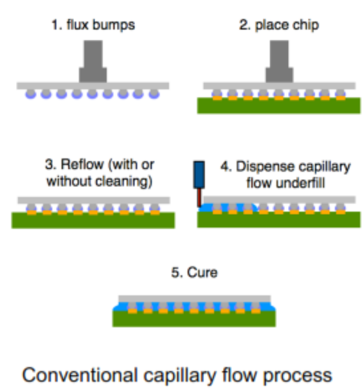


Figure 1: Traditional Flip Chip Assembly Process

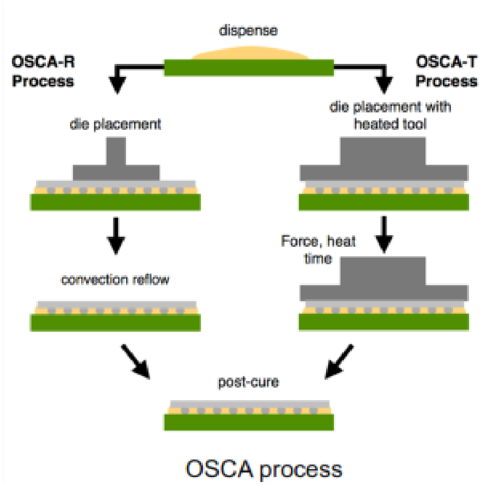


Figure 2: New OSCA Material Flip Chip Assembly Processes

TCB can be used for thin, small pitch ICs with solder bumps or copper pillars for which traditional chip attach processes suffer from die misalignment. The TCB process can be used for various types of assembly including Die to Wafer (D2W), 2.5D Packaging, 3D Packaging, and die to substrate (D2S) which all require different thermal profiles. Materials properties such as curing kinetics, fluxing activity, and viscosity all need to be optimized for the intended process and tool capabilities to give good results. The materials described in prior works for focused on mass reflow processing [4][5][6] do not work well with the rapid TCB processes.

This paper explores the assembly of solder bumped test chips with epoxy-based materials specifically designed for either TCB or mass reflow. Two Kester materials will be presented for TCB processes in this paper. One for processes requiring potentially long pre-staging time, long working life, and wider process windows, and another for operations more focused on shorter cycle times and maximizing throughput. In the following sections, details of the test chips, materials, assembly and reliability tests are given followed by a description of the main test results and their interpretation.

2.0 Experimental Details

2.1 Mechanical Test Chip for TCB and Mass Reflow

A solder bumped mechanical test vehicle was used for TCB and mass reflow assembly experiments. Specifics of the mechanical test vehicles are contained in Table 1.

Table 1: Mechanical Test Chip Characteristics

Property	Test Vehicles		Unit
	Vehicle 1	Vehicle 2	
Die Material	Silicon	Silicon	NA
Substrate Material	Silicon	FR4	
Die Passivation	Silicon Oxide	Silicon Oxide	
Die Solder	SnAg3	SnAg3	
Substrate Pad Metallurgy	Copper	SnAg3	
Die Bump Height	40	90	microns
Die Bump Diameter	60	80	
Die Bump Pitch	100	250	
Die Thickness	750	750	
Die Dimensions	10x10	6x6	mm

2.2 TCB Materials and Assembly Process

Uncured material properties are shown in the Table 2. Material A is the wider process window material and material B is the material designed for faster throughput and for improved HAST performance and will be described in more detail later in the paper. Mechanical builds of test vehicle 1 were made with OSCA Material A. The material was dispensed with a 21-gauge stainless steel needle with an Auger style pump. A SET FC150 Bonder was used to assemble chips using the bonding profile in Figure 3. The following process was programmed to prevent over collapse of the solder bumps. After bonding, assembled chips were post cured at 180°C.

The properties of the uncured OSCA material are shown in Table 2. Material A is the wider process window material and Material B is the material designed for faster throughput and for improved HAST performance and will be described in more detail later in the paper. The properties of the cured OSCA materials for use in TCB processing are shown in Table 3.

