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The Effect of Leadframe Oxidation of a Quad Flat No-Lead Semiconductor Package under Cyclic Loading

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Abstract: This study presents a new cyclic test for the QFN package using the oxidised leadframe and good leadframe, namely the three-point assembly fixture with a rounded contact surface test method. The fixture of the test method is a test assembly that supports a specimen on two anvils or rollers and symmetrically loads the specimen on the opposite surface with an anvil or roller using Micro Tester; a micro tensile tester incorporating a deflection measuring device shall be used to generate a controlled board deflection rate. The validity of the mechanical test method can then be verified based on the stress analysis results and also be obtained in the experiments. Considering the QFN package delamination, lead cracking, package body cracking and cracking between the various lead statistically based on the experiments, it was shown during cyclic loads and the temperature conditions for the QFN package for delamination can be observed.

Key words: Cyclic test, good leadframe, oxidised leadframe, QFN package, thermal cycle

INTRODUCTION

Copper and copper alloys are widely used in microelectronic packaging. The application of copper is in the copper leadframe which serves primarily to support the chip mechanically during the assembly of plastic package and to connect the chip electrically with the outside world. Copper alloy would be an ideal leadframe material from an electric and thermal conductivity standpoint (Zheng, 2003). The relentless drive to meet the demands of compact, lightweight products, such as in mobile communications and Personal Digital Assistant (PDA), has resulted in the ongoing miniaturization of packages. Propelled by a strong desire for product functionality yet increasing compactness, the option of chip scale package is a clear advantage. One of such packages, first presented by Matsushita, is the Quad Flat No-Lead (QFN) which used the copper leadframe and the QFN packages are especially advantageous in high-speed applications because of the low interconnect in inductance (Hirohata *et al*., 2002; Lim *et al*., 2004).

There are two different mechanisms of copper oxidation. In aqueous environments at ambient temperature, thin layers of dicopper oxidize (Cu_2O) first forms on the copper surface by the oxidation and reduction partial reaction. Cu_2O is a p-type semiconductor with negatively charged vacancies (ASM International, 1989). The growth of the Cu_2O takes place on the top of surface through the mass transport of the Cu^+ ions and electrons in a direction normal to the surface via vacancies (ASM International, 1989; Horvath *et al*., 1999). The second stage of oxidation, the formation of the copper oxidize (CuO) from Cu_2O is usually a slower process. It is governed by the in-diffusion of oxygen into the oxide.

Generally, thermal cycle tests (TCTs) are applied to electronic packages under development in order to prove their reliability. Due to the large thermal expansion coefficients mismatch between the IC die and organic substrate, thermal stresses arise under the TCTs (Wu *et al*., 1996). In QFN packages, the packages are encapsulated by Epoxy Mold Compound (EMC) in order to reduce the stresses. EMC makes the reliability of QFN packages much higher. However, according to the EMC selection, delamination may occur during TCTs and lead to failure (Doi *et al*., 1995; Wang *et al*., 1998; Hoang, 1998). Therefore it is important to prove the adhesion reliability of EMC under TCTs. At the early stage of the development, a more effective test method is desirable, because the TCTs are time-consuming. It is also well known that the thermal fatigue of metals could be determined on the basis of mechanical fatigue tests carried out at constant elevated temperatures (Flugge, 1962).

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In this study, the good leadframe and the oxidised leadframe have different structures and compositions. This leadframe is used in Quad Flat No-Lead (QFN) package. Using the oxidised leadframe presents a negative effect on the package reliability. For package reliability, cyclic tests will be performed in order to observe the reliability of epoxy adhesiveness between the package die and the package leadframe. In order to achieve the target, the cyclic three points bending tests have been introduced and performed on to the QFN packages with the oxidised leadframe and the good leadframe.

MATERIALS AND METHODS

A typical leadframe used in QFN package is shown in Fig. 1. Fresh die-pads from copper leadframes were subjected to oxidation under constant temperature in an ambient environment of 30°C/70% relative humidity (RH) within 360 h. The resulting copper oxide thickness was measured using Infinite Focus Microscope (IFM) to measure the volume of the sputter craters. Due to the surface roughness of the copper leadframe, a thicker oxide sample was required to calibrate the sputter rate using IFM.

