

Development of Epoxy Molding Compound for QFN Package

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Abstract:

The market for QFN package is expanding all over the world in recent years. However, compared to normal QFP package, QFN needs to pay more attention to package warpage due to its asymmetric design. It becomes a challenge for epoxy molding compound supplier to design suitable material to satisfy both warpage and reliability. In this study, finite element simulation analysis of package warpage was conducted to calculate the warpage based on EMC properties and package parameters. Influence of EMC properties on panel warpage was discussed. The effect of epoxy resin and catalyst was evaluated. Effect of stress modifier was also tested in this study. The adhesion to lead frame finishing was measured to understand the effect on epoxy resin, catalyst and stress modifier on interfacial adhesion strength. Materials were molded on internal QFN test vehicle and subject to Standard Jedec Level testing. It was found with certain raw material configuration, Jedec MSL 1 with lead free soldering condition can be achieved together with flat warpage.

Key words: EMC, Delamination, Warpage, QFN

Introduction

Compared to traditional QFP (Quad Flat Package) and SOP (Small Outline Packages) packages, QFN (Quad Flat No-lead) is growing very fast due to its higher density, smaller package size and higher productivity. However, the asymmetric design of QFN requires epoxy molding compound (EMC) must satisfy package warpage. In another word, most good EMC for QFP and SOP can't be used for QFN encapsulation due to the high package warpage after molding and post mold cure (PMC). It needs special designed EMC to suit QFN application.

In addition, with the lead free was applied into real life, more challenge was given to EMC supplier to satisfy the 260 °C reflow peak temperature. Lower stress, lower moisture absorption and higher adhesion to various surface

become more and more important for advanced leaded packages.

In this paper, finite element analysis (FEA) was conducted firstly to understand the relation between EMC properties and package warpage according to our internal QFN test vehicle design. Molding compound's raw materials and ratio was studied to improve the molding compound's adhesion, stress and other properties. Jedec MS13 pre-condition test was conducted to determine the performance of different formulation. Finally optimized formulation was recommended for QFN application.

Finite element analysis (FEA)

A commercial epoxy molding compound, KL-G900HP from Henkel Huawei Electronics was chosen as standard EMC. Internal 7x7 QFN package was used to calculate the panel warpage.

The basic parameter was listed in Table 1. Software was used to conduct the calculation. Warpage 0 was assumed happen at 175C (molding temperature).

Table 1 Basic parameters for FEA simulation

		Unit	Value
EMC	Average CTE from 175 to 25	Ppm	7
	Average CTE from 175 to 260	Ppm	27
	E@25°C	GPa	22
	E@260°C	GPa	0.45
Package	Panel Size	Mm	
	Package size	Mm	7x7
	Die Size	Mm	3.81x3.81
	Die attach	Mm	QMI519
	PAD Size	Mm	

In this paper, the plus warpage was defined as the panel warp to compound side. It also can be called as “Smiling face”. Opposite to this, the minus warpage, or “crying face”, was defined as the panel to lead frame side.

It can be found from Fig 1 that the compound properties used in this calculation give “crying face” warpage after molding at room temperature. But the absolute number is not big means the panel is still consider flat. When increase temperature to 260C, the warpage pattern changes to “smiling face”. This was due to the expansion of EMC

CTE and modulus sweeping was done to

understand its effect on warpage. With increasing and decreasing 20% of CTE and modulus, different warpage value was got from the simulation result. The result was listed in Fig 1 as well. It can be see that with reducing of CTE, panel is intend to warp to leadframe side. However, with increasing of modulus, panel is indent to flat. However, the effect of increasing modulus is not as high as increasing of CTE to flat the panel in the test vehicle used in this study.

