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REDUCTION OF WARPAGE OCCURRENCE STACK-DIE QFN THROUGH FEA AND STATISTICAL METHOD

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ABSTRACT

In semiconductor packaging, warpage is one of the critical issues during molding stage. It is related to a thermal mismatch i.e. coefficient of thermal expansion (CTE) values and reliability of passive components in the package. Finite element method (FEM) is able to perform extensive structural analysis of quad flat no-lead (QFN) package designs once verified by experiments. 2^k factorial is employed to analyse the finite element analysis (FEA) in order to determine the significant factors that affect warpage. A QFN stacked-die strip was developed with six different control factors were constructed using Ansys® and particularly for nodal displacement. The displacement results were verified with experiment data. The FEA results were then subjected to 2^k factorial design technique to determine the significant factors. It was found that the mold compound and epoxy layers significantly influenced the warpage formation.

INTRODUCTION

There are many failure factors in IC packaging industries in particular quad flat no lead (QFN) package such as delamination, non-coplanarity on leadframe and warpage. Warpage affects package strength and thus reduce reliability of the final product. It is also known to affect various package assembly stages such as during die mounting, wire bonding, molding and also during package saw [1]. It was found [2] that the different in chemical shrinkage rates of the various layers of the IC packages. QFN package usually undergoes several thermal cycles during its manufacturing stage and this lead to different degree of expansion and contraction of the various layers and hence resulted in warpage. Thus it is believed that by choosing an optimized CTE combination of the various materials, it would reduce the possibility of warpage.

This study is to examine and determine the optimum combination of the CTE values of the various components in QFN design. Conventional QFN package [3] comprises of silicon die, lead frame, epoxy mold compound (EMC) and die paste as shown in Figure 1 [4]. Each of this component that makes up the layer have different CTE values. Six different CTE design parameters were analysed using Ansys® version 10. The FEA results of the node displacement were then subjected to 2^k factorial design analysis to determine the optimum CTE combinations.

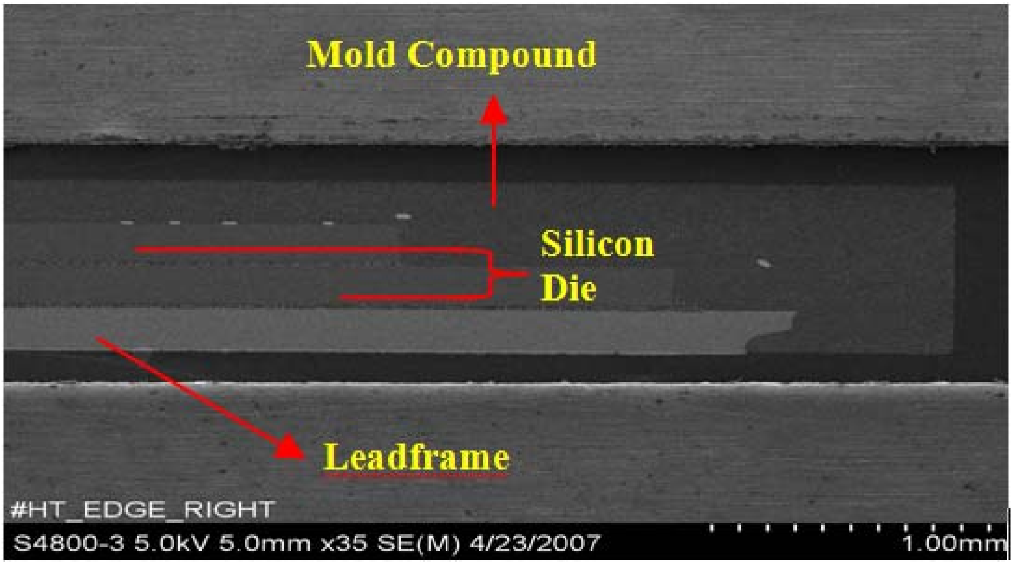

Figure 1: Detail of QFN packages components (Yang *et. al.*).