Using the Energy Dispersive x-ray (EDX) for measure the surface roughness of leadframe, that will produce quantities information on the chemical nature of surface. The surface to be analyzed is bombarded by an electron beam and the x-ray that is produced is used to identify the elemental nature of the surface at the point of impingement was performed on a copper leadframe sample with an oxide layer. The good leadframe and oxidised leadframe can be measure the tensile stress using the Instron Universal Tester (5860 series) for observation of the Young's modulus of different leadframe. An average of three runs was performed on each sample to measure the thickness of the oxide.

For the study case of cyclic testing approach, electronic packages which are the under development process are generally subjected to TCTs to prove their reliability. According to the loads condition, the delamination effect between the EMC, die and leadframe may occur in the TCTs. It is important to evaluate the reliability measure of the epoxy adhesion on leadframe in the TCTs. However, the TCTs usually require one or two months. It is because of one cycle-time is about one hour and 1000 cycles are required for high-reliability packages. By using the mechanical loads instead of the thermal loads, the test-term can then be shortened. If the stress distribution under TCT conditions can be recognized by means of the mechanical loads, it is possible to prove the adhesion reliability for the short-term. The delamination effect in the package occurs at the leadframe and also at the corner of the die/epoxy interface.

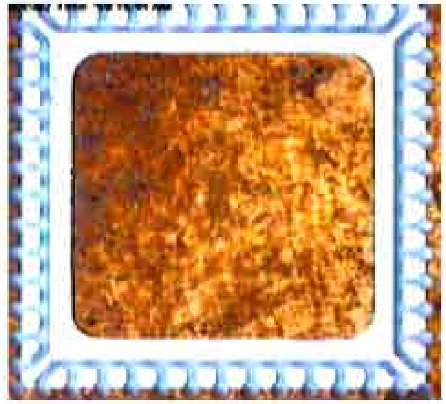

Fig. 1: An image of the leadframe taken using the optical microscope

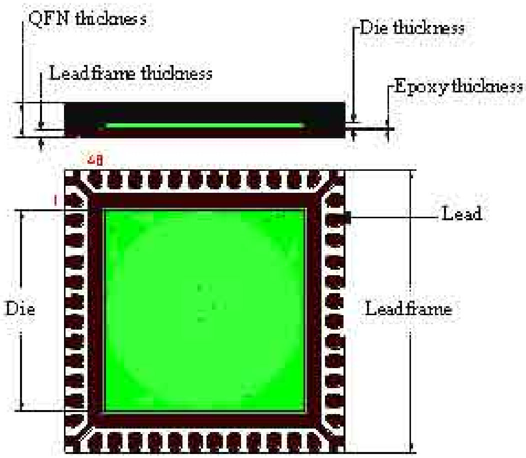

Fig. 2: Schematic diagram of a QFN package showing the side view and the top view

In order to obtain the stress distribution in the leadframe, die and epoxy interface under thermal condition for mechanical cyclic, stress analysis has been performed. The QFN package which is shown in Fig. 2 was used. The outer boundary of the QFN size is 7×7×0.85 mm, the die size is 5×5×0.15 mm and the epoxy thickness between the die and the leadframe is 0.0254 m. It was assumed that the stress in the package was free at the highest temperature 175°C, because it was almost similar to the temperature under resin-curing. The shear and the normal stress distributions at 25°C and the maximum package application is 260°C for QFN package, but the INSTRON Micro Tester 5800 series machine capability have the

Table 1: The cyclic tests conditions used for this study

Temperature (°C)	No. of cycles	Frequency	Amplitude
25	1000	2 Hz	20 N
100	1000	2 Hz	20 N
175	1000	2 Hz	20 N
250	1000	2 Hz	20 N

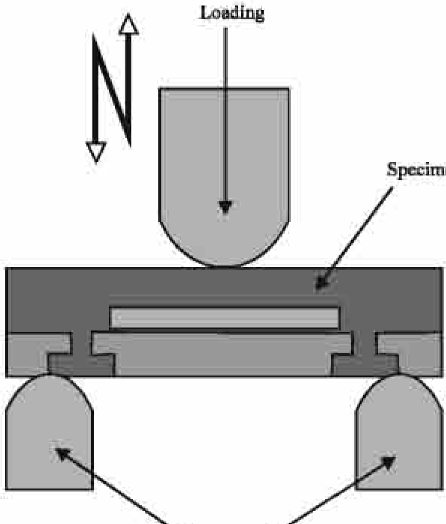

Fig. 3: Schematic diagram of the three point bending test

maximum temperature is only 250°C. The mechanical load applies for cyclic test is negative 20 N. Cyclic tests, as the schematic view is presented in Fig. 3, concerning surface on the package were conducted under the following temperature conditions: 25, 100, 175 and 250°C. Loading cyclic amplitude range is 20 N. The negative (-) of load condition mean the load is following gravity. In this method, the shear stress range is proportional to the range of the load at the center. The cyclic test conditions concerning surface on the package are shown in Table 1.