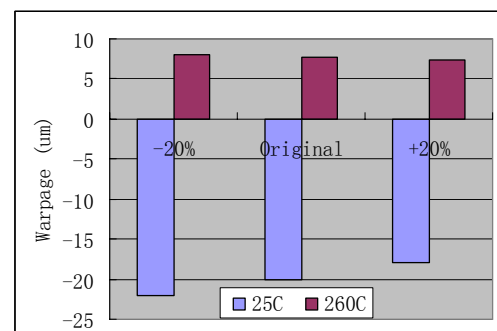


Fig 1a Influence of modulus on panel warpage

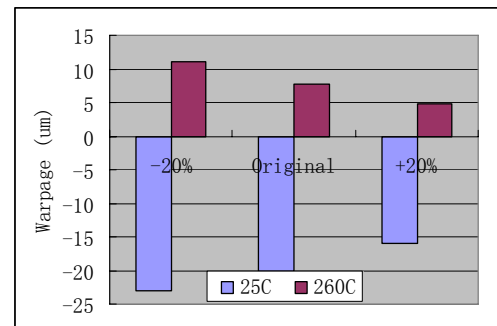


Fig 1b Influence of CTE on panel warpage

Experiment

Tabel 2 Formulation detail

Sample#	1	2	3	4	5	6	7
Filler content, %	89	89	89	89	89	89	89
Resin	A	B	C	D	E	A	A
Hardener	Std	Std	Std	Std	Std	Std	Std
Catalyst	A	A	A	A	A	B	A
Stress modifier	A	A	A	A	A	A	A+B
Coupling agent	Std	Std	Std	Std	Std	Std	Std
Release agent	Wax mix	Wax mix	Wax mix	Wax mix	Wax mix	Wax mix	Wax mix
Pigment	Std	Std	Std	Std	Std	Std	Std

Materials: All raw materials are directly used from Henkel Huawei standard BOM. The formulation detail were listed in Tabel 2.

Sample preparation: All ingredients were mixed together by higher speed mixture to get good blending. Powder was kneaded under 100°C condition by a twin screw extruder to further mix the ram material together. Then the material was cooled down to room temperature rapidly after kneading and grinded into fine powder again. Different specimens were molded by transfer molding according to different requirement for properties testing.

Testing: Molding compound's spiral flow was tested according to ASTM D2123-98 directly using powder sample, under 175°C and 120sec cure time. Hot plate cure gel time was tested according to company internal standard at 175°C as well. To measure the glass transition temperature and coefficient of thermal expansion (CTE), pellet sample with 5mm diameter and 5mm high was molded by transfer molding. The pellet was post cured under 175°C for 6hrs, then measure by TA Q400 TMA with heating rate 10C/min in air atmosphere. TA Q800 DMA was used to measure the storage modulus from room temperature to 260°C, with a heating rate of 3C.min, using 3-point bending method. sample size 13mm x 3 mm x 50mm. Fig 2 shows a

typical TMA (a) and DMA (b) curve.

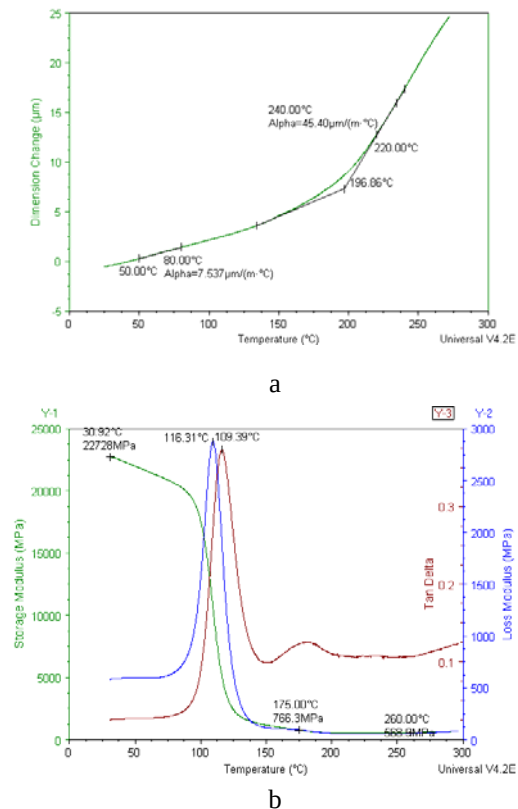


Fig 2 Typical TMA (a) and DMA (b) curve

Adhesion force to lead frame finishing was tested by a tab pull method described in Fig 3. All tab pull sample was undergone Jedec MSL3 (60% relative humidity and 60°C, 40hrs) followed by 3 time reflow with 260°C peak

temperature before testing.

