FEA Simulation and In-situ Warpage Monitoring of Laminated Package Molded with Green EMC Using Shadow Morie System

Zhao Baozong, Vivek Pai, Chinnu Brahateeswaran, Hu Guojun, Spencer Chew, Neephing Chin

Cookson Electronics Semiconductor Products
12 Joo Koon Road, Singapore 628975
bzhao@cooksonelectronics.com

Abstract

The warpage of individual IC panel/package or whole molded strips keeps changing with temperature during the assembly processes from die bonding, wire bonding, molding, post-mold cure to soldering reflow. How to optimize package design and properties of all assembly materials to obtain acceptable warpage level both at room temperature and reflow temperature becomes more challenging. In this study, Finite element analysis (FEA) simulation was performed in warpage prediction of three types of advanced laminated IC packages (PBGA, CSP BGA and PoP BGA). Shadow Morie system was used in monitoring warpage deviation under temperature profile from –55°C to 260°C. Calibration or correction of FEA results can be performed by introducing experimental results from Shadow Morie measurement to fine-tune the modeling so as to obtain more accurate prediction.

Introduction

Warpage is stated by SEMI G54-93 1995 as the loss of planarity of a plastic encapsulated surface, excluding protrusions and intrusions. IC Package warpage is a major concern in package development since large warpage causes problems in downstream process such as machine jamming or cutting line shift during singulation [1]. It is more serious for the Chip-scale-packages (CSP) with large panel before singulation simply because the warpage is proportional to the square of diagonal distance [2]. Large warpage of laminated packages at reflow temperature can also cause reflow failure or solder-joint reliability failure due to high stress between package, solder bass and PCB board. As we know, warpage of a laminated package is mostly caused by the coefficient of thermal expansion (CTE) and modulus mismatch between EMC, die, die attach material, and substrate [3]. As schematically shown in Figure 1, a package shows variable warpage with the introduction of new materials and process temperature along the IC assembly process from die bonding, wire bonding to molding and post-mold-cure (PMC). Among the assembly materials directly used in a laminated package, epoxy molding compound (EMC) as the last introduced material is generally considered to compensate warpage mainly because of the high volumetric percentage occupied by EMC. The cured EMC shows glass transition at certain temperature range (Tg) as the nature of macromolecular polymers. The glass transition complicates warping behavior of a package because the CTE of EMC below Tg as plastic (CTE1) is different from that above Tg as elastomer (CTE2). CTE2 is normally 3 to 5 times of CTE1 variable with filler load in formulations. Similarly a cured EMC shows two modulus E1 and E2, E1 below Tg is 30 to 50 times higher than E2 above Tg. Therefore, the warpage variants significantly at the glass transition temperature range.

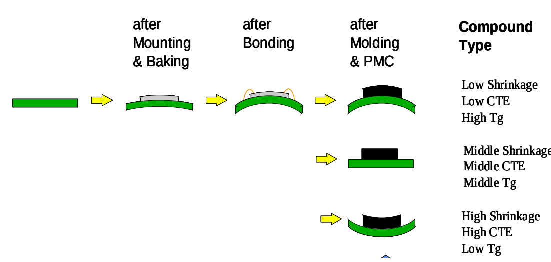


Figure 1 Warpage variants along the assembly process

It is well known that the warpage of a package is dependent on package configuration as well as assembly materials. For example, a doublesided package never has the serious warpage as one-sided package even the die, EMC and substrate used in the package are same [1]. Hence, numeric modeling to predict the warpage behavior is employed so as to save time and cost in building up mechanical model. Bimetallic equation is used to calculate the package warpage where factors counted are molding temperature, CTE of die, EMC and substrate, modulus of EMC and substrate, thickness of package and substrate [4]. FEA as a more advanced approach is widely accepted to provide more information besides warpage such as internal stress distribution by using 2-dimension or 3-dimension modeling. Due to the difficulty in measuring the materials properties in most cases, there is some difference between the simulation predicted results and real case measurement results. A calibration or correction is normally performed by using the experimental results from measurement to fine-tune the modeling so as to obtain more accurate prediction. As a new warpage measurement methodology launched by JEDEC standard JESD22B112 in 2005, Shadow Morie Method is an optical non-contact method to measure warpage using a morie fringe pattern resulting form the geometric interference between a flat reference grating and the projected shadow of the grating on a warped test object. The warpage of devices going through higher temperature reflow soldering can be monitored by using Thermal Shadow Morie Method, while the warpage under low temperature during Thermal Cycling test can be measured with the CoolMorie accessory. Figure 2 shows the system set up and measurement mechanism of TherMorie PS400 from Akromatrix.

