Use of Soldered or Glued PCSB as Interconnection between PCB and Ceramic Package in Harsh Environment

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Abstract

Polymer Core Solder Balls (PCSB) have been used as interconnects between a 16 pin leadless chip carrier (LCC) ceramic package and a small FR4 board. A comparison was made between two different volumes of SnPb solder and an isotropic conductive adhesive (ICA) for the attachment of the PCSB to the board and to the package. Shear testing and electrical measurements were performed to characterize the interconnects as bonded and during thermal shock cycling (TSC) tests. No significant reductions of the measured fracture forces was observed for any of the sample groups. However, using a larger volume of solder or ICA resulted in less degradation of interconnect resistance during TSC, and the results for the solder were overall better than for ICA.

Key words: PCSB, ICA, Solder, Environmental tests, Interconnects, Reliability

Introduction

Several studies have been published about the advantages of using Polymer Core Solder Balls (PCSB) instead of traditional solder balls for interconnects between substrate and package if large thermomechanical stress or severe mechanical loads are predicted during application [1-4]. The use of PCSB shows improved reliability performance during thermal cycling tests and in drop tests. Movva and Aguirre [2] demonstrated a two to three times improvement in reliability using PCSB. Yeng-Ping et al. [4] demonstrated improved reliability using PCSB in drop test compared to lead free solder balls.

The increased performance shown by using PCSB is related to an increased mechanical compliance between the substrate (usually a PCB) and the package. In addition, using PCSB offers a well-controlled stand-off height after reflow, which for instance is favourable in the case of RF applications.

Figure 1 shows an overview of the electronic system that is under development in this work: an FR4 board containing electronic components assembled using PCSB to a 16 pin leadless chip carrier (LCC) from Kyocera. The PCSB have a dual usage, both for facilitating interconnects between the FR4 board and the ceramic package and for a well-controlled stand-off height between the two parts, ensuring sufficient space for electronic components located on the backside of the FR4 board (not visible in the sketch). It is a requirement that the system shown in Figure 1 should survive accelerations exceeding 60 000 g, when properly packaged.

The PCSB used were provided by Conpart, and had a polymer core diameter of 650 µm, a 20 µm thick layer of electroplated copper followed by a 3 µm thick layer of electroplated nickel and then a thin flash of gold. The specific stack of metal layers has been developed for soldering with an added solder paste, or attachment by use of an isotropic conductive adhesive (ICA), as an alternative.

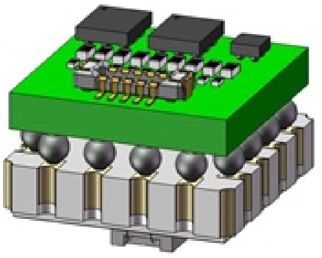

Figure 1: Sketch of the electronic system showing the FR4 board, the PCSB and the ceramic LCC package.

In the majority of recently published studies, the PCSB have been lead free soldered. In this study, the PCSB were either soldered using a solder paste containing lead, or glued using ICA developed by Conpart. The purpose of this study was to compare the electrical resistance and the shear strength of the interconnects, as bonded and after thermal shock cycling tests, for the soldered vs. the glued PCSB.

Sample preparation

Two PCBs were designed for different purposes. The PCB designed for shear tests included single solder points for assembly and shear tests of individual PCSB, as shown in the middle of Figure 2 (numbered 1-24).

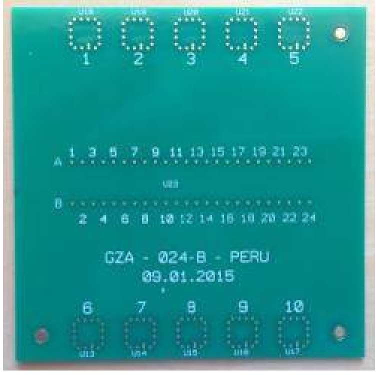

Figure 2: PCB designed for shear tests.

The board designed for electrical testing is shown in Figure 3. The board was designed to measure 28 individual interconnect resistances using Kelvin structures (four packages) and two daisy chain structures each containing four 16 pin ceramic packages (thus with 64 interconnects for each daisy chain). In total, 12 ceramic packages could be assembled onto this board.

Figure 3: Board for Kelvin (left) and daisy-chain (right) measurements.

The solder paste and the ICA were jetted onto the boards and PCSB using a MY 500 jet printing machine. Conpart formulated a custom designed prototype ICA, since there was no commercially available ICA for use in the MY 500 machine. The conductive part of the ICA was made of 5 µm metal coated polymer spheres (MPS). In this case, a 240 nm thick silver layer was used as coating. A SEM image of the MPS is shown in Figure 4.

