A fast moisture sensitivity level qualification method

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ARTICLE INFO

Article history:
Received 30 June 2010
Accepted 19 July 2010
Available online 16 August 2010

ABSTRACT

In this paper, a fast moisture sensitivity level (MSL) qualification method and a fast moisture characterization method are discussed. The fast moisture characterization uses a stepwise method to obtain more reliable and more material moisture properties. The established relationships for moisture diffusion coefficients and moisture saturation levels with respect to the temperature and relative humidity can be used to predict moisture properties in the MSL range. Fast moisture sensitivity level qualification is accomplished with the aid of simulation combined with the characterized moisture diffusion properties. Moisture absorption processes at different conditions are simulated using a 3D model at conditions according to the moisture sensitivity test levels. Simulation of weight change at different condition and simulation of local moisture concentration are performed and compared between different conditions. Simulations show that at 696 h preconditioning time at 30°C/60%RH for MSL level 2a can be decreased to 42 h at 85°C/85%RH. Time required for package reliability and moisture sensitivity analysis is largely shortened.

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1. Introduction

Moisture effects inside a non-hermetic package increase enormously when the package is exposed to the high temperature and solder reflow, such as Pb-free solder reflow at 260°C. Under certain conditions, this effect can cause internal delamination of the packaging materials between the die and epoxy molding compound (EMC)/or EMC and lead frame/substrate [1–6]. In the most severe case, this stress can result in external cracks. This is commonly referred as the “popcorn” phenomenon because the internal stress causes the package to bulge and crack with an audible “pop” sound. Surface mount devices (SMDs) are more susceptible to this problem because they are exposed to high temperature during reflow.

In IPC/JEDEC J-STD-020D [7], there are eight moisture sensitivity levels and they are investigated by different preconditioning methods respectively. According to this standard, moisture absorption time ranges from 48 to 696 h. Using 60°C/60%RH acceleration, the moisture absorption time is shortened to 13–168 h. It is found that moisture absorption time can be shortened using even higher temperature and humidity during experiments. For example, to investigate interface toughness preconditioning at 85°C/85%RH, the sample will be kept in this condition for almost 1 week according to IPC/JEDEC J-STD-020D and then moisture effects can be investigated. It shows that for bi-material samples, moisture saturation reaches in 48 h at the 85°C/85%RH condition [8]. The sample is a bi-material copper and molding compound strip sample. The total thickness of the sample is 0.85 mm and the molding compound thickness is 0.65 mm. This means that fast moisture diffusion can be performed with the aid of fast moisture diffusion if fast moisture diffusion mechanism is known. For the electronic packages, if you want to do fast qualification with the aid of fast moisture diffusion, all the material moisture properties in the package should be obtained before this fast moisture diffusion prediction is performed. JEDE22-A120A [9] introduces a material moisture properties characterization method. However, this will take extra 48 h and great effort to obtain the material moisture properties if you use this method to get the same moisture properties. Moisture properties at different conditions have to be tested repeatedly by using this method. Therefore, a fast method is discussed and summarized here.

According to IPC/JEDEC J-STD-020D [7], 60°C/60%RH moisture absorption is used to do the acceleration for 30°C/60%RH. However, the moisture absorption time is still 168 h long. IPC/JEDEC J-STD-020D just explains that moisture weight increase should equal between the standard and acceleration preconditioning. Here, the increase in moisture absorption weight is calculated and it has been
found that acceleration time is much shorter than the acceleration time required by the 60 °C/60%RH standard. The local moisture concentrations are compared too. Simulation shows that local moisture concentration is also one of the most important factors governing moisture acceleration time.

2. Moisture absorption theory

There are many parameters that govern the moisture absorption process. The moisture weight gain, $M_t$, is determined by:

$$M_t = \frac{m_t - m_0}{m_0} \times 100\%$$  \hspace{1cm} (1)

where $m_t$ and $m_0$ are the weights of wet specimen at exposure time $t$ and the weight of the dried specimen respectively.

