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Development of Epoxy Mold Compound for Lead Free Soldering of Fine Pitch and Stacked Die BGA Packages

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Abstract
A new, green epoxy mold compound has been developed to encapsulate fine pitch PBGA and 3D-stacked die CSP packages. When evaluated on these packages, the compound provided very good wire sweep performance. It also has the ability for lead free solder re-flow at 260oC after JEDEC Level 3 pre-conditioning. In order to minimize wire sweep, a new resin-hardener-catalyst system was developed. The optimized combination of resin system provides extremely low viscosity and long gel time. X-ray results showed that wire sweep less than 2% can be consistently achieved on PBGA and stacked die packages using 0.8mil wire. The low moisture absorption of the new epoxy mold compound minimized delamination between mold compound and die at lead free soldering parameters.

Introduction
Developments taking place in electronic industries have led to fast changes in chip design and packaging technology. In BGAs in order to accommodate more I/Os, bond pad pitch is continuously reduced. Fine pitch BGAs using 0.8 mil and below wire diameters are being developed. Also integration of multiple ICs within a single package in stacked die format is being practiced to improve the package performance and functionality. Stacked die format improves electrical performance and reduces overall package I/O requirements. In recent times packages have been developed with up to five stacks while keeping the package thickness as low as possible.

In fine pitch as well as stacked die packages, by virtue of their design, the wire length and loop height have increased. At the same time due to small bond pitch, wire diameter is being reduced progressively. Such a design makes the encapsulation process more difficult. Wire sweep has become a major issue in these packages and it has driven the demand for mold compounds with very low viscosity, smaller filler size and snap cure behavior so that the wire sweep can be kept under control.

Environmental considerations have made industries to move away from lead based soldering to lead free soldering. Lead free soldering needs higher re-flow temperature of 260°C against 215°C for lead based soldering. At higher reflow temperatures, moisture present in the mold compound will generate more vapor pressure and so package pop- corn failures. In order to minimize this, compounds that absorb minimum moisture are needed.

A new epoxy mold compound, NXG-1FP has been developed with low viscosity, long gel time and smaller filler size. The compound could be used in fine pitch PBGA as well as stacked die BGAs and meet their stringent wire sweep requirements. With its low moisture absorption, it meets the lead-free soldering requirements.

Desired Mold Compound Properties
A mold compound with the following characteristics is required to meet the challenges posed by the new fine pitch packages:

- Low U-curve viscosity and wider U-curve window-for better wire sweep
- Snap cure behavior-for better wire sweep and shorter molding cycle
- Low shrinkage-for low warpage
- Low moisture absorption-for better reflow performance
- Green compound-to address environmental issues
- Good adhesion-for better reliability
- Low modulus-for low stress index and better reliability.

Formulation Chemistry
An epoxy mold compound mainly consists of an epoxy resin, hardener, catalyst and silica fillers. For developing the mold compound, low viscosity epoxy resin and hardener were chosen. The selected resin was biphenyl type and the hardener was phenolic type. A new latent catalyst was used to cure the resin system. The catalyst gives wider U-curve window and longer gel time so that better wire sweep will be achieved. By virtue of their low viscosity, the resin system allows high filler loading. Spherical fillers with minimum surface area were chosen to minimize viscosity increase. The filler system was

optimized for better packing density so that even at high filler loading viscosity remains low. Mean filler diameter has been reduced compared to our conventional formulations. To address environmental issues, inorganic flame-retardants, metal hydroxides and hydrates were used. They are free from Br, Sb and P. Upon degradation, they liberate only moisture and no toxic gases are generated. Other additives like toughening agents and wax system have been optimized as per the requirement. Table 1 provides an overall view of the formulation chemistry.

