Failure Analysis and Precaution of Plastic Encapsulated Microcircuits

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Abstract—The paper introduces the common failure mechanisms and their effect on the Plastic Encapsulated Microcircuits (PEMs). During the reflow soldering procedure, delamination between plastic mold compound/die or plastic mold compound/lead frame interface occurs frequently. Delamination is the channel for vapour to inbreak into the PEMs and affects its reliability. In this paper, the author analyses the failure mechanism of delamination and provides two typical failure analysis cases to explain it. The micro-processor failed because the pop-corn effect leads to delamination between its’ plastic mold compound/lead frame interface. The SRAM failed because the thermal-expansion coefficient mismatch of the plastic mold compound and the die. In the end, some precautions for reducing such failures are presented.

Keywords—plastic encapsulated microcircuits (PEMs), reliability, delamination, failure analysis, coefficient thermal expansion (CTE)

I. INTRODUCTION

Plastic encapsulated microcircuits (PEMs) refer to the semiconductor devices encapsulated in plastic polymer resin material. The polymer resin material has some inherent characteristics different from the metal material, which limits the PEMs’ use in the high-reliability occasions [1]. Since the 1970s, great improvement has been made in packaging materials, chip passivation and production processes, and the reliability of PEMs has been greatly improved. However, there are still many reliability issues. The causes of these reliability issues can be broadly classified into: (1) corrosion failure or popcorn failure caused by inherent seal problem of the plastic materials, (2) chip bonding defects or package defects or passivation defects caused by the production technology problem [2], (3) low-temperature / temperature shock failure caused by the coefficient of thermal expansion (CTE) mismatch of the plastic materials and chips.

II. ANALYSIS OF PEMs FAILURE MECHANISM AND FAILURE MODE

The physical performance and reliability of plastic devices have been greatly improved. However, due to the nature of plastic material properties, such as moisture absorption of plastic material and size changed after moisture absorption occurred, thermal-expansion coefficient mismatch of plastic and other materials, low thermal conductivity, etc. there are still some reliability issues, such as damp invasion and poor resistance to temperature, limiting the PEMs to be applied in the field of high reliability.

A. Delamination in PEMs

Compared to glass and ceramics, plastic materials belong to low-temperature materials. Its glass transition temperature is in the range from 130 to 160 °C. It is enough for the PEM to meet the following three kinds of temperature range requirement: 0 °C ~ 70 °C (commercial temperature), -40 °C ~ 85 °C (Industrial Temperature), -40 °C ~ 125 °C (automotive temperature). These areas are narrower than the traditional military temperature range (-55 °C ~ 125 °C). However, large number of failure cases shows that [3], even if in the above three kinds of temperature range, the proportion of failure of PEM is still very high. Failure analysis of the failed devices shows that the stress of the plastic materials on the chip caused by the outside temperature or low-temperature environment is the main failure mechanism. During the thermal cycling process (from room temperature to the extreme cold environment), the CTE mismatch of the molding compound and substrate or lead frame can cause layering and cracking. In extreme low temperatures, because of the large difference between the storage operating temperature and sealing temperature, the delamination and cracking stress is very large. With the temperature declines, the possibility of cracking increases.

B. Popcorn effect

Before the PEM is installed on the board, moisture intrusion is a very important failure mechanism. Much PEMs failure mechanisms, such as corrosion and popcorn effect, can be attributed to moisture intrusion. When the device temperature arises, open-circuit failure often happens. So, plastic devices are also prone to intermittent problem caused by hot. When the device is heating, the moisture adsorbed in the shell vapors rapidly, leading to large vapor pressure and make the mold compound material (epoxy resin compounds) expansion, accompanied by layered peeling and cracking phenomenon, commonly known as “popcorn” effect. In the mold material expansion process, the internally generated shear stress may affect the well-wire. The greatest stress is in the chip corner, which will lead to serious bonding line tilt, bonded joints cracking and bonding wire disconnected, causing...
electricity failure. It is worth noting that this effect is more strongly for the large number pin-count PEM.

The above two situations can lead to delamination in the PEM. Although the failure mechanisms are different, the final effect is the same. They will affect the long-term reliability of the device, or make the device fail in a very short time.

