Compression Molding for Thin PoP Top Packages

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Abstract:

The package on package (PoP) has become the preferred method for vertical stacking of logic processors and memory in mobile applications. The industry is constantly working toward reducing the total stack height, and current road maps point toward a total stack Z-height of 1mm. One approach to reduce the package height is to reduce the mold cap thickness as well as reduce the mold cap clearance (the distance between the top silicon die to the mold top). In this study, we used the compression molding for manufacturing top PoP packages with 200µm, 250µm, 300µm, and 350µm mold cap and with sub-100µm mold cap clearance. As part of the mold material selection, two different form factors, granular and powder form, of the mold compound were used for the compression mold process. The key objective for this study is to investigate compression mold process and to study its effect on the package integrity.

The major challenge for PoP stack up is the package warpage at reflow temperatures. All the PoP packages must meet certain critical warpage criterion to meet board mount yield requirements. Warpage of the packages was measured by the shadow moiré method, and the warpage results for the packages molded by the transfer mold were compared against that of the compression molded packages. Results indicate that there is considerable difference in warpage behavior betwee n the pellet and powder form of the same mold compound. However, the granular form of the same mold compound resulted in similar warpage behavior of the pellet form mold compound. Further analysis was done to compare the filler distribution in the mold for transfer versus the compression mold process. Results indicate much uniform filler distribution in compression mold furthering evidence that the warpage for the unit level package will be uniform across the strip. Warpage results were analyzed using finite element methods, and the results are extrapolated to different package XY dimensions. The data obtained from these experiments show that the compression mold method can be potentially implemented for thin PoP top packages in the future.

Keywords: package on package, compression mold, warpage, granular

Introduction

The general PoP configuration is described in Figure 1. PoP packaging allows for the top package (memory) and the bottom package (processor) to be built separately under their own ideal processes at high yields and then be joined together at the very end of the assembly process. The wider acceptance of the package on package (PoP) in mobile phones indicates that the technology has come a long way in the last decade since it was first introduced (Ref.1). The PoP configuration has come to be the favored technology for small form factors for applications such as smart phones and netbooks.

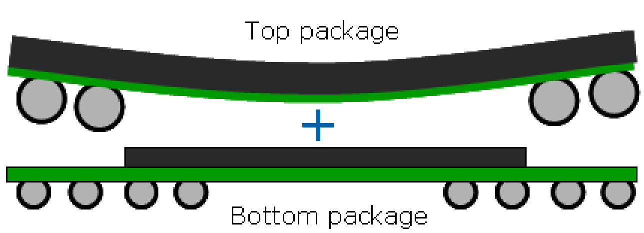


Fig. 1 Generic PoP configuration

Feature rich mobile phones continuously require a higher system density (from a packaging perspective, this means more functional silicon volume), which, in turn, results in reduced PCB board area availability. Another thing to be noted is that in the mobile phone platforms, limitations are also posed on the total Z-height of the components and stack ups. The first generation of PoP stack up consists of a bottom package with a single logic processor either in flip-chip form or center-gate molded and a top memory package with single or multiple memory die, with the typical ball pitch at the interfaces being 0.5mm or 0.65mm.

The next generation of a PoP stack will consist of higher processor density along with the higher memory density. One approach to obtain the increased processor density means stacking die even in the bottom package. The stacked die at the bottom will increase the bottom package thickness, and this will result in the increased total Z-height of the PoP stack up. This will create a challenge to reduce the overall Z-height of the PoP stack up. Several options to address this include reducing the solder interconnect height at the top and bottom package interface and decreasing the Z-height of the top memory package. Reduced solder height at the interface requires a smaller solder ball diameter and a smaller SRO (solder resist open). This reduced solder height must also clear the bottom package mold. To enable this, work is being done on the bottom package to make it accept interconnects through the mold at the interface (Ref.2).

The challenge for the top memory package suppliers is that they must reduce the overall package Z-height. This will require reducing the substrate thickness and reducing the mold cap thickness. If the mold cap thickness is being reduced to maintain the same or increased memory die density, one also has to reduce the die thickness to accommodate the die.