Table 1 - Formulation Chemistry of the Formulation

Resin	Biphenyl Hybrid
Hardener	Phenolic
Resin/Hardener ratio	Standard
Catalyst	Latent
Filler, %	86-88
Filler Type	Spherical
D (v, 0.1)	4.3
D (v, 0.5)	21.4
D (v, 0.9)	51.2
Toughening Agents	Standard type
Flame Retardant	Metal Hydroxide and Hydrate

Compound Manufacturing Process

The mold compound was manufactured as per our standard process. It involves physical mixing of raw materials using high-speed mixer, ball milling and then melt mixing by twin screw compounding extruder. The extrudate after grinding into granules is blended using post blender before storing in cold room. This process sequence ensures homogeneous mixing of all the ingredients including the catalyst and the final properties of mold compound are confirmed to be uniform.

Characteristics of Mold Compound

Spiral Flow

Flowability of an epoxy mold compound is measured using spiral flow test. In spiral flow test, ability of a mold compound to flow under a specified load and temperature is measured. Spiral flow measured in terms of inch (or cm) is the measure of viscosity and gel time of the mold compound. A compound with lower viscosity and longer gel time do have longer spiral flow. In general, a compound with longer spiral flow would have lower wire sweep than a compound with shorter spiral flow.

NXG-1FP, at about 88% filler loading, has 73” spiral flow and 18sec-gel time (Table 2). The long spiral flow and optimum gel time have been achieved in this formulation through low viscosity resin/hardener, spherical fillers and latent catalyst. The viscosity of the resin and hardener are one of the lowest for the commercially available materials. Spherical fillers with their lower surface area exhibit minimum resistance to flow. With high filler packing density more resin has been made available for easy flow. In addition to that latent catalyst with its slow curing nature enhances the flow. The compound was molded in to bars at 170, 175 and 180°C for in-mold cure time from 40 sec to 100sec. Hot hardness was measured on the molded bars at each condition and the obtained results are shown in Figure 1. The results indicate that the compound develops good hardness even at 60sec in-mold cure time. Even though the compound has longer gel time of about 18 seconds, good hardness has been obtained at lower in-mold cure time. The results indicate that the compound is suitable for shorter molding cycles.

Table 2 - Flow Properties of the Mold Compound

Property	Units	Value
SF, 175C/1000psi	Inch	73
Gel Time, 175C/1000psi	sec	18
Hot Hardness, 175C/75sec	Shore-D	75
U-Curve Viscosity, 175C/215psi	Poise	65

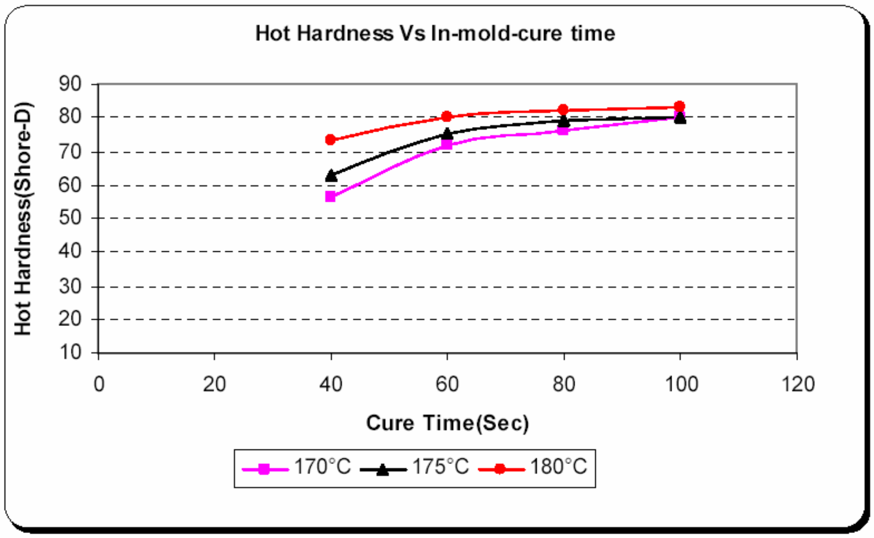


Figure 1 - Hot Hardness Vs In-Mold Cure Time U-Curve Viscosity

U-Curve Viscosity

U-Curve viscosity is measured using Capillary Rheometer. It determines the lowest possible viscosity that a mold compound can reach during molding. Also the length of time the compound will remain at a specified viscosity, in other words gel time, could be estimated. These two factors are directly related to the wire sweep. A compound with lowest U-curve viscosity and longer U-curve window will have lower wire sweep.