Table 2: Uncured properties of OSCA Materials for TCB

Property	Material A Value	Material B Value	Units	Method
Viscosity at 75C	25	40	Poise	Brookfield, 5 RPM
Complex Viscosity at 25C	29	38	Pa-sec	Oscillatory Rheometer
Dispense Temp Range	20 -70	20-30	C	
Filler Content	65	65	wt %	TGA
Avg. Filler Size	0.5	0.5	micron	
Max Filler Size	2	2	micron	
Density	1.7	1.7	g/cm^3	Liquid pycnometry
Pot life at 25C	>8	5	hours	Dispensing R&R
Pot life at 25C	>8	2	hours	+25% in viscosity
Appearance	White	White		

Property	Material A Value	Material B Value	Units	Method
Tg	117	129	C	TMA inflection
CTE1	29	28	ppm/C	TMA
CTE2	91	92	ppm/C	TMA
Modulus	5.813	Pending	GPa	ASTM D790
Stress at Break	91	Pending	MPa	ASTM D790
Strain to Break	2.3	Pending	%	ASTM D790
Fracture Toughness K1C	2.7	Pending	MPA(m)$^{0.5}$	ASTM D5045
Density	1.7	1.7	g/cm^3	Gas pycnometry
Cure Shrinkage	0.9	0.9	%	
Thermal Conductivity	0.52	Pending	W/m-K	ASTM 1461
Die Shear	50	80	kg-f	J-STD
Die Post HAST 50 hr	35	76	kg-f	J-STD

Table 3: Cured Properties of OSCA Materials for TCB

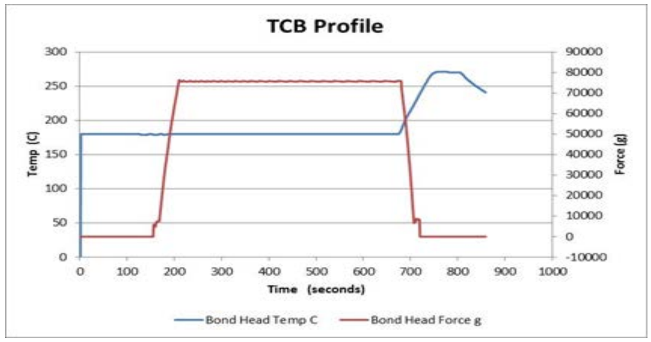


Figure 3: TCB Process for Vehicle 1 builds with Material A.

2.3 Mass Reflow Materials and Assembly Process

OSCA materials for mass reflow are of interest to develop for end markets in need of high device throughput. However, restrictions on using chemicals such as organometallics, along with the drive for smaller geometries have prompted a need to develop new materials that improve upon the previous generation of materials. [7] The uncured properties of the OSCA material for mass reflow are listed in Table 4 and the cured properties are listed Table 5. The material was dispensed with a 21-gauge stainless steel needle with an Auger style pump. A SET FC150 Bonder was used to pick and place chips. Test vehicle 1 was used. After placement chips were reflowed as shown in Figure 4. After bonding, assembled chips were post cured at 180°C.

Table 4: Un-Cured Properties of the OSCA Materials for Mass Reflow

Property	Material C Value	Units	Method
Viscosity at 25C	0.9	Pa-s	Brookfield, 5 RPM
Dispense Temp Range	18-25	C	
Filler Content	40	wt%	TGA
Avg. Filler Size	0.5	micron	
Max Filler Size	2	micron	
Density	1.2	g/cm^3	Liquid pycnometry
Pot life at 25C	8	hours	+25% in viscosity

Table 5: Cured Properties of the Cured OSCA Material for Mass Reflow

Property	Material C Value	Units	Method
Tg	141	C	TMA inflection
CTE1	77	ppm/C	TMA
CTE2	217	ppm/C	TMA
Modulus	488	MPa	ASTM D638
Tensile Strength	23	MPa	ASTM D638