FEA Modeling and Warpage Measurement

Three types of laminated packages, PBGA, CSP BGA and PoP BGA with configuration details listed in Table 1 were studied. FEA simulation was performed using Ansys® software with CTE and E of green EMCs. Warpage of individual package or strip panel was measured with TherMorie PS400 and CoolMorie system. The in-situ monitoring of warpage was performed by programmed phase measurement under simulated reflow temperature profile.

Table 1 Configuration Details of Studied Package

	Pacakge Type	Package/Panel size	Body size	Die size	Substrate thickness	Die thickness	Mold cap	D/A thickness
1	PBGA	35x35	30x30	9.0x9.0	0.36	0.33	1.17	0.03
2	W-CSP BGA	10x12.5	10x12.5	9.318x9.492	0.29	0.28	0.52	0.025
3	PoP BGA	14x14	9.5x9.5	6.66x6.75	0.3	0.1	0.27	0.025

Results and Discussion

1. PBGA package

FEA modeling on PBGA package with the configuration listed in Table 1 was conducted in 2-dimension. Figure 2 shows the simulated warpage at –55°C, 25°C, 150°C and 260°C. The package is in a concave warpage (smiling face) after cooling down to room temperature from molding temperature which is considered as none warpage reference temperature by ignoring the in-mold-cure shrinkage. This is mainly because the thermal shrinkage of EMC (sum of contribution from CTE1 and CTE2 with Tg) is higher than the shrinkage of substrate. With temperature further down to –55C which is a lower than Tg of any commercial so that thermal shrinkage of EMC is only dependent on CTE1, the package becomes less smiling or even flat as a result of lower CTE1 of EMC compared with CTE of substrate. On the other hand, since the thermal shrinkage of EMC is fully from CTE2 as Tg=145°C<150°C and much higher than CTE of substrate, the package shows much higher warpage at 150°C than at 25°C. Going to reflow temperature 260°C, convex warpage (crying face) is predicted simply due to the higher CTE2 of EMC than CTE of substrate.

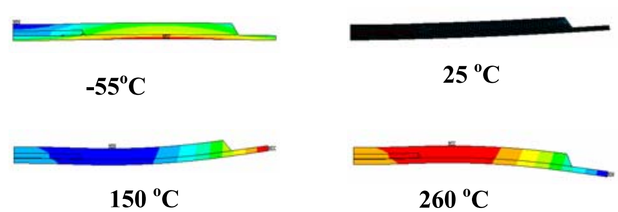


Figure 3 Warpage predicted from FEA on PBGA at different temperature

The warpage of PBGA package with the same configuration molded with green EMC1 whose properties were input for FEA modeling was measured with TherMorie system. 3-D contours and diagonal line scans are shown in Figure 4. The warpage goes through the deviation from smiling at 25°C to less smiling or flat at –55°C, to back to smiling at 25°C, to more smiling at 150°C, to crying at 260°C, to smiling at 25°C again. The measurement results show the same trend predicted by FEA simulation. However, warpage difference is observed by comparing the data under same temperature as shown in Figure 5. The FEA warpage is generally less than the real measurement regardless of temperature. Significant difference at 150°C around Tg=145°C between FEA and measurement is because the real CTE/E of EMC material are continuously changing during the glass transition temperature range (about 30°C), not a straight jump as simplified by FEA. Another reason also contributing to the difference is the fact that Tg for modeling measure by TMA is normally 10 to 30°C lower than the Tg from DMA, so that the modulus at Tg (TMA) is still E1 while CTE1 transmits to CTE2. The temperature at which there is zero warpage is about 210°C by the measurement compared with 175°C which is defined as the zero displacement reference temperature in FEA. The higher zero-warpage temperature confirms the existence of cure shrinkage during the cross-linking of epoxy groups from epoxy resin with hydroxide groups from hardener although epoxy is one of the lowest cure shrinkage resins. How to measure cure shrinkage and how to use cure shrinkage in FEA will be discussed in a separate paper.

