Accelerated Moisture Sensitivity Test Methodology for Stacked-Die Molded Matrix Array Package

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Abstract

The existing IPC/JEDEC of moisture/reflow sensitivity classification determines the time of accelerated equivalent soak by the equivalency of moisture concentration at the critical interface with the standard sensitivity test. This paper proposes a new methodology of accelerated moisture sensitivity test based on the equivalency of both local moisture concentration and overall moisture distribution for stacked-die molded matrix array package (MMAP). The new methodology can ensure the same failure rate of cracking/delamination by the equivalency of local vapor pressure, interfacial adhesion as well as the thermo- and hygro- stresses. Finite element analysis (FEA) is applied for moisture diffusion and vapor pressure analysis under the conditions of 30°C/60%RH and 60°C/60%RH, respectively. At 70 hours at 60°C/60%RH, both the local moisture concentration at critical interface and overall moisture distribution of package become identical with that at 216 at 30°C/60%RH, indicating that 70 hours is the equivalent soak time compared to the standard MSL-3 for this type of MMAP packages. Such an equivalency of the new accelerated test conditions is proven by moisture/reflow experiments under various soak times at 30°C/60%RH and 60°C/60%RH. Damage response assessed from inspection for internal cracking/delamination indicates that the accelerated test procedures are well correlated and considered indistinguishable in terms of failure rate.

Introduction

The development of three-dimensional (3D) microelectronic packaging with multi-die stacking technology has become essential to increasing functionality with higher memory capacity in more complex and efficient architectures. Molded matrix array package (MMAP) is a new packaging technology with smaller feature sizes, which allow multiple chips stacked vertically. One of the key challenges for developing MMAP is to meet the requirement of moisture/reflow sensitivity test without cracking/delamination in die-attach films.

Moisture/reflow sensitivity test for plastic surface mount devices (SMDs) has been defined and outlined in the IPC/JEDEC industry standard J-STD-020 [1]. This test specification has established exposure conditions of temperature, humidity, and time, as well as the classifications of reflow profile, for which the moisture sensitivity rating of plastic packages are classified and referenced. The moisture/reflow sensitivity test consists of two stages. Stage I is moisture soak, in which a specific combination between temperature, humidity and time is defined to mimic humidity exposure of plastic packages in field use conditions. Stage II is rapid heating to simulate the surface mounting soldering reflow process. The entire packages are exposed to an elevated temperature environment with peak temperature as high as 260°C.

Moisture/reflow sensitivity test is a precursor test to most reliability tests. However, the duration required for this standard test is too long, which is unproductive and costly. For example, the moisture sensitivity level 3 (MSL-3) requires 216hrs moisture soak at 30°C/60%RH. The long test time has significantly hindered the time-to-market for new product development. In order to devise an accelerated moisture sensitivity test, JEDEC specification J-STD-020 has recommended an accelerated preconditioning for 40hrs exposure at 60°C/60%RH, which is equivalent to standard MSL-3 preconditioning. Such an accelerated test reduces the total required moisture soak time for MSL-3 by approximately a factor of five. However, such an equivalency is established for leaded packages only with predominant failure mechanism of delamination between molding compound and leadframe. Furthermore, the activation energy of molding compound for diffusion must be in the range of 0.4-0.48eV in order to use the ‘equivalent’ soak time. The existing methodology for accelerated moisture sensitivity test is developed based on the equivalency of local moisture concentration at the interest of location [2-4]. It has been assumed that the failure is predominantly controlled by local moisture concentration, which will induce vapor pressure and reduce interfacial adhesion. However, the moisture-induced failure during reflow is also affected by thermal stress and hygro-stress.

This paper introduces a new methodology of accelerated JEDEC/IPC moisture sensitivity level test for stacked-die MMAP. The methodology is developed based on the equivalency of *both* local moisture concentration and overall moisture distribution of packages. Finite element analysis is applied for moisture diffusion and vapor pressure analysis under the conditions of 30°C/60%RH and 60°C/60%RH respectively to determine the equivalent soak time. The equivalency of the new accelerated test conditions is proven by moisture/reflow experiments under various soak times at 60°C/60%RH.

