2^{nd} Level Reliability Improvement on WLCSP

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Abstract

Recently the package market is demanding the smaller package size and the lower impedance electrical path with a short interconnection. The wafer level chip scale package is one of them, which has the solution of the market needs above. However, WLCSP technology is still not fully accepted on the large device size that is larger than 5mm × 5mm. It needs to overcome 2^{nd} level reliability issue on both solder joint and drop reliability test. To improve 2^{nd} level reliability, we need to apply the longer stand-off design such as Cu -post and double solder ball instead of single solder ball, and low modulus material on polymer layer under the solder pad for releasing thermal stress which result in the solder joints crack due to CTEs (Coefficient of Thermal Expansion) mismatch between organic PCB and WLCSP. In this paper, the double ball structure is introduced as one of them can provide the longer stand off. In addition of improving 2^{nd} level reliability and drop test it may need to apply different solder ball component properties to increase Thermal cycling and drop test. The WLCSP structured a double solder ball showed a better 2^{nd} level reliability result. This paper describes the molding process for double ball process and 2nd level reliability by solder property variation.

Key word: TC Reliability, Drop, Double Ball, WLCSP and Molding

Introduction

In recent years, the electronic package has been widely produced to support multi-functions, and it is also required to keep thinner and smaller size with lower build cost. The Wafer Level Chip Scale Package (here after WLCSP) has emerged as one of solution for low to medium pin-count applications and meet above needs. WLCSP type component is an excellent solution and now commonly used in mobile electronic products. However, this kind of wafer level package has still more risk for 2^{nd} level reliability to the failure than conventional QFP, BGA and CSP type components, therefore, how to optimum the structure and material to secure high reliability of WLCSP is very important.

One of approach to meet this require, this package usually used underfill process as one of solution to reliability increasing because it has the thermal expansion mismatch between the silicon chip and the organic PCB (3 ppm /℃ silicon versus 14-~16 ppm/℃ for FR-4).[1,2] The underfill operation increases the manufacturing cost and reduces the throughput. In addition, reworking an underfilled chip on PCB is very difficult. [2] Therefore, the WLP without underfill gradually evolve into another master stream in the electronic packaging industry. [3]

The other one is a change of solder material and a stand-off height control using encapsulation process for Cu-post or double ball process.[4] In case of Cu-post, it needs more lithography process and is hard to increase the post height by electroplating because of plating rate and plating photo resister or Dry film resister thickness. According to Topper's research, the wafer level double ball structure is promising to improve 2nd level reliability.[5] Also this structure is the least expensive approach as it does not require electro-plating and photolithography. This study focused on stand-off height and Ag proportion to enhance the TC reliability and drop reliability in board level. The higher stand-off lead the better TC reliability and lower Ag proportion lead the better drop reliability and worse TC reliability. [6] To increase the stand-off, we adopt the double ball process with printing and ball placing with solder proportion control.

In this report, the FEM simulation was performed to stress analysis and failure mode by molding effect. solder ball type and solder ball composition were chosen for WLCSP board level reliability evaluation, board level drop test and thermal cycling test are adopted to analyze these variables effects on WLCSP solder joint life.

Wafer level package design and process

WLCSP design

Currently it 's difficult to directly adopt over 5mm × 5mm WLCSP on substrate which occurred the 2nd level reliability issue by CTE mismatch. To solve these issues, this study carries out the no underfill concept in large die WLCSP. the Package size is adopted by 7.8mm × 8.6mm to study of 2nd level reliability which is general DDR 3 die size and solder ball location. Because DDR 3 aggressively need fast signal response time by a short interconnection. And the target stand-off height is 450mm which is considered by solder ball height and molding thickness. Figure 1 is tested WLCSP design.

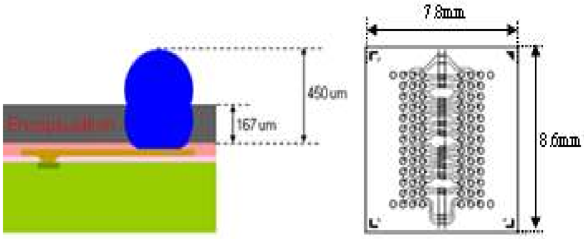


Figure 1 Wafer level package design

The table 1 is WLCSP specification. To meet upper design, it's applied double ball process and molding process. The FR-4 substrate was adopted by test PCB for TC and Drop test.