U-curve viscosity data of the mold compound is given in Table 2. The compound has viscosity of 65 poise under our internal test method. The viscosity value is very low compared to any standard mold compound. It has been achieved through using very low viscosity resin/hardener system. The catalyst, due to its latent nature does not react early so that viscosity remains low for longer time. The spherical filler combination with its better packing density and minimum surface area is responsible for low viscosity even at high filler loading.

In order to understand the effect of molding temperature on the viscosity, experiments were run at five different temperatures, from 165°C to 185°C at 5°C interval. The results are shown in Figure 2. Viscosity of the mold compound reduces with increasing die temperature. However, the gel time and the U-curve window get narrowed down with increasing molding temperature. At standard molding temperature of 175°C, the compound remains at viscosity below 200 poise (reference value) for about 7 seconds. It is one of the longest duration for an epoxy mold compound.

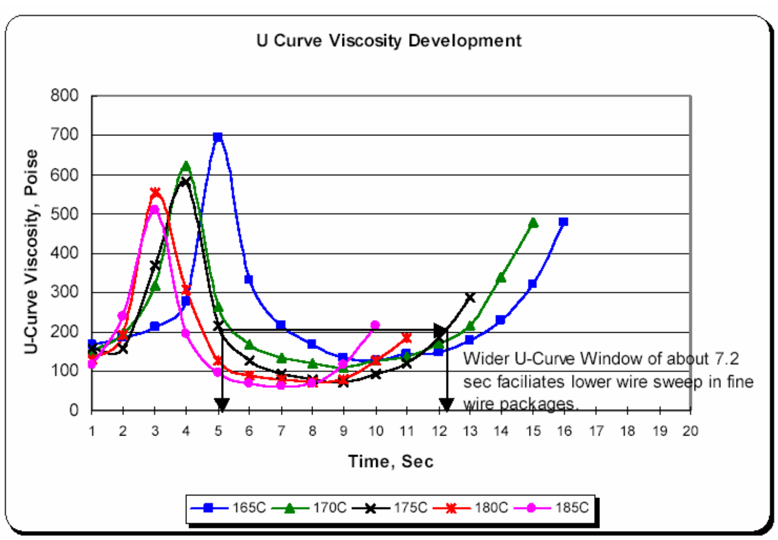


Figure 2 - U-Curve Viscosity at Different Temperatures

Wire Sweep

The compound was molded onto 35x35 PBGA packages with three different wire diameters, viz., 0.8, 0.9 and 1.0 mil dia and wire length 180-200 mil. Then the molded units were subjected to wire sweep analysis. The average wire sweep along with maximum values are shown in Table 3.The compound on 1.0 mil dia wire gave 1.07% sweep and it increased with reducing wire diameter. The maximum wire sweep obtained for 1mil dia was only 1.9% and whereas for 0.8mil wire it was 3.5%.

Wire sweep of a package is determined by the wire configuration and the mold compound properties. Factors like wire diameter, length and loop height considerably affect the wire sweep. As observed in the experiment, reducing wire diameter increases the sweep. Stiffness of a wire is reduced when the wire diameter is reduced. During transfer molding, a less stiffer wire is bound to get easily swayed away by the mold compound flow. Increasing wire length as well as loop height also make the wire less rigid and sweep is increased. With the continuous reduction in bond pitch and increase in foot print area, wire diameter is getting reduced day by day along with increasing wire length and loop height.

