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EFFECT OF DIE CONFIGURATIONS ON WARPAGE ISSUES FOR QFN PACKAGES

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ABSTRACT

One of the latest developments in packaging technology is QFN (Quad Flat Non-lead) package. This paper describes a warpage study on a QFN package. The objectives of this study to investigate the warpage issues for QFN package with different die sizes. It was found that the balance between the bending at the edge size region and the die attach region controls the package warpage. The warpage was attributed to a large mismatch of coefficient of thermal expansion (*CTE*). The QFN package of 7 mm x 7mm with different die size were prepared to study the effect of die size on warpage issues and two types of mold compounds were prepared to study the effect of the coefficient of thermal expansion (*CTE*). The Finite element analysis was also presented in this paper. In these studies the effect of post mold cure on package warpage was also examined and the warpage of the QFN package was measured by using Smartscope Optical Gaging. The measurements were done after molding and after post mold cure process. The results showed that warpage is larger for stacked die package as compared to single die package and that the die size of 2mm x 2mm has the minimum warpage.

INTRODUCTION

Quad Flat Non-lead (QFN), a type of leadframe chip scale package, is getting popular as a low cost solution for applications with low pin count requirements. QFN is also known as micro leadframe, micro lead package, quad outline non-lead or small outline non-lead. A leadframe of QFN 7 mm x7 mm package is used in this study [1]. QFN also offers many advantages over other IC package types, such as low cost, small size, low profile, high thermal and electrical performance and good production yields [3].

With the package towards thinner and smaller denomination, the package warpage effect becomes more important [1]. The different coefficient of thermal expansion (*CTE*) values of different mold compound formulations and assembly materials are considered as the main cause of the package warpage. Beside that the imbalance in *CTE* between mold compound, Cu leadframe, die and die attach epoxy also causes a warpage on the leadframe [2]. Warpage is specially generated during cooling process from mold temperature to room temperature. Mold temperature is usually about 175ºC, which is over the T_g of mold compound, therefore the mechanical properties of the mold compound change severely in this step [3]. Warped QFN

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maps induced during the molding process is shown in Figure 1.

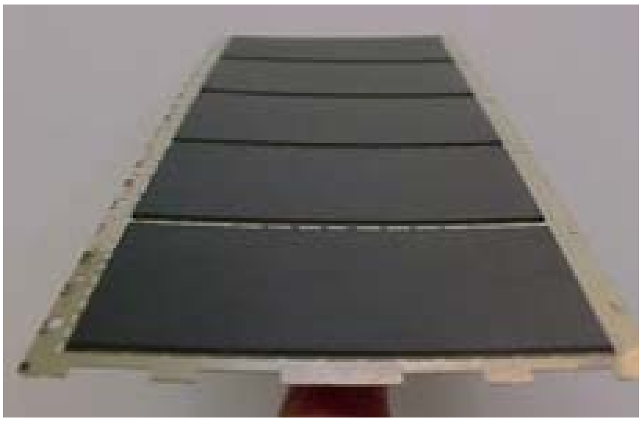

Figure 1: Warped QFN maps induced during the molding process.

As the package increases and the chip decreases, maintaining package planarity becomes more difficult particularly in asymmetric structure. Since the degree of package warpage depends on the package design, materials selection, and assembly process, there are several methods that can be used to reduce package warpage [4]. This paper discusses a study to evaluate the effect of die configurations on the package warpage of QFN packages. The warpage behaviour of QFN package is discussed based on experimental results. The selection of mold compound types A and B for QFN is based upon the low shrinkage and low warpage property. A series of molding experiments for QFN packages, in which variation of the die size, 5 mm x 5 mm and 2 mm x 2 mm for single die package. For stacked die package the mother die are used is 5 mm x 5 mm and the daughter die size is 2 mm x 2 mm., mold compound type which could cause excessive warpage were used. The warpage after molding and after post-cure was measured. Beside that, finite element models were used for pre-experimental evaluations and analysis. The finite element simulations help to give insight into the various process features that could be responsible for the package warpage [5].

METHODOLOGY

In our study, QFN packages were evaluated for package warpage using different mold compounds. All test vehicles devices were 48 leads with 7 mm x 7 mm body size. In our experiment different size dies of 2 mm x 2 mm and 5 mm x 5 mm die sizes were used. In this study, the QFN packages were evaluated using different mold compounds with different properties. The critical material properties of mold compound for both of type A and type B are recorded in Table 1.

