TCoB Reliability For Epad LQFP 176 in Automotive Application

Cha Chan Lam, Kong Chet Hung, Niessner Martin Richard
Infineon Technologies (Malaysia) Sdn. Bhd.
Free Trade Zone, Batu Berendam,
75350 Melaka.
ChanLam.Cha@infineon.com, ChetHung.Kong@infineon.com, Martin.Niessner@infineon.com

Abstract

Exposed pad in QFP packages were introduced in the late 1980s and become more and more popular in Automotive industry because of their excellent thermal performance and relative lower cost with higher pin count. However the Thermal cycling on Board (TCoB) reliability for exposed pad for QFP had been a challenge as the requirement become more and more stringent in Automotive industry especially in safety device application.

Currently, there are not many studies are available on QFP platform as the Gullwing lead on QFP can perform better than solder ball (BGA platform) & Leadless (QFN platform) due to the Gullwing lead profile provide the flexibilty (mechanical spring effect) to obsorb the thermal mismatch better during TCoB stress. But this scenario had been change as the Automotive TCoB requirement had been significant increase in safety device application. In this work, 3 different low alpha mold compound type are selected for assessment based on the knowleage and understand in order to meet stringent customer requirement. Prior to actual experiment, the TCoB performance for each mold compound type had been simulate and predict by an establish simulation model. The simulation model is based on Robert Darveaux's model [1] for BGA solder fatigue life prediction using full 3D FEA modelling. The experiment was conducted on LQFP176 Epad package with the body size of 24 x 24 x 1.4 mm^3 .[see fig 1 & 2]

Along with the experimental run, a TCoB solder joint failure for LQFP176 Epad was found before the targeted TCoB performance, this results does not correlate with the simulation result; Extensive failure analysis was carried out to confirm the solder joint failure mechanism. Technical hypothesis was generated to identify the key influencing factor and their impact on the package TCoB solder joint failure. The simulation mode was then carried out to understand the mechanical degradation in the solder joint failure based o the Failure analysis result.

The investigation indicate that beside the well know critical factor, the TCoB lifetime is also very sensitive to the package die pad delamination, when serious die pad delamination is present, the thermal mechanical stress can break the Lead frame connecting tie bars and lead to lateral thermal expansion mismatch at solder joint to increase where majority of the stress will transfer to solder joint.

As TCoB stress is a long cycle stress, it is recommended to optimize delamination performance before subject to actual TCoB stress, this is able to mitigate the risk and save a lot of resources and time.

Lastly, the TCoB reliability design guidelines for exposed pad package are proposed to improve the solder joint reliability in order to meet customer stringent requirement.

1. Introduction

Exposed pad in QFP packages are getting more popular in automotive industry as compare to BGA and QFN because of their excellent thermal performance and better reliability performance if compare to BGA and relative lower cost with higher pin count and the Gullwing lead profile ability to allow solder joint inspection after SMT process if compare to QFN. However, the challenge of bigger packages in QFP (176 pin count) is not only on package reliability, but also critical on Solder joint reliability during Temperature Cycling on Board (TCOB).

In this work, a new Bill Of Material (BOM) set was evaluated on low k wafer technology. TCoB experiment sample are plan based on the existing know how and experience. Unfortunately, the samples were fail to meet customer requirement where electrical failure (open) was started to report after ~2000 cyc.

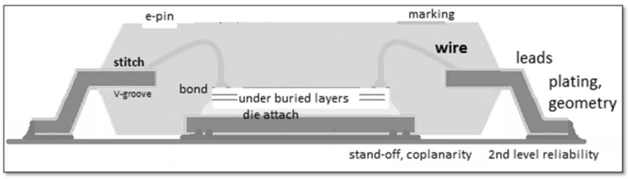

Fig. 1 : Schematic cross section of QFP Epad

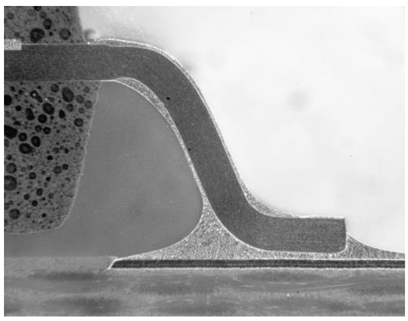

Fig. 2 : Good Solder joint cross section for QFP Gullwing lead

Failure analysis was carried out to identify the rootcause. The identified critical factor is then verify using the simulation model, the impact of variations on the identified geometry parameters on the TCoB lifetime of a LQFP176 Epad was then investigated.

