

## MODELING OF WHOLE FIELD VAPOR PRESSURE DURING REFLOW FOR FLIP CHIP BGA AND WIRE BOND PBGA PACKAGES

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### ABSTRACT

In this paper, FEA models are built for both flip chip BGA (FCBGA) and wire bond PBGA packages to predict the moisture distribution, followed by the calculation of vapor pressure distribution in the package using the micro-mechanics approach with consideration of the micro-void effect. Results show that the vapor pressure saturated much faster than the moisture diffusion, and a near uniform vapor pressure is reached in the package. The vapor pressure is strongly dependent on the temperature and its magnitude can't exceed the saturated pressure at the corresponding temperature, even when more moisture is added in. The vapor pressure introduces additional mismatch to the package besides the CTE thermal mismatch. Vapor pressure-induced expansion is directly related to the vapor pressure distribution, rather than the moisture distribution. Moisture desorption during reflow is also studied and it has significant effect on the moisture distribution, but not on the vapor pressure distribution.

### 1. INTRODUCTION

The moisture-induced failures, e.g., popcorn and delamination, of IC packages are common phenomenon during solder reflow. The failures

are due to sudden vaporization of moisture absorbed by the package at high temperature condition. Therefore, it is critical to evaluate the strength of internal vapor pressure generated in the package during reflow. The popcorn failure was first postulated by Fukuzawa et al. [2] in 1985, and later supported by many publications [1, 3, 6-11].

JEDEC standard [5] is widely used to conduct reliability test on moisture sensitivity of the electronic packages. Kitano et al. [6] showed that the package cracking is not controlled by the absolute water weight gain, rather it is due to the local moisture concentration at the critical interface. Therefore, the moisture diffusion modeling is required. However, the modeling of ensuing vapor pressure within the package during the reflow is the key element in understanding the failure mechanism. Previous researchers [3, 6-8] assumed that the delamination exists before the reflow, and considered the vapor pressure as traction loading subjected to the delaminated interfaces. There were some studies done and a few methods were proposed to estimate the vapor pressure acting on the delaminated interface. Since the vapor pressure is generated anywhere in the package, it is necessary to investigate the whole field vapor pressure distribution before the package delamination.

## 2. VAPOR PRESSURE MODELING

For plastic materials such as mold compound, the saturated moisture concentration ( $C_{sat}$ ) is a few orders larger than the corresponding saturated ambient water vapor density during the moisture preconditioning, e.g.,  $r_g$  at 85°C/85%RH (see Table 1). This implies that the moisture absorbed by plastic materials is partially condensed into water in the microvoids or free-volume of the materials. During the reflow, the moisture vaporizes at high temperature and produces internal vapor pressure. The vapor pressure, however, will maintain at its saturated pressure as long as the moisture in the voids is not fully vaporized.

Table 1. Properties of moisture preconditioning for a typical mold compound

Moisture Preconditioning	Saturated Vapor Density $r_g$ (g/cm <sup>3</sup> )	Saturated Moisture Concentration $C_{sat}$ (g/cm <sup>3</sup> )
30°C/60%RH	r	

(2), when saturated, the local concentration,  $C$ , is same as  $C_{sat}$ . So, the initial void volume fraction can be expressed as following

$$f_0 = \frac{C_{sat}}{r_m} \quad (7)$$

Since  $r_m \approx 1.0\text{g/cm}^3$ , we have

$$f_0 \approx C_{sat}|_{100^\circ\text{C}/100\%RH} \quad (8)$$

where  $100^\circ\text{C}/100\%RH$  is selected as the near-saturated condition. Eq. (8) provides a simple way to predict the approximate magnitude of the voids existing in materials. The estimation is at the lower-limit since the moisture usually exists as a mixture of water and vapor at  $100^\circ\text{C}/100\%RH$ . Table 2 lists the results of the initial void volume fraction for some commonly used plastic materials in IC packages, computed by eq. (8), using the moisture property data given by Galloway et al. [3]. It shows that the values are usually between 1% and 5%.