Methodology of Accelerated IPC/JEDEC Moisture Sensitivity Level Test

The soak is the exposure of an electronic package for a specified time at a specified temperature and humidity. Assuming the package is in the state of zero stress at the molding temperature, the package suffers the thermal stress due to coefficient of thermal expansion (CTE) mismatch between different materials at the soak temperature [5-7]. The thermal stress, σ_T, at the soak time can be expressed as

$$\sigma_T = E\cdot\varepsilon_T = E\cdot\alpha\Delta T \quad (1)$$

where E is elastic modulus, ε_T is the thermal strain, α is the CTE, and ΔT is the temperature change.

Similarly, assuming the package is in the state of zero stress due to hygroscopic swelling when it is fully dry, the hygro-stress is applied on the package due to coefficient of moisture expansion (CME) mismatch at the soak humidity [8-12]. The hygro-stress, σ_H, at the soak humidity can be expressed as

$$\sigma_H = E\cdot\varepsilon_H = E\cdot\beta C \qquad (2)$$

where ε_H is the hygro-strain, β is the CME, and C is the moisture concentration.

During the soak, the moisture condenses in the micropores or free volumes of porous materials. The moisture vaporization generates high vapor pressure causing the pore swelling or even braking at the high reflow temperature [13-17]. Generally, the driving forces inducing the failures of cracking/delamination are thermal stress, hygro-stress and vapor pressure in the moisture sensitivity level test.

The existing methodology for accelerated moisture sensitivity test is developed based on the equivalency of local moisture concentration at the critical interface. Local moisture concentration determines local vapor pressure and interfacial adhesion. The equivalency of local moisture concentration can ensure the equivalency of local vapor pressure and interfacial adhesion theoretically. However, the equivalency of local moisture concentration is not enough to ensure the equivalency of local thermal stress and hygro-stress, because the local thermal stress and hygro-stress are affected by the overall temperature and moisture distributions of the whole electronic package. Therefore, to ensure the equivalency of all driving forces (i.e., thermal stress, hygro-stress and vapor pressure) in the standard and accelerated moisture sensitivity level test, not only the local moisture concentration at the critical interface but also the overall temperature and moisture distributions of the whole electronic package should be equivalent to achieve the equivalency of failure characterization and failure rate.

This paper introduces a new methodology for that will accelerate IPC/JEDEC moisture sensitivity level test for stacked-die MMAP. Because there is no big difference of the thermal stress at two soak temperatures (like 30°C and 60°C), the methodology is mainly developed based on the equivalency of *both* local moisture concentration and the overall moisture distribution. The local moisture concentration equivalency would be established first to ensure the equivalency of vapor pressure. Further, in order to ensure the equivalency of hygro-stress within two different soak conditions, the overall moisture distribution would be indistinguishable.

Analysis of Moisture Diffusion and Vapor Pressure Modeling

The novel direct concentration approach (DCA) is adopted for the moisture diffusion modeling to determine the equivalency of local moisture concentration as well as the overall moisture distribution under 30°C/60%RH and 60°C/60%RH. The DCA can be applied for the moisture diffusion modeling under both constant and varying ambient temperature and humidity [18,19]. In this approach, the moisture concentration is used as the field variable directly and constraint equation is used to ensure the interfacial continuous condition. A kind of 3D ultra-thin stacked-die MMAP is adopted for the modeling. Normally, the MMAP composes molding compound (MC), silicon die, die-attach film, solder resist (SR) and bismaleimide-triazine (BT) core, as shown in Fig. 1. Half package is modeled due to the symmetry. 2D model is adopted for the simplicity. In the previous study, most cracking/delamination failure of die-attach film was found in the bottom film. Therefore, the study of local moisture concentration and vapor pressure focuses on the bottom film in this paper.