III. EXAMPLES OF FAILURE ANALYSIS OF PEMS

A. Popcorn effect leads to delamination failure

Mobile computing microprocessor is packaged in a 256 pin PBGA. The failure mode is that procedures can not be loaded. According to the I-V characteristics test results, several pins of the failed samples were found open to the GND pin, Fig.1. By pressing the probe on the abnormal pins, it presented good I-V characteristics as the good samples. It showed that these pins had intermittent lead contact. By C-SAM inspection, delamination was found between the plastic mold compound/lead frame interface (Fig.2). The delamination location was consistent with the I-V Characteristic Test.

Delamination between plastic mold compound/lead frame (PCB) interface is the failure cause of the failed sample. The delamination led to poor lead contact or bonding wire open, resulting in failure of the device. The cause of delamination is that the plastic material is prone to absorb moisture. The interface of the plastic and other materials is a good channel for moisture to inbreak. Therefore, device in plastic package is very sensitive to moisture. No matter during transportation, assembly or being used, care should be paid to take measures to protect it from moisture. Otherwise, moisture will be easy to inbreak the device. During the reflow process, the high temperature will lead to the moisture boiloff and expand. Then, the popcorn effect may happen and result in delamination in device. Finally, the device failed and lost its function.

Mount the sample with epoxy resin, then grind and polish to make cross-section analysis on it. When polish the sample to the solder ball Row 1, obvious delamination was found between the plastic mold compound and PCB interface, Figs.3 and 4. That is to say, there is delamination between lead frame and Plastic Mold Compound interface. And the inner structure of BGA package is shown in Fig.5. The location of delamination could be seen from Fig.5.

B. CTE Mismatch of the plastic materials and the die leading to failure

SRAM, packaged in 144pin LQFP. It lost its function as soon as it was powered on. The register can only read the address and all the output showed high resistance state.

I-V characteristics test showed more than 60% pins of the failed samples were open to the GND. By C-SAM inspection, delamination was found between the plastic mold compound/die interface. And delamination was basically at the edges of chips. Decapsulation and Internal Visual Inspection showed a large area of chip existed delamination and damaged, the passivation layer, metal layer, insulating layer or even the chips all had been peeled off.
Figure 6. delamination was basically at the edges of chips

Figure 7. a large area of chip existed delamination and damaged

There is big mismatch between the thermal expansion coefficient of the epoxy materials (25ppm / °C) and chips (2.3ppm / °C). When the big size chip PEM is experienced reflow soldering, the thermal stress will impose shear stress on the interface of the plastic material/die. The cause for the shear stress may be the temperature changes dramatically in the soldering process. The shear stress will lead to the passivation, multi-layered wiring peeled off and even damage the chip, resulting in device failure. When the devices were exposed to the humid environment for a long time, water intrusion and accumulated in the chip around. In the high temperature mutation process, the above phenomenon is prone to happen.

IV. EVALUATION METHOD AND DETECTION MEANS OF PEM DELAMINATION

Reliability evaluation of PEMs is mainly referred to the exposed flaws technology, and is very difficult by conventional screening to discover the defects in the device before using it. But when be soldered or in the process of application, the defects will happens, resulting in failures of component.

Moisture intrusion is related with time. The longer time, the greater the moisture and humidity outside is, and the shorter time for the moisture in the plastic device to reach saturation is. At the same time, such failure will be also subject to the common effects of temperature and humidity, so we can carry out accelerated testing with the integrated stress of temperature and humidity. For different plastic devices, we can use the experience of value to develop the corresponding test program, which is 85 °C, 85% RH, 500 hours of high temperature hot flushes test. According to standard EIA/JEIDA-22-A110-A, the HAST test under 130°C can take place of 85 °C / 85% RH hot flushes test, so less time will be spent for the evaluation result of device humidity.

Temperature cycling is also a very sensitive test for PEMs. The physical injury caused by thermal expansion and contraction would damage the device, such as packaging and the internal structure of cracking or delamination. It will also lead to mechanical damage, leading to changes in electrical characteristics.

The most effective method of monitoring the delamination is acoustic microscopy (C-SAM) detection technology. The technology shall be used in the adhesive and stratified conditions of materials or the structure of mold plastic materials and other materials. Specific monitoring contents include the plastic mold compound/lead frame interface (PCB), plastic mold compound/die interface, die/PCB interface, as well as the empty mold material or chip cracking. Such monitoring is non-destructive. Checked by C-SAM Inspection, analysis of its lead frame and packaging materials, chip and package materials layered case, make the judge that if the device through the high-temperature hot flashes trial or not.

