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INVESTIGATION OF WARPAGE INDUCED ON MOLDED STRIP OF QFN PACKAGE

U. Mokhtar[1], R. Rasid[1], I. Ahmad[1], Z. Endut[2], S. Esa[2] and K. Krishnasamy[2]

[1]*Advanced Semiconductor Packaging (ASPAC) Research Laboratory,*
Universiti Kebangsaan Malaysia,
43600 UKM Bangi, Selangor, Malaysia
[2]*AIC Semiconductor Sdn. Bhd.,*
Kulim Hi-Tech Park, Kulim, Kedah, Malaysia.

ABSTRACT

Warpage is known to be one of the primary molding issues during assembly of QFN package. It affects the package sawing process, and cause reliability issues. The main cause of warpage of area array packages is the coefficient thermal expansion (CTE) mismatch between the moulding compound and other components inside the package. The objective of this study is to investigate the warpage induced on the moulded strip of QFN package, by using different mold compounds which have different CTE values. The effect of thermal properties and filler content is also investigated. In this study, the QFN strips are moulded with different mould compounds. Nonlinear large deformation finite element analysis is performed to compare with the experimental result. It shows that different mould compound properties will result in different warpage.

INTRODUCTION

Plastic packaging in the electronic industry has been popular during the past decades. One of the reasons is its low cost compared to ceramic packaging. Epoxy moulding compounds (EMC) are used in plastic packages due to their lower cost and good environment resistance ability [1]. However, non-uniform volume shrinkage of EMC often causes warpage after moulding, especially area array packages of IC packages such as BGA and QFN (Quad Flat Non-lead) packages. In general, different coefficients of thermal expansion (CTE) values of different epoxy compound formulations and assembly materials are considered as the main cause of package warpage.

Epoxy moulding compounds, as the largest components in packages, usually dominate the warpage. Epoxy moulding compound are composite materials composed of resin, hardeners, fillers, catalysts, coupling/release agents and small percentage of other ingredients. The formulation percentage can be adjusted and materials properties can be changed accordingly. It is meaningful to control package warpage through manipulating materials properties of moulding compounds, such as T_g, CTE and curing shrinkage. CTEs of moulding compounds are largely controlled by filler contents, such as percent loading of silica fillers. Curing shrinkages are

Corresponding Author: umi_libra30@yahoo.com

dominated by polymerization methods and curing kinetics. T_g, defined as the temperature that about 50 to 100 units in a polymer chain are able to move freely, usually depends on the stiffness of polymer chains, chain lengths and free volume between the chains [2].

In this paper, different mold compounds were used to investigate the warpage of the moulded array strips after moulding and post mould cure process. Chemical shrinkage of the mould encapsulation during post mould cure is another factor that can cause warpage. Finite element analysis was also conducted to investigate the differences. Finite element analysis (FEA) is a method of finding approximate mathematical solutions to physical problems. Nonlinear large deformation FEA has been performed to investigate the impact epoxy moulding compound (EMC) material properties, lead frame strip size, and mould block layout on the warpage and stress induced [3].

The QFN Package And Map Mold Manufacturing Process

One of the latest developments is packaging technology is the QFN package, which is both a chip scale package and plastic encapsulated package with lead pad on bottom. QFN packages provide many advantages over other leadframe package configurations, such as low cost, small size, low profile, high thermal and electrical performance and good production yields. Compared to leaded packages with similar body sizes and lead counts, the QFN offers far superior thermal performance because the leadframe is on the bottom of the package and the die-pad is exposed, resulting in effective removal of heat [4].

Warpage causes a moulded object to bend or twist out of shape and alters not only the dimensions but also contours and angles of the object. Product warpage in moulded polymer parts can have a major effect on product performance and is therefore undesirable example; warpage not only obstructs the delicate sawing process, but also can cause assembly problems and reliability issues [4].

The major process for manufacturing QFN package is a so-called map moulding or array moulding technology, which in principle is a transfer moulding process followed with the singulation process. In industries, the encapsulation matrix is called ‘map’. Figure 1 shows a moulded strip after array moulding process, which contains 4 maps and totally over 200 QFN units. From business point of view (cost-reduction), it is essential to decrease the number of maps, 5-map to 4-map and eventually a 1-map assembly. Decreasing the number of maps will increase the space available for products, but as such, will also increase the amount of warpage in the map [4].

