Failure Analysis of Interconnection Fault in a PoP Module Applied for Mobile Phone

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Abstract

A typical early fault case of some mobile phones was studied in this paper. The failure phenomenon was manifested as that the mobile phones could not be powered on after one year in their service, with the malfunction rate having reached about 2% of the whole yield in the same manufacturing lot as the fault machines returned from client side continuously. The results of fault location showed that there was interconnection failure in the main chip module, which used package on package (PoP) packaging. A series of experimental technique was used for the failure analysis, such as 3D X-ray inspection, shadow moiré test, microsectioning, scanning electron microscope (SEM), electron backscattered diffraction (EBSD) analysis, etc. The results showed that some solder joints' through cracking in the PoP module was the immediate cause of the mobile phones' malfunction, and the main reason for the cracking was thermal-mechanical fatigue with recrystallization microstructure degradation. It is important to further study on the technological method for controlling grain orientations in electronic interconnections.

Key words

Failure analysis, Interconnect reliability, PoP module, Recrystallization

I. Introduction

Current portable electronic products are driving component packaging towards three-dimensional (3D) technologies for integrating multiple memory die and application processors [1]. As an increasingly promising mainstream package technology, package on package (PoP) provides good flexibility of combination and sourcing, which facilitates flexible design and product upgrading for electronic terminal equipments [2]. For example, PoP has become an effective solution for mobile phones, due to the flexible integration and business model benefits that package stacking provides. However, there are still inherent challenges with respect to board-level and system-level quality/ reliability, which are not as well-studied as with the more common single-die BGAs [3, 4]. Interconnection fault may be usually caused by some solder joints' cracking, which could result in the system being scrapped. Fault localization and failure analysis for the 3D system-level module become more challenging, especially as the never ending drive of smaller, lighter and more advanced features on handheld products. As the dimensions of the solder joints in the PoP module scale down to the crystal grain size, the failure behaviors will become very different from that of bulk solder material [5]. The failure of micro solder joints in the PoP module is usually a complex thermal-mechanical induced microstructure degradation process, which is attributed to the mechanical mismatch of the different constitutive materials [6].

Therefore, it is important to study the failure behavior of PoP solder joints from the perspective of microstructure evolution during the PoP module's production as well as its service. In addition, more attention should be paid to the failure analysis technology research in order to further reveal failure mechanism and then to improve the reliability of the handheld products.

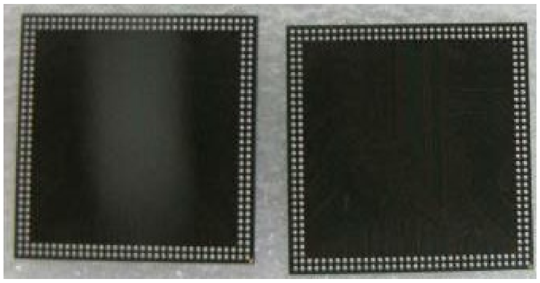
In this paper, a failure case of solder joints' cracking in a PoP module assembly applied for mobile phones was investigated and the failure cause was revealed. Furthermore, the package fatigue mechanism was determined, from the perspective of Pb-free solder crystal structure evolution.

II. Sample and Methods

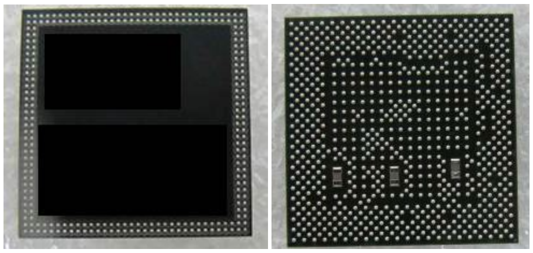
A. Sample Discription

The samples for this research were some failure motherboards used for a new type of mobile phones. The corresponding fault was manifested as that the mobile phones could not be powered on after one year in their service, with the fail rate of about 2% in the same manufacturing lot. This resulted in continuous customer returns.