2. Material data and Results

In this project, A new low-k wafer technology was introduced with new BOM set. 3 different type of low alpha mold compound had been identified and selected for this TCoB experiment. [see table 1]

Package body	24 x 24 x 1.4 mm^3		
Die Size	8.4 x 7.9 x 0.6mm^3		
Leadframe Type	uPPF LF		
LF Thickness	5 mil		
Glue	Conductive epoxy glue		
Wire	Au, 25um		
Test board	1.6 mm (4 Cu layers)		
Mold compound	A	B	C
Tg[℃]	125	125	125
CTE1(10-5/C)	9	8	11
CTE2(10-5/C)	4.0	3.8	3.6
Flexural modulus (N/mm2)-room temp	24k	26k	25.5k

Table I : Experiment BOM data

The TCoB profile used is as below table. [see table II]

Condition	Fast TCoB
Temp.cycle	-40℃/+125℃
Furnace Chamber	2 chamber (air to air condition)
Physical transfer time	~ 7 sec
Ramp up/down time	10-11 min
Dwell time	19 min
Cycle time	60 min
Board thickness	1.6mm Automotive

Table II: TCoB Proflie

The TCoB stress sample for EMC A & B shown electrical failure before the targeted cycle's time reached. Only EMC C can able to meet the TCoB stress requirement. This is not expected and not correlated with the pridiction from the simulation results. Failure Analysis is carried out on the failure samples. Cross section shown the failure pin (open) are localize on corner pin [see Fig 3], This is correlates with simulation result where the highest accumulated of stress is happened on corner pin.

.

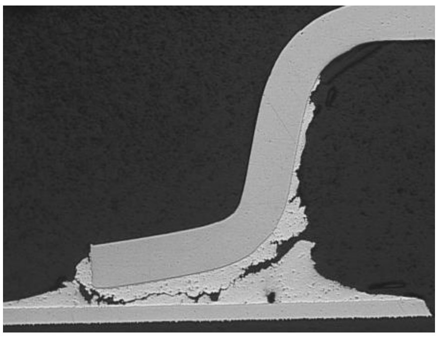

Fig. 3: Cross section for 100% Solder joint open/ failure lead during TCoB

Cross section on good pin shown the solder joint crack is always started on inner solder joint and propagrate to outer solder joint. This observation is correlates to simulation results where the highest accumulation of creep strain is always near to the package side.[see fig 4]

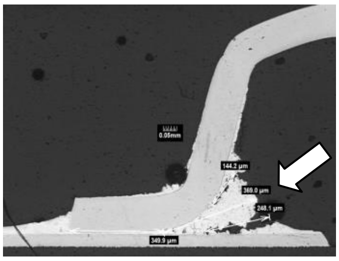

Fig 4: cross section on good pin

SAT on the failure units shown there is severe die paddle delamination happened at the die paddle area, (>75%). Fig 4 is the SAT images on the sample after we found the electrical test failure on the sample.

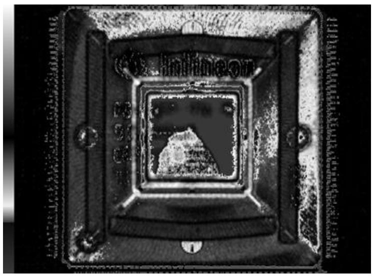

Fig. 4 : SAT for fail sample

Xray inspection found there is broken tie bar on the leadframe for these fail samples. Further cross section on the failure units confirm the LF tie bar which connecting the Epad to the ground ring had broken. [see fig 5 & 6]

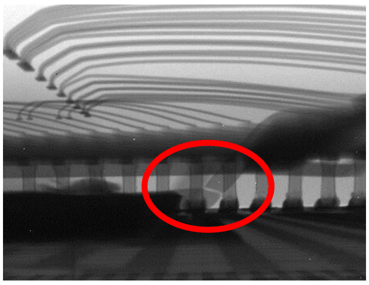

Fig. 5 : Xray observed LF tie bar had broken

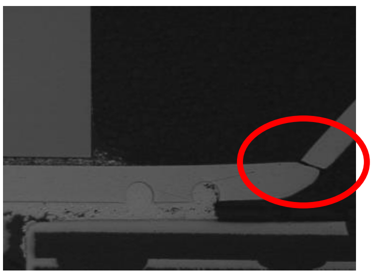

Fig. 6 : cross section on LF tie bar

3. Rootcause finding and Failure mechanism discussion

After the complete the rootcause finding through a systematic 8D approach and is and is not analysis by comparing to previous available results, the main root cause hypothesis/differences observed is on the severe delamianation observed during this experiement. In order to understand the failure mechanism of die pad delamination to the solder joint failure for QFP platform, the simulation model are carried out by introduce such defect in the package to understand impact of die pad delamination toward solder joint failure. Then, the various packages parameter is investigated to understand better the impact of different parameter factors on the TCoB lifetime for a LQFP176 epad packages.