In our study, the dummy strip was used to evaluate package warpage using different mould compounds. All test vehicles have 48 lead with a dimension 7 X 7mm and a body thickness of 0.85 mm. This package was evaluated because larger packages tend to exhibit more warpage. A QFN package with a 0.2mm thick copper leadframe

Corresponding Author: umi_libra30@yahoo.com

and a die pad size of 5.8 X 5.8 mm was used in the evaluation.

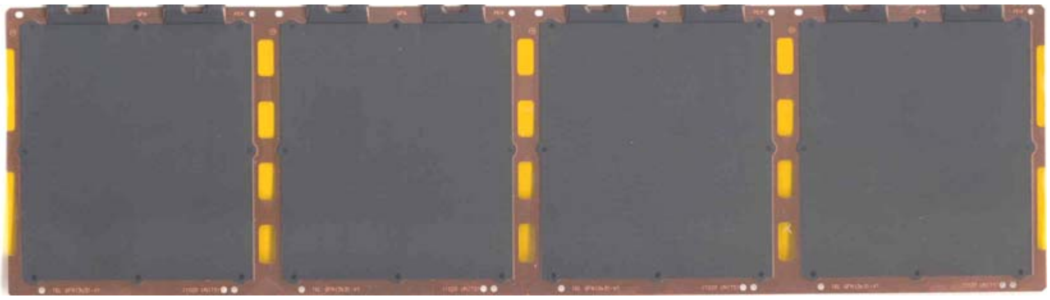

Figure 1: Top view of a molded strip, which has 4 maps.

METHODOLOGY

The thermal and mechanical properties of the leadframe materials used in this package are presented in Table 1. The different mould compounds properties are major factors affecting the warpage performance were evaluated. Three different new generation low stress mould compounds were evaluated. Table 2 shows the material properties for the different mould compounds used in the study. The new mould compounds (Compound A and B) are based on the multi-aromatic epoxy (MAR) compound. These compounds have higher flexural modulus, lower coefficient of thermal expansion, and higher filler contents than those of the biphenyl epoxy or a new resin system from another supplier, Compound C. Two samples were assembled for each of the current and new mould compounds. Compound B is a new type from supplier which evaluated for low stress mould compound. Low stress mould compound was evaluated to reduce stress for mould sweep and warpage phenomenon. Compounds A, B and C using the 250 x 70 mm Cu leadframe.

The C194 leadframe were transfer moulded at 175°C in a conventional mould chase with equal top and bottom cavity thickness. The samples were then post mold cured at 175°C for five hours in a convection oven. After the moulded strips were cooled to room temperature, they were measured for warpage at the four diagonal corners using a smartscope gaging optometry. This process flow is presented in Figure 2.

Figure 2: Warpage test flow.

Corresponding Author: umi_libra30@yahoo.com

Table 1: Properties of Leadframe [5].

Component	*Young's modulus (GPa)*	*Poisson's Ratio*	*CTE (ppm/ °C)*
Leadframe (Cu)	123	0.35	16.3

Table 2: Material properties for different mold compounds.

	A	*B*	*C*
% of Filler	90	90.5	88.5
Epoxy	MAR/MAR2	MAR/MAR2	Biphenyl' +hyrophobic
CTE1 (ppm/e^{-6})	0.8	0.7	1
CTE2 (ppm/e^{-6})	3.9	3.4	3.4
Tg	140	140	135
Modulus @ RT (e^{6})	28000	29000	24000
Modulus @ 260 °C (e^{6})	800	900	580

Warpage Measurement

The technique of Smartscope Gaging 250 Optical testing was used to measure package body warpage after encapsulation process and after post mould cure. The measurements are cost effective, nondestructive and can be undertaken quickly as shown in Figure 3. Unlike other package (TSOP, SOIC and CSP), BGA and QFN package only has one side overmoulded.