Table 1 WLCSP specification

Items	Specification
Die size	7.8mm × 8.6mm
Thickness	0.3 mm
1st Ball height	0.3 mm
2nd Ball height	0.3 mm
Molding thickness	0.15 mm
Ball pitch	0.5 mm
Pad size	0.28 mm
Board Thickness	1.0 mm (FR-4)

WLCSP Process flow

Figure 2 illustrated the WLCSP process flow and simple result for each process.

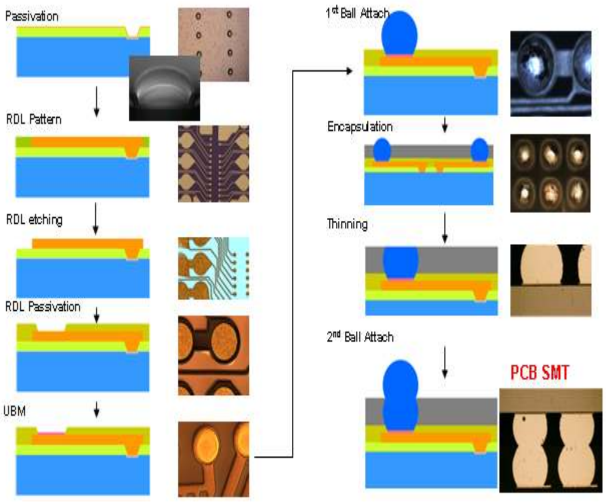


Figure2 Wafer level package process

First of all, the wafer have to applied 1st passivation process to reduce the stress for circuit and prevent capacitance issue and isolated the electrical connection with Redistributed layer (here after RDL). And then the bonding pad is routed to composite the electrical pattern by RDL patterning. And then the passivation process was performed on RDL pattern. Conventionally the cup type under bumped metallization (here after UBM) structure is normalized on WLCSP and Flip chip. This study is performed Electroless-plating Nikel Immersion Gold (here after ENIG) which is normal surface finish process on PCB UBM for cost reduction as it does not require sputtering and photolithography. Finally the single ball structure was made by ball attach process. To make a double ball structure, the single ball WLCSP have to be applied additional encapsulation process and 2nd ball attach process. After encapsulation, we applied wafer thinning process to make an even surface to 2nd ball attach and molding thickness control.

Result

FEM analysis

To compare the stand-off height, this study has designed the three type structures such as single ball, double ball, and single molded ball. The single ball has a lower stand –off by one solder. Double ball and single molded has increased a stand off by encapsulation. They have just process difference which is printing or ball placing

To analysis stand-off height effect, the WLCSP has compared the stress and life time estimation through FEM simulation during TC cycle. Figure 3 is stress distribution for each WLCSP structure. As shown in Fig. 3, the stress is decreasing by higher stand off.

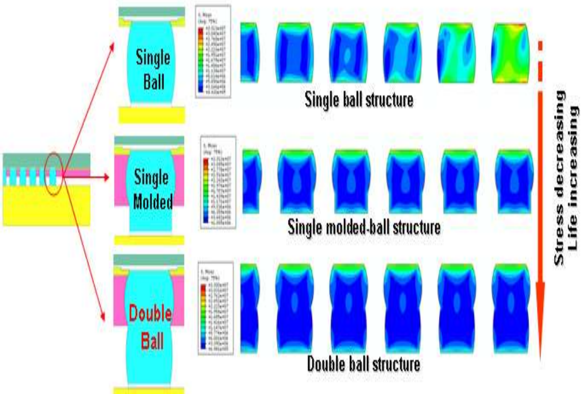


Figure 3 Stress Analysis during TC cycle

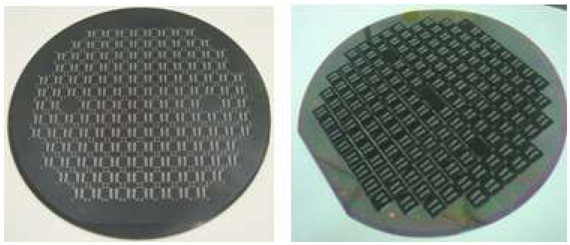
Table 2 TC Life time estimation

Structure type	TC Life
Single ball	316
Single Molded ball	1490
Double ball	1724

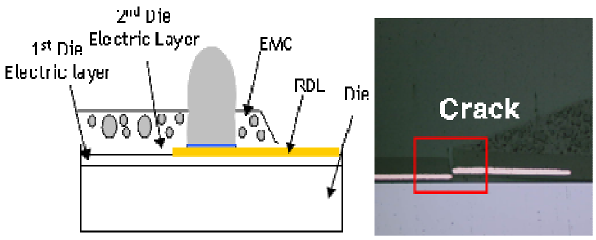
Table 2 is the estimated life time by FEM simulator during 0℃ ~ 125℃. Staked ball structures which are double ball Structure and single molded structure are estimated better TC life time than single ball. It has showed the higher stand-off lead better TC life time.