RESULTS AND DISCUSSION

Surface analysis of the leadframe: Surface roughness is the measure of the finer surface irregularities in the surface texture. These are the results of the manufacturing process employed to create the surface. Surface roughness (R_a) is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micrometers. ISO standards use the term CLA (Center Line Average). Infinite Focus Microscope (IFM) analysis was used to observe the microstructure and surface roughness the good leadframe and oxidised leadframe shown in Fig. 4 and 5. From the results, the roughness for the good leadframe is 4.143 μm and the roughness for the oxidised

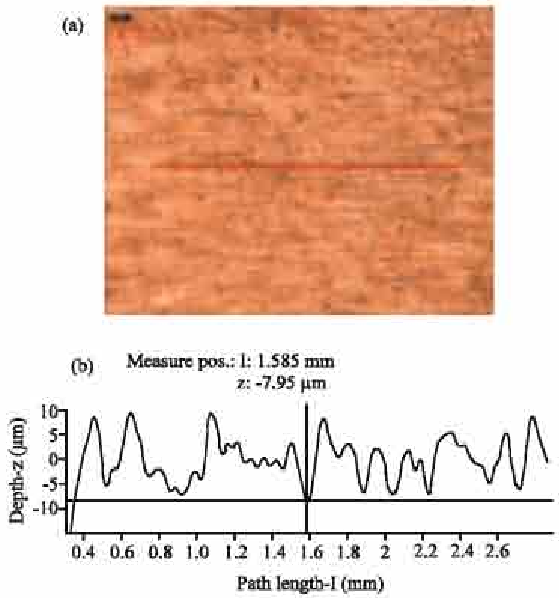

Fig. 4: Good leadframe (x25): (a) Microstructure view, (b) Surface roughness graph, R_a = 4.143 μm

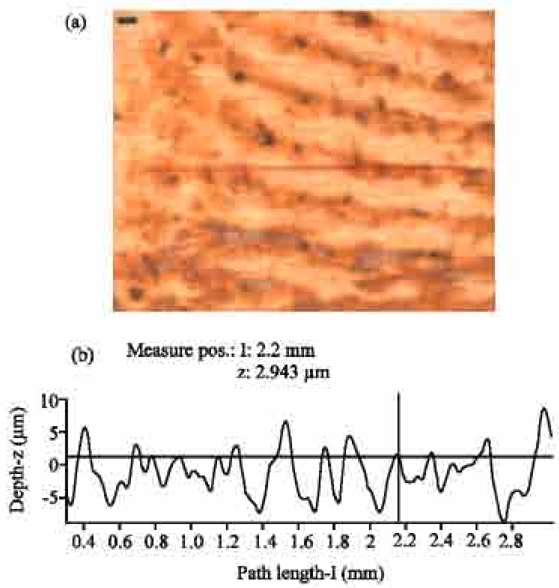

Fig. 5: Oxidised leadframe (x25): (a) Microstructure view, (b) Surface roughness graph, R_a = 3.205 μm

leadframe is 3.205 μm. The oxidised leadframe has a thin layer of oxidation, because of that, the surface roughness of the oxidised leadframe was lower than the surface roughness of the good leadframe. The layer of oxidation gives the lower adhesion strength on the epoxy and molding compound, there are effect for delamination on epoxy and molding compound in the QFN package.