Table 2. Initial void volume fraction for some common materials in IC packages

Material	BT	Die Attach	Mold Compound	Solder Resist
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$f_0$  (%)

8wTcLaa as 56.25 49 TD /234 -0 m 122TD /234 -01 S 134TD /234 -0 m 161TD /234 -01 S 165 0.7234

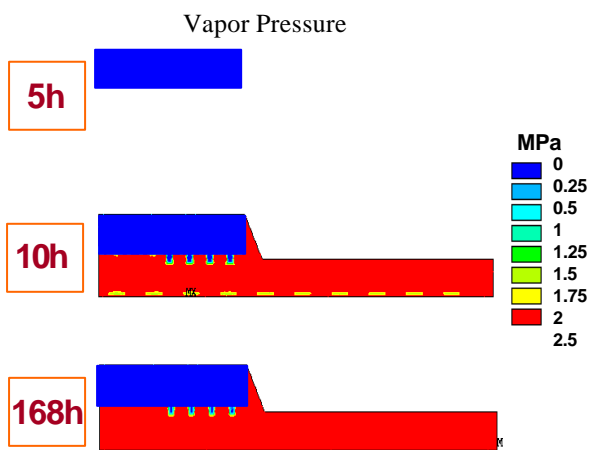
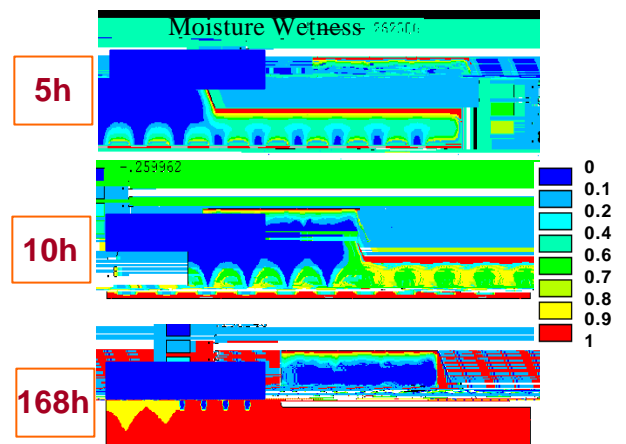


Fig. 4. Transient vapor pressure distribution in FCBGA at level 1, 220°C

For wire bond PBGA, the moisture diffusion and vapor pressure also have different distributions. At level 3 (192 hours), the moisture diffusion is still far from saturation, but the vapor pressure is already saturated in more than half of the package. As a comparison, the moisture diffusion and the vapor pressure at level 1 condition (see Fig. 8) are much more saturated than in level 3 (see Fig. 6 & 7).

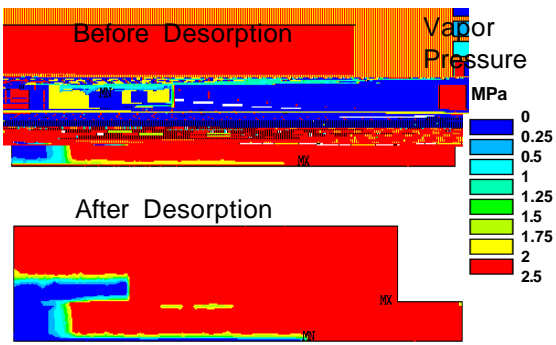


Fig. 11. Vapor pressure distribution in wire bond PBGA before and after desorption

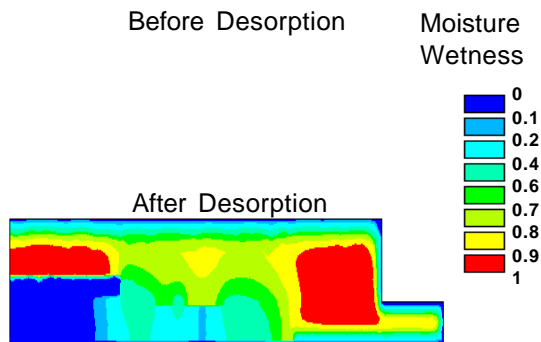


Fig. 12. Moisture distribution in wire bond PBGA before and after desorption

Again, the moisture distribution during reflow is affected by the moisture desorption, but the vapor pressure distribution is almost remain unchanged.