$M_{sat}$ is the saturated moisture gain in the sample and is dependent on the temperature and relative humidity. It can be determined by [4]:

$$M_{sat} = k_0 \cdot X_{RH} \cdot e^{-\left(\frac{H}{RT}\right)}$$  \hspace{1cm} (2)

where $k_0$ is the proportional constant, $X_{RH}$ is the relative humidity factor which varies from 0 to 1, i.e. 0%RH to 100%RH. $H$ is the activation energy constant, $R$ is the universal gas constant, 8.314 J K$^{-1}$ mol$^{-1}$. $T$ is the absolute temperature. $M_{sat}$ can be obtained by performing moisture absorption tests at different temperatures and different relative humidity levels. A linear fit of $\ln(M_{sat})$ versus the reciprocal of the absolute temperature $1/T$ is used to determine the activation energy constant. From the intercept with the $\ln(M_{sat})$-axis, at $1/T = 0$, $k_0$ can be determined.

Diffusion coefficient ($D$) [5] is supposed to depend on the initial diffusion coefficient ($D_0$) as follows:

$$D = D_0 \cdot e^{-\left(\frac{E_D}{RT}\right)}$$  \hspace{1cm} (3)

(3) can be rewritten in the following form:

$$\ln D = \ln D_0 - \frac{E_D}{RT}$$  \hspace{1cm} (4)

The diffusion activation energy $E_D$ is determined from the slope of data plot of $\ln D$ against $1/T$. From the intercept with $\ln D$-axis, at $1/T = 0$, $D_0$ is formed [5].

3. Moisture sensitivity level conditions and JEDE22-A120A

In this standard Table 1, only one accelerated condition 60 °C/60%RH is used, but MSL preconditioning time is still in the range of 10–168 h. Accelerated method equivalent cannot be used until material moisture properties must be characterized at these conditions. JEDE22-A120A, a commonly used material moisture absorption standard is introduced. Moisture absorption properties at 30 °C/60%RH, 60 °C/60%RH and 85 °C/60%RH 85 °C/85%RH conditions are also needed for fast moisture diffusion calculation. But using this standard, moisture absorption properties can be obtained at only one temperature and relative humidity condition. Therefore, four different tests have to be performed. Another shortcoming of JEDE22-A120A is that using this method you have to take the sample in and out from the oven repeatedly to measure the weight change of the sample. Therefore, it is difficult to obtain reliable diffusion parameters of the material tested.

4. Fast moisture properties characterization of packaging materials

4.1. Test sample preparation

Test samples must be flat discs or coupons. To approximate one dimensional diffusion, for a coupon of length $L$, width $W$, and the thickness $h$, the following relation must be met [8]:

$$h < 0.05(W \times L)/(W + L)$$  \hspace{1cm} (5)

The recommended sample thickness should be in the range from 0.3 to 1.0 mm to ensure fast moisture saturation. Three kinds of packaging materials, namely die attach, molding compound and underfill, are used in our packages. The die attach contains about 90% silver particles. The molding compound contains about 90% silica particles. The underfill filler content is less than 50%. Samples are prepared by using processing parameters recommended by the material supplier.

4.2. Test procedures and equipment

The samples are pre-dried at 125 °C for 24 h in the oven. According to JEDEC-A120A [8], time intervals should be spaced to allow...
adequate measurement duration and to capture the initial quick weight change and to provide a good spread in the data points during the later stages of the weight change curve. Using traditional oven method, material moisture properties can be obtained but this method is not sufficient for obtaining more material moisture properties characterization and doing prediction. Therefore, in order to overcome the above shortcoming, a temperature and relative humidity cycling/stepping method is used to perform moisture absorption. Using this method and Eqs. (2) and (3), the material moisture properties can be characterized and predicted.

Programmable moisture absorption balances can be used for moisture absorption tests. However, for most moisture absorption ovens, high temperature and high relative humidity levels are not always stable. High temperature and high relative humidity parameters can then be extrapolated from low temperature and low relative humidity material moisture properties. And this extrapolation is proved by comparing test and simulation of a bi-material model [9].

Fig. 1a shows that relative humidity value is varied in a stepwise manner. The time span at each relative humidity change ranges from 300 to 600 min depending on the sample thickness and packaging materials. The temperature is set at a fixed temperature for each test. To assure good testing results, test temperature and relative humidity should be stable during the tests, especially at high temperature and high relative humidity.