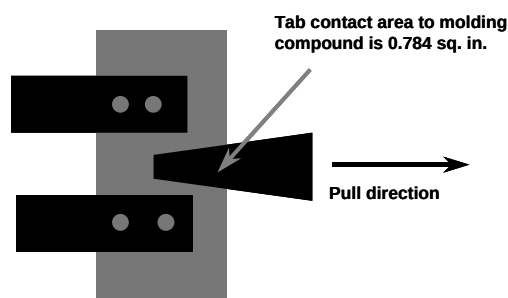


Fig 3 Design of Tab Pull

Warpage measurement: molded device was post cured 4 hrs under 175C. After cooling to room temperature, Shadow Moiré was used to measure the panel warpage. Fig 4 shows a typical shadow moiré pattern.

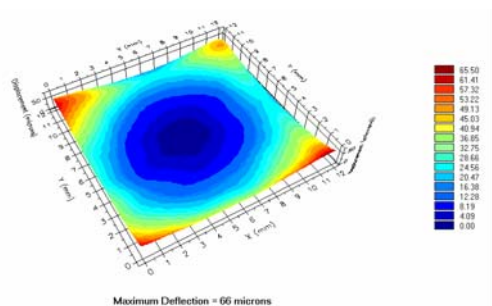


Fig 4 Example of Shadow moiré result

Precondition Test: Henkel Internal QFN test vehicle was selected to conduct precondition test of different EMC sample. The detail parameter of this test vehicle was listed in Table 1 already. After molding and 4 hrs post mold cure at 175C, the molded device was sawed into individual packages before it was baked under 125C for 24hrs. Then the units were subjected to Jedec MSLevel 2 and MSL1 condition, followed by 3 time reflow with 260C peak temperature to finish the precondition. The units before and after precondition were scanned to check the internal delamination.

Results and Discussion

Influence of Epoxy Resin:

There are totally 5 different kinds of epoxy resin were studied in this paper (sample 1-5). Because epoxy resin's structure can determine most of EMC's properties, significant difference between the sample1-5 was observed. The basic physical properties of sample with different epoxy resin were listed in Table 3

Table 3 Properties of sample with different epoxy resin

Sample#		1	2	3	4	5
Epoxy Resin		A	B	C	D	E
Tg	°C	112	102	97	106	98
CTE1	Ppm	8.5	8	8.2	7.1	7.6
CTE2	Ppm	38	32	34	27	30
Modulus @25°C	Gpa	25.6	26.1	27.2	22.9	25.8
Modulus @260°C	Gpa	0.78	0.65	0.65	0.44	0.7
Moisture Abs PCT 24hrs	%	0.39	0.37	0.34	0.32	0.36

Different Tg was found with different epoxy resin chemistry. Resin A have the highest Tg and Resin C shows the lowest. However, all 5 sample's Tg does not consider high due to the low crosslinking density of the resin selected compare to traditional EOCN or mutli-functional epoxy resin. Usually with the lower crosslinking density, lower moisture absorption and high adhesion can be achieved.

EMC's CTE (coefficient of thermal expansion) was determined by material's filler content due to the super lower CTE if silica filler compare to organic resin. However, it doesn't mean that resin will not affect the CTE value. With the same filler loading, different CTE can be achieved by verifying resin chemistry structure. Among the 5 resin evaluated in this paper, resin D and E give the lower CTE both below and above Tg compare to other resins. According to our FEA result, the lower CTE will finally benefit warpage of the QFN panel

Same trend was found on modulus. Even with the same filler loading, the modulus of the 5 samples are also different. Lowest modulus was found with epoxy resin D. In addition, lowest moisture absorption rate was also got from the epoxy resin D.

Panel warpage of sample1 to sample 5 was shown in Fig 5.