Figure 3: Smartscope Gaging 250 Optical.

Corresponding Author: umi_libra30@yahoo.com

As the moulding compounds cure and cool, the package reaches a gel point and the components of the package are bound together by a cross-linked polymer network where no component can expand or shrink freely. Due to the differences in chemical shrinkage as well as the coefficient of thermal expansion (CTE) of the package components, warpage occurs in either the “crying face” (edges down) or “smiling face” (edges up) orientation [5]. Other term for crying face and smiling face in these studies are coilset warpage and crossbow warpage. Figure 4 shown the warpage orientation definition is induced, due to the CTE thermal mismatch.

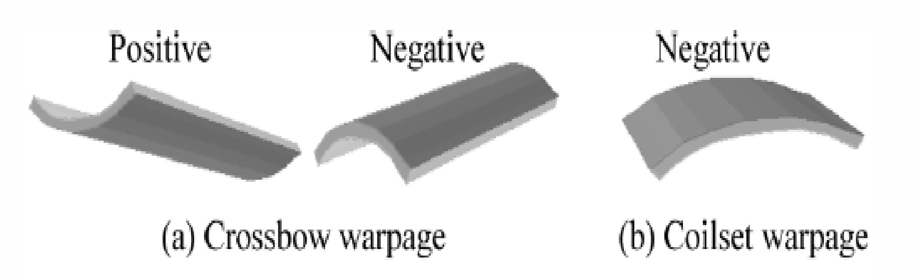

Figure 4: Different warpage types of molded strip.

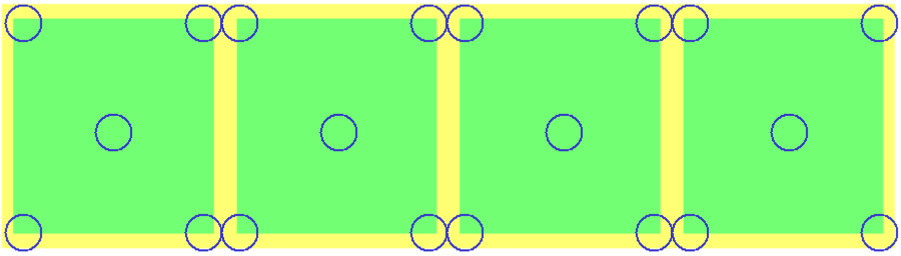

Figure 5: Measurement points of warpage.

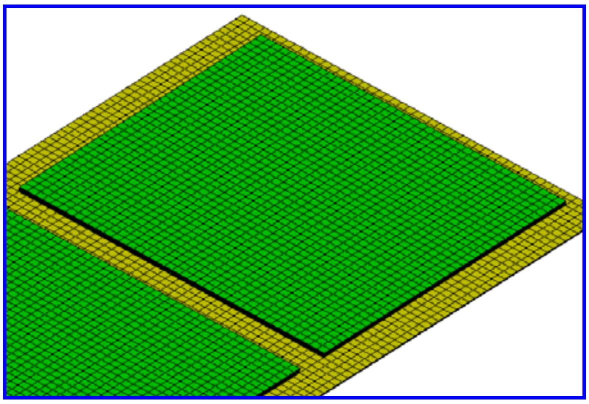

Figure 6: Finite element model of mold compound and leadframe.

Corresponding Author: umi_libra30@yahoo.com

This microscope offers versatility and high performance three-axis measurement of parts and electrical components, with very high precision. Each strip has four blocks. The locations of warpage measurement were chosen at the four diagonal corners of each block as illustrated in Figure 5. The difference between the vertical displacement value at the central point and the minimum value at the four corner points is defined as the block warpage. The maximum warpage value of the four blocks is taken as the warpage of the moulded strip.