Fig. 1b shows a SGA-100 oven. It can perform two kinds of moisture absorption and desorption tests. One is isothermal moisture absorption test and another is temperature and humidity cycling test, which means that temperature and relative humidity can be changed at the same time. It can automatically plot the sample weight change with time at weight sensitivity of 1 μg.

4.3. Test results

The die attach test sample (16.08 × 5.04 × 0.335 mm³) is dried in the oven for 24 h at 125 °C and then put in the SGA-100 moisture absorption balance. For example, the temperature is set at 40 °C and relative humidity is programmed in a stepwise manner: 0%, 80%, 5%, 60%, 5%, 40% and 5%RH. At every relative humidity level, the time span ranges from 200 to 600 min.

Fig. 4a shows a typical test result of a moisture absorption experiment of the die attach material. In the graph, the solid line is the sample weight gain (M/w), the dashed curve is the temperature and dot-dash curve is the relative humidity. It is noted that the sample weight decreases initially because 0%RH is set. With increasing relative humidity levels, the sample weight increases and decreases with decreasing relative humidity. Moisture equilibrium is reached at each relative humidity level.

5. Characterizations of moisture absorption properties of packaging materials

5.1. Characterization of diffusion coefficient

Using Eq. (4), diffusion coefficient can be determined. Diffusion coefficient at different temperature can be obtained from the initial slope of $M_t/M_{sat}$ versus $t^{0.5}$ (see Fig. 2b). In order to ensure the repro-

![Fig. 1.](image1.png) (a) %RH changes with time at fixed temperature. (b) SGA-100 gravimetric moisture absorption balance.

![Fig. 2.](image2.png) (a) Moisture absorption test result of die attach at 40 °C. (b) Slope of $M_t/M_{sat}$ versus $t^{0.5}$ for die attach.
duction and decrease test error, every test is repeated three times.

Table 2 shows the diffusion coefficients of die attach at different temperatures.

The slope of ln $D$ versus $1/T$ can be used to obtain $E_D$ and $D_0$ (see Fig. 3a). The values for die attach are:

$$E_D = 37.16 \text{ kJ/mol} \quad \text{and} \quad D_0 = 7.0E - 6 \text{ m}^2/\text{s}$$

Using the same method, the diffusion coefficient of molding compound and underfill are characterized. The data obtained from tests and curve fit for molding compound and underfill are listed in Table 4.

It can be seen that if three moisture absorption tests at different temperature combined with relative humidity stepping are performed, then the packaging material moisture properties can be calculated and predicted.

### 5.2. Characterization of saturated moisture content

Using Eq. (2) and combining with tests results of die attach, saturated moisture content can be characterized at certain temperature and relative humidity. A linear fit of ln $M_{sat}$ versus $1/T$ is used to determine the activation energy constant, $H$. From the intercept with ln $M_{sat}$-axis, at $1/T = 0$, $k_0$ is obtained (see Fig. 3b). Real line is the three test data fit line and dash line is the linear fit line of ln $M_{sat}$ versus $1/T$. The data obtained from Fig. 5 are:

$$H = 3.46 \text{ kJ/mol}, \quad k_0 = 1.087$$

Using the same moisture absorption and characterization method, moisture absorption parameters for molding compound and underfill are characterized. Results are listed in Table 4.

### 6. Moisture diffusion simulations

#### 6.1. Moisture diffusion theory

A 3D finite element model is constructed by using MSC.Marc Mentat software. In the model, the transient moisture diffusion equation is analogous to the transient heat conduction equation [4], see Table 3, and can be described as

$$\frac{\partial C}{\partial t} = D \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} \right)$$

#### 6.2. Moisture diffusion simulation

In order to perform the coupled moisture diffusion hygro-thermal mechanical simulations, two symmetric 3D finite element models are used: the bottom part is used as moisture diffusion model and the top part is used as hygro-thermal mechanical model, see Fig. 4.

This is a quarter flat no lead (QFN) package ($6 \times 6 \times 0.85 \text{ mm}^3$), top and middle green blocks are passive and active die, respectively. They are connected by the micro solder bump after the first reflow. Unworkable underfill is used to strengthen the solder bump interconnection. The active die is glued to the bottom copper pad and heat is dissipated by this copper pad.