Fault location was isolated by functional tests, which showed that the main chip modules' (with PoP packaging) failure was the root cause. Failure analysis was performed, focusing on the solder joints' interconnection in the PoP modules. The PoP module consisted of four main structures, the substrate, the molding compound (MC), the silicon die stack and solder balls. There were three dies stacking in the top package (named as DDR package) and one die in the bottom package (named as BB package). Images of the DDR package and BB package are as shown in the Fig. 1. The top package, bottom package, and the printed circuit board (PCB) were connected together by the Sn-3.0Ag-0.5Cu solder ball arrays after reflow soldering, and the diameter of the solder joints was about 250μm.



(a) DDR package (Top package)



(b) BB package (Bottom package)

Fig. 1 Images of the DDR package and BB package

B. Failure Analysis Methods

A series of experimental technique was used for failure analysis, such as 3D X-ray inspection, shadow moiré test, microsectioning, scanning electron microscope (SEM), electron backscattered diffraction (EBSD) analysis, etc.

Visual Inspection

Visual inspection was conducted to observe the soldering quality of the PoP solder joints under the stereomicroscope. Some solder joints' surface defects (such as surface cracks, poor wetting, and so on) can be detected by this inspection.

3D X-Ray Inspection

3D X-ray inspection was conducted to observe the PoP solder joints in the failure motherboards samples, focusing on the process defects, such as solder joint voids, cracking, head in pillow (HIP), etc. 3D X-ray inspection combined with functional testing was used for accurate fault isolation.

Microsectioning and microscope analysis

Microsectioning was conducted for the main PoP solder joints, and the microstructure was observed by optical microscope and SEM. Solder joints' cracking modes can be confirmed by this microscope analysis.

Shadow moiré test

Shadow moiré test was performed during the reflow cycle to determine the warpage deformation behavior of the PoP packages with temperature.

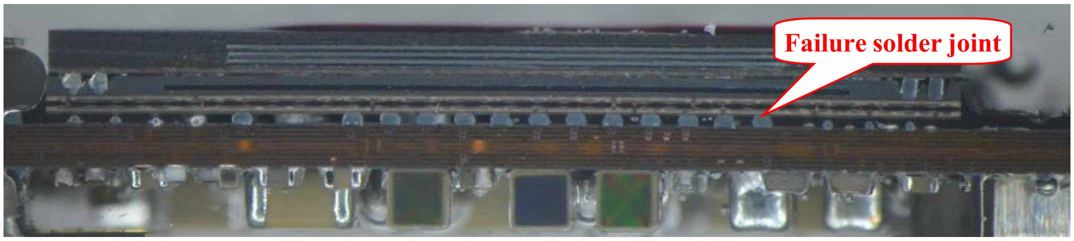
EBSD analysis

EBSD analysis was conducted to characterize the grain orientations for the solder joints' material, aiming to further determine the failure mechanism from the perspective of Pb-free solder crystal structure evolution.