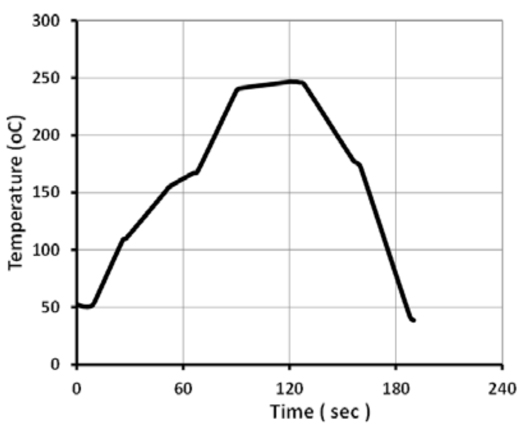


Figure 4: Mass Reflow Profile used in the Assembly Process

2.4 Scanning Acoustic Microscopy (CSAM)

After assembly a Sonoscan Gen5 innovative acoustic imaging system was used to look for assembly defects in the assembly.

2.5 Die Shear Testing

The die shear was performed 6mm square blank die were bond to silicon substrates with a 50-micron spacer. The shear test was performed using a Dage 4000 with a DS100 kg cartridge operated at a test speed of 25 mils per second.

3.0 Results and Discussion

3.1 TCB Materials

A representative example of a test chip bonded using the TCB process and Material A in Figure 5 shows that the solder balls appeared exhibited the typical barrel shape of a well interconnected ball-pad joint. There was some variation in collapse height. Different collapse heights were observed due to the difficulty in evenly removing pressure to prevent over collapse during the ramp to liquidus, although this is not expected to be a problem with a solder capped copper pillar bump because the pillar height controls the standoff height. An SEM image in Figure 6 shows a relatively uniform intermetallic layer was formed after the TCB process. Assembled modules were analyzed by CSAM for voiding after assembly and post cure. Typical examples in Figure 7 show that neither voids nor filler or organic entrapment or filler separation were seen within the solder bump or interfaces.

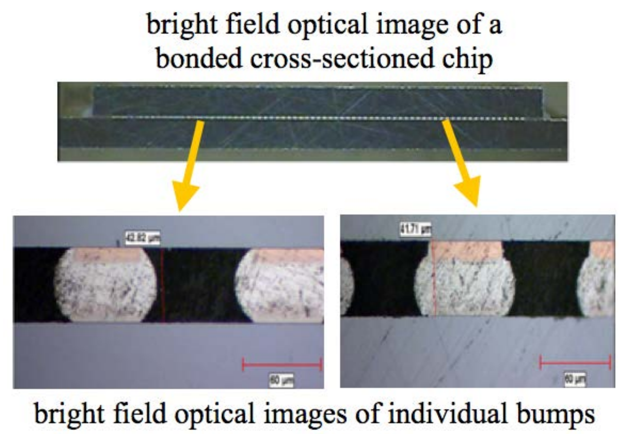


Figure 5. Optical images of a bonded cross-sectioned chip with close up views of individual bumps. Bonded with Material A.

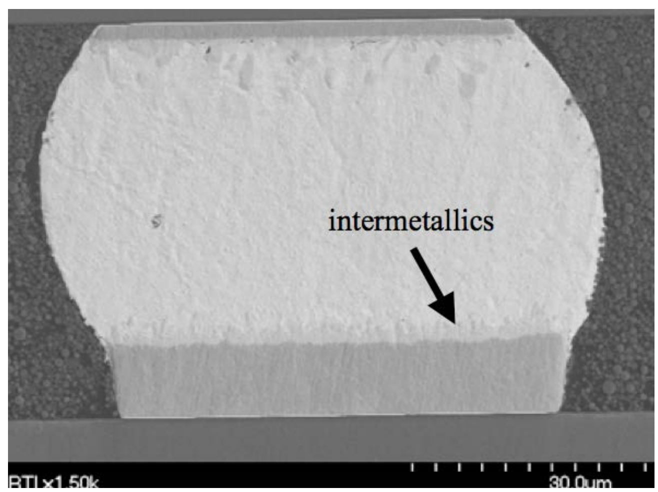
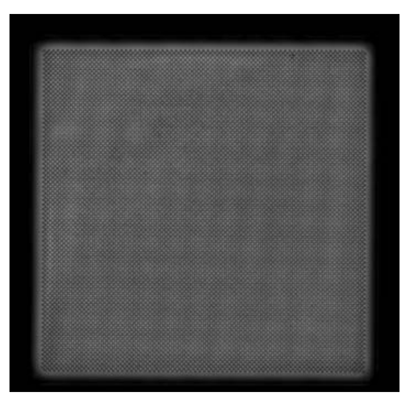
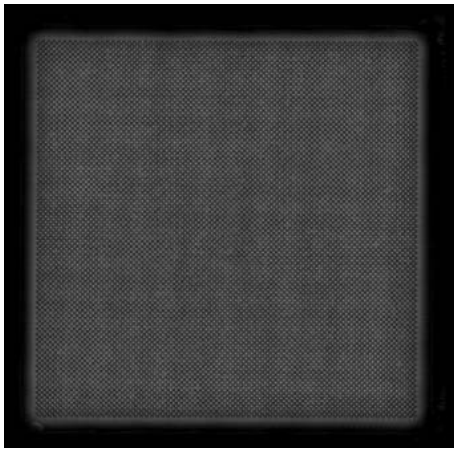