Finite Element Analysis

Finite element analysis will give a useful insight into the interaction between the packages elements if, the model used were validated by experimental measurement. Typical FEA model result is shown in Figure 2. Thermal loading is applied to

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simulate the cooling process after molding i.e., it reduce from 175 ºC to 25 ºC. In this study, stacked die and single die design for QFN packages are modelled by using FEA. FEA results only showed that the mold compound warpage and stress because it is more susceptible to failure compared to copper leadframe.

Table 1: Critical material properties of mold compound used in this study.

Property	EMC Type A	EMC Type B
Spiral flow (cm) at 175°C	115	120
Gel time (sec.) at 175°C	35	40
Viscosity (poise) at 175°C	108.2	100
CTE 1 (e-6/C)	8	7
CTE 2 (e-6/C)	39	34
Filler content (%)	90	90.5

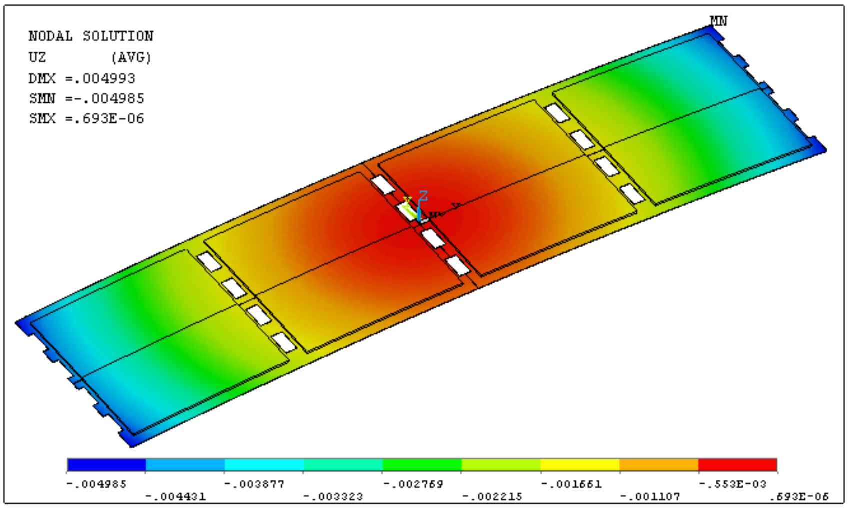
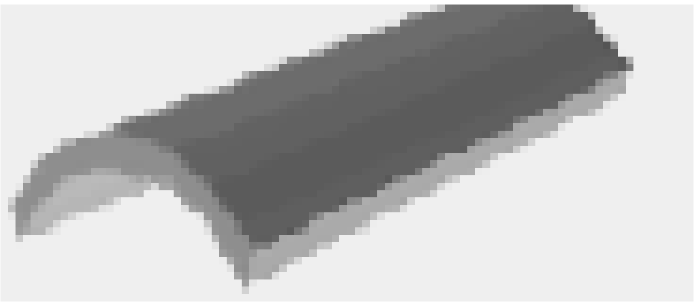


Figure 2: Finite element model of mold Compound and leadframe of the molded array package.



Convex Warpage (Crying Face) Substrate has a lower CTE than the molding compound.

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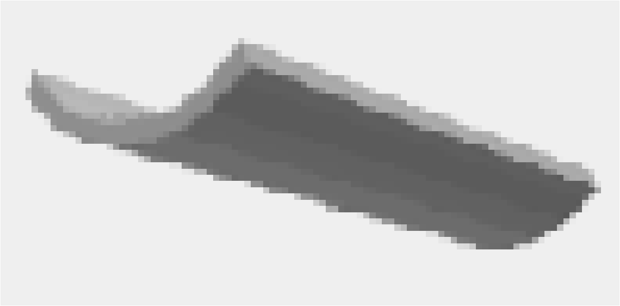

Concave Warpage (Smiling Face) Substrate has a higher CTE than the molding compound.

Figure 3: Definition of the warpage shape.