Transfer mold is the *de facto* mold method in the semiconductor industry. But this method has limitations when it comes to accommodating very low mold cap clearance. Some issues that arise include mold voids, bond wire sweep, and the filler segregation. (Ref.3). In recent years, the compression mold is slowly being introduced in semiconductor packaging. For example, the fan-out WLP package uses compression mold for the molding of the wafer. Also, several studies in recent years have been done to evaluate the compression mold as an alternative mold method for semiconductor packaging (Ref.4, 5).

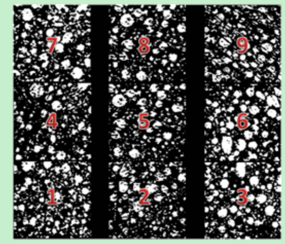
In the present study, we report the compression molding of PoP top memory packages. Several different mold compound materials were evaluated for the compression molding process. Packages with several mold cap thicknesses, including 200µm, 250µm, 300µm, and 350µm, were compression molded. Filler segregation studies were conducted on these packages and compared against the transfer molded packages. A key parameter for accepting the mold compound for PoP packages is the warpage at reflow temperatures. Shadow Moiré method was used for measuring the package warpage at solder reflow temperatures. Also, we compare package warpage characteristics for compression molded packages against the transfer molded packages. Finite element analysis was carried out to extrapolate the results for packages with different XY dimensions.

Mold Material Selection/Advantages of Compression Mold

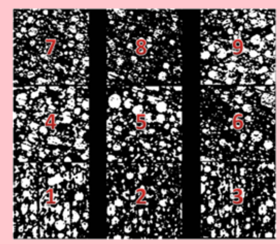
Transfer mold has been a very successful method for encapsulating silicon. It has also been limited by significant processing issues, primarily associated with the need to flow the mold compound long flow distances through narrow features in a relatively short amount of time. Mold compound formulation has made significant advancements to meet the requirements of package configurations. The long flow distance of transfer mold can lead to the following.

- Relatively large velocity of the material is required to fill the mold cavity before the material cures, resulting in the risk of wire sweep.
- Long flow distance within the features of the product, especially between the array of top die and mold cap, leading to voids.
- The combination of the velocity and flow gaps results in areas of higher shear rates, encouraging like-sized particles to segregate and group together, leading to filler non-uniformity in the mold matrix. The subtlety of package warpage is dependent upon a homogenous mix of mold compound in the final cured state, yet there is evidence that the filler particles migrate during the liquid state of the transfer mold process (Ref.3).

Compression Molding			
Location		Image#	Mean
Gate	Left	1	76.97
Gate	Center	2	64.87
Gate	Right	3	82.12
Center	Left	4	61.73
Center	Center	5	66
Center	Right	6	88.76
Vent	Left	7	86
Vent	Center	8	67.7
Vent	Right	9	74.68
		avg	74.3
		stdev	9.8



Transfer Molding			
Location		Image#	Mean
Gate	Left	1	99.13
Gate	Center	2	59.1
Gate	Right	3	73.15
Center	Left	4	99.94
Center	Center	5	87.78
Center	Right	6	62.64
Vent	Left	7	73.35
Vent	Center	8	50.98
Vent	Right	9	101.24
		avg	78.6
		stdev	19.1



Transfer Mold on average had more filler area by	5%
Transfer Mold has more filler variation than comp mold by	51%

Figure 2 General comparison of filler distribution between two process types

Compression molding processes differ from transfer molding processes. The material is delivered into the cavity by the product into the material in the Z-direction, eliminating the long flow distances. Shorter flow distance also means less overall shear and velocity of the material, resulting in less filler migration and less wire sweep (Ref.6).

Experimental Results and Analysis

<u>Comparison of Compression Mold *Vs* Transfer Mold</u>

For top PoP packages that tend to have thin mold caps, it is necessary to choose a mold compound with lower coefficient of thermal expansion CTE1 (below Tg) and CTE2 (above Tg) and lower cure shrinkage. Previously, we have successfully selected mold compounds based on this criterion that resulted in meeting warpage requirements (Ref.7). These packages were molded using the transfer mold method, which uses the mold material in pellet form. In contrast, the compression mold uses either a granular or powder form of the mold material. The granular or powder form of each molding compound material is prepared before the pelletizing process in the conventional molding compound manufacturing processes. To implement the same mold compounds that were successful in transfer mold, we requested our mold material suppliers to provide these mold compounds in either granular or powder form of which the final cured material properties are exactly the same as the pellet form of the corresponding molding compound materials.