Previous research of other packages [5] had found that the leadframe will be significantly deformed due to the chemical shrinkage of molding compound. This took place at the molding process temperature of 175°C. The chemical shrinkage, *s*, generated during the cooling of the molding compound can be estimated using equation (1), with CTE values, α_1 and α_2, assumed to be constant below and above T_g.

$$s = \int \alpha(T)dT \approx \alpha_1(T_g - 25°C) + \alpha_2(175°C - T_g) \quad \text{for } 25°C < T_g < 175°C. \qquad (1)$$

The equation showed that low CTE values [6,7] and high T_g [8] of layer properties are beneficial in reducing warpage by reducing chemical shrinkage occurence.

METHODOLOGY AND MODELING

Two different materials i.e leadframe, die attach film, epoxy and mold compound were studied, and these material properties were given in Table 1. These properties are used in this study in order to obtain the optimised CTE combinations of the various layers. Elastic modulus value were measured at temperatures below glass transition temperature, T_g. In this paper, both modeling and 2^K factorial were used to obtain the optimum of warpage package as shown in Figure 2. From the flowchart, all the parameters on characteristics material, especially CTE value were used in the FEA software to get displacement values. The displacement results were then and analysed as a combination factor to find the minimum warpage value for the package model.

Table 1: Parameter of material properties.

	Flex.modulus @RT(e+9)	Poisson's ratio	cte 1 (ppm/e-6)	cte 2 (ppm/e-6)
leadframe A	118	0.35	17.3	-
Leadframe B	128.9	0.34	16.6	-
Silicon die	169	0.26	2.8	-
Epoxy A	3.1	0.35	40	150
Epoxy B	10	0.35	81	181
Die Attach A	1.66	0.26	80	170
Die Attach B	5	0.35	15	-
Mold Compound A	29	0.3	7	34
Mold Compound B	23.7	0.35	9	34

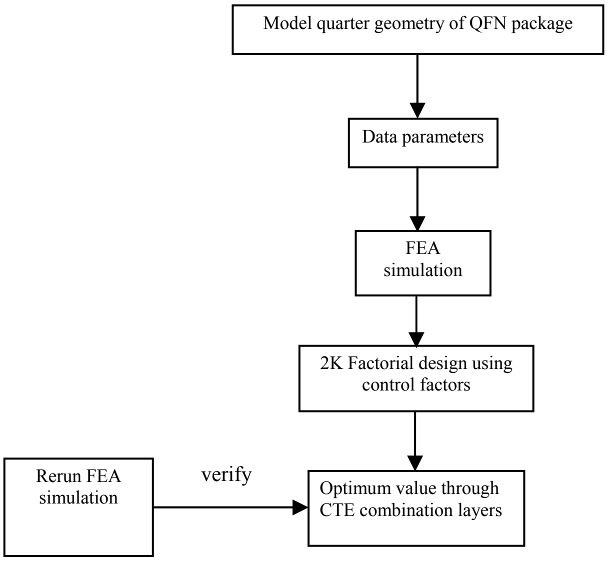

Figure 2: Flowchart of warpage solution technique.

Finite Element Model

A finite element technique is a method of finding approximate mathematical solutions of physical problems. It is also used to predict the failure caused by package warpage in semiconductor industry [9]. Kelly [10] had conducted both simulation and experimental for power quad flat pack (PQFP) packages. The result showed that it was possible to reduce the warpage and package shear stress either by lowering CTE or using the high T_g of EMC with CTE.

Ansys® software was used as a finite element modeling tool. As the geometry of package is symmetrical, only one-quarter of the package needs to be modeled with symmetrical boundary condition. The FEA model of package strip is shown in Figure 3. The model used a 3D eight nodes brick element and meshes of 200 elements for generate quad meshing. A symmetrical boundary conditions were applied to the surface at x=0 and y=0 and node at origin (x=0, y=0 and z=0) to prevent free rigid body motion and a thermal loading is applied to simulate the cooling after molding process, i.e. from 175°C to room temperature.

