Research on Over-Temperature using of PEM Evaluation Method in Military

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Abstract: In order to evaluate the reliability of over-temperature using of Plastic Encapsulated Microcircuit (PEM) in military, this paper designs tests to simulate environmental suitability and lifetime by analyzing the failure mode and mechanism of PEM (the plastic encapsulated microcircuit). Based on the analysis, the evaluating tests are designed and conducted, and the result shows that HAST (High accelerated stress temperature), temperature cycling, and Steady state life test under the operating condition but within the maximum temperature limit, can be chosen to evaluate the reliability of the devices used over-temperature in sequence. This provides a set of feasible evaluation methods for the over-temperature using of PEM, which can effectively guarantee the quality and reliability of PEM, also provides theoretical basis for the subsequent formation of effective evaluation methods and standards for the screening and detection of the over-temperature using of PEM.

1 INTRODUCTION

Plastic package is the main form of electronic components packaging, for its low cost, small size as well as light weight, etc. It is a statistical fact that 92% of IC components and discrete devices use the plastic package at present.

As the moisture absorption and the mismatch of thermal expansion coefficient of epoxy resin, the plastic encapsulated microcircuit (PEM) is generally limited to apply in the field of aerospace, military and high reliability industry. One of the most serious problems is its narrower temperature range. Comparing with the glass and ceramic, encapsulation materials belong to low temperature, and its vitrification transition temperature is between 130~160°C, it mainly satisfies the requirement of the temperature range of the 3 followings: 0°C ~70°C (commercial), -40°C ~85°C (industrial) and -40°C ~125°C (car), all the 3 temperature ranges are narrower than military temperature range (-55°C ~125°C). Besides, there are many other application environments that are even more extreme, such as cold climate of avionics and spacecraft requires -65°C or less, and the ignition control is up to 175°C, even the aviation electronic distribution control system reaches 225°C. If the PEM is directly used in target temperature conditions without evaluation and assessment, it usually causes problems such as high failure efficiency and low reliability of electronic products (LIANG Yuan, et.al, 2015). Therefore, it is urgent to establish an evaluation method and procedure for the over-temperature using of PEM to ensure the quality and reliability, which can provide theoretical basis for the subsequent formation of effective evaluation methods and standards for the screening and detection PEM in over-temperature using.

2 FAILURE MODE AND MECHANISM ANALYSIS OF OVER-TEMPERATURE USING OF PEM

Recently, the PEM reliability has greatly improved along with the progress of the packaging materials and coating process, while the reliability requirement is much higher, but the main failure mode for PEM is still delamination, especially serious for the plastic power device with hermetic

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problem in the condition of high temperature with high voltage and large current. In the process of reliability testing and servicing, it is common to find delamination between epoxy molding compound (EMC) and the lead frame, as well as the micro-chip and substrate, which leads to a series of failure modes, such as plastic strain crack, passivation layer damaged, leakage current increased, PN junction damaged, etc (AndrewA.O.Tay, 1996).

Normally, there is boundary layer (transition layer) between the copper substrate and epoxy molding compound (EMC) in PEM. The transition layer, different with other part of epoxy molding compound, is the weakest position of all adhesive interface, and makes the delamination occurring and spreading under the stress of thermal and humidity. If the delamination occurs between EMC and chip, it will cause an increase in the bonding wire resistance as well as leakage current and decrease in breakdown voltage even turn to open-circuit due to mechanical tensile damage, also the passivating layer are destroyed, which provides an easier channel for the moisture immersing into the chip surface and lead to the metal layer corrosion; While if the delamination occurs between EMC and copper substrate or lead frame, it will lead to Popcorn Effect, while provides an channel for the moisture immersing. In conclusion, once the delamination occurs between EMC and other material, even if the area is small, it will become the source of delamination, and gradually expand in the actual usage by thermal stress or mechanical stress until it fails (PoPeom, 1995; Sheng Nian, 2014). The table below shows the failure analysis of PEM in main operating stress.