Figure 6. An SEM image of a typical solder bump after the TCB process. Bonded with Material A.



(a)

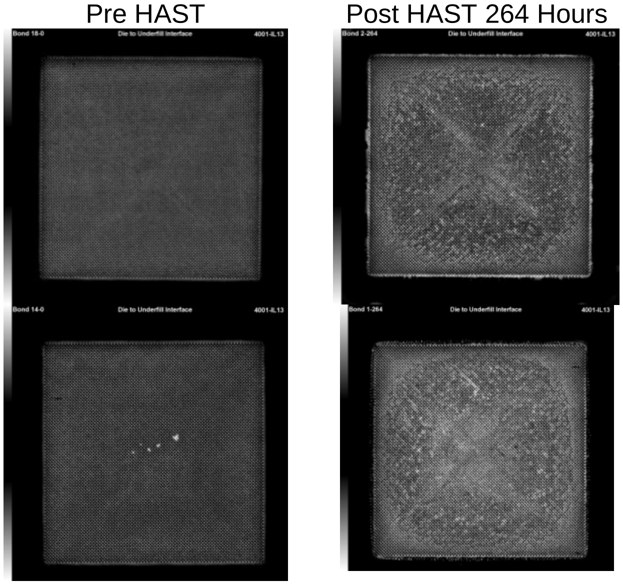


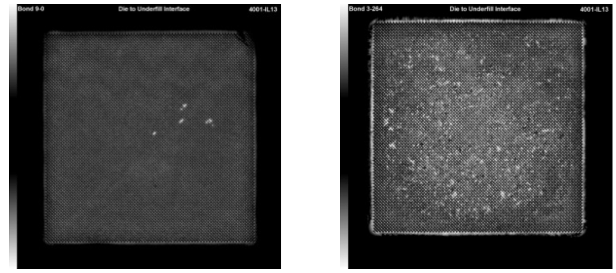
(b)

Figure 7. CSAM images of Test Vehicle 1 assembled with Material A after post cure.

After confirming void free assemblies after post curing, further chips were assembled with Material A and subjected to J-STD HAST testing at 121°C/2 atm/100% RH and were examined using CSAM. The CSAM images in Figure 8 show some voids at time zero due to air entrapped during dispensing of the material. After 264 hours, the CSAM images show some voiding as well as the "X" shape corresponding to the geometry on the bond head. The voiding after 264 hours of HAST does show the moisture in the HAST chamber is penetrating into the assembly and degrading some of the chemical bonds. The glass transition temperature of Material A is 117°C (Table 3) which is below the IPC HAST chamber meaning that the polymer network was in an expanded state, making penetration of moisture into the assembly easier.

Pre HAST Post HAST 264 Hours





(a) (b)

Figure 8. CSAM images of Vehicle 1 at (a) 0 and (b) 264 hours of IPC HAST conditions. Bonded with Material A.

Die shear test results in Figure 9 show that the die shear strength started to decline at 75 hours and continued to decrease until 240 hours. This is consistent with the penetration of moisture into the package, which most probably attacks the chemical bonds between Material A and the substrate and/or die surfaces.