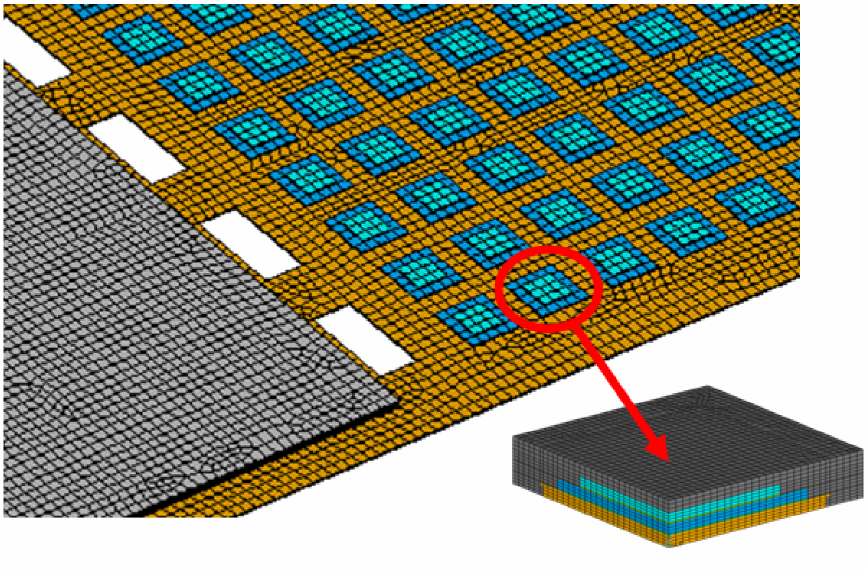

Figure 3: FEA model of stacked die QFN packages strip.

2^k *Factorial Model*

2^k factorial design was chosen to analyse the warpage effect. It is able to determine the relationship between factors and output response of the process [11]. The goal of the design of experiment is to evaluate the warpage condition based on different of CTE between leadframe, epoxy, silicon die, die attach and mold compound of QFN package strip. The models are based on two level designs with two variable inputs which are defined as high and low. This factorial design will generate the factor and responses i.e ΔCTE between material and displacement of packages strip. Table 2 shows the control factor for different CTE properties of each components of QFN packages design.

Table 2: Control factors for different CTE properties on stacked-die QFN packages strip.

	Control factors	Low Level (e^{-6})	High Level (e^{-6})
A	Different CTE between Leadframe and epoxy	22.7	64.4
B	Different CTE between epoxy and bottom die	37.2	78.38
C	Different CTE between bottom die and DAF	12.2	77.38
D	Different CTE between DAF and top die	12.2	77.38
E	Different CTE between Top die and mold compound	4.2	6.38
F	Different CTE between Mold compound and leadframe	7.6	10.3