Table 1. The analysis of PEM in main operating stress.

No.	Failure Mode	Failure Mechanism
1	Die crack, die adhesive failure	Temperature stress
2	leakage current increased, PN junction damaged	Thermal-electric stress
3	Migration intermetallic compound, Ohmic contact degradation	Thermal stress
4	Delamination	Humid-thermo stress

3 RELIABILITY EVALUATION OF OVER-TEMPERATURE USING OF PEM

3.1 Select the Test Methods

Based on the analysis above, as well as combining with GJB 7400-2011 “General specification for semiconductor integrated circuits of qualitied manufacturer certification” (G. Eason, et.al, 1955), which is used to qualify the PEM used in military, the high temperature storage, HAST, Temperature cycle, and Steady state life test which are chosen to qualify the reliability of PEM. Besides, the external visual inspection, electrical performance test in room temperature and Scanning Acoustic Microscope (SAM) test are conducted after each test. Meanwhile, in order to verify whether the different temperature have different impact in structure and performance for PEM, comparative tests are also carried out.

3.2 Select the Test PEMs

This paper selects PEM ADV7123KSTZ140 as the test sample. The maximum operating temperature specified in the device manual is 85°C, but it is tested the maximum operating temperature in actual use is 115°C.

In order to verify whether the device at 85°C and 115°C temperature stress have the different impacts on the performance and structure, 20 fully qualified devices are selected to test under the manual regulation temperature stress 85°C, marked as 1-1; 20 fully qualified devices are selected to test under the actual temperature stress 115°C, marked as 2-1; 20 fully qualified devices with delamination (without pins) at the lead frame are selected to test under the manual regulation temperature stress 85°C, marked as 1-2; 20 fully qualified devices with delamination (without pins) at the lead frame are selected to test under the actual temperature stress 115°C, marked as 2-2. The devices information and the test method are shown in table 2.

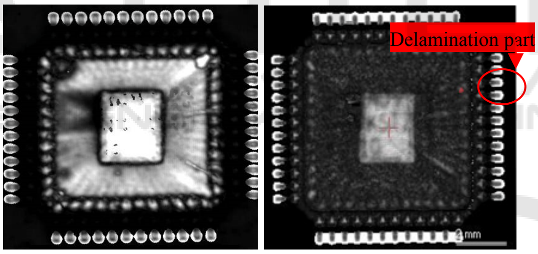
3.3 Process of the Tests

3.3.1 High Temperature Storage

After the high-temperature storage test for 48hours, it is found that the functional performance parameters of these 4 groups do not change too much, and the delamination area of the 1-2 and 2-2 groups do not expand obviously, while there is no obvious change of the 1-1 and 2-1 groups, which indicates that different high-temperature storage had little impact on the PEMs, and the typical test results are shown in figure 1.

Table 2. The devices information and the test method.

No.	Items	Test condition of 1-1, 1-2	Test condition of 2-1, 2-2
1	High temperature storage	85□,48h	115□,48h
2	HAST	85%RH/85□, 1000h	85%RH/115□, 1000h
3	Temperature cycle	-40□~85□ , 500 times	-40□~115□ , 500 times
4	Steady state life test	1000h, 85□	1000h, 115□
Devices information			
No.	External visual inspection	Electronic performance	SAM
1-1 2-1	qualified	qualified	qualified
1-2 2-2	qualified	qualified	Defective but not rejected

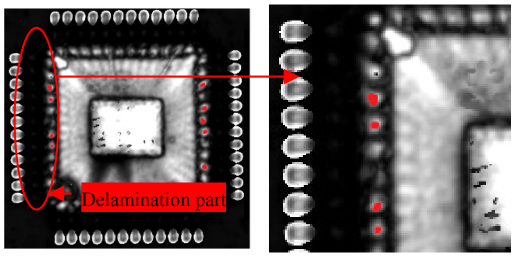


(a) Qualified (b) Defective but not rejected

Figure 1. SAM after high-temperature storage.