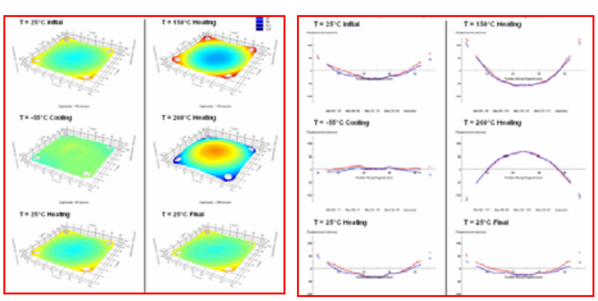


Figure 4. PBGA package 3-Dcontour and diagonal line scan from Shadow Morie Measurement

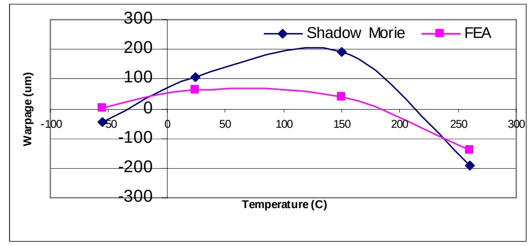


Figure 5. Comparison of package warpage under different temperature from FEA and Shadow Morie measurement

Figure 6 shows in-situ warpage measurement results of other two green EMCs on the same PBGA package from room temperature to 260°C. It can be seen that the package without die shows much more smiling warpage (positive value) compared to that with die for EMC2, while the package even convert to crying face at room temperature for EMC3. It can be seen from the warpage profile that the Tg of EMC2 is approximate 100°C while 130°C for EMC3.

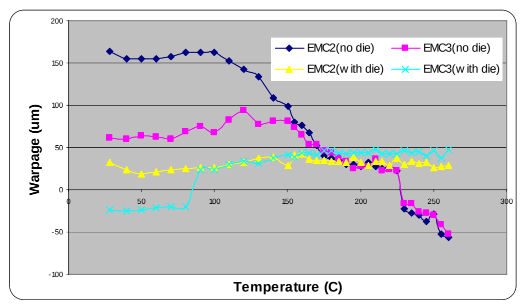


Figure 6 In-situ warpage monitored using shadow Morie

2. CSP BGA

As changing from DDR1 to DDR2, DRAMs are increasingly packaged in area array CSP or FBGA format from current TSOP format. Since the die is arranged in cells and bond pads are arranged in the center of the chip, BGA with window on the solder pad side becomes the special character of these packages (e.g. mBGA, Window BGA (Figure 7(a)). As Window CSP BGA packages are normally designed in special configuration with large die or even exposed die, thin substrate, low package thickness, and die attach film instead of epoxy, serious crying warpage was observed after map type molding with normal PBGA EMC as shown in Figure 7(b). FEA simulation provided the warpage behavior of 4 green EMCs summarized in Figure 8. it can be seen from the results that the warpage at room temperature is much higher than that at 260°C, therefore higher CTE is needed to reduce the smiling warpage at room temperature. Good matching was achieved between simulation results by introducing cure shrinkage and Shadow Morie measured data.