RESULT AND DISCUSSION

2^k *Factorial Analysis in Warpage Analysis*

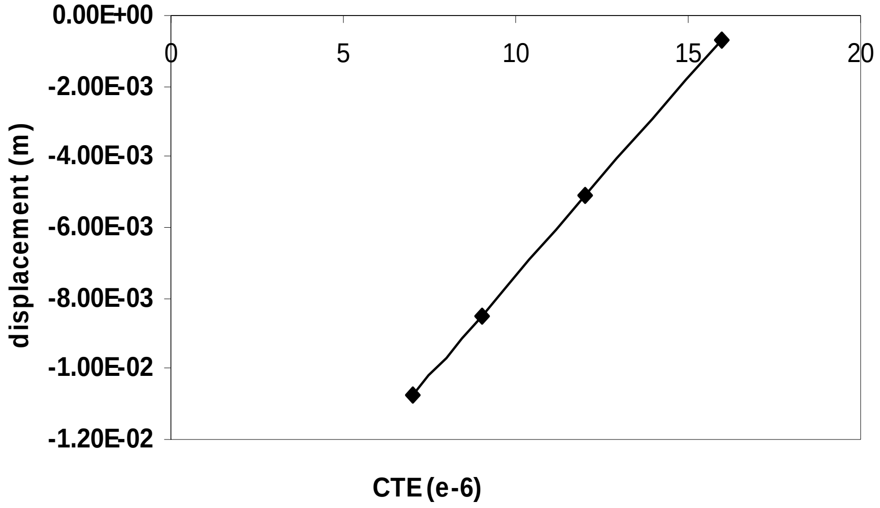

Figure 4: FEA warpage result on different CTE.

By using Minitab® software, a matrix table was generated which consists of combinations of six selection factor and two different levels of CTE for each factor. From the statistical analysis, this type of factorial design will provides a result that which factor has a significant effect on the warping condition. Usually, Minitab® was used to solve and generate the statistical result to optimised data processing. Centre point was used in the experimental matrix table in order to increase the power the statistical model [12].

Figure 5 shows that only two control factors have a significant effect on the warping condition. The difference in CTE within leadframe and epoxy are the largest main effect for the warping condition, followed by the difference within CTE of EMC and leadframe. By using the 2^k factorial, it was pointed out that levels of both factors stated locate at critical level and influenced to warpage package.

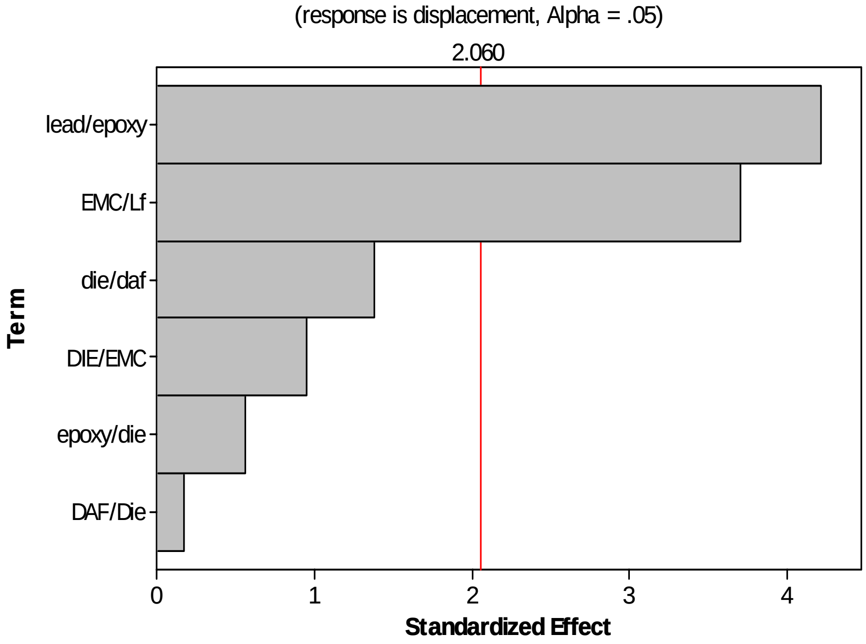

Figure 5: Pareto chart of the effect factor for the warping condition.

Figure 6 shows that a big difference in CTE between epoxy and leadframe that may contribute to maximise warping condition for the QFN stacked die package whereas a smaller difference in CTE within epoxy and leadframe can lead to minimise warping.