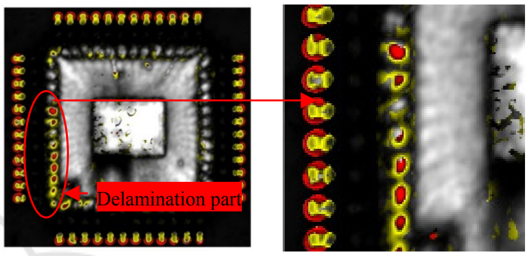
3.3.2 High Accelerated Stress Temperature

The second test is High accelerated stress temperature (HAST), it is found that the functional performance parameters of these 4 groups do not change too much, still qualified. Group 1-1 and group 2-1 have no obvious defects such as cavities and cracks arise. Meanwhile the delamination area of groups 1-2 and 2-2 increased, but groups 1-2 was slightly less than that of groups 2-2. It can be inferred that HAST can makes the delamination area expansion. However, the expansion is related to temperature: with the same humidity, the higher the temperature, the larger the delamination area, while the lower the temperature, the smaller the delamination area (Xiao haihong, 2009), and the typical test results are shown in figure 2 and figure 3.



(a) Global photo of SAM (b) partial enlarged detail

Figure 2. SAM of group 1-2 after HAST.

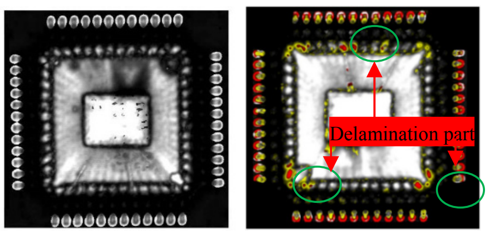


(a) Global photo of SAM (b) partial enlarged detail

Figure 3. SAM of group 2-2 after HAST.

3.3.3 Temperature Cycle

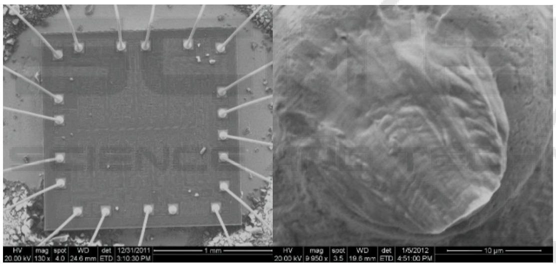
The third test is temperature cycle. It is found that the functional performance parameters of these 4 groups were still qualified, like it after HAST. Group 1-1 and group 2-1 have no obvious defects such as cavities and cracks arise. Meanwhile the delamination area of groups 1-2 and 2-2 increased than the area after HAST, and the functional performance of these 2 groups are abnormal, and the typical inspection results are shown in figure 4. That is because the temperature change rate of temperature cycle is large, and the rapid temperature gradient will make the thermal stress increase which makes the failure rate increase.



(a) Group 1-1, 2-1 (b) group 2-1, 2-2

Figure 4. SAM after temperature cycles.

Though the SEM examination for the group1-2 and group 2-2 which have the abnormal functional performance, it is found that as the bonding line is embedded in the packaging material and passes through the bonding layer, the stress on the bonding line will increase rapidly when the bonding layer fails. The mismatch of thermal expansion coefficient will result in repeated stress on the bonding line at the interface with fatigue fracture. In the early stage, crack initiate at stress point due to the repeated action, and the stratification distance becomes larger, the contact area becomes smaller or even disconnects, resulting in parameter deviation or open circuit at the low temperature. After the temperature return to room temperature, the size of the delamination decreases, the contact at the crack of the bonding line resumes the connection, and the electrical properties and functions return to normal. If the bonding line crosses the delaminated interface, it will cause fatigue fracture of the bonding line under the action of thermal stress, which will obviously increase the area of the disposed layer of the lead frame with abnormal function and performance of the PEMs (Driel, W.D.V, 2005). Typical detection results are shown in figure 5.