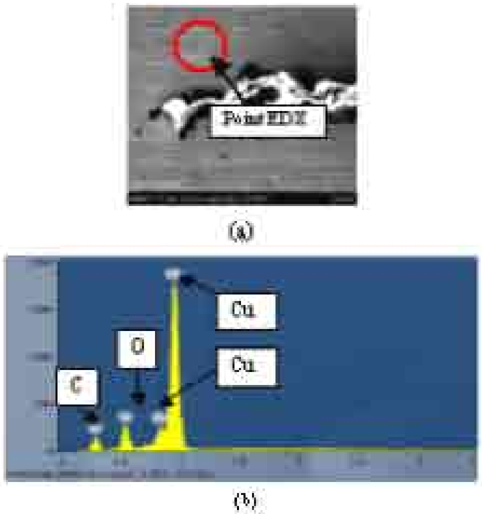

Fig. 6: EDX result for a good leadframe (a) Microstructure scanning view (50 μm), (b) spectrum view to show material composition

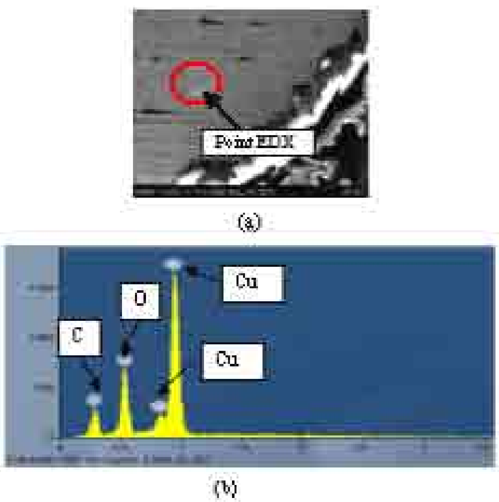

Fig. 7: EDX result for an oxidised leadframe: (a) Microstructure scanning view (50 μm), (b) spectrum view to show material composition

As shown in Fig. 6 and 7, the area of the surface that was analyzed was smaller compared to some other processes, but the depth of the analysis is so great, about 1 μm, that this technique really produces analysis of the leadframe. This process is most effective on metallic leadframes and it is most commonly used for analyzing particles or phases that come to surface (Budinski and Budinski, 2005). Surface analysis of leadframe, C194 using the EDX demonstrates the copper oxidation in the copper interface after under constant temperature in an ambient environment of 30°C/70% RH within 360 h. Figure 6 shows

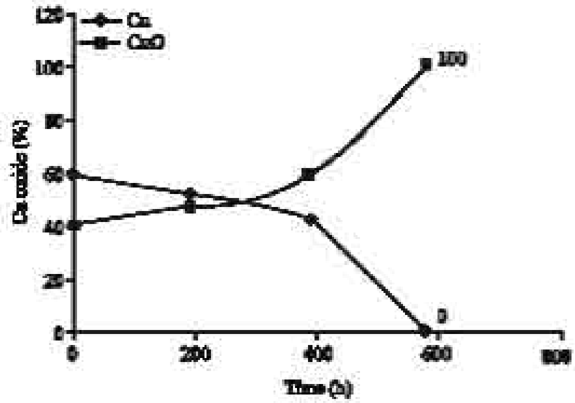

Fig. 8: Copper oxide concentration and rate of corrosion as a function of exposure time (Horvath *et al.*, 1999)

a great amount of Cu, C and CuO/Cu_2O at 0 h corrosion, the oxidation of this leadframe was found to be at 10% oxidation. Figure 7 shows the decreasing of Cu and the increasing of CuO/Cu_2O after 360 h (15 days) corrosion and the oxidation of this leadframe is 50% oxidation. As a result, Fig. 6 was considered as a good leadframe and Fig. 7 was observed as an oxidised leadframe.

Figure 8 shows the corrosion rate of copper leadframe as the function of autoclave test time. Initially, Cu has higher percentage than CuO, which is 59 and 41%, respectively. However, the CuO concentration increases gradually after 384 h under autoclave test. At 576 h, the Cu completely turns into CuO, while no indication of the Cu existence was detected (Horvath *et al.*, 1999).

From the uniaxial tensile test method of both leadframe type, the monotonic mechanical properties of this material can then be obtained. One of the important property that needed to be addressed is the Young's modulus, which is the value which can indicate the level of elasticity for metallic component/materials. From the related test result, the good leadframe has higher Young's modulus value, E, at 64.39 GPa and the method of obtaining this value is shown as the gradient line on the elastic part of the stress-strain curve in Fig. 9. On the other hand, the Young's modulus value for the tested oxidised leadframe was obtained at the value of 56.45 GPa, which is shown in the graph plot of Fig. 10. By comparing these two values, the oxidised leadframe has lower E value and this situation occurred as the oxidation layer provides lower strength to the metallic materials, particularly for the tested copper leadframe.