Quad Flat Non-lead (QFN) Warpage

Since the package thickness is very small, internal stresses can cause external deformation, commonly known as warpage phenomenon. Warpage changes the lead coplanarity and will negatively affect the assembly process. The ultimate goal is to choose suitable materials and assembly processes to minimize warpage and the internal residual stresses [6]. Figure 3 shows the warpage orientation definition formed due to the CTE thermal mismatch.

Figure 4: Smartscope Optical Gaging.

Warpage measurement

Normally in the IC manufacturing production, the time allowed for thawing of mold compound is about 24 hours. This is sufficient to enable the temperature to be uniform throughout the mold compound before the actual molding step. The crucial process parameter is the sample exposure time that is required to simulate the actual conditions in factory floor [7]. For different die configurations i.e stacked die

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package and single die were used in this study. Other samples are two types of single die packages with different die size of 5 mm x 5 mm and 2 mm x 2 mm were assembled for each mold compound. After the wire bonding process, the units were transfer-molded at 175 °C in a conventional molding machine with uneven top and bottom cavity thickness. The samples were then post-mold cured at 175 °C for 6 hours in a conventional oven. The process of heating (1-6 hours at 175°C) the molded package is called post mold cure [4]. In this study, warpage of the QFN package is measured by using Smartscope Optical Gaging as shown in Figure 4. The warpage was measured after the molding process and after the post mold cure process.

RESULTS AND DISCUSSIONS

Stacked die

The package warpage was measured before and after post mold cure (PMC) and compared to it as shown in Figure 5. The package is QFN stacked die with package size 7 mm x 7 mm with 48 leads. The result shows warpage values decrease after PMC process. It is because after molding process, the compound becomes solid and more stable with the cross linking reaction. However when the package is heated up after thermosetting, the reaction continues to make higher degree of cross linking. As a result, transition temperature (T_g) of the post mold cure package will increase because of high degree of crosslink. From the measured data, samples molded with molding compound type B warped the most while samples with molding compound type A warped the least. Mold compound type B has lower *CTE* than mold compound type A. The maximum warpage is -0.85 mm for mold compound type A and minimum is -0.54 mm for mold compound type B. In the case of mold compound type B, the *CTE* is lowest but the T_g is highest.

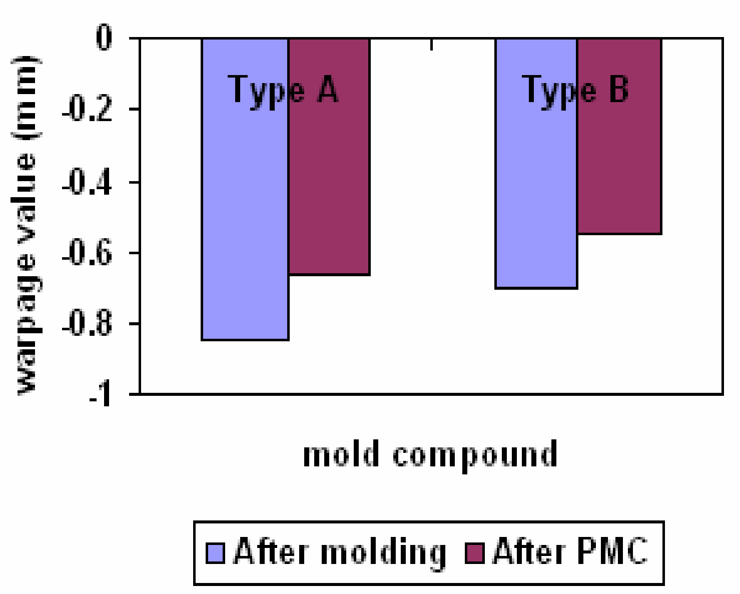

Figure 5: Package warpage of QFN Stacked die before and after PMC single die.

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The package warpage of QFN single die is shown in Figure 6. The package size is also 7 mm x 7 mm with 48 leads. The effect of stacked die and single die was also studied. Compare to stacked die and single die package, the warpage of the single die have low warpage value. The stacked die package will cause more warpage as expected. Experimental results showed the same warpage directions for stacked die and single die QFN package, with both warping in the crying face direction. The finite element analysis also predicted that both of the stacked die and single die package warpage showed a crying face type.