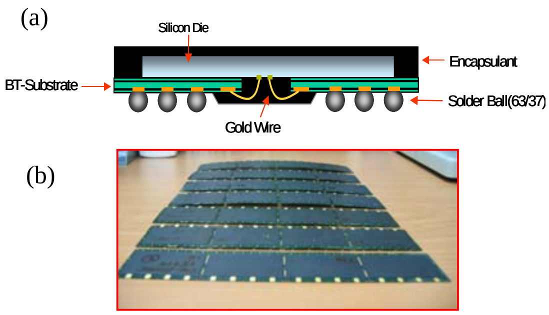


Figure7 (a) W-CSP BGA package with solder ball, (b) W-CSP BGA strips molded with different EMCs

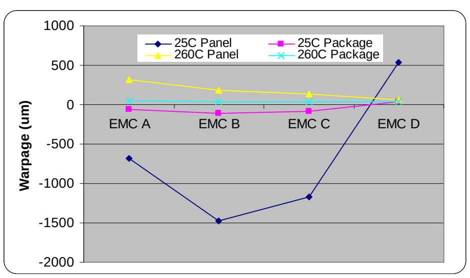
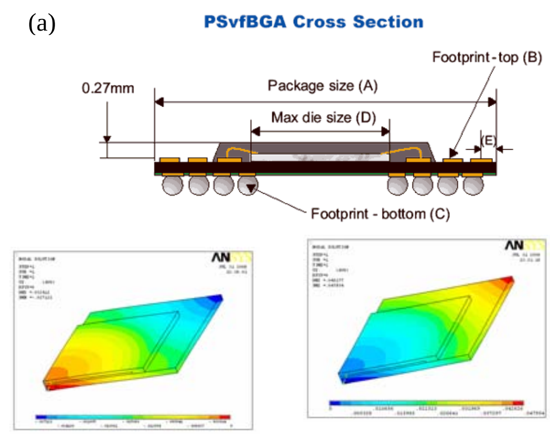


Figure 8 Predicted panel and package warpage of EMCs with different properties

3. PoP BGA

As an approach for system integration by stacking, package on package (PoP) brings new challenges to EMC either on moldability or warpage control. The warpage of PoP BGA package should be control with certain level both at room temperature so as to pass the package stacking process with one extra reflow process and board level reliability. Warpage contours under 21°C and 260°C are shown in Figure 9 from FEA modeling. In order to find the material property window to meet the warpage requirement both under 21°C and 260°C, sweeping excierse with variable E and CTE was carried out in FEA simulation with the results shown in Figure 10. For this particular PoP package at room temperature, increasing E or CTE will decrease the warpage (less crying) compared to the original EMC. The warpage will be reduced to 35um from 65um by increasing 20% of CTE. Since E normally decreases when increasing CTE by using lower filler load or lower Tg resin chemistry, the negative effect of E should be considered in EMC product development.



(b) 21°C (c) 260°C

Figure 9(a) PoP BGA package and (b) (c) 3-D modeling contours

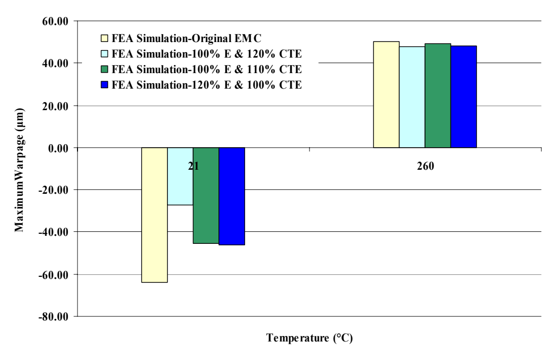


Figure 10(a) Material property sweeping on PoP BGA package

Conclusions

Finite element analysis (FEA) shows reasonable accuracy in warpage prediction of advanced laminated IC packages such as PBGA, CSP BGA and PoP BGA. Shadow

Morie system can be used as a new methodology in monitoring warpage deviation of packages under temperature profile from thermal cycling temperature to reflow temperature. Calibration or correction of FEA results can be performed by introducing experimental results from Shadow Morie measurement to fine-tune the modeling so as to obtain more accurate prediction. Material property sweeping excierse in FEA modeling provides important information either for assembly houses in screening EMC candidates or EMC supplier in product development.

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