Cyclic analysis: The equipment that was used in the cyclic test was the INSTRON Micro Tester 5800 series, as shown in Fig. 11. The specimen which was fabricated as

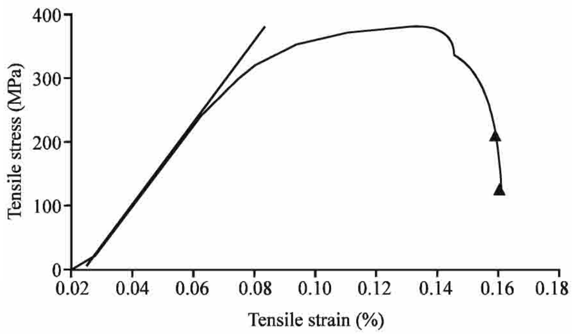

Fig. 9: A plot of material stress versus strain for a good leadframe

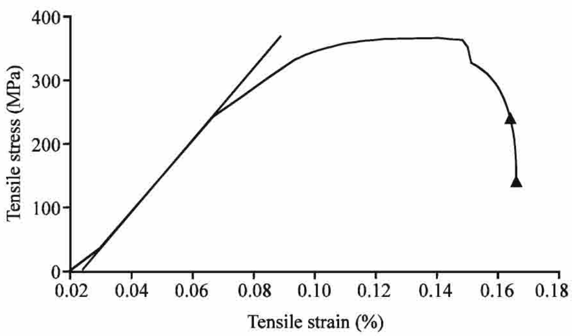

Fig. 10: A plot of material stress versus strain for an oxidised leadframe

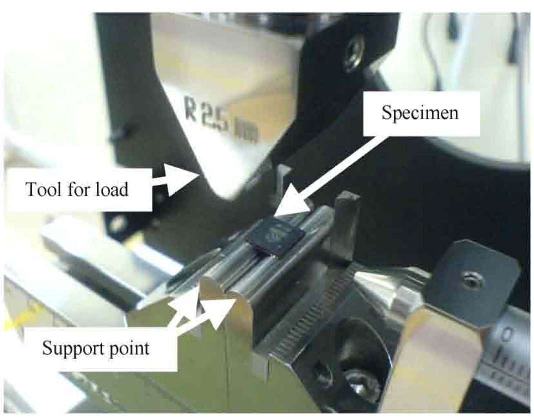

Fig. 11: A partly view of the microtester used for the cyclic tests

the single die of a QFN package was supported with the microscale of the three points supporting system. The concentrated load was given repeatedly at the center of the package. After the cyclic tests were performed, the existence of the delamination was then observed using the Scanning Acoustic Microscope (SAM). The SAM method can be said as the established failure analysis

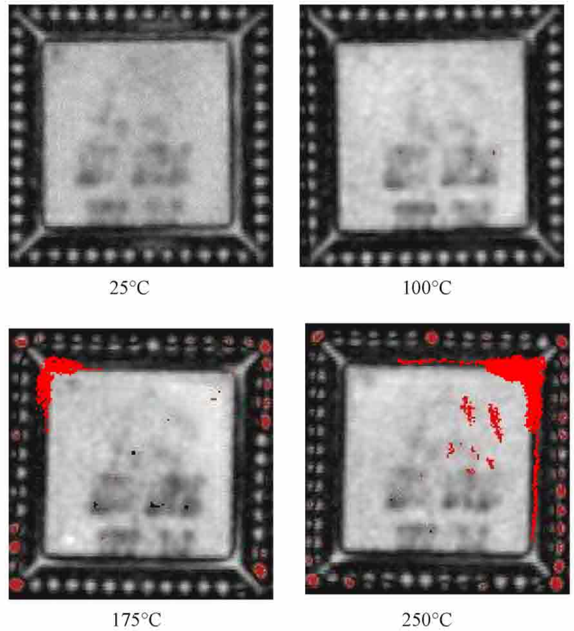

Fig. 12: C-SAM images for the good leadframe under different temperature levels after 1000 repetition of constant cyclic loadings have been applied on the package

technique used in the current semiconductor packaging industries in order to detect disbands or delaminations between package interfaces, such as the interfaces between the plastic resin package materials, the die, the die paddle, the lead frame and the die attach material. For this reason, the root causes of delamination at the lead frame paddle and mould compound interface were mainly contributed by the die attaches paste voids or incomplete die attach coverage, high stress concentration and weak adhesion strength. Two types of SAM can be applied for the purpose of this analysis, i.e., the C-SAM for detecting the delamination effects on surface on the package and the through scan for detecting the delamination effect on interface die and epoxy.