3.1 Workflow of the Simulation

The Fatigue life modeling used in this experiment is develop by Darveaux [1], the simulation workflow are as below. [see Fig 8]. First, the material models, package geometry, TCoB profile and other critical paramater are identify, only linear elastic material data is used. the simulation will then generate the Damage parameter based on the volume-averaging of creep strain calculation. Lastly the Damage Parameter from the simulation will correlated to the experiment TCoB lifetime N_f . These fatigue life model had showns an accuracy of 25% [2].

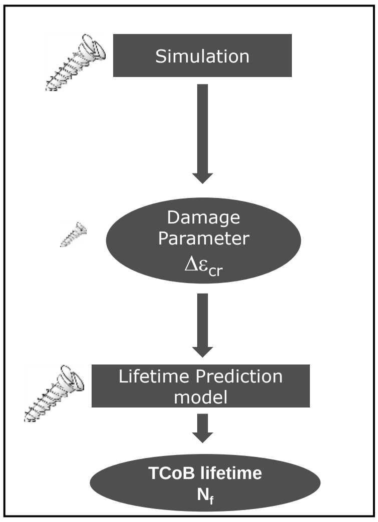

Fig. 8 : Workflow of the Simulation

In order to simulate the impact of die pad delamination toward TCoB performance, the below assumption was made for the simulation of the delaminated fail sample:

- Die-glue-interface is completely delaminated
- Diepad and mold compound-interface is completely delaminated
- Connections between die paddle and ground ring are broken
- Diepad/epad remains soldered on board whilst the rest of the package is free to move

3.2 Result Discusssion

The simulation results shown delamination will reduced overall system bending, including PCB [see fig 9]. Less overall bending will resulting into an increase lateral thermal expansion mismatch. Thus increased the amplitude in individual pin bending. It is also shown that the delaminated package results into an increased ‘deformation amplitude’ of the pins (~8-10%). Increased „deformation amplitude“ results into higher creep strain on the solder joints and eventually leads to earlier solder joint failure.

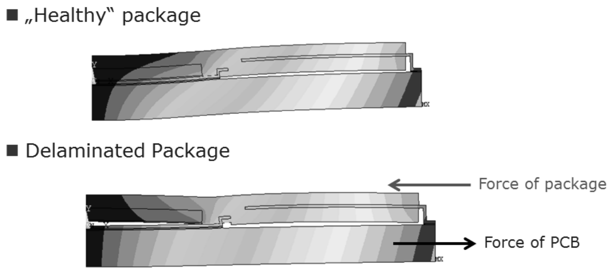

Fig. 9: Delamination Analysis (2D-model)

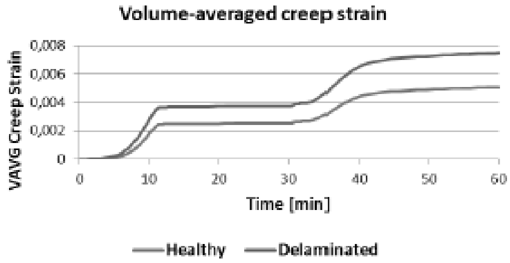

Fig. 10: Creep Strain on solder jointfor good and delaminated sample

Based on simulation data, the die paddle delamination & broken connecting tie bar will significant reduce the TCoB reliability by -36%. When a correlation is perform between experiemtn actual result vs simualtion results, it shown a good accuracy of < 25%. [see fig 11]

Configuration	Exp. $N_{f\ vs}$ Sim. N_f Rel. Diff.
EMC A full die-paddle delam + broken connects	4%
EMC B full die-paddle delam + broken connects	14%

Table III: Experimental result vs Simulation result for delamination sample

4. Critical Parameter Study of QFP Solder Joint Reliability

In this critical parameter study, the package geometry selected as the control or reference package is LQFP175 Epad with 24mm x 24mm x 1.4 mm thickness. the influncing factor and sensitivity of various package parameters is investigated by the established Fatigue life modeling. This included the die size, die thickness, lead foot length, lead size, lead pitch, Lead coplanarity, the material properties of the mold compound, die attach and the PCB were simulate to understand the impact on the solder joint reliability.