Finite Element Analysis (FEA)

Finite element analysis was used for warpage simulation. Commercially available software ANSYS was used as the structure analysis solver. In this paper, FEA modelling is performed for map-mould. It consists of a leadframe and moulding compound which encapsulates each matrix. Nonlinear large deformation FEA has been performed to investigate the impact of EMC material properties, leadframe strip size, and mold block layout on the warpage and stress induced. Only mould compound and leadframe elements are generated to reduce the computational time. Due to symmetry of the strip, a quarter's model was constructed with symmetrical boundary conditions imposed. The FEA model is shown in Figure 6. The element sizes have to be small in x and y directions, in order to keep reasonable aspect ratios of the solid elements. Thermal loading is applied to simulate the cooling process after moulding, i.e., from 175°C to 25°C. At the moulding temperature, the package is assumed to be stress free. FEA results only showed the EMC warpage and stress because it is more susceptible to failure compared to copper leadframe [3].

RESULTS AND DISCUSSION

QFN Strip Warpage

The warpage primarily results from internal stresses caused by the CTE mismatches between the package constituents as the devices cool from the curing temperatures to 25°C and volumetric shrinkage of the epoxy resin during the curing process. The difference in CTE's is a major cause of internal stress. Since the reduction of mismatch of CTE's reduces the stress, the EMC should have a CTE as close as possible to the other package constituents. Volumetric shrinkage depends on the amount of filler in the EMC. EMC with higher filler content generally has lower shrinkage.

Strip warpage measurements were taken from all the QFN samples for different EMC before and after post mold cure. The QFN bends crossbow edges up of the as shown in Figure 7. The average strip warpage value EMC is shown in Table 3. From the measure data, samples molded with EMC C warped the most while samples with EMC B warped the least. EMC C has a higher CTE than EMC B. The maximum warpage before and after PMC is 1.7776 mm and 1.3464 mm for EMC C. In the case of EMC A, the CTE is lower but the Tg is highest than EMC C but same with EMC B. Minimum warpage for EMC B is 0.7272 mm and 0.9286 mm due to its low stress properties. The material with higher elastic modulus is generally warped less

Corresponding Author: umi_libra30@yahoo.com

than that with lower elastic modulus. Therefore, the CTE's are dominant in the strip warpage of QFN.

Figure 7: QFN strip showing the 'smiling face' (edge up) orientation.

Table 3: Average volumetric shrinkage and strip warpage for different type of mold compounds.

	EMC A	*EMC B*	*EMC C*
% Shrinkage	8.68	4.27	0.05
Warpage, strip after molding(mm)	0.7422	0.7272	1.7776
Warpage, strip (mm) after PMC	1.1834	0.9286	1.3464

FEA Results

The process conditions are as follows: the epoxy system is cured at 150ºC for 700 min and then the moulded strips are cooled down to room temperature (25ºC) with a cooling rate of 5 ºC/min. The leadframe and die-pad are considered elastic and ideally plastic. The encapsulating epoxy is modelled with the described cure-dependent viscoelastic model. The material properties used in the simulation are shown in Table 1 and 2. Warpage in the moulded strips is caused by the curing shrinkage during cure and thermal mismatch of the constituents during cooling down.

Figure 8 shows the warpage patterns for the 4 map moulded strip at the end of curing and cooling down to room temperature. Here we take the maximum Z (out of plane) displacement as indication of the strip warpage. It can be seen that the strips bend downwards by curing and thermal stress as well. The main reason is that the CTE of the encapsulated epoxy is much larger that the CTE of the base metal. Figure 9 shows the warpage in 'crying face'. During isothermal curing, the curing warpage is confined in the mould. When the package is released from the mould, it is warped due to the residual stresses [6].