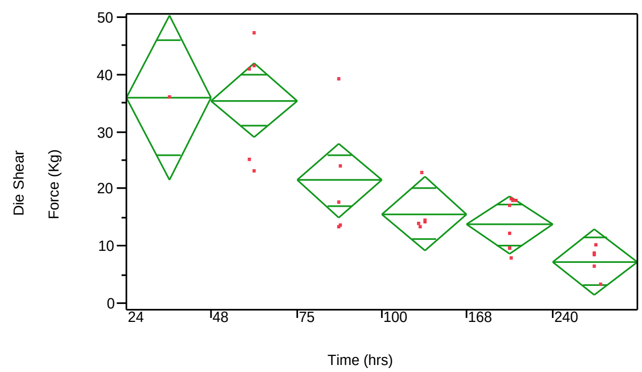


Figure 9. HAST performance of Material A in Die Shear

Material B was developed with two ideas in mind: minimizing the time in the bonder and improving performance in the HAST chamber. A four minute b-staging process at 110°C was done after dispensing but before placement prior to bonding, for 4 seconds at 250°C. The bonding profile is shown in Figure 10.

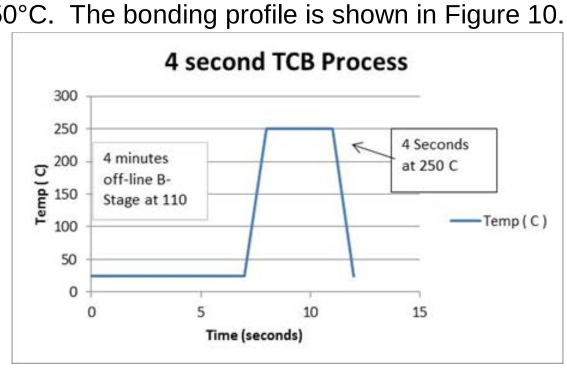


Figure 10. TCB profile for decreased cycle time of Material B.

In addition to the mechanical builds in shown above, die shear samples were also made with material A to quantify the adhesion strength. The die shear testing was done with a 5x5mm square die to a blank silicon substrate. A standoff height of 25 microns was obtained through the use of glass spacer beads. The CSAM images of the die shear samples of Material A and Material B are shown in Figure 11. It is clear from the images that Material B has held up better than Material A after 264 hours.

Pre HAST Post 264 hours

Material A

Material B

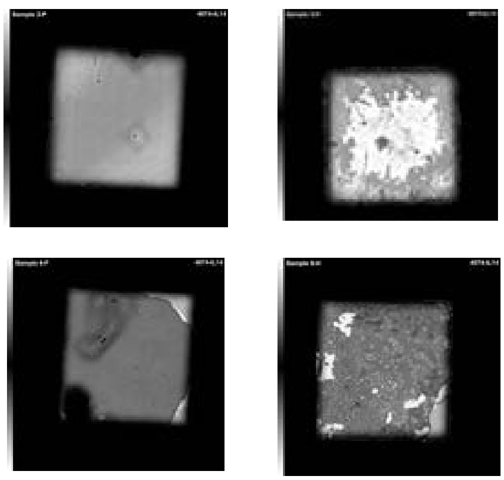


Figure 11. CSAM Image of the Die Shear Assemblies of Material A and B pre and post HAST.

The die shear force of Material B after HAST in Figure 12 also degraded with time. Figure 13 shows that the die shear strength of Material B degraded slightly less than Material A.

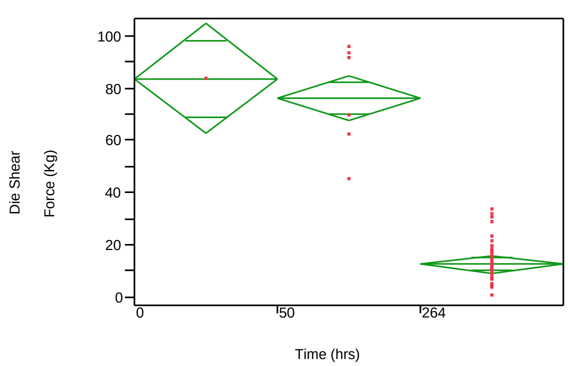


Figure 12. HAST performance of Material B in Die Shear

Figure 13 shows a comparison of the 48 and 50 hour test HAST die shear results for A and B respectively, and shows that Material B did increase the HAST performance by increasing the glass transition temperature. A comparison of the process times for Material A and B is shown in Table 6.