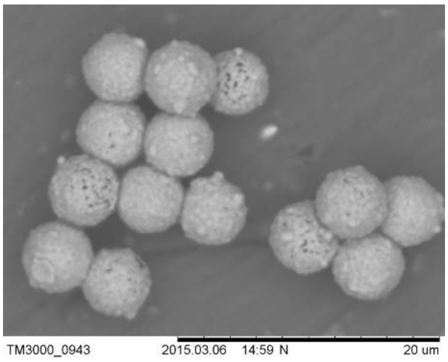

Figure 4: SEM image of 5 µm polymer spheres with Ag coating.

To allow the ICA to be jetted, it was necessary to add a thixotropic agent to obtain a suitable shear thinning behavior and to prevent sedimentation of the particles. Curing time and temperature for the ICA were 30 minutes and 150 °C, respectively.

The applied solder paste was Almit Sn62U SS4M, product no L 038-0187. The flux content was 15 wt%, the metal content 85 wt% and the particle/powder size was 10-28 µm. Two different amounts of solder paste and ICA were used in the experiment. The amounts of solder and ICA were denoted $V1_{solder}$, $V2_{solder}$, $V1_{ICA}$ and $V2_{ICA}$, respectively. $V2_{solder}$ was $2.5\times V1_{solder}$. According to the input to the MY 500 jetting machine, $V2_{ICA}$ should have been $2.5\times V1_{ICA}$, but that was not strictly valid due to the rheological properties of the applied ICA. Furthermore, $V1_{solder}$ should have been equal to $V1_{ICA}$, but for the same reason, this was also only approximately valid. The PCSB and the ceramic packages were all mounted onto the PCB using a My 9 pick and place machine.

At the shear test boards, the larger volume of ICA/solder was deposited on row A, and the smaller volumes on row B, then the PCSB were placed and the boards were then soldered/cured. Figure 5 shows a shear test board mounted using solder.

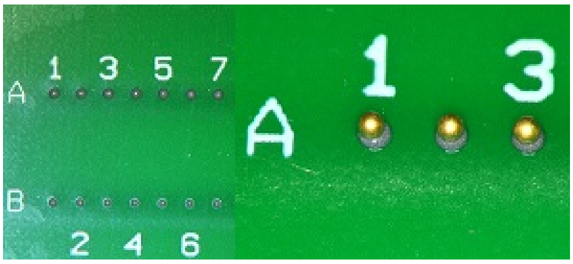

Figure 5 Left: Image of the larger (row A) and smaller (row B) volumes of deposited solder. Right: Image of PCSB placed into solder paste before reflow.

Figure 6 shows the sequence for the mounting of the samples prepared for electrical testing. In the images in row A, PCSB soldered to the board are shown. The difference between the two solder volumes is clearly visible; several of the PCSB were more or less completely covered with solder after the reflow for the larger volume, $V2_{solder}$, whereas the gold coating of the PCSB was still clearly visible for the smaller volume of solder, $V1_{solder}$. Images of solder paste deposited on top of the PCSB are shown in row B. The solder paste remained on top of the PCSB and did not flow down to the PCB. Packages mounted onto the PCSB after a final reflow are shown in the images of row C.

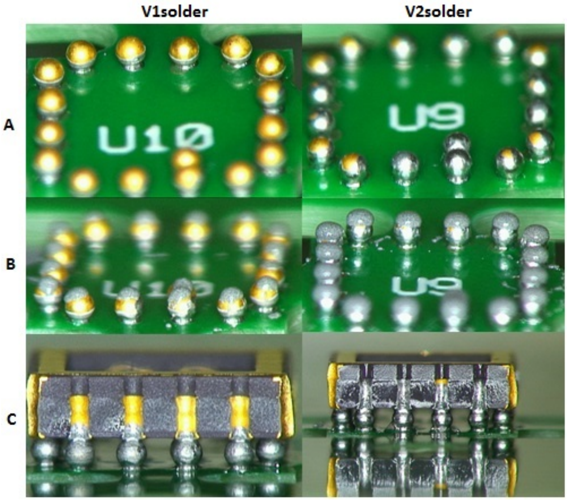

Figure 6: The process steps for assembly of packages onto boards using soldering of PCSB.

Figure 7 shows the corresponding mounting process when using ICA. The images in row A show the two different volumes of ICA jetted onto the board. PCSB were picked and placed onto the jetted material. Images of ICA jetted on top of the assembled PCSB are shown in row B. Note that the ICA did not flow down onto the PCB, but remained on top of the PCSB. The final systems assembled and fully cured are shown in row C.