The SAM images of the leadframe and die interface after the cyclic test (after 1000 repetition of constant cyclic loadings) are shown in Fig. 12 and 13. The through scan images which were obtained of the leadframe and epoxy interface after the cyclic test (after 1000 cycles) are shown in Fig. 14 and 15. The results obtained from the cyclic test indicate that the delamination effect were caused due to the cycle loads and the parts failure coincide with those in the case of mechanical cyclic tests.

The delamination propagation along the die-pad and mold compound interface of QFN package used the C-SAM method. The QFN package using the oxidised

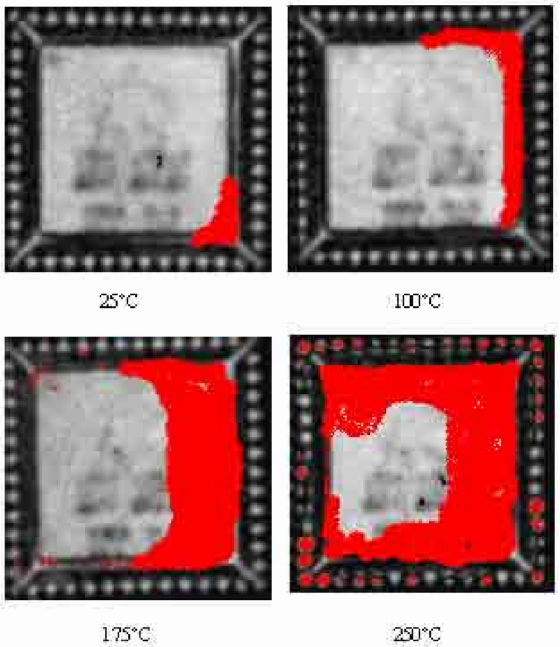

Fig. 13: C-SAM images for the oxidised leadframe under different temperature levels after 1000 repetition of constant cyclic loadings have been applied on the package

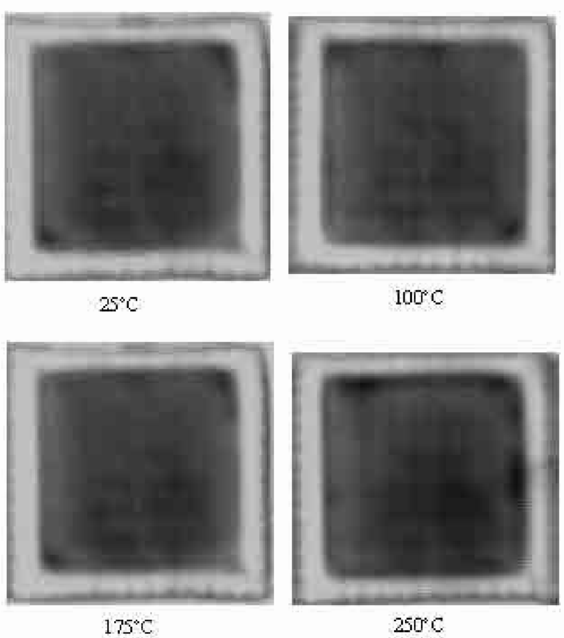

Fig. 14: Through scan images for the good leadframe under different temperature levels after 1000 repetition of constant cyclic loadings have been applied on the package