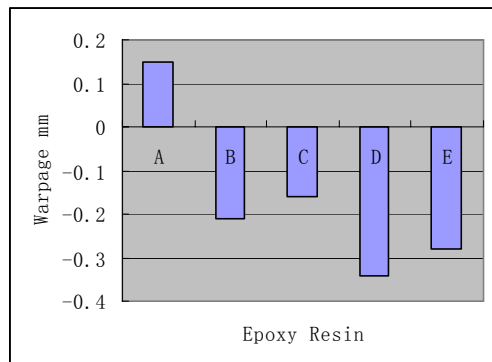


Fig. 5 Influence of epoxy resin on panel warpage

Crying face warpage was observed except sample1. It is due to the highest CTE value of sample 1 compare to other samples. With lower CTE value, the warpage become more crying. However, the modulus doesn't influence warpage much compare to CTE.

The adhesion to varies LF finishing of different epoxy resin was compared in Fig 6. Very significant effect of epoxy resin on adhesion was founded.

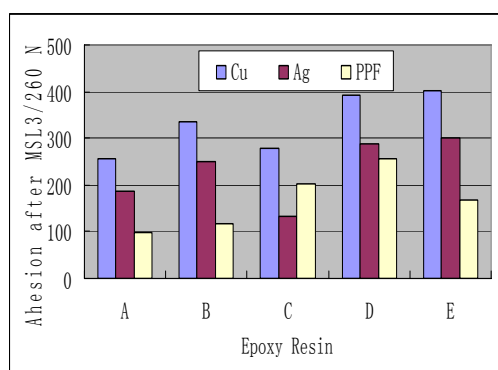


Fig 6 Influence of epoxy resin on adhesion

It can be seen that epoxy resin A gives the poorest adhesion to all the 3 type LF finishing among all the epoxy resin tested, and resin D

gives the highest adhesion. However from Fig 7 It is also interested to see the difference between resin B and C. Resin C can provide good adhesion retention to Ni/Pd/Au surface compare to Resin B. However Resin B shows much higher adhesion retention to Ag plating. Base on the result, It was suggested that people need to pay attention the compatibility between epoxy resin chemistry and lead frame plating during epoxy resin selection.

EMC sample were molded on internal 7x7 QFN test vehicle to check the reliability capability of different epoxy resins. Two kind of lead frame finishing were evaluated in this study. Delamination after standard Jedec level preconditioning was summarized in Table 4.

Pad delamination was found with resin A and B on PPF plating after MSL2. With increasing the condition to MSL1, only sample 4 is able to provide 0 delamination. Delamination was occurred on pad (Sample 3) and die attach area (sample 5). The lesser delamination can be attributed to the higher adhesion to Ni/Pd/Au surface after MSL3 and reflow. The highest adhesion compound, sample 4 with epoxy resin D, can clearly pass MSL1/260 on this test vehicle without any delamination.

Different behavior was observed on Ag plated frame. Only sample 4 and 5 (with resin D and resin E, respectively) is able to pass MSL2 with reflow without any delamination. However, when the sample went through MSL1 and reflow, all 5 samples have delamination on pad. Sample 5 with epoxy resin E have the lesser delamination compare to others (<10%).

The delamination behavior of the samples with different epoxy resin can be related to the different adhesion performance to the lead frame finishing. The highest adhesion to Ni/Pd/Au was got from epoxy resin D, which also is the only sample being able to pass MSL1 among all the 5 samples. For Ag plated lead frame, the least delamination was found from sample5, which also has the highest adhesion to Ag finishing.

Effect of catalyst

Novel latent catalyst was evaluated in this study to check the effect of different catalyst on EMC properties as well as the reliability. Sample 6 was made from sample 1 by changing the catalyst with catalyst B. Longer gel time and spiral flow was achieved with catalyst B. In the mean time, the floor life of EMC was improved too. The detail data was listed in Table 4.

Table 4 Comparison of EMC sample with different catalyst

Sample#		1	6
Catalyst		A	B
Gel Time	Sec	33	35
Spiral Flow	Inch	36	42
Tg	°C	112	99
CTE1	ppm	8.5	8.6
CTE2	ppm	38	33
Modulus @25 °C	Gpa	25.6	24.2
Modulus @260°C	Gpa	0.78	0.81
Moisture Abs / PCT 24hrs	%	0.39	0.34
Adhesion after MSL3/260	Cu	255	392
	Ag	187	278
	PPF	98	152

It was also found that compare to our standard catalyst, the latent catalyst also can provide the benefit of lower moisture absorption and higher adhesion strength.