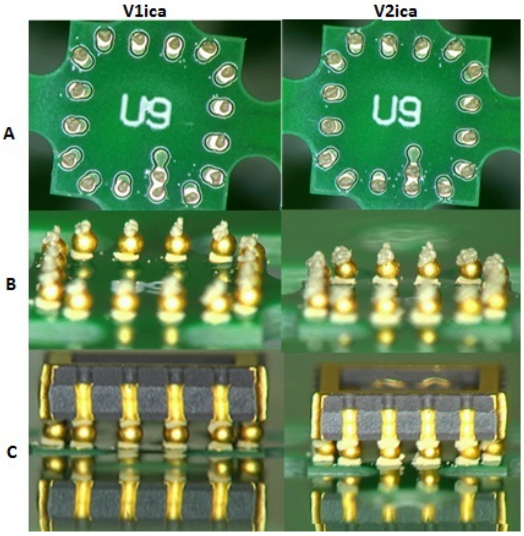

Figure 7: Process steps for assembly of packages onto boards using ICA and PCSB.

In total, four boards with solder and four boards with ICA were made, and one of each sample group (solder/ICA) was kept as a reference. The remaining boards were exposed to thermal shock cycling (TSC) tests. Table 1 gives an overview of the number of Kelvin structures/daisy chains that were available for testing for each volume of ICA/solder paste during the temperature testing.

Table 1: Overview of number of electrical test structures measurable during electrical testing for different ICA/solder paste volumes.

	$V1_{solder}$	$V2_{solder}$	$V1_{ICA}$	$V2_{ICA}$
Kelvin structures	28	44	28	44
Daisy chains	1		1	

Experiments

Shear tests were performed for single PCSB to compare the shear strength of ICA and solder. The effect of different volumes of solder paste/ICA on the shear strength, before and after thermal cycling, was investigated. The boards were shock cycled from -55 °C to +125 °C in a Heraeus HT 7012S2 thermal cycling chamber with 10 min dwell time for 500 cycles with a short transition time between the cold and hot chamber (6-7 s). The tests were performed using a die shear tester (Dage 4000 Plus), and the setup is shown in Figure 8. The shear height and velocity were 150 µm and 10 µm/s, respectively.

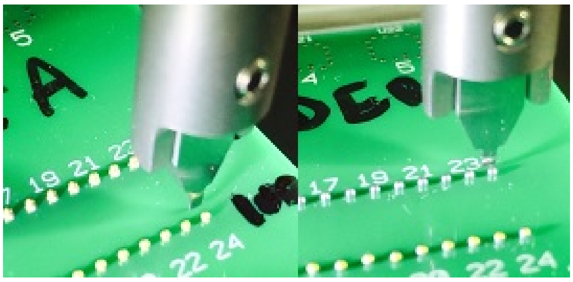

Figure 8: Shear testing.

The TSC for assembled packages was performed using a CST130/2T Thermal Shock Chamber from Angelantoni Industries. The temperature range was between -55 °C and + 125 °C with at least 15 min dwell time at each temperature. The transition time between hot and cold chamber was less than 1 minute.

A Keithley 3706 System Switch/Multimeter was used for measurements of the Kelvin structures. Each resistance value was measured 30 times, and the average value and the standard deviation were calculated. First, the boards containing ICA were cycled for a total of 1048 cycles. The temperature shock cycling test was paused after 184 and 564 cycles and the interconnect resistances measured at room temperature. The boards containing solder were exposed to 1003 cycles. The cycling was paused after 184 cycles and the interconnect resistances measured at room temperature. During the temperature shock cycling, some of the interconnect resistances were measured *in-situ* for the boards with $V2_{solder}$ and $V2_{ICA}$.

Results and discussions

The shear strength results are presented in Figure 9, where the fracture forces are shown for each sample group. A total of 11 samples of each group were tested before TSC. After TSC, 12 samples were tested for each group using ICA, 6 samples for which $V1_{solder}$ was used, and 10 samples for which $V2_{solder}$ was used.

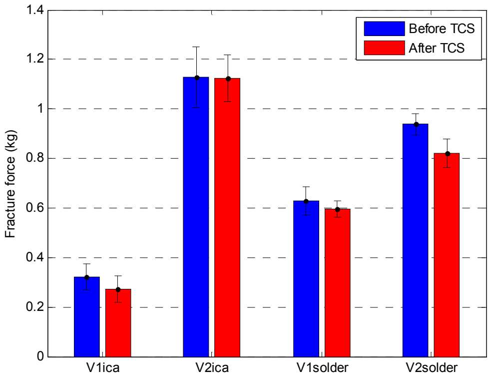

Figure 9: Shear test results of the various sample groups. Errorbars represent ± 1σ.

