

Reliability Investigations of BGA-Interconnections between RF-LTCC-Modules and PCBs

Authors

Dieter Schwanke, Thomas Haas, Christian Zeilmann

Micro Systems Engineering GmbH & Co.

Schlegelweg 17

D-95180 Berg/Germany

Phone : +49 9293 78 174

E-Mail: dschwanke@mse.biotronik-erlangen.de

Klaus Halser, Matthias Klein

Fraunhofer Institut für Zuverlässigkeit und Mikrointegration IZM

Gustav-Meyer-Allee 25

D-13355 Berlin

Phone: +49 30 46403 275

E-Mail: halser@IZM.Fraunhofer.de

Abstract

Within the scope of the German national funded project PROKOSMOS modular LTCC radio-frequency modules have been developed with BGA interconnections to the third level packaging PCB and Flip Chip (μ -BGA) to the first level packaging. Besides this, a variety of necessities defined for RF-Modules like cavities, buried passive components, fine line print, vertical shielding by via stacks and frame soldering / brazing have been integrated.

Further investigations have been done to apply thin film structures on LTCC "as fired" surfaces to enhance the LTCC potentiality at structure areas where the possibility of fine line printing is exceeded. This will be brought to the market together with Reinhardt microtech under the label FINEBRID.

One of the basic tasks have been the application of BGAs as interconnection to RF-PCBs. The chosen ball size was 200 μ m/300 μ m with pitches of 500 μ m and 700 μ m; for other parts 800 μ m ball size. The use of placed balls was investigated as well as reflow bumping with printed solder. Besides the solder balls also coated polymer balls have been tested to show whether the higher flexibility of the polymer balls will enhance the reliability during thermal cycling of the connected modules. As an other potential for an enhancement of the reliability the underfill technology was seen.

This paper will first give a brief introduction which type of LTCC – modules have been manufactured, which RF- relevant necessities have been implemented, which bumping technologies have been tested, which potential reliability enhancements have been investigated and which improvements really led to higher numbers of thermal cycles and which facts are really responsible for the reliability performance of BGA between LTCC and PCB besides the difference in TCE.

1. Introduction

The goal of the public funded project PROKOSMOS was to establish or to optimise manufacturing methods which allow to manufacture multifunctional LTCC-substrates for radio frequency applications [1].

The focus was on housing integration of the substrate by application of e.g. lead frames and leads directly on the substrate by using also brazing technology and the interconnection to the next higher or lower packaging level by using flip chip technology or BGA technology.

Besides these key requirements further RF-relevant requirements had to be fulfilled like fine line structuring, embedded passive components, cavities, vertical shieldings and waveguides by use of via arrays.

Also in the focus were the reliability requirements especially of the interconnects between the different packaging levels.

A schematic cross- section of a LTCC – module is shown in Fig. 1.

Fig. 2 shows examples of fine line structures and sophisticated cavities.