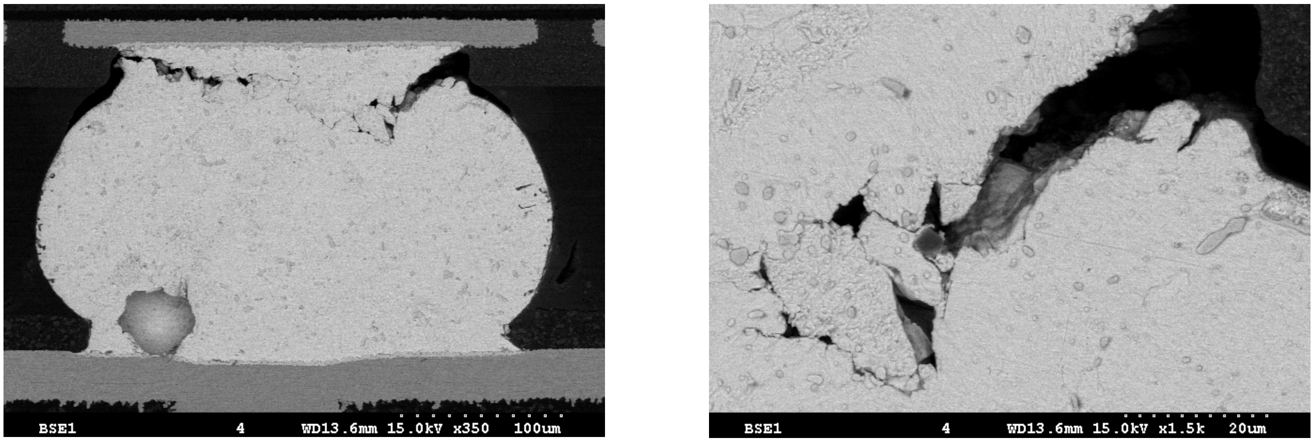
III. Results and discussion

The results of fault isolation tests showed that the failure points lie in the bottom solder joints layer, which connected the BB package and the PCB. And the failure solder joints mainly lie in the middle of the BB package, but just in the die edge row, in the horizontal plane, as shown in Fig. 2 (a). This failure phenomenon of solder joints with location feature was related to the stress/ strain distribution in the PoP module. Under the periodic temperature cyclic loading in service, the solder joints in the die edge row, in the horizontal plane, were most vulnerable to thermo-fatigue failure due to the most complex coefficient of thermal expansion (CTE) mismatch effect.

The failure mode of the solder joints was further confirmed under SEM. The main crack had run through the solder joint, with the propagation path being about 45°to the BB package pad plane, as shown in Fig. 2 (b) and (c).



(a) The failure solder joints' location



(b) Failure mode of the solder joints confirmed under SEM

(c) The cracking propagation path being about 45°to the BB package pad plane

Fig. 2 Micromorphology of some representative failure solder Joints

Shadow moiré test was performed for the BB package during the reflow cycle to further determine the thermal deformation behavior according to JESD 22B112 [7]. Fig. 3 shows the setting reflow profile. According to JEITA ED-7306 [8], the warpage direction definition is shown in Fig. 4. Looking at the side of the package with the solder balls facing down, the concave shape was defined as smiling warpage and the convex shape was defined as crying warpage. The data of concave shape warpage was negative value and data of convex shape warpage was positive one.

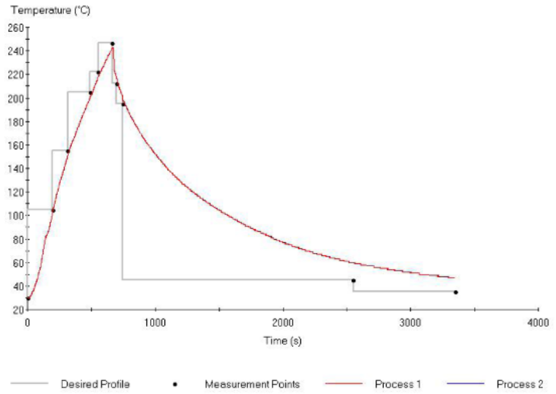
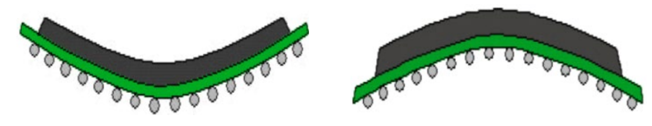


Fig. 3 Plot of Package Body Temperature vs Time



(a) concave/smile shape ("-") (b) convex/sad shape ("+")

Fig. 4 Definition of Package Warpage

The solder balls in the packages were removed before the thermal shadow moiré test. Fig. 5 shows the representative evolution curve of package warpage versus reflow temperature for the package samples. The results showed that the BB packages exhibited repeated warpage evolution during reflow process. And there was not significant corresponding relation between the maximum warpage position and the failure solder joints' location, as shown in Fig. 6. It could generally rule out the possibility of that soldering defects resulted in the early failure of the mobile phones.