For warpage comparison between mold compound type A and type B, the result showed that the mold compound type B have low warpage value. It is because the *CTE* for mold compound type B are low compare to mold compound type A. The results also showed that after PMC the warpage value are lower than before PMC. The material with lower *CTE* is generally warped less than that with higher *CTE* [1]. For different package, there is significant warpage change of stacked die package compared to single die package. For single die package the warpage value is the lower than the warpage value for stacked die package. The warpage for stacked die package is higher because of the coefficient of thermal expansion (*CTE*) mismatch between mother die and daughter die, leadframe and mold compound. The coefficient of thermal expansion (*CTE*) and elastic modulus of EMC are major factors of the thermal stress, because the *CTE* of EMC is higher than the chip and substrate [7]. Beside that, the warpage mode also changes by the insertion of the die, and the shape depends on the die size. It is interesting to see that insertion of die can make the package warpage concave [4].

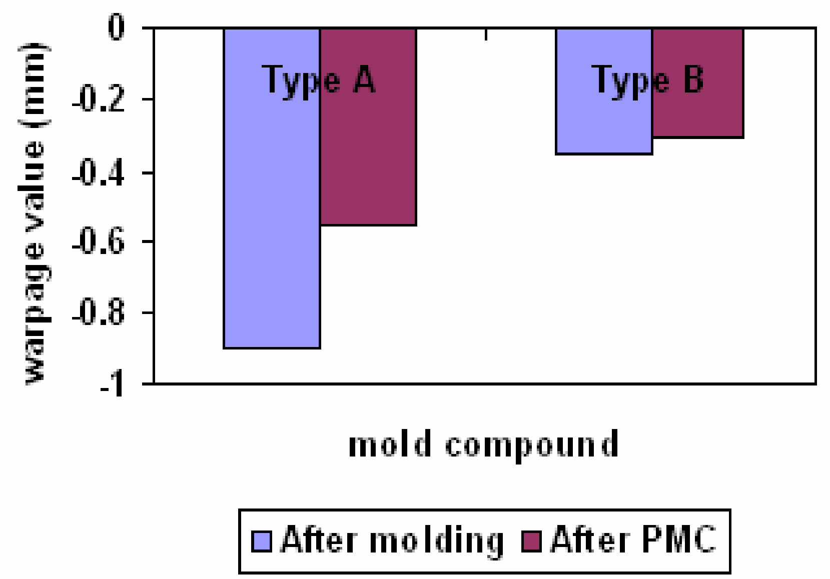

Figure 6: Package warpage of QFN single die before and after PMC.

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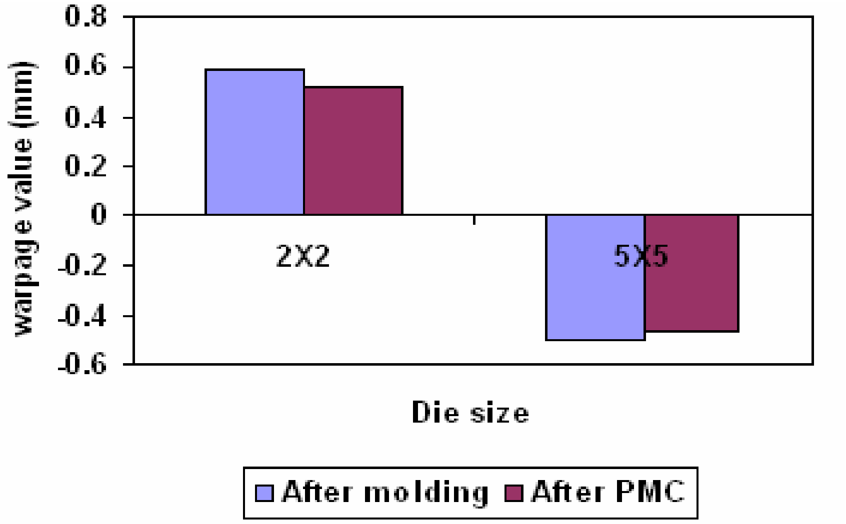
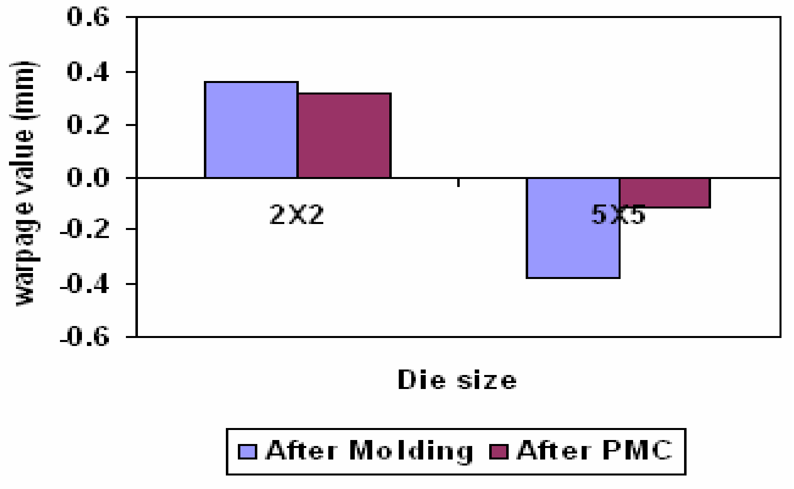


