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2018

Xu, C., Zhong, Z. W., & Choi, W. K. (2017). Thermal test effect on fan-out wafer level package strength. 2017 12th International Microsystems, Packaging, Assembly and Circuits Technology Conference (IMPACT), 2017, 271-274. doi: 10.1109/IMPACT.2017.8255915

<https://hdl.handle.net/10356/102486>

<https://doi.org/10.1109/IMPACT.2017.8255915>

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Thermal Test Effect on Fan-out Wafer Level Package Strength

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ABSTRACT

Fan-out wafer level packaging technology becomes more and more popular and attractive of its flexibility for integration of diverse devices in a very small form factor and it is also a cost effective packaging solution. As fan-out wafer level package (FOWLP) is composed of various materials, the proper structural design and material selection are essential to achieve reliability requirements. In this study, FOWLP material especially the epoxy molding compound (EMC) thermal properties are evaluated to understand the effect of thermal factors on EMC strength. The long term thermal test is applied and the EMC flexure strength increases significantly after the high temperature storage test.

INTRODUCTION

The FOWLP has the feature of thin, and it is always applied to volume sensitive electronic devices. Since the low package strength results in package crack issues. Therefore, the FOWLP strength is critical to its reliability. There was much research on the die strength [1]. The die surface condition is critical. The wafer grinding and wafer sawing affect the die surface condition [2]. The FOWLP are composed of various materials. The physical and chemical properties of each material are different especially the coefficients of thermal expansion (CTE). Therefore, the proper material selection is very important to FOWLP reliability.

The epoxy molding compound (EMC) is a very important material in fan-out wafer level packages, and it is the fan-out area of FOWLP. The molding process is carried on after the pick and place process in the FOWLP assembly process. The molded wafer requires to be fully cured before transferring to the next process [3]. There are two rounds of curing process after the molding process. The first round curing process occurs immediately after the molding process, and it is completed within the molding machine. The curing time is ten minutes, and the temperature is 125°C. The second round curing process is conducted in a separate oven. The curing time is one hour, and the temperature is 150°C. The second round curing process is also called post-mold curing (PMC) process. The molded wafer sometimes faces warpage issue after the molding process. The high warpage issue is very serious. The 12-inch wafer level packaging technology shows a good trade-off between the yield and reliability currently. The high warpage wafer often causes machine handling issues. The machine sometimes cannot handle the wafer or fail to handle the wafer. The former only causes the process delay or abort. However, the latter is more serious, and it causes the wafer damage and machine breakdown. The reason of warpage is the mismatched CTE. Therefore, the EMC material with low CTE is preferred.

In the earlier FOWLP strength evaluation work [4-7], we found that the FOWLP strength increases significantly after lithographing passivation layers and suffering thermal reliability tests. The thickness of passivation layer is 10 µm, and it should not affect the FOWLP strength seriously. Therefore, any FOWLP material property is changed after the passivation lithographing process. The FOWLP wafer is required to cure after the passivation lithographing process. The curing temperature is 225°C, and the duration is two hours. The thermal reliability tests also store the FOWLP wafer in a high temperature oven for hundred hours. The FOWLP strength increases after both thermal processes. Therefore, the thermal process is the main effect factor on the FOWLP strength. The compositions of FOWLP in our previous work are the silicon die, EMC and passivation layers. Therefore, we think that EMC should be affected by the thermal process.

The high temperature storage (HTS) test is used to determine the effect of time and temperature on electronic devices. The testing specimens are stored in a chamber at the certain high temperature. The high temperature vaporizes the moisture and isolates the humidity effect on electronic devices. The HTS test environment is similar to a long time operating electronic device. The difference is the HTS test heats the electronic devices by the external heat source while the electronic device is heated by itself. Therefore, the main purpose of HTS test is to evaluate the electronic devices life span for a long time operating condition. The JEDEC standard JESD22-A103 - 'High Temperature Storage Life' regulates the apparatus and procedures of HTS test. There is seven kinds of standard HTS test temperature form 85°C to 300°C. The most frequently used temperatures are 150°C and 175°C. The 150°C HTS test is known as the normal HTS test, while the 175°C HTS test is known as the accelerated HTS test. The accelerated HTS test provides a challenging environment to the specimens, and it accelerates the specimen failure and shortens the testing time. The main failure mode of HTS test is functional failure such as electrical failure or interconnection failure. The reason is the changes in material properties during the test. The electronic devices such as IC chips or packages are made up of various materials. The HTS test provides a high temperature and high energy environment to drive various materials to interact with each other. Therefore, some new materials are formed after the HTS test, which affects the package reliability. The intermetallic compound (IMC) is formed after the HTS test. The IMC has the feature of brittle and easily crack under any thermal or mechanical loading. Once the crack occurs within the IMC, the package electrical interconnection is affected and the package function may be failure. However, the IMC effect on packages with less material composition is minor such as pure silicon wafers, stacked chips and wafer level packages [8, 9].

In this study, the long term thermal test was applied to the EMC specimens. The objective of this study is to evaluate the long term thermal test effect on EMC.

METHODOLOGY

We used pure EMC specimens (as shown in Figure 1) in this evaluation work. There were three kinds of EMC specimen, and they were named as EMC-1, EMC-2 and EMC-3. The physical properties of EMC specimen are listed in Table 1. The specimens were diced into the size of 10 mm × 10 mm, and all the specimen thicknesses were 650 μm.