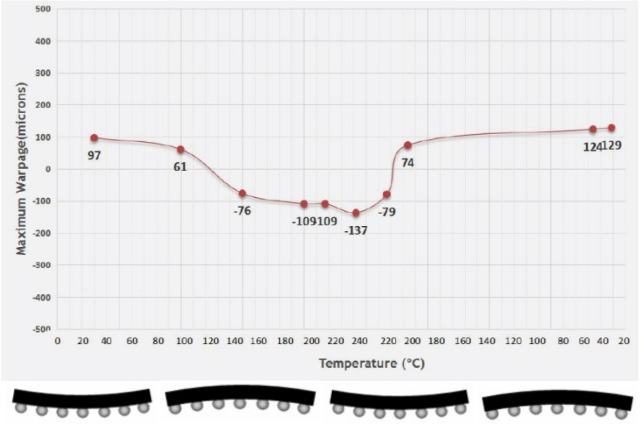
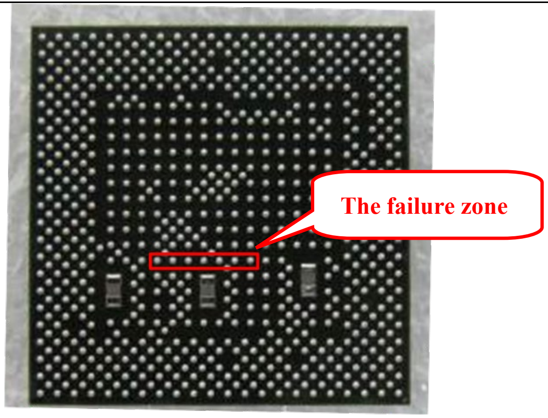
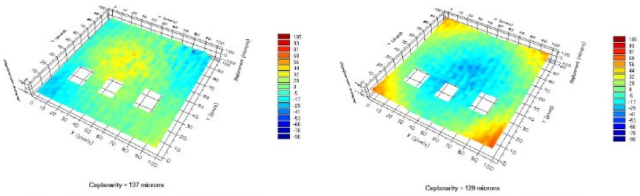


Fig. 5 Warpage evolution during reflow process



(a) The failure solder joints' location



T = 242 °C Heating, -137 microns T = 40 °C Cooling, 129 microns

(b) Representative 3D Thermo-moiré Plots

Fig. 6 The failure solder joints' location and the package warpage distribution

Comparative analysis of EBSD orientation maps was conducted for the two kinds of solder joints, failure solder joints and passing solder joints in the same failure PoP module. The results showed that the passing solder joint was typically composed of a few grains, and most of the interfacial Sn grains were with grain boundary perpendicular to the pad connecting interface, as shown in Fig. 7.

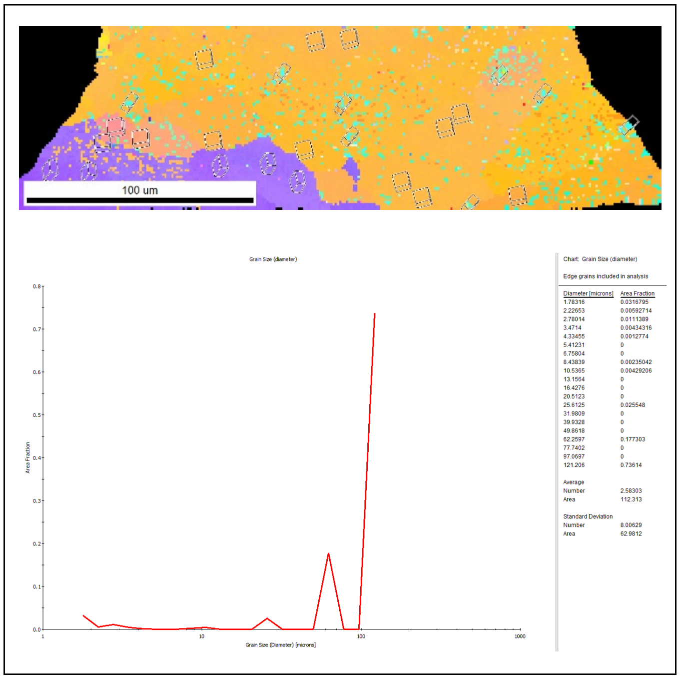


Chart: Grain Size (diameter)

Edge grains included in analysis

Diameter [microns]	Area Fraction
1.78316	0.0316795
2.22653	0.00592714
2.78014	0.0111389
3.4714	0.00434316
4.33455	0.0012774
5.41231	0
6.75804	0
8.43839	0.00235042
10.5365	0.00429206
13.1564	0
16.4276	0
20.5123	0
25.6125	0.025548
31.9809	0
39.9328	0
49.8618	0
62.2597	0.177303
77.7402	0
97.0697	0
121.206	0.73614
Average	
Number	2.58303
Area	112.313
Standard Deviation	
Number	8.00629
Area	62.9812

Fig. 7 EBSD orientation map for some passing solder joint

For the failure solder joints, recrystallization occurred in the localized regions along the crack propagation path, in which the pre-existing interfacial Sn grains' boundary was about 45°to the pad connecting interface, as shown in Fig. 8. The diametes of the newly formed small grains along the crack propagation path were in the range of 5~20μm, which agreed well with the results obtained in previous studies [5, 6].