Most delamination occurred after installation of the PEM to the circuit board. So not only all unused devices shall be detected 100%, but also the PEM installed on the circuit shall be random checked to determine whether the welding process will cause a new stratification or injury.

V. PREVENTIVE MEASURES OF REDUCING THE FAILURE

A. Device assembly

1) According to the moisture sensitivity grades, the temperature and humidity storage environment for PEM should be corresponding controlled. In the reflow soldering process, appropriate temperature change rate and temperature range should be carefully selected to avoid and control the delamination phenomena.

2) If the PEMs’ requirements for storage time and temperature/humidity in the environment exceeds the sensitivity level of standard plastic integrated circuits, appropriate high-temperature baking, such as 125°C / 24h, should be carried out before the PEMs are reflow-soldered. By this way, the possible adsorption of moisture in the PEM may be ruled out, preventing delamination between the interface of the plastic compound/die or substrate from occur, even the popcorn effect.

3) To the plastic device by reflow welded in the plate (even if no failure and cracking), also be suggested that scanning acoustic sampling.

4) The PEM stored more than three years should not be installed and used.

5) PEM is assembly soldered to the circuit board, and after treatment by cleaning, an additional coating to enhance the capacity of anti-humidity.

B. Product design

1) Products should be designed to meet the requirements of the use of the environment and through testing or analysis to verify whether it has achieved reliability goals. The evaluation by conventional tests (high temperature hot flushes or temperature shocks) or screening methods [4], can reveal weak links or unsatisfactory performance of the design.
During the product design, the emergence and spread of heat should be considered to avoid the reliability problems caused by temperature.

**C. Technology and Material Control**

During the entire production of plastic device, process control should be increased and the main measures are:

1) Reduce the content of water vapor in the packaging body, to avoid delamination effects. In order to prevent water intrusion, a good passivation coating (using phosphate glass or silicon nitride) is necessary. In order to improve the adhesive strength between the plastic material and the lead frame, ion contamination in the encapsulation materials should be reduced or impurities ion-trapping agent or ion scavenger in the encapsulation material be added. In order to extend the path of the water vapor permeability, filler is joined in the plastic material or low-absorbent material is used, etc.

2) Reduce bubble inside the plastic package to avoid the emergence of crack. When resin is put into the cylinder, the high temperature resin is put on the top and the low temperature resin is put underneath. This will generate difference in temperature during the resin warm-up process. During preheating, the high temperature resin melts first and fills gap between the cylinder and the resin. By this way, air flow away and will not enter the internal resin.

3) Reduce impact of the metal framework on the package. Choose copper lead frame to get good thermal match. Add one precision pressure process for the step-by-step mode devices to remove the burr during the plastic package forming, to reduce the stress.

4) During being packaged, the package atmosphere should be very dry

5) Before being packaged, components should be baked for a long time in a vacuum or under high temperature in order to remove water vapor.

6) Attention to prevent the staining halogen.

**D. Packaging, transport and use**

1) During the transportation, handling, storage of plastic device, a certain degree of protective measures must be taken. Measures to protect the packaging process are as follows: moisture-proof protection (to prevent moisture intrusion), physical injury protection (to prevent lead bending or breaking), anti-static discharge protection, etc.

2) Attention should be paid to strict enforcement of the relevant operational procedures during the device testing, assembling and debugging, to prevent electrical overload or ESD failure.

**VI. CONCLUSIONS**

Because of the plastic materials and processes improvements and enhance, as well as in size, weight, cost, availability, performance and technology and advanced design, plastic devices is increasingly being used in avionics, communications, space application fields.

The users of plastic encapsulated devices must understand the unique physical characteristics, reliability and its related issues. Delamination is a common failure phenomenon in plastic devices.

The study of the plastic device reliability evaluation caused by delamination is a long-term job, hence it is necessary to test a large number before judgments is made. In the use of plastic encapsulated devices, appropriate preventive measures shall be taken to reduce the occurrence of failure.

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**REFERENCES**