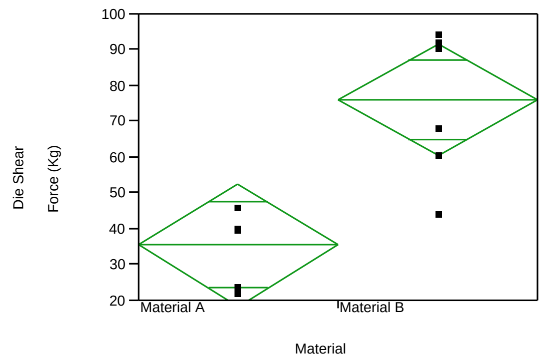


Figure 13. HAST Die Shear Comparison of Material A and B.

Table 2. Process Comparison for Material A and B.

	Material A	Material B	Unit
Time in the TCB Bond Step	120	4	seconds

Good solder ability was observed after cross-sections and is shown in the images below for Test Vehicle A in images 6, 7, and 8. Note the dark spots are not filler entrapment, nor voids, but diamond grit from the cross-sectioning.

3.2 Mass Reflow Materials

Low and high magnification SEM images of cross-sectioned chips are shown in Figure 14 and Figure 15 respectively. Good Intermetallic formation is seen to the copper substrate pad and even wetting down the side of the copper pad showing that the OSCA material had not gelled during this process. The dark masses in the solder joint are not voids, but rather artifacts of the cross-section sample preparation. A typical CSAM image in Figure 16 shows the test assemblies did not shown any voids.

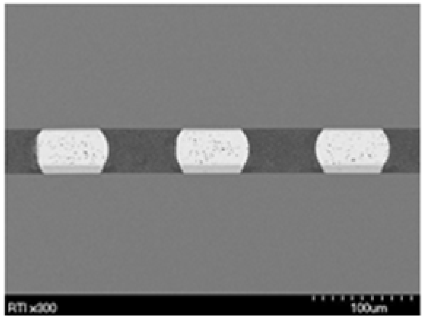
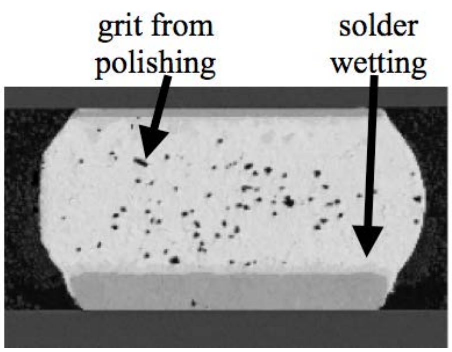
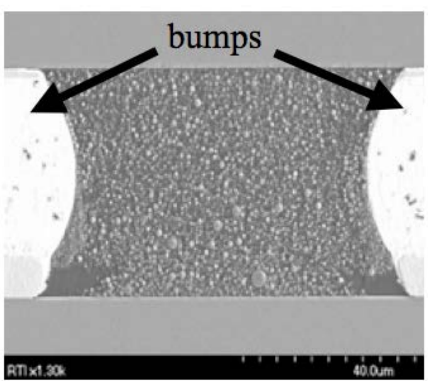


Figure 14. Cross Section of Vehicle 1 with Material C.



(a)



(b)

Figure 15. Cross Sections of Vehicle 1 with Material C.