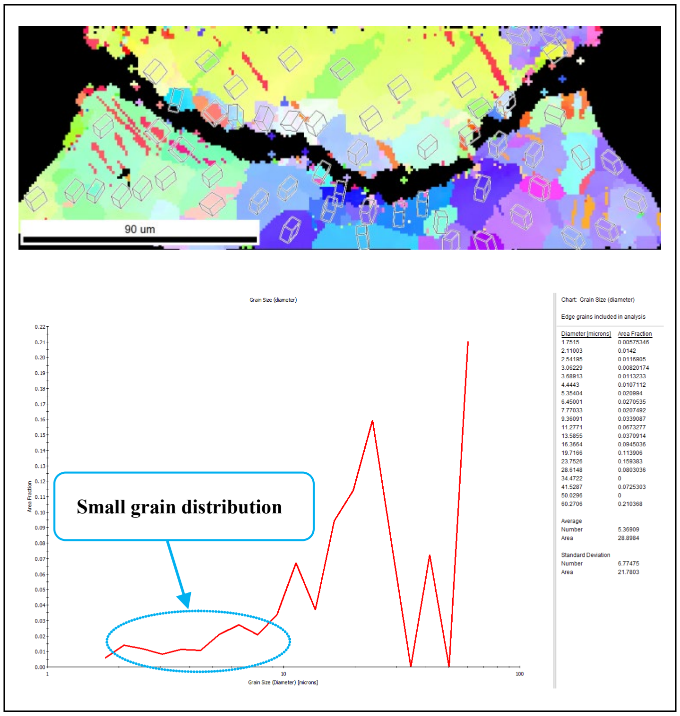


Chart: Grain Size (diameter)

Edge grains included in analysis

Diameter [microns]	Area Fraction
1.7515	0.00575346
2.11003	0.0142
2.54195	0.0116905
3.06229	0.00820174
3.68913	0.0113233
4.4443	0.0107112
5.35404	0.020994
6.45001	0.0270535
7.77033	0.0207492
9.36091	0.0339087
11.2771	0.0673277
13.5855	0.0370914
16.3664	0.0945036
19.7166	0.113906
23.7526	0.159383
28.6148	0.0803036
34.4722	0
41.5287	0.0725303
50.0296	0
60.2706	0.210368
Average	
Number	5.36909
Area	28.8984
Standard Deviation	
Number	6.77475
Area	21.7803

Fig. 8 EBSD orientation map for some failure solder joint

For solder joints with multiple grains, the distribution of stress and strain depends on grain orientation, and recrystallization/ cracking tends to divert from the connecting interfacial region into the bulk solder along the pre-existing grain boundary. Some special solder joints, with grain boundary perpendicular to the interface, have strong anti-deformation capacity, exhibiting higher reliability. However, the solder joints with the original grain boundary inclining at 45°to the connecting pad, strain/ stress concentration will be produced in the grain boundary zone with the combining actions of shear stress and anisotropy of Sn grains, which will accelerate the crack initiation and propagation. As a result, fracture occurred along the original grain boundaries, leading to the early failure of the solder joints.

III. Conclusion

Some solder joints' through cracking in the PoP module was the immediate cause of the mobile phones' malfunction, and the main reason for the cracking was thermal-mechanical fatigue with recrystallization microstructure degradation. The main cracks' propagation path was about 45° to the BB package pad plane. Grain orientation has an important influence on the solder joints' failure behavior. For the solder joints with the original grain boundary inclining at 45°to the connecting pad, fracture is apt to occur along the original grain boundaries, leading to the early failure of solder joints. It is important to further study on the technological method for controlling grain orientations in electronic interconnections [9].

Acknowledgment

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