Compression mold experiments were conducted with both the granular form and the powder form of the mold compounds. We also made packages with the transfer mold, to compare the warpage results. The package stack up used in the experiment is shown in Table.1

Table.1 Package Stack Up for Transfer Mold Vs Compression Mold Experiments

	Transfer Mold	Compression Mold
Package dimension	14mm X 14mm	14mm X 14mm
Mold cap thickness	0.4mm	0.35mm
Substrate thickness	0.10mm	0.10mm
Die attach1	20µm	20µm
Die1	40µm	40µm
Die attach2	60µm	60µm
Die2	40µm	40µm
Die attach3	60µm	60µm
Die3	40µm	40µm

The mold cap thickness chosen for compression mold is 350µm, leaving a mold cap clearance of 90µm. For transfer mold experiments, to use the same die stack up, we had to use 400µm mold cap because this mold process requires a larger mold cap clearance of 140µm. (The same warpage trend is expected for these packages even though the mold cap thickness differs by 50µm.)

We used the shadow moiré technique to characterize the package warpage as a function of temperature. Quantification of warpage variation is done by checking the warpage contours on the surface of the package in the dead bug (solder lands facing up) position at each temperature during the reflow process and then plotted over the whole temperature range as per JESD22B112. Six units per leg were measured inside the Thermo-Moire Analysis tool where the units were subjected to a simulated reflow profile with a peak temperature of 250°C. The measurements were taken on the surface of the package without actual solder balls. The direction of the warpage (positive or negative) is defined as shown in Figure 3.

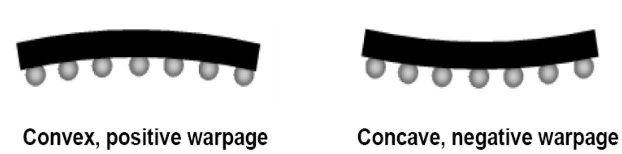


Fig. 3 Definition of warpage sign

Figure 4 compares the warpage results for transfer molded package against the compression molded package with a powder form mold compound.

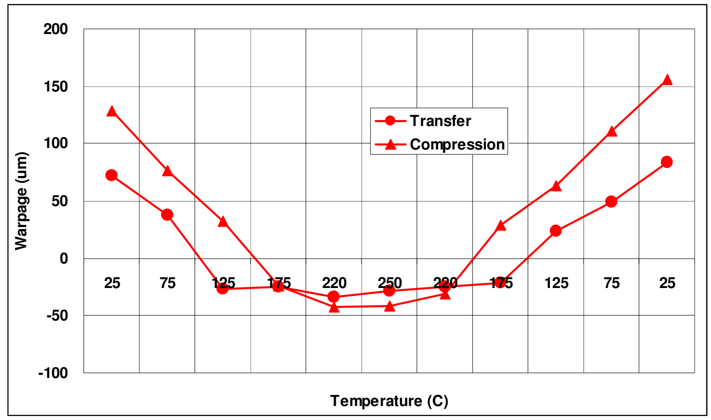


Fig.4 Warpage results: compression mold with powder form vs transfer mold

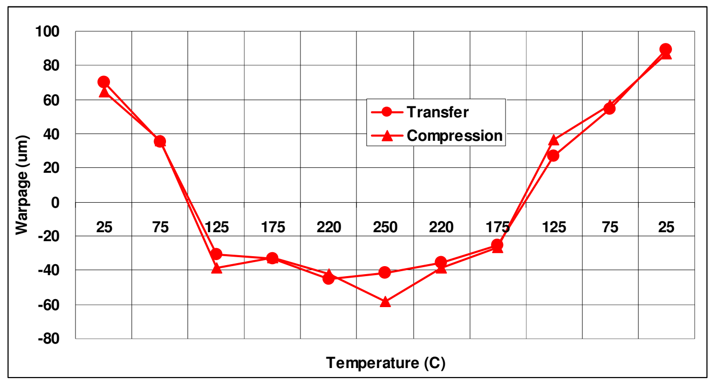


Fig. 5 Warpage results: compression mold with granular form vs transfer mold

This work, Figure 4 and Figure 5, also indicates the different warpage performance between the powder form (a heterogeneous mix of grain sizes) and the granular form (a homogenous mix of grain size). It should be noted that some shearing in the material is beneficial, and the granular form does mix more as it collapses the grains. The granular form also heats more uniformly. The powder form is a mix of grain sizes that can result in binding during dispense and results in less uniform heating. There have also been cases of powder material entraining air in the matrix. As a result, the powder form processing tends to be less consistent in results. However, the magnitude of difference in performance in this case needs additional exploration to determine the rational and cannot be fully explained here.