In order to keep sweep minimum, viscosity of the mold compound has to be engineered to be low. In addition to that a longer gel time is necessary to ensure that the compound does not undergo fast cure during molding leading to higher viscosity. Also maximum filler size has to be curtailed so that they flow through smaller bond pitch without any issues. The newly developed compound, as described above, do have low viscosity, longer gel time and reduced filler size to meet the stringent wire sweep requirements. The results obtained on three different wire diameters confirm that the compound is capable of meeting the requirements of advanced packages.

The mold compound was also evaluated on 2+1 and 3+1 stacked die CSPs of 45x45 size. In both the configurations at 0.8 mil wire dia, the compound consistently produced wire sweep below 1% (Table 4). Compared to fine pitch PBGA packages, stacked die packages pose more challenges to mold compounds in terms of flow requirements. The results obtained on stacked die CSPs indicate that with its lower viscosity, the compound is capable of producing very low wire sweep (figure 3).

Table 3 - Wire Sweep Data of the Mold Compound on Different Wire Diameters

Wire Diameter	Wire Length	Wire Sweep, %	
		Average	Maximum
0.8 mil	180-200 mil	1.92	3.5
0.9 mil	180-200 mil	1.43	2.5
1.0 mil	180-200 mil	1.07	1.9

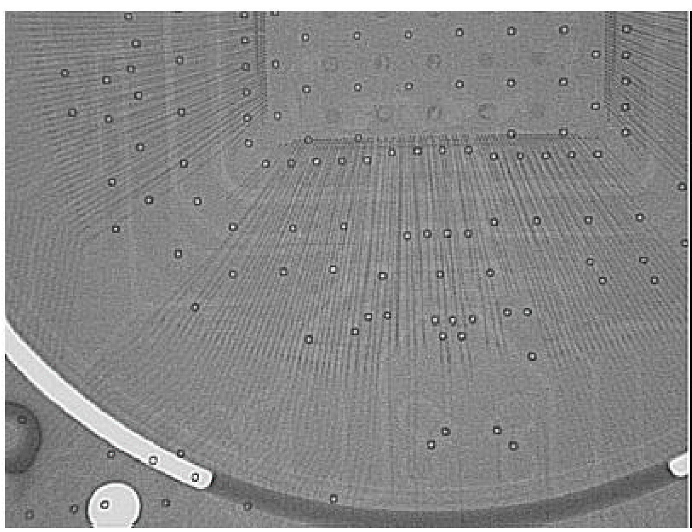


Figure 3 - X-Ray Wire Sweep Photographs of 0.8 mil Dia Wire Bonded BGA Units

Table 4 - Wire Sweep Data of 2+1 and 3+1 Stacked Die BGA Packages

Package	Wire die/Length/Height	Wire Sweep
2+1 Stacked die CSP, 45.45	0.8/100/15	<1%
3+1 Stacked die CSP, 45x45	0.8/150/25	<1%

Solder Reflow Performance Adhesion strength and the amount of moisture absorbed determine the solder reflow performance of a mold compound. Adhesion strength to different substrates was measured using button shear test and the obtained results are shown in Table 5. The data indicates that compound has good adhesion to solder mask, gold and other substrates. In addition to that the compound absorbs very low moisture compared to conventional compounds. When boiled in water for 24hr it absorbs only 0.23%. Combination of good adhesion strength and low moisture absorption provides good reliability performance to this compound.

The molded units were subjected to JEDEC L3 moisture soaking and reflow at 260°C for three cycles. C-SAM and thru-scan carried out on these units are shown in Figure 4-6. Due to very good adhesion strength and low moisture absorption of the mold compound, there was no delamination in the package. Adhesion to the solder mask as well as passivation layer was in tact and there was no sign of delamination. The results confirm that the compound is suitable for lead free soldering requirements. Apart from these, the compound has performed well in temperature cycling and PCT tests. The compound has also been found to give void free moldings and good coplanarity performance.