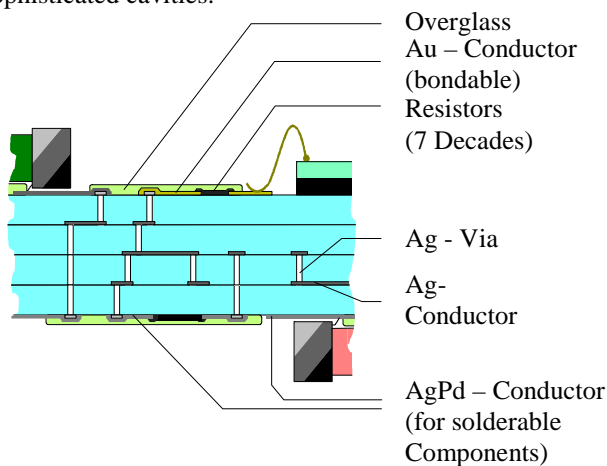


Fig. 1: Schematic cross-section of a LTCC-Mixed-Metal-Multilayer-Structure

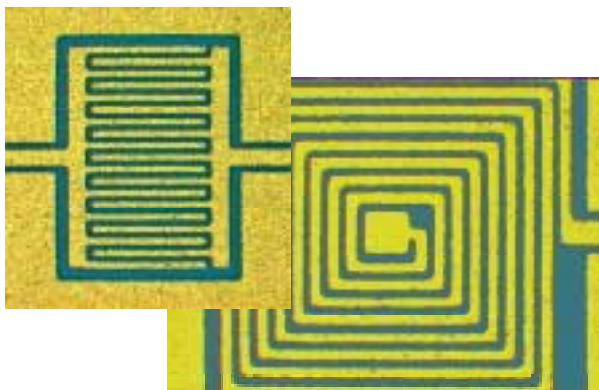
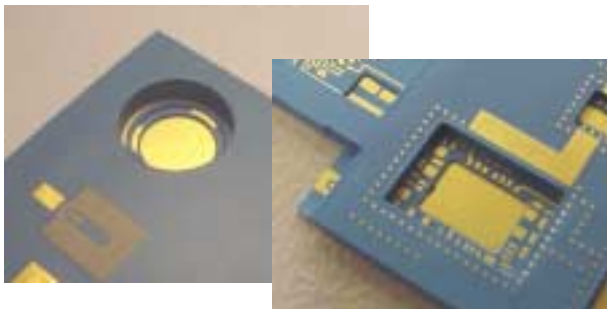


Fig.2: Sophisticated cavities and fine line structures (50 μm Lines / 50 μm Spaces in selected areas)

2. Further Tasks for LTCC-Technology within the PROKOSMOS Project

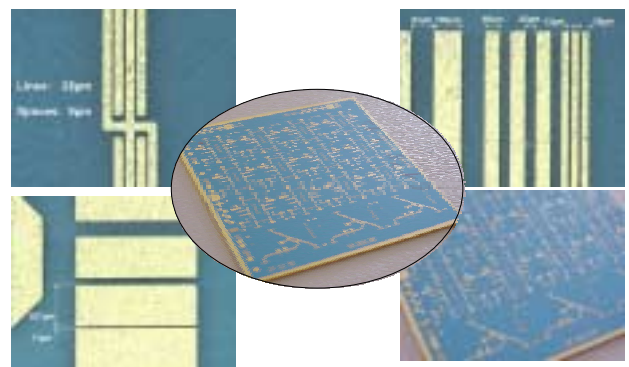
Beside the already mentioned items a variety of RF-relevant techniques had to be integrated like embedded passive components and the integration of the LTCC-substrate into the module housing by brazing a lead frame directly on the substrate to achieve the basis of a hermetic tight covering of the RF-module.

For a cost improvement the substrates had to be manufactured in a multi-array mode and nevertheless the

substrates and also their I/O connections like BGAs had to fulfil specific reliability requirements.

In parallel several considerations about the limitations of fine line printing have been made and due to the fact that the thin film manufacturing company reinhardt Microtech was also a partner in this project, investigations have been started to apply thin film directly on the untreated surface of a LTCC substrate.

The background of the consideration was to use the cost efficient screen printing for the most of the structures and to apply thin film on selected areas where a fine line application for RF relevant structures below 50 μm was necessary. The goal was to widen the procedural limits of screen printing caused amongst others by paste rheology. Exemplary results are shown in Fig.3.



TF: reinhardt microtech

Fig.3: Thin Film application on an untreated, unpolished LTCC substrate surface

It was shown that a good line resolution eg. 28 μm lines and a spacing of 9 μm could be achieved (see Fig.4)



Fig.4: Example of the line resolution of Thin Film on an "as sintered" LTCC surface

Reliability investigations on both DuPont LTCC systems have been done (DP951 tape and DP 943 tape, low loss tape for wideband applications at higher frequencies).

The Thin Film (TF) structures on LTCC withstood tests like :

50 cycles $-55^{\circ}\text{C} / +125^{\circ}\text{C}$;

50 shock cycles $100^{\circ}\text{C} / 0^{\circ}\text{C}$;

1000 hrs at 125°C and

1000 hrs at $85^{\circ}\text{C} / 85\%$ relative humidity

This combination of thin film and screen printed LTCC became a new product of the two partners MSE and reinhardt Microtech which got the name FINEBRID.

The manufacturing of the first RF structures to show the RF reliability is currently in progress.