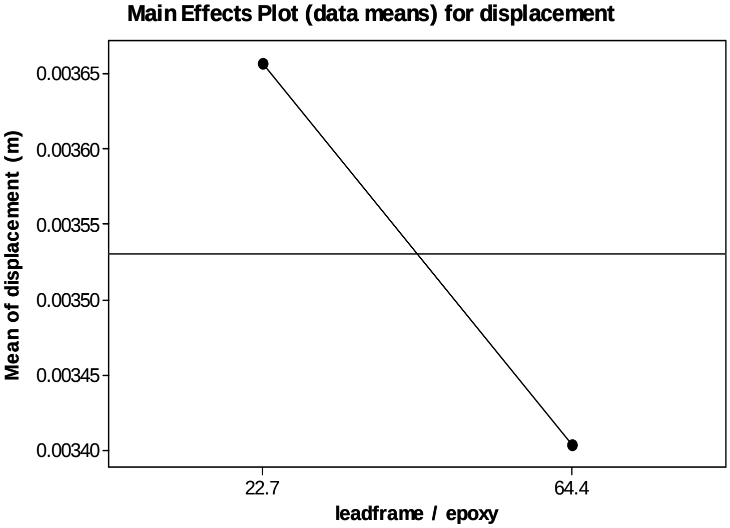

Figure 6: Main effect plot for ΔCTE within leadframe and epoxy layer.

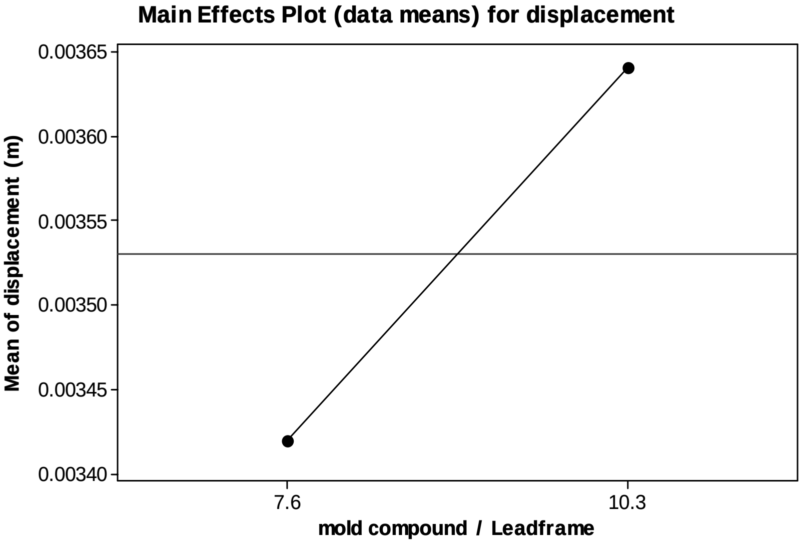

Figure 7: Main effect plot for ΔCTE within mold compound and leadframe.

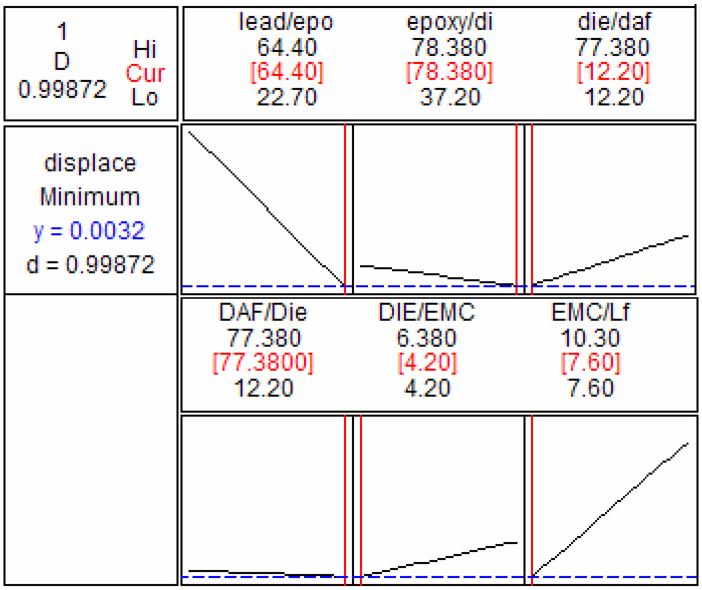

Figure 8: Six combination factor of differential CTE for selection material in stacked die QFN.