(a)



(b)

Figure 7: Effect of die size warpage after molding and after PMC: (a) Mold compound type A, (b) mold compound type B.

Die Size

The effect of die size is shown in Figure 7. The larger dies will cause less warpage as expected. The average strip warpage value for mold compound type A is shown in Figure 7 (a) and warpage value for mold compound type B is shown in Figure 7 (b). From the measured data, samples molded with die size 5 mm x 5 mm warped the most while samples with 2 mm x 2 mm warped the least. The larger die has lower stress than the smaller die. The maximum warpage is -0.59 mm for mold compound type A with in die size 2 mm x 2 mm and minimum -0.112 mm for mold compound type B with in die size 5 mm x 5 mm. In this case of different die sizes, the larger die shows the lower warpage value. The more contacting area between the heat spreader and the leadframe will produce less warpage [1].

The mold compound *CTE* has effect on the warpage issues. Thermal stresses develop when the package cools from molding temperature due to the large thermal mismatch in *CTE*. Thermal stresses increase with increasing *CTE* mismatch and *E* (elastic modulus*)* [6]. From the Figure 7 the results also showed that mold compound type B has lower warpage than mold compound type A. Mold compound type B has a lower *CTE* than mold compound type A. In the case of mold compound type B, the *CTE* is lowest but the Tg is highest. Therefore the total shrinkage is less than the mold compound type A and the warpage is also less. The material with higher elastic modulus is generally warped less than that with lower elastic modulus [1]. As shown Fig 7, the warpage data also showed that the warpage value decreased after post mold cure. Chemical shringkage of the mold compound during post mold cure is another factor that can cause warpage [5].

Figure 5, 6 and 7 showed the warpage variations during IC manufacturing process based on the experimental observation. Thermal mismatch between package constituent materials is the major cause of IC package warpage. To minimize the warpage problem, a thorough understanding of epoxy molding compound (EMC) properties with molding parameters is necessary as EMC is epoxy-based with time and temperature dependent viscoelastic properties. This paper first addressed the effect of die configurations on the package warpage of QFN packages. Using such experiment the effect of different die size and mold compound's thermal properties of the different package and die size is optimized to reduce the package warpage. Secondly the effect of the post mold cure process on the warpage issues was also examined in this study.

CONCLUSION

Experimental results showed similar warpage directions for stacked die and single die package, with both warping in the crying face direction. For die size, the small die 2 mm x 2 mm moving into the smiling face direction as the effective *CTE* increases. The finite element analysis also predicted that both the stacked die and single die package warpage should be along on the crying face. For single die package the wapage value is the lower than the warpage value for stacked die pacakege. For single die package with different die sizes showed that the die size 5 mm x 5 mm has a lower warpage than die size 2 mm x 2 mm.

From the QFN package size study, it can be observed that as the *CTE* value of mold compound decreased, the molded strip warpage reduced. By FEA analysis results and experimental work, it is shown that larger die size has less warpage and crying face warpage. The results of these experiments and analysis show that, the effect of die configuration on warpage problems are an important issues in molding process. However the package warpage increased as the filler content of the compound decreased for both a large die and small die due to the decrease in chemical shrinkage. The material with higher filler content is generally warped less than that with lower *CTE*. Post mold cure after molding process also needed to reduce warpage.

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