3. Manufacturing of Demonstrators for the partners EADS and Siemens

In a close cooperation between MSE, EADS and Siemens a variety of test vehicles and demonstrators have been manufactured. The task for the final demonstrators of the both users EADS and Siemens was to apply BGA as interconnection to the next lower level packaging (PCB).

Based on the simulations the measurements on the test vehicles gave indications about the compatibility between simulation and measurements. These findings delivered the basis for designing the final demonstrators.

Fig. 5 shows the final demonstrator designed by EADS. Also a cut-out of the final Siemens demonstrator is shown. The chosen I/O connection technology to the PCB was BGA.

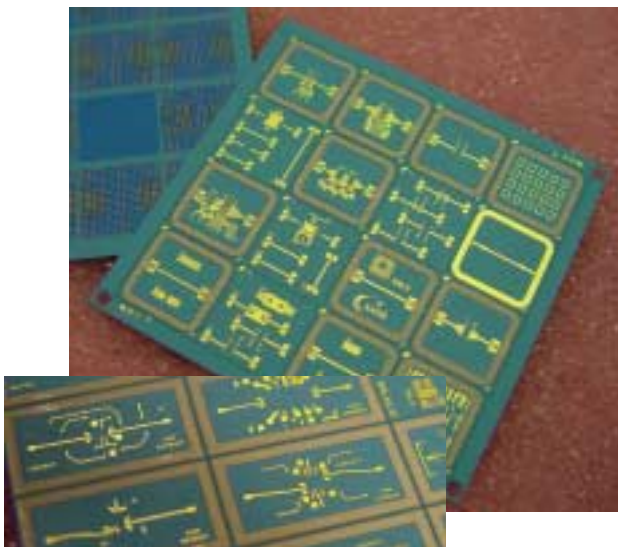


Fig. 5: Final EADS demonstrator; final Siemens demonstrator (small picture, cut-out)

The both demonstrators had a characteristic pitch array. EADS designed a pitch size of $700\ \mu\text{m}$ with a ball size of $300\ \mu\text{m}$ and Siemens an array of $500\ \mu\text{m}$ with a ball size of $200\ \mu\text{m}$. The EADS BGA pitch could be manufactured by use of reflow-bumping with eutectic solder as well as for the $500\ \mu\text{m}$ pitch of the Siemens demonstrator bumps with a height of $170\ \mu\text{m}$ and a diameter of $270\ \mu\text{m}$ could be realized on a pad of $200\ \mu\text{m}$.

Measurements showed that it was possible to compensate the deviation in the simulation. The both pitches are shown in Fig. 6.

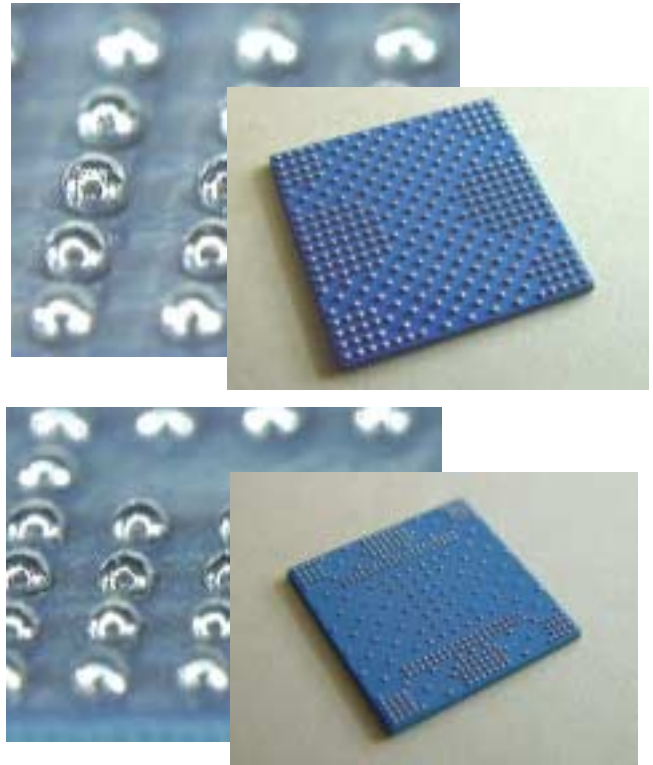


Fig. 6: EADS BGA pitch $700\ \mu\text{m}$, $300\ \mu\text{m}$ ball size; Siemens BGA pitch $500\ \mu\text{m}$, $200\ \mu\text{m}$ ball size (lower pictures); both stencil printed with Pb37Sn63 solder and reflowed