Warpage Results for Ultra Thin Mold Cap

The aim of this paper is to study the feasibility of ultra thin mold cap packages with compression mold. Transfer molded PoP top packages were limited 350µm mold cap with a 150µm mold cap clearance. As stated before, because of process limitations, reducing the mold cap further in transfer mold will encounter require severe limitations, such as reducing the silicon density or coping with the wire sweep issues.

Here we prepared packages with ultra thin mold caps using the compression mold. The mold cap thickness considered here is 200µm, 250µm, and 300µm. The package details used in this study are shown in Table.2. Based on the results in previous sections, we selected granular form of mold compound in these experiments.

Table.2 Package Stack Up for Thin Mold Cap Compression Mold Experiments

	0.2mm Mold Cap	0.25mm Mold Cap	0.30mm Mold Cap
Package dimension	14mm X 14mm	14mm X 14mm	14mm X 14mm
Mold cap thickness	0.2mm	0.25mm	0.3mm
Substrate thickness	0.10mm	0.10mm	0.10mm
Die attach1	20µm	20µm	20µm
Die1	40µm	40µm	40µm
Die attach2	20µm	60µm	20µm
Die2	40µm	40µm	40µm
Die attach3	-	-	60µm
Die3	-	-	40µm
Mold cap clearance	80µm	90µm	80µm

Figure.6 shows the room temperature co-planarity data for these packages. Both the 0.2mm and 0.25mm mold cap packages fail to meet assembly manufacturing spec limit of 70µm (2.8 mils) max. The package with the 0.3mm mold cap can meet this spec limit. Results show that as the mold cap thickness is reduced, the co planarity increases, indicating that there is lack of sufficient mold compound volume to compensate for the CTE mismatch between the silicon to substrate. As the package cooled from the high temperatures, the higher CTE substrate will tend to shrink more, resulting in a convex (positive) warpage. If there is sufficient volume of the mold compound available, then the mold compound with its CTE1 ~ 10 ppm will match more closely with the substrate CTE than the silicon die, which has CTE of 3 ppm. This would have reduced the room temperature warpage quantity. Because the co-planarity is very critical during the downstream process, such as SMT, it is essential to take further steps to reduce the co planarity. Further studies are planned to study the effect of the low CTE substrate core materials to reduce the room temperature co-planarity.

Figure.7 shows the warpage results for these packages measured using the shadow moiré method at room temperature to the solder reflow temperatures. The warpage behavior at the room temperature follow closely with the co planarity data obtained for these packages. However, at or near the reflow temperatures (220°C through 250°C), the thinner mold cap has higher concave warpage.

Previous studies have shown that the warpage behavior of the top PoP package near reflow temperatures expected to be affected by the thermal shrinkage and the chemical shrinkage of the mold compounds (Ref.7). Thermal shrinkage is the result of CTE2 (CTE value above Tg) and chemical shrinkage