(a) Global photo of SEM (b) partial enlarged detail

Figure 5. SEM of group 2-1 and 2-2 after Temperature cycle.

3.3.4 Steady-State Life

The remaining two groups (groups 1-1 and 2-1) were tested at 1000h, 85h and 1000h and 110 steady-state life. It is found that the group 1-1 is functionally qualified at 1000h and 85°C, also without any delamination inner the devices; but the leakage current degradation of 2-1 was significantly greater than that of the group 1-1, as shown in figure 6.

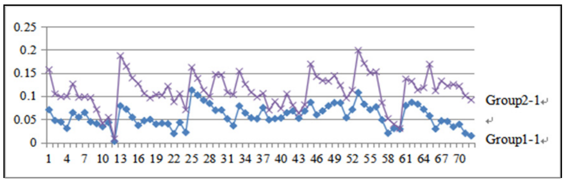
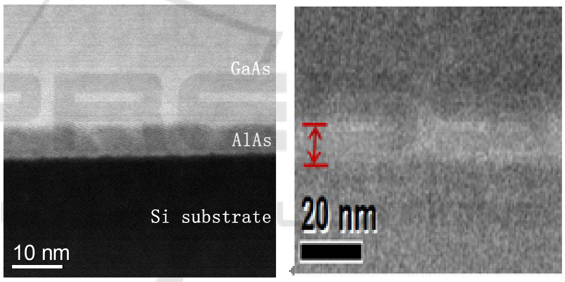


Figure 6. Typical inspection results of leakage current.

Though the SEM examination for the group 1-1 and group 2-1, It is found that the gate oxide thickness of group 2-1 is about 5nm, much less than the gate oxide thickness of group 2-1, about 10nm, that is because the lattice under high temperature is unstable and the interface state of oxide layer increases, resulting in the reduction of the thickness of the gate oxide layer. through the thick oxide breakdown voltage is (1.4~3)×107V/cm, eigen breakdown voltage of oxide layer is (8~10)×106 V/cm. In general, under the action of electric pressure, thin gate oxide layer is more likely to cause breakdown, accompanied by thermal carrier effect (TEVEROVSKY A, 2003). Typical inspection results are shown in figure 7.



(a) Global photo of SEM (b) partial enlarged detail

Figure 7. Thickness of group 2-1 and 2-2 after Steady-state life test.

3.3.5 Comparative Tests

The comparative tests are conducted in order to verify whether the different temperature have different impact in structure and performance for PEM. We choose 5 devices from the group 2-1 after steady-state life, and 5 new and qualified devices as the comparative ones. According to GJB 4027A-2006, method 1100, the external inspection, X-ray inspection, SAM, internal inspection and SEM are carried on by sequence, it is found that there is no obvious difference between these 2 groups, which means the tests for group 2-1 do not cause other potential damage to the devices.

4 CLOUSION

For PEM with inherent defects, they have poor environmental adaptability, are more easily to fail and have lower reliability in usage under overtemperature conditions. This is because the mismatch of thermal expansion coefficient can cause stress at the interface between chip and package. The temperature gradient caused by rapid temperature change will increase the stress and accelerate the failure rate. If the bonding line crosses the layered interface, it will cause fatigue fracture of the bonding line and abnormal function and performance of the device under the action of a wide range of temperature stress. It can be seen from the results of tests in this paper, that HAST, temperature cycle, and steady life test in actual usage temperature can lead to device failure, inherent defects effectively eliminate and encapsulation device used in over temperature potential failure under the application, evaluation device environment adaptability; However, under the condition of high-temperature storage, the device can only bear high-temperature stress, and the absence of a temperature gradient prevents the device from potentially failing. And the temperature cycle, HAST and steady life test in actual temperature do not cause other potential damage to the devices.

The research results in this paper can effectively ensure the quality and reliability of devices over-temperature using, and provide a theoretical basis for the detection, evaluation, screening and failure analysis for the PEMs used in over temperature.

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