Besides a variety of initial occurring problems described in the next chapter it was recognized that the different CTEs of the LTCC and the PCB caused a severe reliability problem. Tests with thermal cycling ($-55^{\circ}\text{C}/+125^{\circ}\text{C}$) showed that these construction was only able to withstand 20 cycles to failure.

4. Manufacturing Problems of Reflowed BGAs and the Establishing of Placed Solder Balls

In the following pictures the main problems of reflow solder balling are described. One of the problems has been the inhomogeneous distribution of the amount of solder paste during printing, which caused in some areas a coalescence of balls which is shown in Fig. 7. One of the reasons for this inhomogeneous printing results was paste rheology and also the printing process itself. A remedy was found by use of special fine pitch solder paste and a new automated solder printer.

Another problem has been missing bumps caused by a poor wettability of the solder pads (Fig. 8). This was solved by an additional activation of the solder pads.

In parallel investigations have been made with a placement of $300\ \mu\text{m}$ eutectic Sn63Pb37 balls from PFARR Stanztechnik.



Fig. 7: Coalescence of stencil printed and reflowed eutectic balls caused by inhomogeneous amount of solder

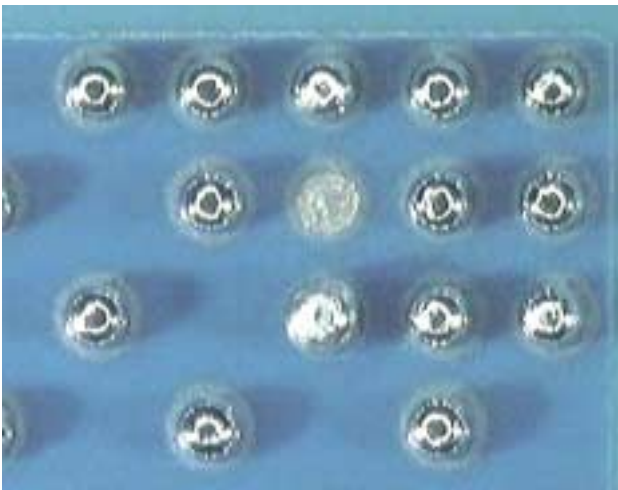


Fig. 8: Missing bumps caused by poor wettability of the solder pads

Independent of the balling method of solder balls the reliability tests at the FhG IZM showed insufficient results. The coefficient of thermal expansion (CTE) of LTCC is 5.8 ppm/K vs 14.4 ppm/K of the PCB. The characteristic life time of eutectic solder ball packages was only 20 cycles. This was the reason to start investigations of coated polymer core balls SOL from Sekisui.

5. Investigations of the Reliability Behaviour of Coated Polymer Core Balls (SOL)

The idea was that the much higher flexibility of the polymer balls can produce a relief of the reliability problems. The balls provided by Sekisui are coated with copper and eutectic Sn63Pb37 solder and the tested ball size was 300 μm as well as 800 μm .

Within the PROKOSMOS project reliability test vehicles have been designed with both used pitches in this project. One side was represented by LTCC modules where the BGA balls were placed. The other side was

designed with the same complementary pitches on PCBs, so that in total a kind of daisy chain was realized when the BGA was soldered on the PCB.

The ball placement of the 300 μm balls was done by FhG IZM, the placement of the 800 μm balls by MSE. The reflow soldering was done by EADS. An example of these PCB test vehicles is shown in Fig. 9 with a 700 μm pitch.