As expected, the fracture force increased for larger volumes of both ICA and solder. The effect was most pronounced for ICA. The fracture forces were not significantly reduced as a result of the thermal shock cycling.

The fracture surfaces for the ICA samples were a mix of adhesive fracture to the pads and cohesive fracture inside the ICA as shown in Figure 10.

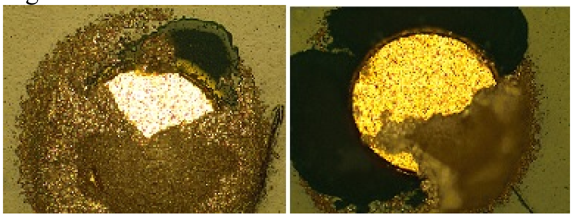

Figure 10: Mixed fracture surfaces for $V2_{ICA}$. Left: Before TSC. Right: After TSC.

For the soldered samples, mostly cohesive fracture in the solder was observed, as shown in Figure 11.

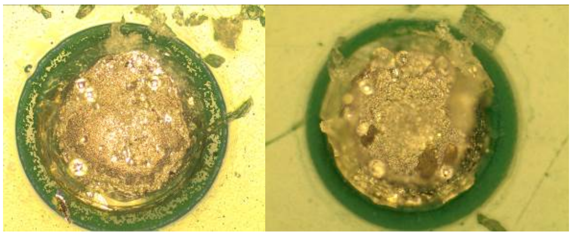

Figure 11:$V1_{solder}$ fracture surfaces. Left: Before TSC. Right: After TSC.

The fracture modes were the same within each sample group before and after thermal exposure, supporting the observation of limited degradation.

The resistances of all the samples with electrical test structures were measured after the boards had been mounted and prepared for TSC. The average values and the standard deviations are presented in Table 2.

Table 2: Average interconnect resistances for PCBS with ICA and solder paste as measured before thermal shock cycling.

	Initial interconnect resistance (Ω)	Number of measured resistances
$V1_{solder}$	0.034 ± 0.003	44
$V2_{solder}$	0.034 ± 0.003	56
$V1_{ICA}$	0.046 ± 0.003	44
$V2_{ICA}$	0.047 ± 0.006	56

It is noteworthy that the average interconnect resistance was close to identical for the different volumes of solder paste/ICA, respectively. Solder paste has a bulk resistivity in the range of 12-14 x 10^{-6} Ωcm [5], thus soldering offers very high conductivity between soldered joints. The conductivity of ICA is dependent upon the volume content of MPS, the size of the MPS and the thickness of the metal coating of the MPS [6, 7]. Thus, as predicted, the interconnects formed with ICA had a slightly lower conductivity then the ones that were soldered.

Table 3-6 show the interconnect resistances and the standard deviations when using ICA or solder with different volumes as a function of temperature shock cycle numbers. If the measured interconnect resistance exceeded 0.1 Ω, it was considered as a failure, and these values were skipped in calculating the average interconnect resistance after cycling.

Table 3: Change in interconnect resistance as a function of number of temperature shock cycles when $V1_{ICA}$ is used (failed interconnects excluded).

No of temp cycles	Interconnect resistance (Ω)	No of valid resistances	Increase (%)
0	0.046±0.003	28	
184	0.05 ±0.006	28	8.7
564	0.064±0.013	23	39.1
1042	0.07±0.014	14	52.2

Table 4: Change in interconnect resistance as a function of number of temperature shock cycles when $V2_{ICA}$ is used (failed interconnects excluded).

No of temp cycles	Interconnect resistance (Ω)	No of valid resistances	Increase (%)
0	0.048±0.006	44	
184	0.048 ±0.006	44	0
564	0.057±0.011	41	18.8
1042	0.069±0.016	37	43.8

Table 5: Change in interconnect resistance as a function of number of temperature shock cycles when $V1_{solder}$ is used (failed interconnects excluded).

No of temp cycles	Interconnect resistance (Ω)	No of valid resistances	Increase (%)
0	0.035±0.002	28	
194	0.037 ±0.002	27	5.7
1003	0.039±0.003	27	11.4

Table 6: Change in interconnect resistance as a function of number of temperature shock cycles when $V2_{solder}$ is used (failed interconnects excluded).