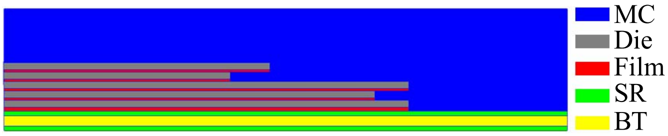


Fig. 1: The schematic structure of MMAP

I. *Moisture Diffusion Modeling*

The moisture soak history at bottom film interface under 30°C/60%RH and 60°C/60%RH is shown in Fig 2. The local moisture concentration at bottom film interface is saturated for 100hrs and 40hrs under 30°C/60%RH and 60°C/60%RH, respectively. It means from 40hrs under 60°C/60%RH, the local moisture concentration is equivalent with that under MSL-3, i.e., 216hrs under 30°C/60%RH.

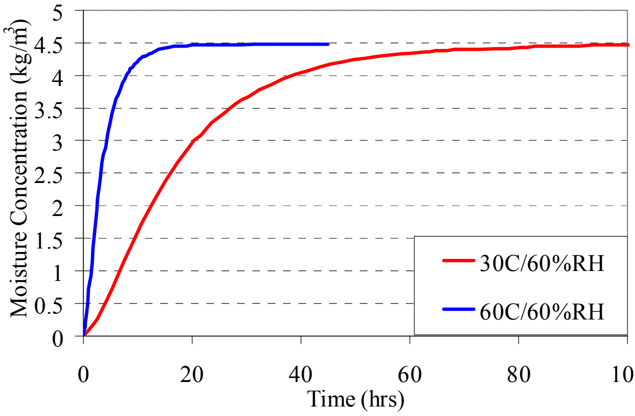
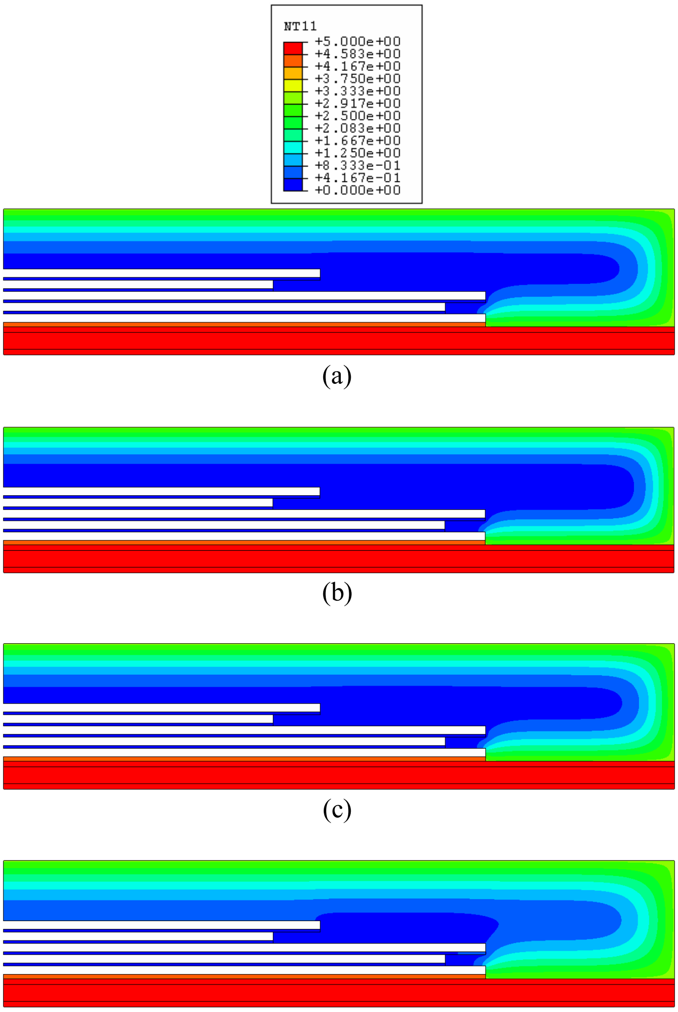