Encapsulation result

The molding process and ball placing process are key technology which makes the higher stand-off to distribute the solder stress during TC reliability tests. To increase the stand off height, we have considered two encapsulation methods which are molding and printing process. The printing process has some limitation for patterning and void control and grinding process even if it got a better warpage than molding process. Moreover the printing method have to use a liquid encapsulant which is 3~5 time to power encapsulant on compression molding process. The printing pattern control is difficult and the abnormal molding pattern lead redistribution layer (here after RDL) crack by stress concentration. Figure 4 displays the wafer encapsulation result. Fig.4 (a)-(b) is encapsulation result. Fig. 4 (c) is RDL crack by stress concentration by molding edge shape. So this work selected the compression molding process which had even molding thickness and shape.



(a) Molding result (b) Printing result



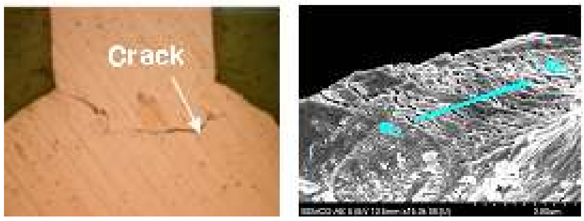
(c) RDL Crack by printing pattern

Figure 4 Wafer Encapsulation process

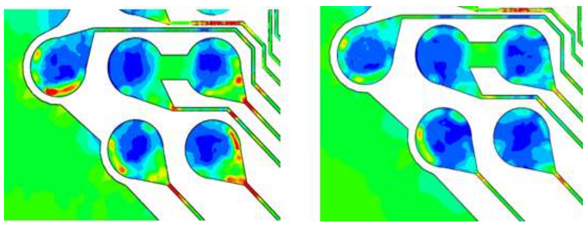
After molding process, the wafer was applied thinning process to make an even surface for 2nd ball attach and molding thickness control.

Analysis of failure mode

The TC reliability which is quick method to analysis failure mode was preformed on double ball and single ball structure. In case of single ball, the RDL layer was occurred by concentrated stress near solder pad during TC cycle.



(a) RDL Neck Crack (b) Stress Strain



(c) Single Ball (d) Molded

Figure 5 RDL Crack Analyses

Figure 5 show the RDL crack analysis at -25~125 thermal cycle. The Fig.5 (a) is the RDL crack issue in single ball. And (b) illustrated the stress strain of RDL crack area by thermal shock. FEM simulation was performed to analysis this trouble. Fig.5 (c) showed the high level RDL stress at the end of the fillet which leads the RDL crack at fillet area during The TC cycling. The Fig.5.(d) is RDL stress distribution after molding process. The stress isn't concentrated the RDL neck by FEM simulation. It's evidence of molding process needs for large die WLCSP.

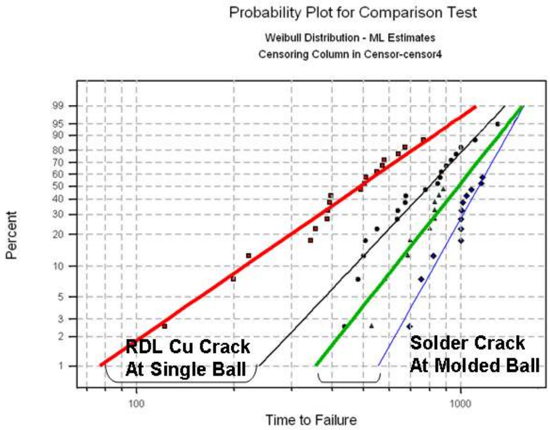
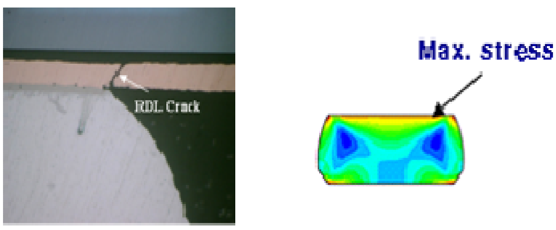
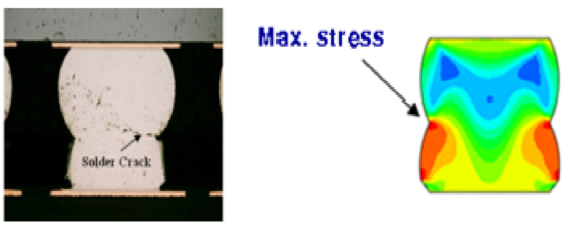