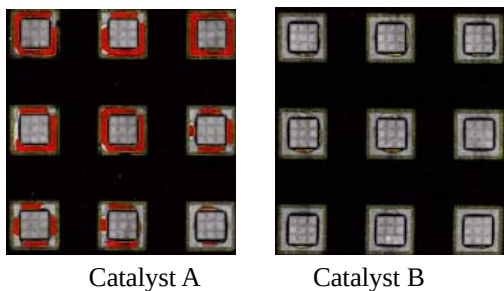


Fig 7 Comparison of delamination on Ag frame of two samples with different catalyst

Above fig showed the effect of catalyst B on reliability. Significant improvement was observed by changing the catalyst. It is suggested with the more latent catalyst B, higher Jedec level may be achieved.

Effect of stress modifier:

Package internal stress is one of the major reason causes failure. To reduce package stress, add stress modifier into EMC is one of the common methods. However, the effect of different stress modifier is different as well. In this study, a new type stress modifier B was evaluated compare to our standard stress modifier. The properties comparison was listed in Table 5.

Table 5 Comparison of EMC sample with different stress modifier

Sample#		1	7
Stress modifier		A	B
Tg	°C	112	109
CTE1	ppm	8.5	5.7
CTE2	ppm	38	33
Modulus @25 °C	Gpa	25.6	25
Modulus @260°C	Gpa	0.78	0.62
Moisture Abs / PCT 24hrs	%	0.39	0.38
Adhesion after MSL3/260	Cu	255	296
	Ag	187	256
	PPF	98	102
Warp at room temp	mm	0.15	-0.48

Tg, moisture absorption and room temperature modulus were not affected by the stress modifier type. However, lower CTE and high temperature modulus was achieved with new type of stress modifier, which results more crying panel warpage base on our 7x7 test vehicle. Higher adhesion to Ag was also observed with stress

modifier B. This was also caused delamination disappear on Ag frame after MSL2 and reflow.

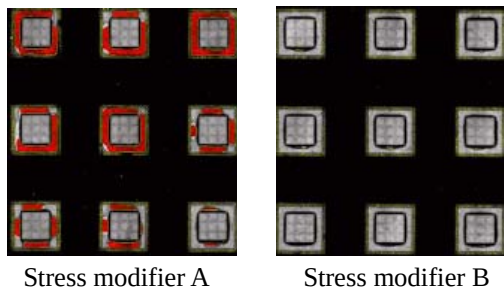


Fig 8 Comparison of delamination on Ag frame of two samples with different stress modifier

Conclusion: Different epoxy resin, catalyst and stress modifier were tested in this paper. It was found that epoxy resin had significant effect on most of EMC properties, hence influenced the QFN warpage, adhesion and delamination of packages. Latent catalyst shows better performance than normal catalyst. New stress modifier also can provide better adhesion with lesser delamination after precondition.

Reference:

[1] X.Y. Du, G.C. Xie, W. Tan, "Stress Reduction

of Epoxy Molding Compound and its effect on Delamination", 2007 IEEE, 2007. pp.26-28

[2] T.Y. Lin, C.M. Fang, Y.F. Yao, and K.H. Chua, "Development of the Green Plastic Encapsulation for High Density Wirebonded Leaded Packages," *Microelectronics Reliability* 43 (2003) pp. 811-817

[3] V. Kenner, B. Harper and V. Itkin, "Stress Relaxation in Molding Compounds," *Journal of Electronic Materials*, Vol.26, No.7 (1997), pp.821-826

[4] G. Kelly, G., "The Simulation of Thermomechanically Induced Stress in Plastic Encapsulated IC Packages," Kluwer Academic Publishers. (Boston, 1999)

[5] K. Kowata, K. Iko, H. Tabata, "Low stress resin encapsulations for semiconductor Devices", *IEEE Transactions on Components, Hybrids, and manufacturing technology*, Vol.8, No.4, 1985, pp.486-489

[6] P.Liu, L.Cheng and Y.-W.Zhang, "Interface delamination in plastic IC packages induced by thermal loading and vapor pressure - A Micromechanics Model, IEEE 2003