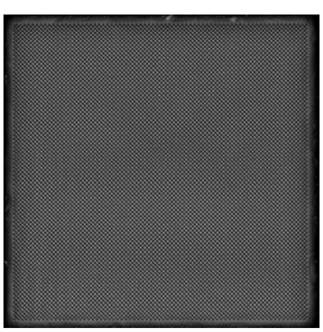
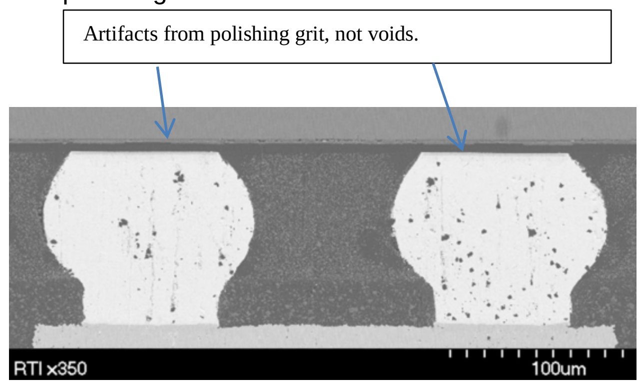


Figure 16. CSAM of Test Vehicle 1 built with Material C.

The same process was then applied to the Mechanical Test Vehicle 2 and its FR4 based substrate. A cross section is shown below in image 10 and 11. Good wetting of the solder to solder is observed, (Note the dark spots are not voids or entrapment but diamond grit from the polish process). Excellent solder to solder wetting of the solder to solder is observed, (again note the dark regions are diamond grit artifacts from the cross section polishing.



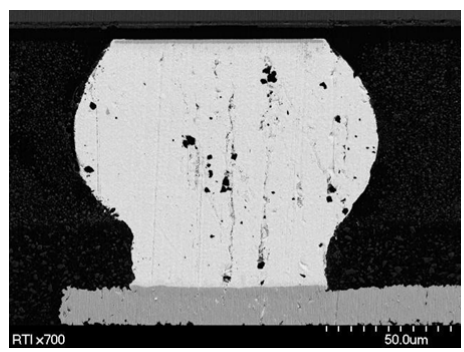


Figure 17. Cross Sections of Test Vehicle 2 with Material C.

These FR4 substrates were outgassed by preheating to drive out any volatile components prior to processes. This pre heating was done in Nitrogen to minimize any oxidation of the metal surfaces of the substrate. A reduction in volatiles was observed by processing the substrate through a 150°C bake out and the entire reflow profile, however it was not eliminated. A comparison of the outgassing is illustrated below of optical images of the substrate when processed with a clear glass cover slide over the OSCA material.

No Substrate Degassing Substrate Degassing

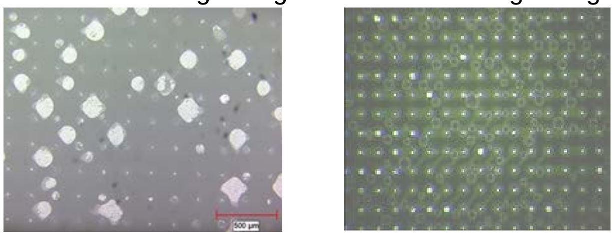


Figure 18. Vehicle 2 Substrate Outgassing Images.

This outgassing of the substrates clearly helped to reduce the number of voids observed, however it is did not eliminate them. With this conclusion, that the outgassing of the substrate could not be completely eliminated, further work will be conducted on non-FR4 substrates such at BT, or silicon interposer. Reliability testing such as HAST was not performed on these samples due to substrate outgassing and the detrimental effect it would have on the assemblies.

Conclusions

OSCA materials for both TCB and mass reflow processes have been introduced. Solderability has in a TCB processes have been shown with two different materials tuned for processes at the extremes of 120 to 4 second bonds. CSAM images have shown void free assemblies with both of these processes with these tuned materials to the process with filler loading up to 65%. HAST data up to 264 hours was presented, along with CSAM images after testing. Material B with a Tg greater than the test condition had a better HAST performance than the Material A whose Tg was 117 C.

Mass reflow solderability has been shown with 40% loading. Void free assemblies were shown on Silicon substrates, however outgassing from organic FR-4 based substrates were entrained in the OSCA-R material.

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Sonoscan, Elk Grove Village, IL

Illinois Tool Works Tech Center, Glenview, IL:

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