A Micromechanics Approach for Polymeric Material Failures in Microelectronic Packaging

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Abstract

This paper presents a micromechanics-based approach to investigate the moisture-induced interface delamination of polymer materials at soldering reflow in electronic packages. We start from a model study on vapor pressure based on a micro-void approach. Then the works of single void behaviors subjected to thermal and internal vapor pressure are introduced. The focus is on the *unstable* void-growth when the finite-deformation is considered. Detailed discussions are given to illustrate why the current models do not explain well the phenomenon observed in actual packages. Since the interface delamination is considered as consequences of the void growth, nucleation and coalescence, the Gurson's model is introduced to link the microscopic single void behaviors to the macroscopic continuum descriptions. It shows that the developed vapor pressure model provides the evolution equation for the vapor pressure as one of additional internal variables for the modified Guron's model. Finally a discussion is given on the moisture-induced failure mechanism analysis. It is emphasized that the moisture-induced interface delamination not only depends on the vapor pressure, but also on the interface strength as function of moisture as well.

1. Introduction

Polymer materials have wide applications in microelectronic packaging. Some polymer materials are used in bulk form such as encapsulant (mold compound), carrier or printed circuit board (FR4 and BT). Some polymer materials are used as adhesives such as die-attach, underfill, or other structural and thermal adhesives. Polymers are also used in thin- or thick- film

Traditional approach to deal with the delamination uses linear or nonlinear interface fracture mechanics, by which the failure is represented by a global parameter such as energy release rate, without the incorporation of microscopic aspects of the rupture process[4,5,6,7]. By this approach, a pre-existing macroscopic crack prior to the reflow soldering is assumed. And the vapor pressure is taken as traction loading on the delaminated crack surfaces. Such an analysis is very helpful to understand the package behaviors in stages 3 and 4 during reflow to prevent the delamination propagation and package cracking, but provides little insights on the failure-mechanism for the initiation of delamination. The process for stages 3 and 4 is usually very rapid and difficult to control once there is a small delamination initiated along the interface.

Therefore, it is critical to understand the failure mechanism in stage 2, i.e., the initiation of the delamination. Two key issues are associated with the delamination formation. One is the modeling of vapor pressure evolution as function of moisture, void size and temperature rise. The other, the dependency of the interface strength as function of temperature and moisture. The void growth, nucleation and the subsequent coalescence have been long recognized as the ultimate failure mechanism of the interface delamination for the moisture-induced failure [8,9]. Therefore, a micro-mechanics-based approach is introduced to investigate the problem.

In this paper, a vapor pressure model is introduced first based on a micro-void approach[3,10,11,12]. The key features associated with this model are highlighted. This model is extended to consider the effects of thermal expansion and void growth. Next the works of the unstable growth of a single-void subjected to the vapor pressure and thermal loading [13,14] is introduced and applied to analyze the void behaviors in a humid envorimental condition. Then a continuum description with consideration of the internal vapor pressure as an additional variable is introduced by using the Gurson model [15]. The concept of cell model [16]and its application[17] in electronic packaging is briefed. Finally, the mechanism analysis for the moisture-induced veM.5625 T0.5 4.5 T
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where ρ_g is the saturated vapor density, which can be obtained from the steam table as function of temperature.

When the moisture is at mixed liquid/vapor phase, it is necessary to know at which temperature the moisture can be *fully* vaporized. This temperature is called the *phase transition temperature*, denoted by T_1, which can be

solution[13]. With $f \to 1$, equation (8) gives $dV/dV_0 \to \infty$. It is true for a single void due to the volume

$$\frac{( )+ (, , _0, _0, _0)}{_0} = \int_{e_1}^{e_2} \frac{( )}{1-\exp(-\frac{3}{2}e\emptyset}$$

T

0

ent void volume fract

f 0=0.05

initial void volume fraction is in the range 0.01-0.05. It shows that the vapor pressure takes a significant portion over the critical stress. When the lead-free solder material is used, the reflow temperature can be as high as 260-270 °C. Therefore, the saturated vapor pressure can reach 5.51MPa. Besides, the yield stress s_0 can be even lower. The impact of the vapor pressure on the void unstable behaviors will become even more significant.

Although the predicted critical stress from the elastic-plastic model shows the important role of the vapor pressure on void deformation, the model is not able to make differences for the void behaviors at interface and in bulk. As we know, the unstable void growth is present at interfaces only during the reflow. In addition, the model is not able to explain some other phenomenon associated with the moisture-induced failure as well. For example, Fig.6 tells us that the cell may collapse when the temperature is reached to the level where the thermal stress alone reaches the critical stress for a given initial void volume fraction (case 1). However, a package without moisture intake will very unlikely fails even though the package is heated up well above the reflow temperature.

Many of the polymer materials used in electronic packages are thermoset materials, which display a rubble-like state above the glass transition temperature. The stress-strain relation expressed by the equation (18) may not be appropriate for a rubber-like material.

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at different temperature levels when the moisture is in mixed phase. This saturated vapor pressure at 220°C can be as high as 2.32MPa. The complete vapor pressure model provides the evolution process of the vapor pressure as function of moisture, void volume fraction, and the temperature.

The model study of a single-void subjected to the thermal stress and vapor pressure provides some key insights of the void behaviors. When the finite deformation is considered, the void growth becomes unstable once the applied stress reaches it critical stress, and the cell will 'burst' suddenly. Based on the single void model and the vapor pressure model, the critical temperature can be determined, at which the cell starts to collapse when the sum of the thermal stress and the vapor pressure reaches the critical stress. Since the void model is limited to the homogenous material only, it does not explain fully the failure at the interface.

The Gurson-Tvergaard model is introduced to link the microscopic variables of a single void and the macroscopic variables in continuum level. A complete continuum description is given with three internal damage variables: void volume fraction, matrix material yielding strength as well as the vapor pressure. The concept of cell model is also introduced to model a special material layer where delamination is present. The discussions are made on the validity of the Gurson's model for polymer materials.

Finally a discussion is given on the failure mechanism of moisture-induced delamination. It shows that the micromechanics approach introduced in this paper provides key insights into the failures of packages arising from the thermal and vapor pressure effects on the initiation of micro-voids. However, one of main missing points in current model studies is the lack of incorporation of the interface characteristics as function of moisture absorption. The interface delamination not only depends on the vapor pressure, but also on the interface strength as well. The interface adhesion after moisture absorption at high temperature becomes one of most important indicators to identify the failures. It is noted that the interface strength at high temperature is a *comprehensive* property. Thermal stress and vapor pressure come with the temperature rise automatically and thus are the 'built-in' stresses.

Acknowledgmentsts -92ol2 streat the

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