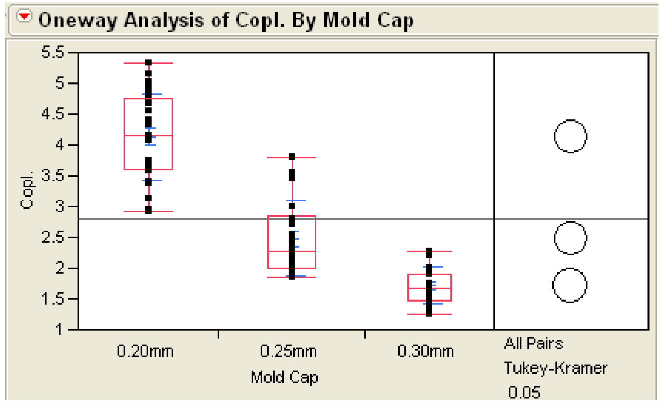


Fig. 6 Room temperature co planarity measurements

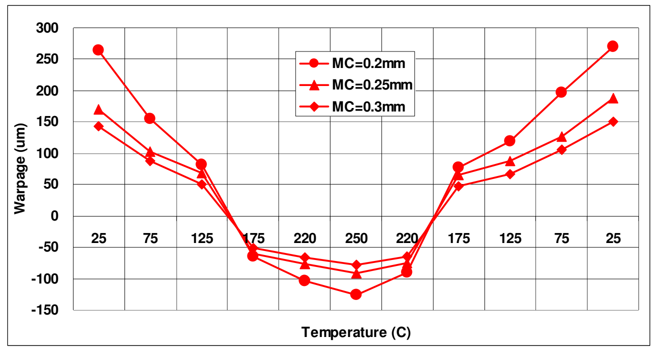


Figure 7 Warpage results for compression molded thin PoP packages

is the result of the cure shrinkage of the mold compound. Also, it is possible to affect the signature (positive or negative) of the package warpage based on these parameters.

For the packages used in these studies, as the mold cap thickness is reduced, the impact of the mold compound to influence the package warpage is also reduced. Hence, we cannot expect the above mentioned warpage behavior in these packages. Table 3 shows the reduced mold compound to substrate volume as the package mold cap reduced from 0.3mm to 0.2mm.

Table.3 Mold to Substrate Volume Ratio for Thin Mold Cap Packages

Mold Cap (mm)	0.2	0.25	0.30
Mold Compound to Substrate Volume Ratio	1.57	1.94	2.2

At reflow temperatures, it is expected that the substrate will expand more because of its larger CTE; thus, the CTE mismatch between the silicon to substrate will create –ve warpage. A large enough quantity of mold compound with a lower cure shrinkage and high CTE2 ~ 30 ppm would have compensated for this mismatch.

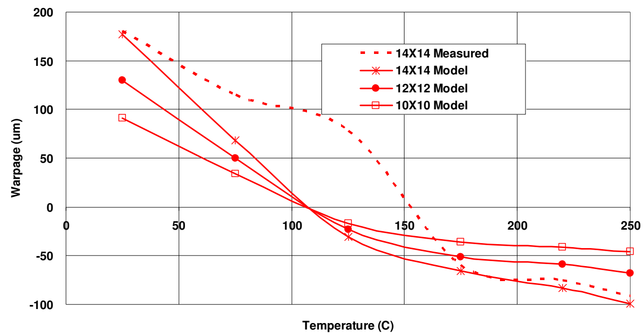


Fig. 8 Warpage results for compression molded thin PoP packages

The top PoP package considered in this study is 14mm X 14mm. Other commonly used package sizes include 10mm X 10mm and 12mm X 12 mm. To study the warpage behavior for these packages, finite element analysis is employed. In the analysis, the thermal shrinkage and the chemical shrinkage for the mold compound were included. The substrate is modeled as multi-layered substrate (consists of solder mask, copper, and substrate core). The die XY dimensions are proportionately reduced for the smaller packages to keep the package silicon content similar. First the FEM results were verified against the experimental results for the 14mm X 14mm package. Later, the same set of model parameters were used to estimate the smaller package warpage. Results of the FEM simulations are shown in Fig.8 for a package with 0.25mm mold cap. Results indicate that as the package XY dimensions are reduced, we can expect the room temperature co planarity to be reduced as well as the reflow temperature –ve warpage to be reduced.

Conclusions

The comprehensive study in this paper shows that the compression mold is an effective solution for thin mold cap PoP top packages. Compression molding has the characteristics of lower mold flow velocity and absence of mold shear, which makes it an ideal molding method for thin mold cap packages. It effectively resolves the manufacturing issues encountered in transfer molding for packages with sub-100µm mold cap clearance. The study found that compression molding and transfer molding yielded equivalent package warpage when using the granular forms of mold compounds. This study also found that when reducing package mold cap thickness, the co-planarity at room temperature became a concern. Finite element simulations indicated that the co-planarity, as well as warpage of small size packages (12mm x 12mm and below), could be controlled under 100µm in these cases. Future work is to evaluate the impact of different properties of the granular mold compounds and low CTE core substrates to further minimize the package warpage at both room temperature and reflow temperature.

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