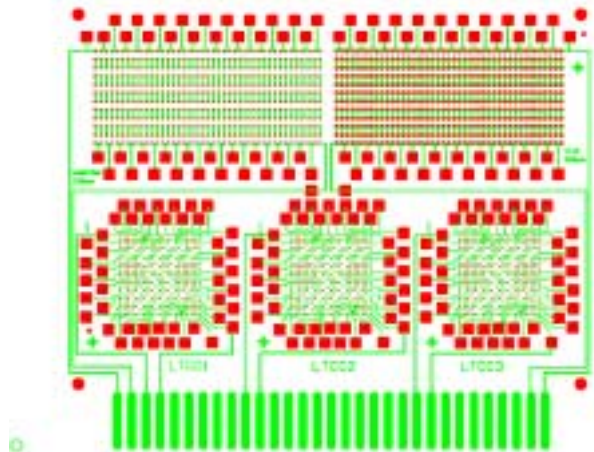


Fig. 9: PCB pattern (2 mm thick) with 700 μm pitch for reliability testing (connected with 15 x 15 mm LTCC components); top structures for PCB testing.

The balls have been placed at FhG IZM by use of a PAC TEC Solder Ball Bumper (SBB) which has the capability to place the balls sequentially [2]. This machine is designed for the bumping of fully metalized solder balls. The balls are separated with a rotating metal disk and transferred through a capillary to the solder bond pad by a nitrogen flow. Then a laser beam is melting the surface of the ball right before placement.

But applying the standard SBB process no appropriate parameter window could be achieved. A lower laser energy led to insufficient ball adhesion, a higher could destroy the coating of the balls. This was the reason, that it was not possible to combine placement and reflow at the SBB for the SOL (Sekisui) balls. Hence, the SBB was only used for ball placement



Fig. 10: Manually placed SOL balls on LTCC (MSE)

Fig. 10 shows an example of manually in flux placed and reflowed eutectic Sn63Pb37 - coated SOL (Sekisui) 300 μm balls (pitch 500 μm , pad 200 μm , solder temp. 182,7°C).

An initial test was to solder two LTCC reliability test substrates together and separate them thereafter by force. The result showed two aspects; only a few of the balls joined together and the joined balls cracked within the coating (see Fig. 11 and 12). This appearance was similar to that what in [3] was found (see Fig. 13).

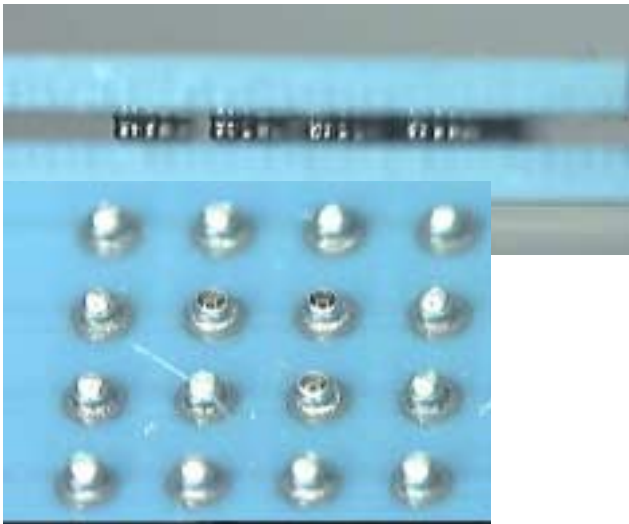


Fig. 11: Solder joined LTCC / BGA reliability test pattern; thereafter separated by force (lower picture)



Fig. 12: Detailed picture of the damaged coating of the SOL balls; the polymer ball is transparent

The reason for the poor solder adhesion of the upper substrate was, that there was no additional solder print. The amount of the solder only of the coating was too low to achieve a good adhesion.

The typical failures after thermal cycling in investigations of solder joints with high-melting Pb90Sn10 balls have been different. In this case most failures have been detected in the interface between the eutectic solder and the high melting solder balls. This agrees with the region of highest shear strain determined by FE-simulation for comparable packages in former investigations [4].