### 4.3

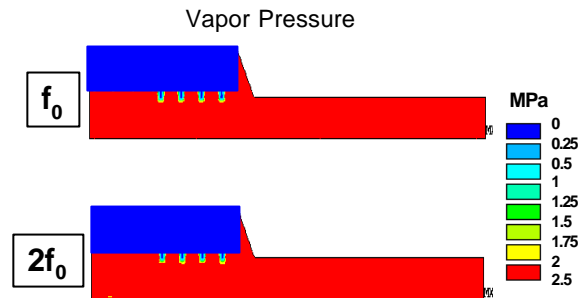


Fig 13. Effect of  $f_0$  on the vapor pressure distribution of FCBGA

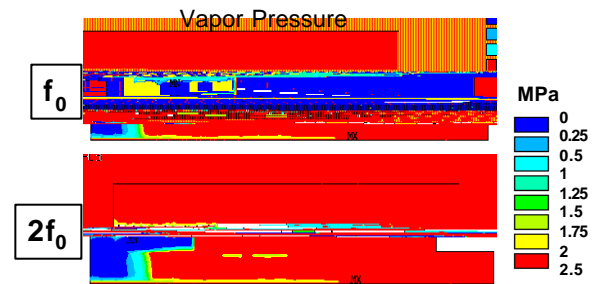


Fig 14. Effect of  $f_0$  on the vapor pressure distribution of wire bond PBGA

However, the interfacial adhesion will be significantly decreased with more moisture absorption. When the adhesion strength is reduced to the level below the vapor pressure, delamination will occur. Therefore, the knowledge of material interfacial adhesion strength with moisture effect at high temperature condition is important in determining the failure criteria.

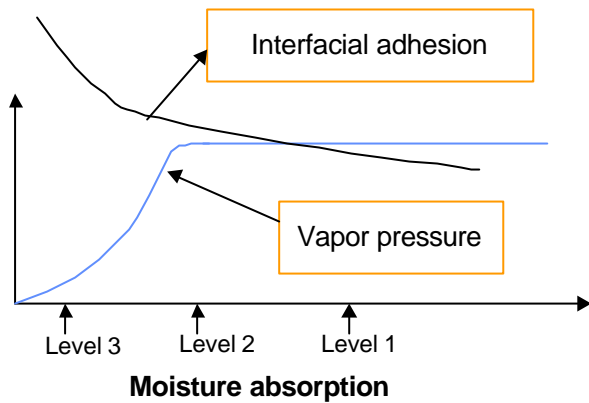


Fig. 15. Relative effect of moisture absorption on interfacial adhesion and vapor pressure

#### 4.5 Vapor Pressure-Induced Expansion

The previous FEA results conclude that the vapor pressure saturated much faster than the moisture diffusion. This implies that the vapor pressure may be uniformly distributed in the plastic material regardless of moisture saturation. The Young's modulus of plastic material drops a few orders at the reflow temperature, thus the vapor pressure-induced expansion may become as important as thermal expansion. For instance, assume the Young's modulus of a typical underfill at 220°C is 500 MPa, and Poisson ratio is 0.3. Therefore, the volume change caused by vapor pressure,  $P_g(220^\circ\text{C})$  of 2.32 MPa, can be estimated as

$$\frac{\Delta V}{V} = \frac{1-2\nu}{E} p = 1.856e-3 \quad (11)$$

which is comparable with expansion due to the CTE thermal mismatch. It is obvious that the vapor pressure-induced expansion introduces additional mismatch. It must also be pointed out that such an expansion is directly related to the vapor pressure distribution, rather than the moisture distribution.