Corresponding Author: umi_libra30@yahoo.com

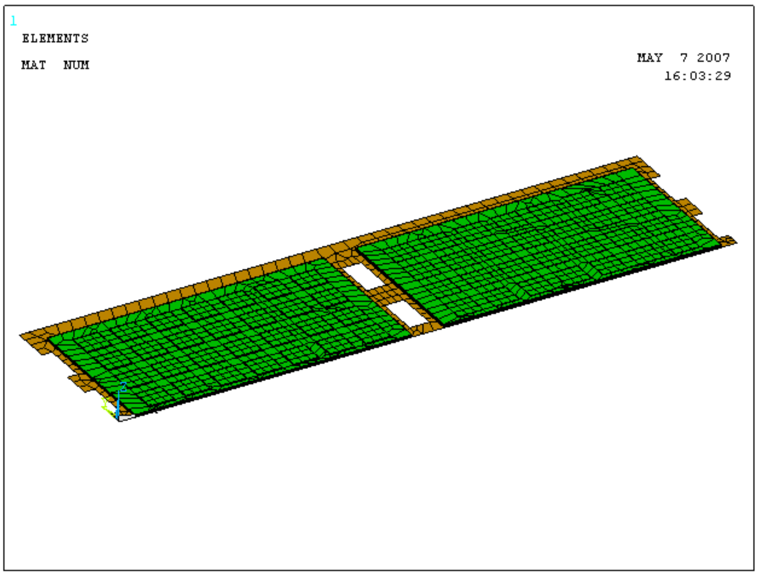

Figure 8: Model FE meshes for a mold strip.

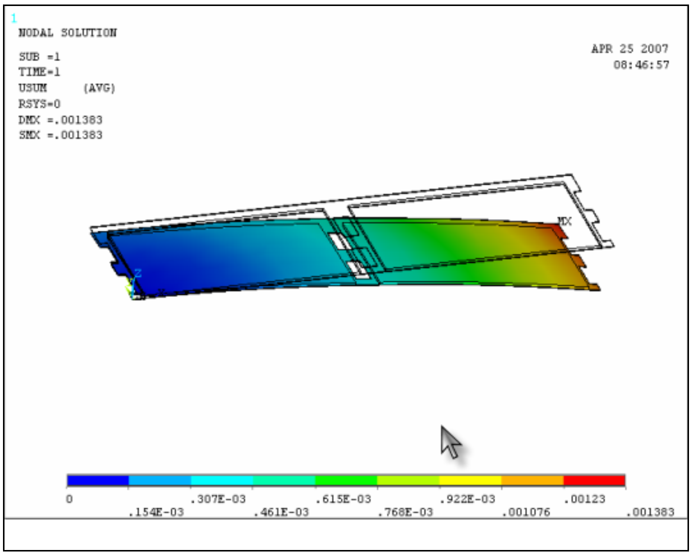

Figure 9: A typically crying face warpage calculated by finite element analysis.

CONCLUSIONS

The strip method warpage for QFN package was studied using finite element analysis method. The strip warpage resulted from the constituent structure and the thermal mismatch of EMC and substrate. The increase of filler content result in the decrease of CTE and increase of elastic modulus, and then the lower filler EMC has better strip warpage than the higher filler EMC.

Corresponding Author: umi_libra30@yahoo.com

REFERENCES

[1]. L. C. Hong. (2004); Simulation of Warpage Considering Both Cure induced Shrinkage During Molding in IC Packaging, *Polytronic.*

[2]. K. Irving, C. J. Zhang, L. Rector and M. Todd, (2006); Low Warpage Molding Compound Development for Array Packages, *Electronic System integration Technology Conference Dresden*, *Germany*.

[3]. C.C. Ng, G. Govindasamy and T. M. Y. S. Tuan Ya, (2005); Warpage Analysis and Thermo-Mechanical Stress Modeling of QFN Molded Strip. *5th ASEAN ANSYS User Conference 2005.*

[4]. D. G.Yang, K. M. B. Jansen, L. J. Ernst, G. Q. Zhang, J. G. J. Beijer and J. H. J. Janssen, (2005); Numerical modeling of warpage induced in QFN Array Molding Process. *IEEE 6th International Conference on Electronic Packaging Technology*.

[5]. Y. T. Park, Y. K. Whang, J. K. Hong and K. Y. Byeon, (2006); Warpage Analysis of FBGA (Fine Ball Grid Array) Package by the Altered EMC (Epoxy Molding Compound) Filler contents. *Key Engineering Materials*. 306-308: 625-630.

[6]. D. G. Yang, K. M. B. Jansen, L. J. Ernst, G. Q. Zhang, J. G. J. Beijer and J. H. J. Janssen, (2005); Experimental and Numerical Investigation on Warpage of QFN Packages induced during the Array Molding Process. *IEEE 6th International Conference on Electronic Packaging Technology*.

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