Figure 6 Molding Effect during TC tests

The experimental was performed to analysis the molding effect. Prepared samples are molded WLCSP and single ball WLCSP. The packages were subjected to thermal cycle reliability (TC) test which condition is 0℃ ~ 125℃ and -55℃ ~ 125℃. Figure 6 is TC test result for double ball and single ball. It show the molded structure have the better reliability than single ball by higher stand off height. Because decreasing stress is required as increased stand off using encapsulation. Thus this study adopt the solder ball stack method to increase the stand-off



(a) Single Ball Failure mode and Analysis



(b) Double Ball Failure mode and Analysis

Figure 7 Analysis of Failure mode

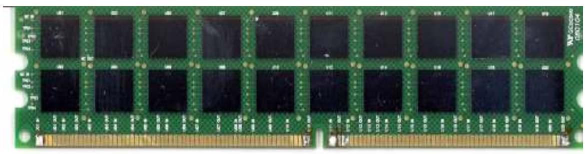
Figure 7 is failure analysis result. Fig. 7 (a), (b) showed dominant failure mode during TC cycling and stress concentration point by FEM simulation. The main failure of single ball is RDL crack and molded is solder crack. FEM simulation and TC test result indicate the concentrated point transfer RDL Layer to bulk solder by molding.

2nd Level TC reliability result

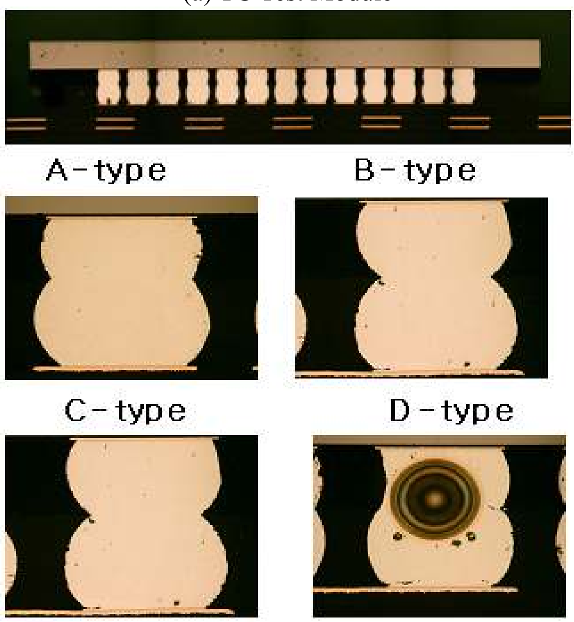
To improve the 2nd reliability, the stand-off height is important to distribute the solder joint stress. [6] This research selected the cost saving process which is ball attach process. It's difficult to apply a fine pitch device below 0.3 mm but it's effective for cost saving as it does not require the sputtering and electroplating.

Table 3 Solder ball type (SnAgCu system)

Solder	Type
A	Ultralow Ag, Low Cu
B	Low Ag, Low Cu
C	STD Ag, Cu
D	Polymer Core



(a) TC Test Module



(b) Cross Section view

Figure 8 SMT Result on TC Board

The solder ball type and component was studied on improving 2nd reliability. Table 3 is a studied solder type. Generally the 2nd reliability depends on the material proportion which decided Intermetallic compound (here after IMC) growth between UBM and Solder. Thus the Ag proportion is a 2nd reliability key factor on material choice. Lower Ag proportion drives the ductile which is improving the drop property but decreasing the 2nd level TC property. However, the higher stand-off height is reducing the solder joint stress between WLCSP and FR-4 PCB. This test focused on the trade–off between drop reliability and TC reliability by Ag proportion and stand-off. Also polymer core was reviewed on stress release of solder joint and RDL.

As shown in Fig. 8, (a), the 2nd TC test board was used by a memory module board. Fig.8 (b) showed a cross section view on each double shape by solder type. As shown in Fig. 8, (b), a total stand-off height of over 400 um was achieved using this double ball process. D-type solder had a different shape with polymer core which was moved by specific gravity difference with solder and polymer core during soldering process.