Fig. 2: Moisture soak history under 30°C/60%RH and 60°C/60%RH

To determine the overall moisture distribution of the whole package, the contour study is developed for soak with 216hrs under 30°C/60%RH and soak with 45hrs, 70hrs and 88hrs under 60°C/60%RH, as shown in Fig. 3. It is observed that although the local moisture concentration at bottom film reaches same at 45hrs under 60°C/60%RH (45hrs-60°C/60%RH) as that under 30°C/60%RH for 216hrs (216hrs-30°C/60%RH), the overall equivalency of moisture distribution is not reached yet at this time. Not only the local moisture concentration at bottom film interface but also overall moisture distribution under 70hrs-60°C/60%RH are equivalent with that of soak for MSL-3 (216hrs-30°C/60%RH). Therefore, the vapor pressure, interfacial adhesion and hygro-stress are equivalent under these two conditions at high reflow temperature. It means the equivalent failure characterization and failure rate would be achieved under these two conditions.



(a)

(b)

(c)

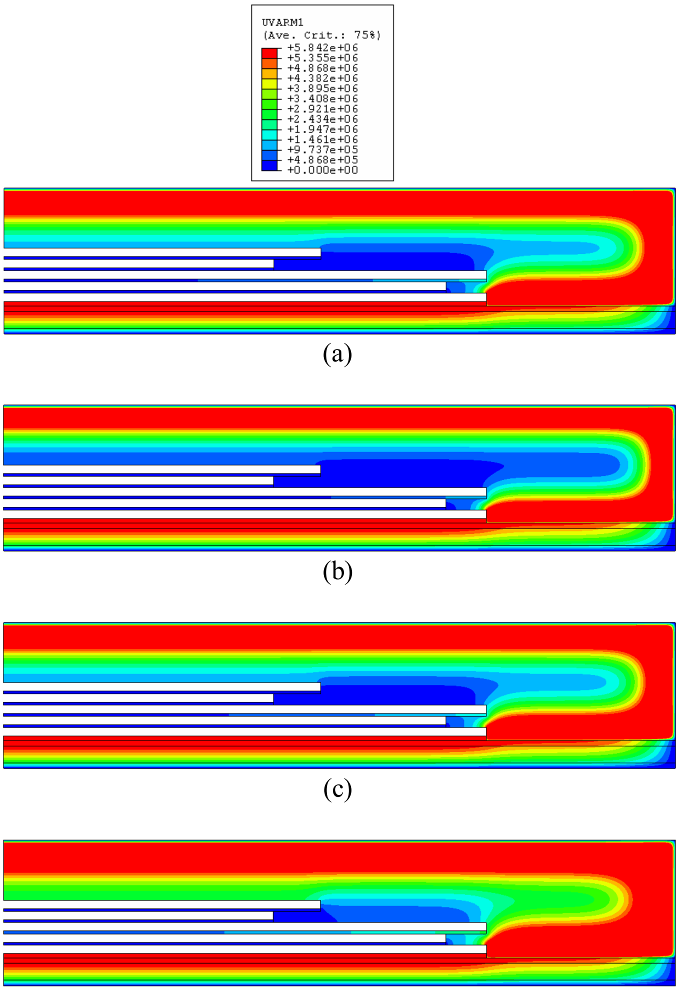
(d)

Fig. 3: Moisture distribution contours of soak with (a) 216hrs under 30°C/60%RH and (b) 45hrs, (c) 70hrs and (d) 88hrs under 60°C/60%RH

II. Vapor Pressure Modeling

To validate the equivalency of vapor pressure at the conditions of 70hrs-60°C/60%RH and 216hrs-30°C/60%RH at high reflow temperature, the vapor pressure modeling is performed based on the simplified micromechanics vapor pressure model [18,19]. The simplified micromechanics vapor pressure model is developed with the user-defined subroutine based on the widely used micromechanics vapor pressure model [14-17].

Fig. 4 shows the contours of vapor pressure distribution under 216hrs-30°C/60%RH and 45hrs, 70hrs, 88hrs-60°C/60%RH when the reflow temperature is 260°C. The vapor pressure is equivalent at the conditions of 70hrs-60°C/60%RH and 216hrs-30°C/60%RH.