Table 5 - Adhesion Properties of the Mold Compound

	Units	**Value**
Button Shear Strength		
BGA Substrate (Solder mask)	Lb.f	350
Cu	Lb.f	210
Au	Lb.f	125
Ag	Lb.f	35
Ni/Pd	Lb.f	55
Cr	Lb.f	80

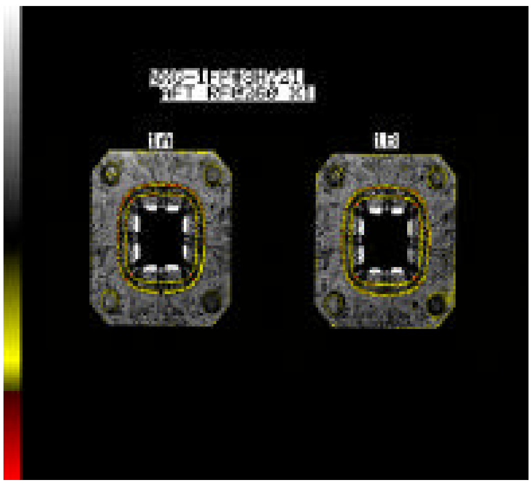


Figure 4 - C-SAM before L3 Conditioning (after, 260C/1Cycle Reflow)

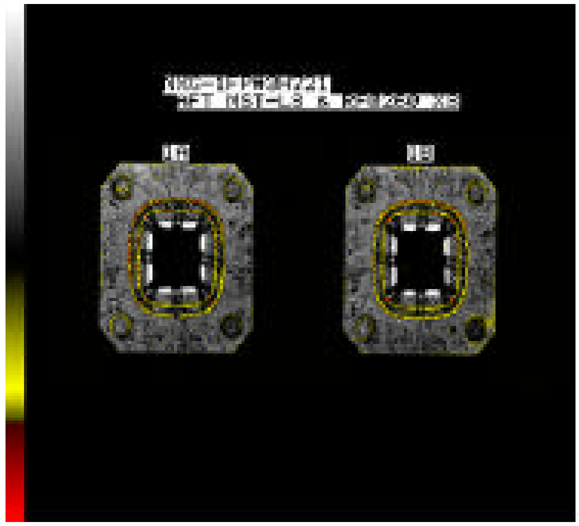
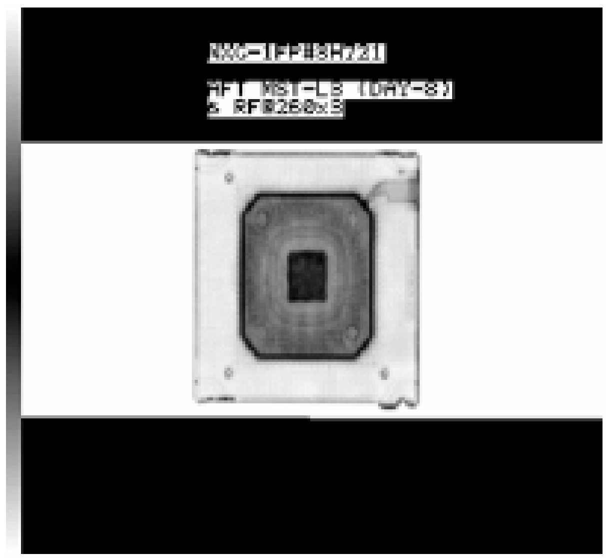


Figure 5 - C-SAM after L3 Conditioning and 260C/3Cycles Reflow



6 - Thru-Scan Picture after Moisture Soaking and 260C/3 Cycles Reflow

Conclusion

The new green epoxy mold compound formulated meets the requirements of new packages that are emerging in the market. The compound has very low viscosity and longer gel time, which provided very good wire sweep on fine pitch BGA and stacked die CSPs. With its low moisture absorption of 0.23%, the compound passed L3/260C reflow condition. The compound has also passed PCT and T/C on different package configurations.