TABLE 1. THE PHYSICAL PROPERTIES OF EPOXY MOLDING COMPOUND SPECIMEN.

Specimen	Viscosity (Pa*s)	Tg by DMA (°C)	Flexure Modulus by DMA (GPa)
EMC-1	650	160	18
EMC-2	650	165	23
EMC-3	600	165	18

The specimens were suffered by two kinds of thermal tests. For the short term thermal test, we used passivation layer curing process. The peak temperature of passivation layer curing process was 225 °C, and the duration was two hours. The actual duration of one-time passivation layer curing process is six hours. The reason is the oven needs two hours to raise the temperature (from 25 °C) and two hours to fall (down 25 °C). There were two readout points selected – one-time passivation layer curing and three times passivation layer curing. For the long term thermal test, we used high temperature storage test. The high temperature storage test followed the JEDEC standard JESD22-A103, and we used condition B. The storage temperature was 150 °C. There were two readout points selected – 500 hours and 1000 hours. Therefore, there were four readout points totally in this work.

FIGURE 1. ILLUSTRATION OF EMC SPECIMENS.

The three-point bending test was applied in this work. The Instron universal tester 5569 with a maximum 1kN capacity load cell was used. The three-point bending fixture was customized, and it can achieve a very narrow span. In this work, we fixed the fixture span

at 8 mm, and the loading speed was 6 mm/min (0.1mm/s). The three-point bending test was conducted at the room temperature 25 °C. The specimen backside (as shown in Figure 1) faced down during the three-point bending test. The flexure strength of EMC can be obtained by

$$\sigma_{3PB} = \frac{3Fl}{2wh^2} \quad (1)$$

Where F is the flexure load obtained from the three-point bending test, w is the EMC width, h is the EMC thickness and l is the three-point bending fixture span

RESULTS

In our previous research [10], the short term thermal test effect on EMC strength was evaluated, and the evaluation results are shown in Figure 2. The flexure strength of all EMC specimen increases rapidly after one-time passivation layer curing process. This phenomenon matches the previous research statements [11-13]. The increased glass transition could lead to the increase in flexural modulus of EMC. The EMC flexure strength still shows the growth trend after three times passivation layer curing process. Therefore, we cannot judge whether the EMC flexure strength becomes stable based on the previous experiment. A long term thermal test is required to implement the evaluation work.

FIGURE 2. THREE-POINT BENDING TEST AVERAGE FLEXURE STRENGTH OF EMC SPECIMEN (SHORT TERM THERMAL TEST EFFECT).

Figure 3 shows the three-point bending test average flexure strength of EMC specimen, and it includes both short term and long term thermal test observation points. The specimen average flexure strength curves show two trends. The average flexure strength of EMC-1 and EMC-3 specimen increases after 500 hours high temperature storage test. However, their flexure strength decreases after 1000 hours high temperature storage test. EMC-2 specimen average flexure strength almost remains the same after 1000 hours high temperature storage test.

FIGURE 3. THREE-POINT BENDING TEST AVERAGE FLEXURE STRENGTH OF EMC SPECIMEN (LONG TERM THERMAL TEST EFFECT).

All the specimen flexure strength increase significantly after 500 hours high temperature storage test compared with the specimen flexure strength after three times passivation curing. That means the flexure strength of EMC specimen do not become stable after three times passivation curing process, and they still have the space to increase. However, the flexure strength of EMC shows the downward trend after 1000 hours high temperature storage test. EMC-1 and EMC-3 flexure strength drop significantly. EMC-2 flexure strength change is not obvious. A longer high temperature storage test may be required to evaluate whether EMC-2 flexure strength becomes stable. However, based on the current evaluation work, the performance of EMC-2 is superior, and it may be a good choice for the fan-out wafer level packages.

FIGURE 4. SIDE VIEW OF EMC SPECIMEN AFTER THE HIGH TEMPERATURE STORAGE TEST.

Figure 4 shows a side view of one kind of EMC specimen after the high temperature storage test, and this specimen warpage is very high. The flexure strength of this EMC specimen is higher than our EMC specimen flexure strength. However, this EMC material is not a good choice for building fan-out wafer level packages. The reason is the package function should fail at this high warpage, and this EMC warpage is sensitive to thermal.

CONCLUSIONS

The flexure strength of over-molded structure FOWLP always increases significantly after the thermal process. We hypothesize that the increase in package strength comes from the increase in EMC strength, and the EMC strength is affected by the thermal process seriously. We collect three kinds of EMC specimen. The three-point bending test is applied to evaluate the strength of EMC specimen. The Instron universal tester 5569 with a maximum 1kN capacity load cell is used to conduct the 3PB test. The experiment results show that all the EMC specimens flexure strength increase rapidly after one-time passivation layer curing process. However, the growth trends of

EMC specimen flexure strength become stable after three times passivation layer curing process. The reason is the thermal process temperature is higher than the EMC glass transition. The EMC glass transition is increased by the thermal process and leads to the increase in EMC flexural modulus. However, the EMC flexure strength still increases significantly after 500 hours high temperature storage test, and this phenomenon proves that the EMC flexure strength does not become stable after three times passivation layer curing process. Some EMC specimen flexure strength drops after 1000 hours high temperature storage test expect EMC-2.

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