Figure 7 shows a different value for the warping condition. It can be concluded that the low ΔCTE of mold compound and leadframe will lead to maximise the warping condition and a high ΔCTE of mold compound and leadframe will lead to minimise the warping condition. From 2^k factorial, these 6 factors were solved to minimise the warpage critical by optimisation stage. Figure 8 shows that the best criteria for 6 factors is to the minimize the value of warpage. By including the average minimum value, it was obtained that a compatible combination is essential to reduce critical condition and a good selection of material properties at manufacturing stages are also needed.

CONCLUSION

From the QFN warpage study, it can be observed that variation of the CTE value between the package layers can reduce warping in package. From the warpage solution technique, 2^k factorial design was choosing due to its capability and determines the optimum value for reduction warpage by using differential of CTE (ΔCTE) on each QFN components. From the study, it was also concluded that only two out of six selected main factor in ΔCTE that contribute to the warpage condition which are the ΔCTE in leadframe and epoxy and mold compound and leadframe. From optimisation values, the compatible combination can reduce the warpage occurrence by predicting a good selection of material properties before QFN manufacturing stages.

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REFERENCES

[1]. I. Ahmad, I. Abdullah, C. C. Ng, M. Z. M. Talib, U. Mokhtar and A. E. Said, (2007); Warpage and Wire Sweep Analysis of QFN Molded Strip Using Experimental and Modeling Methods, *Proceeding 9th Electronic Packaging Technology Conference (EPTC).*

[2]. K. Oota, and K. Shigeno, (1995); Development of Molding Compounds for BGA, *45th Electronic Components and Technology Conference*, 78-85.

[3]. T. Y. Tee, H. S. Ng, and J. L. Diot, (2002); Comprehensive Design Analysis of QFN and Power QFN Packages for Enhanced Board Level Solder Joint Reliability, *Electronic Components and Technology Conference*, 985-991.

[4]. D. G. Yang, K. M. B. Jansen, L. J. Earnst, G. Q. Zhang, W. D. V. Driel, H. J. L. Bressers and J. H. J. Janssen, (2007); Numerical Modeling of Warpage Induced in QFN Array Molding Process, *Microelectronics Reliability,* **47**, 310-318.

[5]. C. C. Ng, (2001); Approximations and Limitations of Finite Element Analysis in Electronic Packaging, *International Conference on Advances in Packaging,* Singapore, 202-209.

[6]. J. G. Hwang, T. J. Huang and J. J. Lee, (2004); The Thermo-Mechanical Stress Issues in a Thermally Enhanced QFP, *Advanced Semiconductor Engineering Inc.*

[7]. A. Mertol, (1992); Stress Analysis and Thermal Characterization of High Pin Count PQFP, *J. Electron. Packaging*, **114**, 211 – 220.

[8]. J. K. Y. Kong, J. K. Kim and M. M. F. Yuen, (2003); Warpage in Plastic Packages: Effects of Process Conditions, Geometry and Materials, *IEEE Transactions-Electron. Packaging Manufacturing* , **26**, 245 – 252.

[9]. F. Shoraka, K. Kinsman, B. Natarajan, and C. Gealer, (1986); Package and Molding Compound Mechanics, *Proceeding 6th Annual International Electronic Packaging Conference*, 294 – 312

[10]. G. Kelly, C. Lyden, W. Lawton and J. Barret, (1996); Importance of Molding Compound Chemical Shrinkage in the Stress and Warpage Analysis of PQFP's, *IEEE Transactions-CPMT*, **19**, 296 – 300.

[11]. G. Kelly, C. Lyden, W. Lawton, J. Barrett, A. Saboui, J. Exposito, and F. Lamourelle, (1994); Accurate Prediction of PQFP Warpage, *Proceeding of 44th Electronic Component Technology Conference,* 102 – 106.

[12]. D. C. Montgomery, (2002); 5th Edition Design and Analysis of Experiments, John Wiley & Sons, Inc., 24