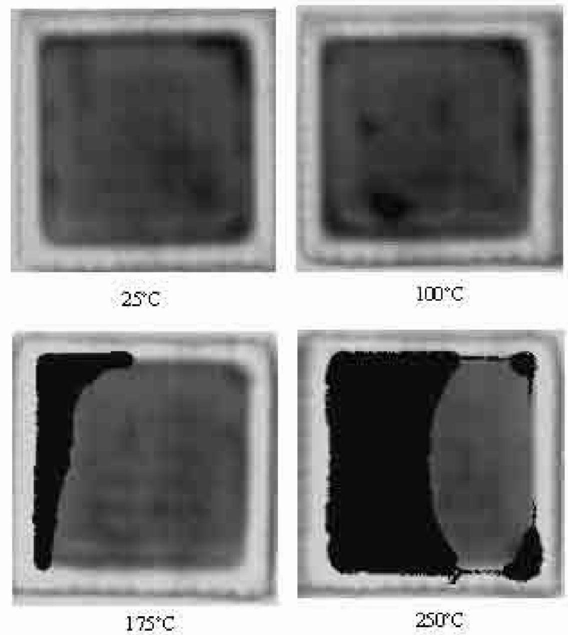

Fig. 15: Through scan images for the oxidised leadframe under different temperature levels after 1000 repetition of constant cyclic loadings have been applied on the package

leadframe showed that the delamination effect started when the test is under 25°C and position in the cornel die. However, the package with good leadframe showed a small size of delamination occurring under 175°C after 1000 cycles of given loads. Thus, it can be suggested that the delamination effect has been increased with the increment of the testing temperature. The delamination occurred because shear stress has a force tends to cause deformation of a material that through slippage along a plane or planes parallel to the imposed stress. After 1000 cycles of repeated load with the temperature condition of 250°C, the QFN package with the good leadframe has no delamination effect between the leadframe and the epoxy interface. No effect has been observed as the adhesive on leadframe and die was stronger compared to oxidised leadframe. The images of these findings can be in Fig. 14 and 15.

The QFN with oxidised leadframe has many delaminations on leadframe and epoxy it is because the oxidised leadframe has oxide layer on leadframe surface. That layer gives low strength adhesive between leadframe and epoxy. The oxidised leadframe can give lowest reliability in QFN package. Figure 16 and 17 show the cross sectional images taken from the three-dimensional X-ray machine, showing the significant images for the

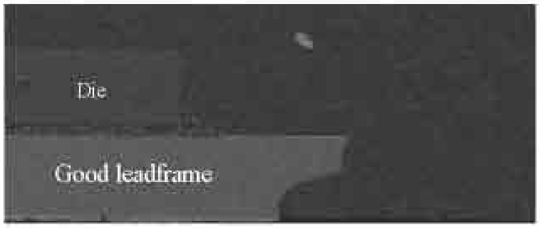

Fig. 16: Cross sectional image focusing at the die attach interface and package using the good leadframe with no cyclic loading applied. No effect of delamination and crack occurrence can be seen in this package

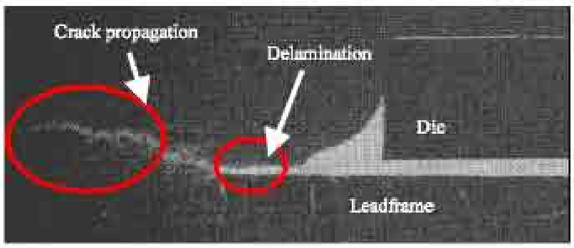

Fig. 17: Cross sectional image focusing at the die attach interface and package using oxidised leadframe. In this image, the occurrence between delamination and package internal crack can be clearly observed

QFN package with the good leadframe and the similar package after cyclic tests, respectively. In Fig. 17, it can be seen that the occurrence of the crack propagation between the die attach interface and leadframe which was caused by the cyclic loading. For this case, the package is said to be failed under constant loading amplitude fatigue condition. This analysis is very useful for the aspect of package reliability under extreme condition, particularly the combination between the repeated loads and elevated temperature.

CONCLUSIONS

The surface of leadframe oxidation under constant temperature in an ambient environment of 30°C/70% RH is mainly composed of Cu_2O with very thin CuO. Not only severe oxidation but also lesser oxidation may cause poor adhesion between leadframe, epoxy and molding compound interface. In this study, a cyclic test method for the QFN packages, namely the three points bend test method, was proposed. In terms of the stress simulation and the test results, the validity of the cyclic test method can be verified.

Considering the delamination effect of the surface die and leadframe and interface die/epoxy statistically based on the assumption of the probability process, it seems that the delamination probability during cycles load can be estimated. This will result in easy delamination or cracking after mechanical cyclic tests under difference temperature in 1000 cycles. Process control nowadays is trying to suppress oxide growth as much as possible. But extremely low oxidation may cause poor adhesion, so oxidation to some degree must be considered in case of low pin count packages. The failure mechanism of delamination seems to be related to the weakening effect caused by internal void growth along material interface.

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