## 5. CONCLUSIONS

The package vapor pressure distribution during reflow is the key factor in understanding the failure mechanism. FEA moisture diffusion models are constructed for both FCBGA and wire bond PBGA packages to predict the local moisture concentration at the critical interfaces, which determines the magnitude of vapor pressure. The vapor pressure is found to be saturated much faster than the moisture diffusion. At reflow temperature, the moisture may not be fully vaporized after the level-1 moisture preconditioning, and thus saturated pressure is reached in most area of the FCBGA and wire bond PBGA packages. The vapor pressure generated can never go beyond the saturated pressure at the corresponding temperature, e.g., pressure of 2.32 MPa at 220°C. The vapor pressure is strongly temperature dependent. Moisture desorption affects the moisture distribution, rather than the vapor pressure distribution.

The moisture affects the package reliability at reflow from two aspects: generation of vapor pressure and degradation of interfacial adhesion. Although the vapor pressure remains at its saturated pressure when more moisture is absorbed, the adhesion strength may continuously deteriorate with additional moisture. When the interfacial adhesion is reduced to the level below the vapor pressure, the delamination will occur. The initial void volume fraction has insignificant effect on the vapor pressure distribution because there is always sufficient moisture concentration in the package to maintain the saturated pressure. However, larger void volume fraction along the interface will weaken the adhesion strength and make it more susceptible to failures.

The vapor pressure induces additional mismatch to the package, which is of the same order as the CTE thermal mismatch. This vapor pressure-induced expansion is directly related to the vapor pressure distribution, rather than the moisture distribution. Therefore, it is important to consider the mismatch caused by vapor pressure in the stress modeling.

## REFERENCES

1. Fan, X.J. and Lim, T.B., 1999, "Mechanism Analysis for the Moisture Induced Failures in IC Packages," ASME International Mechanical Engineering Congress & Exposition, 11<sup>th</sup> Symposium of Mechanics of Surface Mount Assemblies, IMECE/EPE-14, Tennessee, Nashville, November 14-19, 1999
2. Fukuzawa, I., Ishiguro, S., and Nanbu, S., 1985, "Moisture Resistance Degradation of Plastic LSI's by Reflow Soldering," Proc. IRPS, pp. 192-197.
3. Galloway, J.E. and Miles, B.M., 1997, "Moisture Absorption and Desorption Predictions for Plastic Ball Grid Array Packages," IEEE Transaction on Component, Packaging, and Manufacturing, A, 20(3), pp. 274-279.
4. Gurson, A.L., 1977, ASME Journal of Applied Mechanics, 99, pp. 2.
5. JEDEC Standard, 1994, Test method A 112, Moisture Induced Stress Sensitivity for Plastic Surface Mount Devices, Electronic Industries Association.
6. Kitano, M., Nishimura, A., and Kawai, S., 1988, "Analysis of Package Cracking during Reflow Soldering Process," Proc. IRPS, pp. 90-95.
7. Tay, A.A.O. and Lin, T., 1996, "Moisture Diffusion and Heat Transfer in Plastic IC Packages," IEEE Transaction on Component, Packaging, and Manufacturing, A, 19(2), pp. 186-193.
8. Wong, E.H. and Lim, T.B., 1998, "Moisture Diffusion and Vapor Pressure Modeling in IC Packaging," 48<sup>th</sup> ECTC, pp. 1372-1378.
9. Yi, Sung, Goh, J. S. and Yang, J. C., 1997, "Residual Stresses in Plastic IC Packages During Surface Mounting Process Preceded by Moisture Soaking Test," IEEEess Preced TaycASing Surface Mounting Process Preced During Surf14.25 TD 0Jamo Tj 0 -13.5 TD -0 Tc 3