No of temp cycles	Interconnect resistance (Ω)	No of valid resistances	Increase (%)
0	0.034±0.003	44	
194	0.035 ±0.003	42	2.9
1003	0.036±0.003	42	5.9

Two of the resistors (denoted no. 6 and 34) failed for both the ICA and the solder assembled test structures. A failure in the measurement setup was suspected based on this observation, but this could not be confirmed.

The daisy-chain using ICA failed initially, so no measurement result was achieved. For the soldered daisy chain, the measured result is shown in Table 7.

Table 7: Measurement result for the soldered daisy chain ($V1_{solder}$).

No of temp cycles	Resistance (Ω)	Increase (%)
0	3.713	
194	3.767	1.5
1003	3.874	4.3

Figure 12 shows the *in-situ* measured interconnect resistance for one soldered interconnect and one using ICA as interconnect.

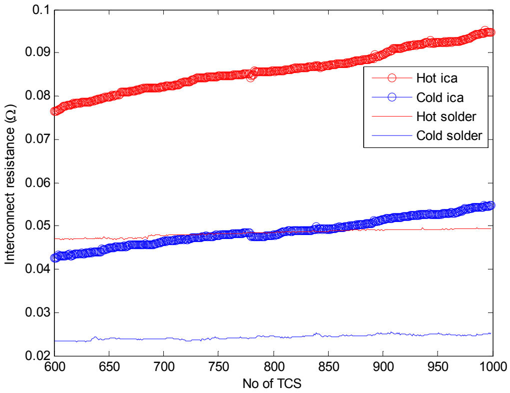

Figure 12: *In-situ* measurements for interconnect resistances (one soldered and one using ICA) from 600 to 1000 TCS.

It is noteworthy that the interconnect resistances using ICA increases significantly more than the soldered interconnect resistances do during the TCS. The initial interconnect resistances were 0.047 Ω and 0.032 Ω for the glued and the soldered interconnects, respectively.

The measurement results showed that solder had a better performance with respect to TSC compared to ICA. The increase of the interconnect resistances was much less when using solder compared to ICA. In addition, fewer failures occurred when using solder. Furthermore, larger volumes of solder/ICA had lower degradation/failures of interconnect resistance during TSC compared to when smaller volumes of ICA/solder were used. This was more pronounced when ICA was used.

There might be several explanations why solder performs better then ICA. First of all, the solder used was qualified for use in the MY 500 jetting machine. The ICA used was a prototype, and not qualified for use in the jetting machine. Hence, the jetting quality using solder is much better with respect to volume and shape, which is clearly visible by comparing row B in Figure 6 and Figure 7. Using ICA, this might have caused contacts with varying contact area, causing more spreading in the values of the interconnect resistances. This is visible in Table 2 where the interconnect resistances using $V2_{ICA}$ have a larger standard deviation than the other groups. Figure 7, row A, also shows that the volumes of jetted ICA on the boards are varying slightly, even though they should always be the same (either $V1_{ICA}$ or $V2_{ICA}$). The variations in ICA volumes were not measured, but such measurements could have given additional information about the performance ICA vs. solder.

During TSC we observed an excessive build-up of ice in the heat exchanger in the cold chamber. This indicates an ingress of moisture during the cycling. A possible consequence can be condensation of water on the cold adhesive as this is moving into the warm and potentially more humid hot air in the heating chamber. It is known that water absorption in an epoxy resin is not fully reversible, and that possible absorbed water from a condensation phase will not be desorbed during the subsequent high temperature dwell [8]. With as little as 30 seconds exposure to condensation for each cycle, the total exposure to water will correspond to several hours during the full TCS. The possible amount of absorbed moisture in the ICA was not investigated. However, it is well known that water molecules diffusing into polymers might cause delamination because of swelling or hydrolysis. For the ICA, corrosion of the Ag coated MPS may also occur due to the penetration of water molecules. Both cases can cause the resistance of the interconnects to increase, and eventually the connection could fail [9].

Conclusions

The measured results showed that using PCSB for connecting an LCC ceramic package to an FR4 board using either ICA or solder was an acceptable solution for our application; the interconnects passed a representative thermal shock cycling test and the fracture strength of the joints was sufficiently high both before and after thermal exposure.

Solder resulted in less change in interconnect resistance as a function of number of thermal cycles than ICA. However, the performance of the interconnects formed using ICA is acceptable for our applications, at least to 184 TCS. The experiments showed that using a higher volume of ICA/solder results in a larger fracture force and a thermo-mechanically more stable interconnect resistance.

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