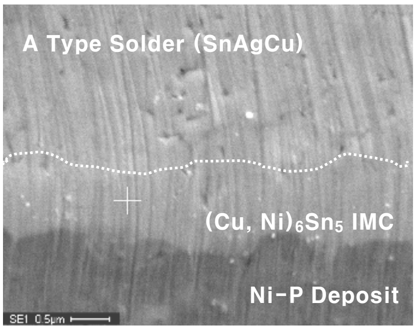
Table 4 is 2nd TC result for 0℃ ~ 125℃. The A-type reliability result is better than others. In case of A type Solder, the failure occurred mainly through the bulk solder. Besides, as shown in Fig.7 for double ball type, all failures were observed within the solder bulk side and not at the interface. But in case of singe ball type, the failure occurred at mainly RDL. It's due to transfer of stress concentration area.

Table 4 2nd TC reliability result

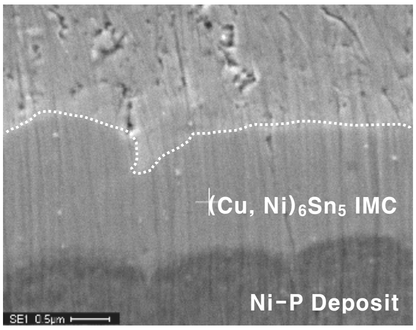
	1st Failure (cycle)	10% Failure (cycle)	Characteristic Life (cycle)	Shape Factor
A	884	892	1,294	6.04
B	418	588	1033	4.0
C	247	377	571	5.43
D	468	528	800	5.41

Figure 9 shows the cross sectional SEM micrographs of the interface solder and immersion Au/Ni-P/Cu bond pad before and after thermal cycling test. During soldering, the solder alloy reacts with the substrate to form intermetallic compound at the joint interface. From the results of EDX analysis, it was found that only one IMC of Cu-Ni-Sn formed at the SnAgCu solder interface, no binary IMC (Cu-Sn, Ni-Sn etc) was detected, rather, it was a complex IMC of Cu, Ni, and Sn with a Ni percentage of 20 ~ 26 at %.

From the typical stoichiometry of Cu_6Sn_5 IMC and knowing the fact that Ni atom can replace Cu from Cu_6Sn_5 IMC [7] we tend to believe that the complex IMC formed at the SnAgCu solder and immersion Au/ Ni-P/Cu bond pad interface is $(Cu,Ni)_6Sn_5$ IMC. No Au was found remaining at the interface of bond pad and SnAgCu solder due to the limited spatial resolution of the SEM. During the soldering reaction, the thin immersion Au (about 0.2um) dissolve within a few seconds. Therefore, it must have diffused into the bulk solder although there is no Au-Sn IMC was found for this study. If Au layer completely dissolved into the molten solder during soldering, the concentration of Au in bulk solder was less than 0.1 at%. A possible explanation is that the Au-Sn IMC are too rare to detect, since the Au plating is so thin for immersion Au/Ni-P/Cu bond pad [8]



(a) As-soldered before TC (0 cycle)



(b) After TC (1000 cycle)

Figure 9 SEM Micrographs of the interface between solder and immersion Au/Ni-P/Cu bond pad

Drop reliability Test

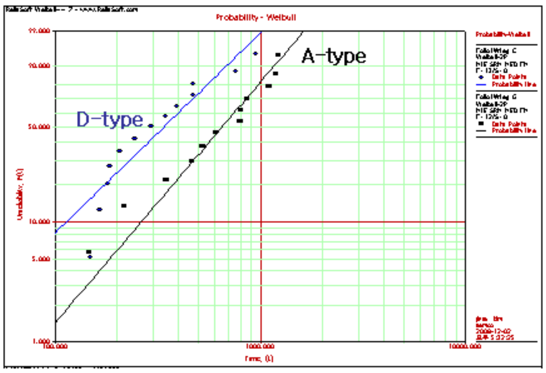


Figure 10 Drop reliability result

The drop test have used a JEDE standard board which made by 8layers FR-4 with 1.0T. The test condition is applied on 1.5G with 0.5msec. Figure 10 show a slop of drop test results. The drop test result for A and D type which got better TC result than other, A-type solder has better result by low Ag proportion. Drop test result of A-type is about 779 cycle of characteristic life time.

Conclusion

In this paper, we describe the 2nd level TC and drop reliability of double ball type WLCSP. The double ball structure promised the improvement of WLCSP reliability. The molding process distributed the RDL stress and increased the stand off height to improve the 2nd level TC reliability. The A-type solder ball has the best result for 2nd level TC reliability and drop reliability. Because the TC reliability was improved by higher stand-off height and the drop reliability was improved by lower Ag material properties.

These results indicate the trade off direction for Ag proportion to improve drop and 2nd TC reliability in double ball structure. We believe that our process, design and material can provide the solution for electronic market with high performance and good 2nd level reliability.

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