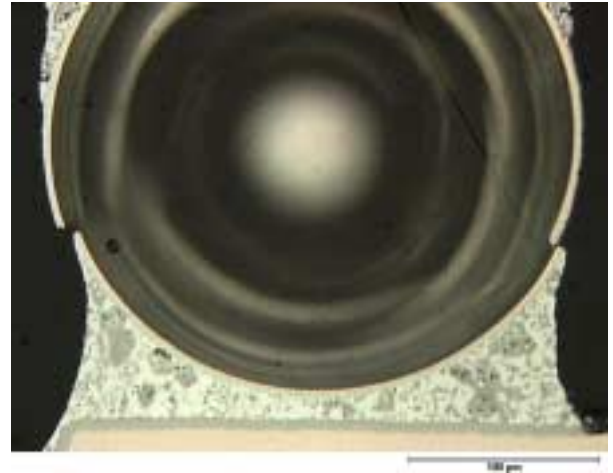


Fig. 13: Cracked coating of a SOL ball after thermal cycling -55°C/+125°C (typical failure) [3]

6. Reliability Results after Thermal Cycling

For the thermal cycling reliability tests two different version of solder joints have been contrasted. On one hand the SOL type joints with the polymer balls and on the other hand eutectic stencil printed reflowed solder balls with underfill. All balls are placed into a solder (SnPbAg₂) depot. For all investigations the already described daisy chain parts consisting of LTCC substrates and PCB carriers with both pitch types have been used.

The experimental set-up was a two chamber arrangement with an air-to-air thermal cycle from temperatures -55°C / +125°C. The dwell time was 15 minutes. The electrical failures in the daisy chains have been detected on-line during the temperature cycling using an Event Detector (Analysis Tech). A failure was defined when 10 events > 1 μs have been detected [4].

Fig. 14, 15 and 16 are illustrating the reliability behaviour of different types of BGAs with the EADS pitch. The defined breakdown criteria is the achievement of the cumulative failures at a level of 63%.

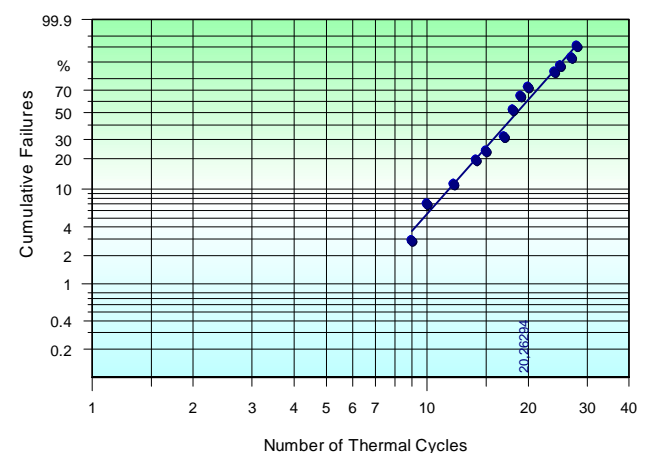


Fig. 14: Cumulative failures of LTCC-BGA with Eutectic SnPb Balls during thermal cycling; $N_f = 20$

N_f represents the number of thermal cycles until cumulative failures of 63% are reached (characteristic lifetime).

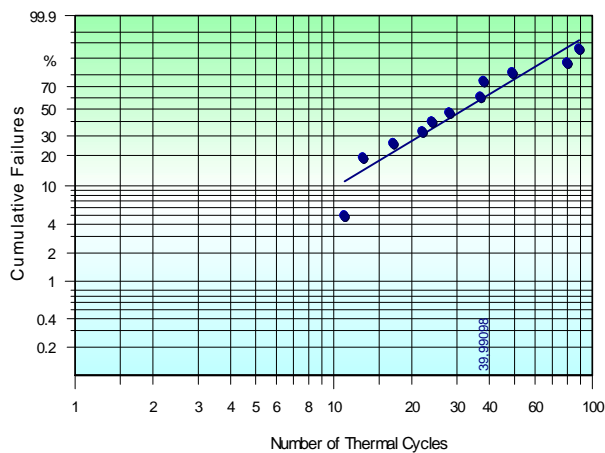


Fig. 15: Cumulative failures of LTCC-BGA with 300µm SOL (Sekisui); $N_f = 40$ cycles