Table 4 presents model parameters for three kinds of packaging materials used in the carrier. Diffusion coefficients and $C_{sat}$ can be obtained at each temperature using parameters in Table 4.

Table 5 shows moisture saturation levels which are temperature and relative humidity dependent.

Fig. 5 shows a 3D wetness distribution at the condition of $85 \degree C/85\%RH$ after 10 h of moisture diffusion. Package model is compared with experimental results to verify this diffusion model [10].

#### 6.3. Weight change calculation

Fig. 6a shows moisture absorption weight changes at different condition and different time. From Fig. 6a, it can be seen that moisture weight changes with time at different conditions. At condition of $85 \degree C/85\%RH$, weight changes reach the highest level after 130 h of moisture absorption. At the condition of $85 \degree C/60\%RH$, weight change almost stops at around 110 h. After 168 h moisture absorption, weight changes at $85 \degree C/85\%RH$, $85 \degree C/60\%RH$ and $60 \degree C/60\%RH$ are 0.0974%, 0.0689% and 0.0528% respectively.
Fig. 6b shows moisture absorption at condition of 30°C/60%RH. It shows that weight change nearly stops around 530 h which then amounts to around 0.0364% weight change.

Corresponding to Table 1, the first two rows of Table 6 show the weight changes at the condition of 30°C/60%RH for different preconditioning time. And time required to reach the above mentioned weight changes needs to be calculated when applying 60°C/60%RH moisture absorption condition. Simulation shows that only 6 h of moisture absorption at 60°C/60%RH is required to reach the same weight change for 696 h moisture absorption at 30°C/60%RH preconditioning. However, standard 60°C/60%RH acceleration time is 168 h. The main reason is due to the small package size and thin layer of packaging material.

In addition, Table 6 also shows the comparison between standard 60°C/60%RH acceleration required time (the third and the fourth row) and 85°C/85%RH acceleration (the last row) required time for reaching 60°C/60%RH acceleration weight change. It can be seen from Table 6 that the moisture absorption time can be largely deceased compared to that of 60°C/60%RH acceleration if 85°C/85%RH acceleration is applied.

### 6.4. Local wetness/concentration calculation

IPC/JEDEC J-STD-020D does not explain the reason why such long moisture diffusion time is needed. However, simulation comparisons show that this long moisture absorption time can be explained by local moisture concentration. Moisture induced failures, such as pop corning and delamination, are caused by moisture, especially critical moisture concentration.

Two critical locations are compared here, as shown in Fig. 4. Location A is at the center of the package between the EMC and passive die interface. Simulation show that moisture saturation is reached within the required time under both 30°C/60%RH and 60°C/60%RH conditions. During reflow, most delamination occurs at that location. The second location is B, which is at the interface between copper die pad and glue if moisture decreases the interface toughness. This location has the longest moisture transport route.

From Table 7, it can be seen that the moisture concentration is not reached even at the condition of 30°C/60%RH for 696 h due to the moisture transfer route. For the acceleration condition of 60°C/60%RH preconditioning, only 168 h moisture absorption, moisture concentration is higher than that of 30°C/60%RH for 696 h preconditioning. Therefore, it can be seen that only moisture concentration at certain critical region is considered, and then preconditioning time will be comparable to that of the standard.

From Table 7, it can be seen that using 85°C/85%RH moisture absorption acceleration for level 2a, moisture absorption time can be shorten from 696 h to 40 h, with factors from 4.9 to 17.4. Failures are compared in paper [11], no delamination is found after reflow in the package with different preconditionings.

### 7. Conclusions

Using this new moisture property characterization method, packaging material moisture absorption properties can be characterized in short time. Furthermore, moisture absorption properties at different conditions can be predicted using this method and a lot time and effort can be saved.
For fast moisture sensitivity qualification, low temperature and low relative humidity moisture absorption can be replaced by high temperature and high relative humidity preconditioning if no new failures are introduced.

Simulation shows that the time for weight increase difference between standard and two acceleration methods is enormous. Acceleration time can be used with the aid of simulation, especially in the case of small package size. In addition, moisture concentration at critical location should be considered in exterminating the moisture absorption time.

### References