The outcome of the investigation are to identify the key parameters having high influence on solder joint fatigue life. This guideline will serve as the TCoB reliability design guidelines for future QFP exposed pad package design in future project.

Design parameter	Design value	% different
Dei pad size (Die size constant)	9.2mm x 9.2mm	--
	11mm x 11 mm	+14%
EMC CTE1(10-5/C)	8ppm	--
	7ppm	-16%
	9ppm	+22%
Package delamination	No die pad delam	--
	100% die pad delam	-36%
LF thickness	5 mil	--
	6 mil	+2%
Die Size (Epad size constant)	7mm x 7mm	--
	5mm x 5mm	+3%
	9.5mm x 9.5mm	-6%
Foot Length	0.612	--
	0.550	-4%
	0.650	+2%
Foot angle	1°	--
	4°	-3.2%
	7°	-5.8%
Shank Angle	6°	--
	10°	+0.3%
	14°	+1.5%
Coplan at Corner pin	0	--
	+80um	-8%

Table IV: Summary of sensitive parameter

5. Optimization Activities

Based on the simulation understanding and results, a corrective action had been trigger to resolve the delamination on die paddle. A slight change had been make on the leadframe design to improve the adhesion strength.

The 2nd TCoB verification sample had been build based on the lesson learnt. The results are meeting the customer requirement. SAT after targeted TCoB stress cycle sample shown free of delamination. [fig 13]

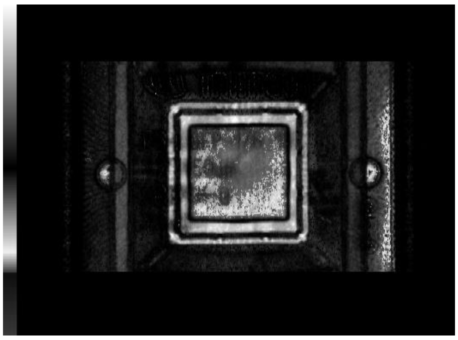

Fig. 13: SAT after targeted TCoB stress cycle

All the sample also demonstrate good results in electrical testing, The mechanicam cross section inspection results also very promising. [fig 14]

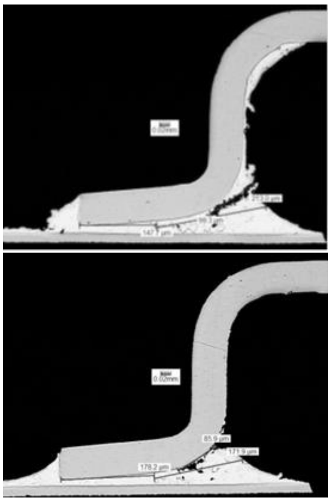

Fig. 14 : Cross section after targeted TCoB stress

6. Conclusions

Many studies had shown the package design and material used in the package design is critical for TCoB reliability performance. This is also applicable for QFP platform. However, In this experiment, one most remarkable result is the very high sensitivity of predicted solder fatigue life due to packages delamination issue after stress.

When package delamination happen during TCoB stress, the lateral thermal expansion mismatch at solder joint will increase causing majority of the stress will transfer to solder joint. Based on simulation data, the die pad delam & broken connecting tie bar will reduce the TCoB reliability by -36%.

As TCoB reliability stress is very time consuming, it is strongly recommended for future TCoB reliability assessment, interim check for packages delamination performance is propose to predict any potential early failure. If package had shown severe delamination at interim check, then back up plan shall trigger to prevent any delay in project execution.

Although the sensitivity of critical parameter had been identify and checked by simulation model, more work is required to correlation the simulation data vs actual experimental data for QFP platform, this is necessary to improve the quantitative prediction accuracy of the simulation model.

Acknowledgments

The authors express their appreciation to Gerhard Schuetz for performing the TCoB stress and support the cross section activities.

References

1. R.Darveaux,"Solder Joint Fatigue Life Model",Proc.TMS Annual Meeting 1997,Orlando, FL,1997,pp.213-218
2. M.Niessner,G.Schuetz,C.Birzer,H.Preu and L.Weiss (2014): Accurate prediction of SnAgCu Solder Joint Fatigue of QFP Packages for Thermal Cycling. EuroSimE 2014.
3. Tong Yan Tee, Hun SN, Danial Yap, Zhaowei Zhong (2003): Comprehensive board level solder joint reliability modeling and testing of QFN and power QFN packages. Microelectronics Reliability 43 (2003) pg 1329-1338.
4. Stephan Stoeck, Heinz Pape (2005): Improving the solder joint reliability of VQFN packages.