(a)

(b)

(c)

(d)

Fig. 4: Vapor pressure contours of soak with (a) 216hrs under 30°C/60%RH and (b) 45hrs, (c) 70hrs and (d) 88hrs under 60°C/60%RH

Experimental Validation

From the modeling analysis, 70hrs-60°C/60%RH can be determined as the equivalency of MSL-3. To validate the modeling results, the moisture/reflow tests were performed on this kind of MMAP under conditions of standard 216hrs-30°C/60%RH and accelerated 30hrs, 45hrs, 60hrs, 75hrs, 88hrs-60°C/60%RH. The sample size was 48 under every single condition. The experimental process followed the recommended procedure in the J-STD-020 [1]. Firstly, the thru scanning acoustic microscope (TSAM) was adopted for the initial inspection to ensure no cracking/delamination occurring before moisture/reflow test. All the packages were baked for 24hrs at 125°C to remove the initial moisture inside. Then the packages absorbed the moisture under the above conditions. After the moisture soak, the packages were subjected to 3 cycles of the certain reflow condition with the peak reflow temperature of 260°C. Lastly, the TSAM was used again for the final inspection to determine the failure rate. The failure rate is defined as

$$R = n_f / n_t \qquad (3)$$

where R is failure rate, n_f is the number of failed samples, and n_t is the number of total samples.

The failure rate under standard 216hrs-30°C/60%RH was 4.6%, as shown in Fig. 5. The failure rates under various conditions of 60°C/60%RH are also plotted in Fig. 5 with logarithmic scale. The failure rates under various conditions of 60°C/60%RH can be fitted as Eq. (4)

$$\begin{cases} R = 0 & \text{if } t < 57.2 \\ R = 10^{0.05(t-57.2)} & \text{if } t > 57.2 \end{cases} \tag{4}$$

where t is the soak time.

By equaling the failure rates under 30°C/60%RH and 60°C/60%RH, the soak time under 60°C/60%RH can be determined as 68.3hrs to be equivalency with the standard 216hrs-30°C/60%RH. The experimental moisture/reflow tests validated the new methodology and the modeling analysis.

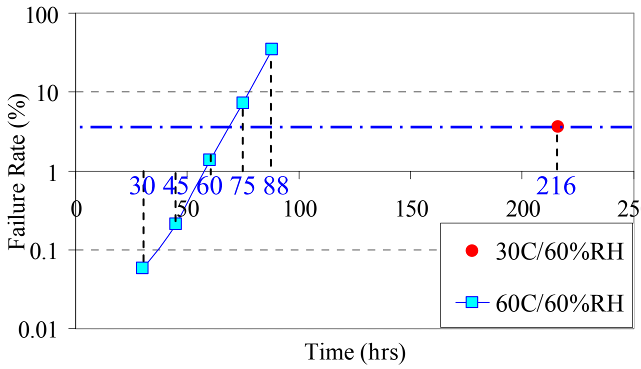


Fig. 5: Failure rate under various conditions

Conclusions

This paper proposes a new methodology of accelerated moisture sensitivity test based on the equivalency of both local moisture concentration and overall moisture distribution for stacked-die MMAP. The new methodology can ensure the same failure rate of cracking/delamination by the equivalency of local vapor pressure, interfacial adhesion as well as the thermal stress and hygro-stress. The novel modeling approaches is applied for moisture diffusion and vapor pressure analysis under the condition of 30°C/60%RH and under the various conditions of 60°C/60%RH. At 70hrs at 60°C/60%RH, both the local moisture concentration at critical interface and overall moisture distribution of package become identical with that at 30°C/60%RH for 216hrs, indicating 70hrs as equivalent soak time compared to the standard MSL-3 preconditioning for this type of MMAP. Such an equivalency of the new accelerated test conditions is proven by moisture/reflow sensitivity experiments under the condition of 30°C/60%RH and under the various conditions of 60°C/60%RH. Damage response assessed from inspection for internal cracking/delamination indicates that the accelerated test procedures are well correlated and considered indistinguishable in terms of failure rate. Such a methodology can be extended to other packages as well.

Acknowledgements

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