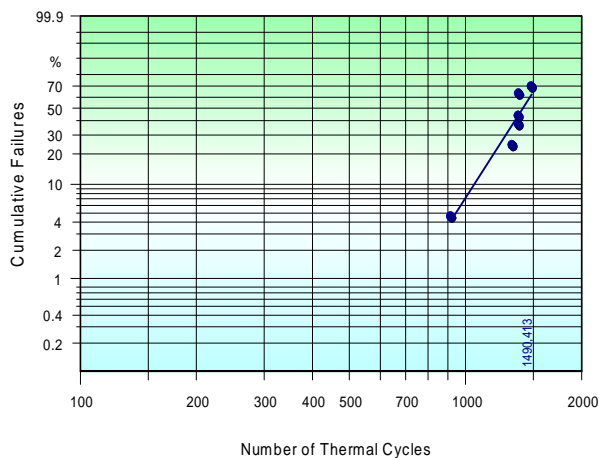


Fig. 16: Cumulative failures of LTCC-BGA with Eutectic SnPb Balls with underfill during thermal cycling; $N_f = 1490$ cycles

An additional test with Pb90Sn10 balls without underfilling provided a characteristic lifetime of $N_f = 26$ cycles (see also Tap. 1).

The results of the investigations on the 500 µm pitch daisy chain parts with 200 µm balls have been very similar. The characteristic lifetime of the BGAs with SOL balls was $N_f = 18$ cycles, those of the BGAs with stencil printed, reflowed eutectic balls and underfilling showed a characteristic lifetime of $N_f = 1247$ cycles (Tab. 1).

Fig. 17 represents a typical failure mechanism detected at the small 200 µm SOL balls.

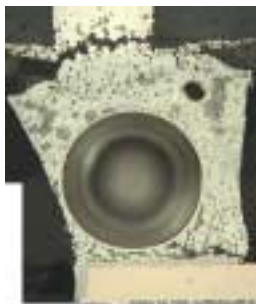


Fig. 17: Typical failure mode at 200 µm SOL coated polymer balls after thermal cycling

Here the volume of the plastic ball is small compared to the amount of solder. The failure mechanism is comparable to full solder balls.

Ball Version	Characteristic Lifetime (thermal cycles up to 63% failures)	
	LTCC 1 Pitch 700 µm Ball Size 300 µm	LTCC 2 Pitch 500 µm Ball Size 200 µm
Sn63Pb37 w/o underfill	20	-----
Pb90Sn10 w/o underfill	26	-----
SOL-Balls w/o underfill	40	18
Sn63Pb37 with underfill	1490	1247

Tab. 1: Summary of the Different Reliability Results

7. Conclusion

The use of SOLs will increase the lifetime of BGAs not significantly, if a considerable CTE mismatch is existing. Other investigations on 800 µm SOL balls (2,54 mm pitch) showed results, which do not agree with the findings described above ($N_f = 700$ cycles). This gives an indication, that the coating of the balls and the amount of solder in dependency on the ball size is important for the lifetime. The smaller the ball, the stiffer is the construction (close to solder balls). In addition the stand-off between LTCC and PCB is important; also for SOL balls.

The characteristic lifetime of a BGA can be increased more effectively by underfilling. This has to be taken in consideration for RF designs. If it is not possible to use underfilling, there remains the trivial requirement to decrease the delta of the CTE of the both components or to define the environmental conditions differently.

8. Acknowledgements

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9. References

- [1] Oppermann, M., LMDS Applications and RF Radio Links go for SMD Based Module Technology-Reality, Experience and Future Trends, IMAPS 2002; Denver, CO, 09/2002
- [2] Kasulke, P. et al., A New Solution for Solder Application to FCA, BGA and CSP Challenges, Proc. Micro System Technologies, 1996, Potsdam, September 17-19, 1996
- [3] Klein, M., Oppermann, H., Behnke, S., Halser, K., Aschenbrenner, R., Reichel, A., A Characterisation of Plastic Core Solder Balls for BGA and Flip Chip Applications, Proc. IMAPS Nordic Conference, Stockholm 30.09.-02.10.2002
- [4] Klein, M., Oppermann, H., Behnke, S., Halser, K., Aschenbrenner, R., Reichel, A., Characterisation of Plastic Core Solder Balls for Flip Chip and BGA Applications, IEEE European Systems Packaging Workshop, Cork, Ireland, 2003 January 20-22