A Novel Method to Predict Die Shift During Compression Molding in Embedded Wafer Level Package

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Abstract

The increased functionality of cellular phones and handheld devices requires system level integration. Thus there is a strong demand in cell phone maker to move to embedded micro wafer level packaging (EMWLP). But the major problem encountered is die shift during compression molding. This paper presents a novel method to predict the die shift during wafer level molding process. A series of parametric studies are performed by changing the die thickness, die pitch distance and top mold chaste compression velocity. The effect of thinning down the chip thickness affects the pressure difference and local shear rate on the chip surfaces. The rate of change of epoxy mold compound fluid pressure across the die top surfaces is not constant. The local shear rate is increasing linearly from the centre of the wafer to the outermost die. From the parametric studies, the die shift is inversely proportional to the die thickness for wafer level molding. Such a phenomenon will reduce the lithography alignment error in the next process. This paper also shows that by reducing die pitch distance of a 5 x 5 mm², 500 μm thick chip, the die shift decreases by a factor of 12%. In addition, the top mold chaste compression velocity contributes to the die shift by as much as 28% when the velocity is reduced by 50% from 100 μm/sec to 50 μm/sec. Finally it is observed from experiment result that the die shift is not constant in all directions.

1. Introduction

Wafer level packaging is gaining tremendous interest throughout the semiconductor industry, due to advantages in cost and performance. The trends in packaging technology are going towards high density integration, low profile package and embedding actives and passives. For a typical cell phone application, we are seeing 80% of the components are passives and contribute to about 70% of the cost of assembly. The increased functionality of cellular phones and handheld devices requires system level integration. Thus there is a strong demand in cell phone maker to move to embedded wafer level packaging (EMWLP) for their product assembly line. The core process of this technology is the encapsulation of silicon die. Brunnbauer et al. [1] demonstrated that compression molding is a promising approach for the embedding of devices with respect to topology, adhesion and reliability properties. The new technology is a competitive solution delivering reliable Ball Grid Array (BGAs) packages. One of the benefits of compression molding is that the mold compound is not touching the tool during processing, as a release film is covering the top tool. This technique is working without runner or venting, so no bleed appears and no material waste is produced. Although, a release film has to be used in the top cavity this presumed cost adder makes on the other side cleaning and conditioning obsolete.

Fig. 1: (a) Single die embedded micro wafer level package with integrated passive device; (b) Two stacked dies embedded micro wafer level package using copper posts [2]

A joint effort by Institute of Microelectronics at A*STAR Singapore and her industry partners has developed an embedded device technology, which is based on a molded 8-inch reconfigured wafer. The package size is 10 x 10 mm² with a package thickness of 500 μm, and the die size 5 x 5 mm², 300 μm thick. The offset distance from the die to package edge is 2.5 mm. The first package is to embed a passive device into the package and the other package is to embed a stacked die assembly with copper posts. This paper...
presents a novel method to predict the die shift during wafer level molding process. The passive, die or stacked dies are placed on a molding tape using pick and place machine. A series of parametric studies are performed by changing the die thickness, die pitch distance and top mold chassis compression velocity. A novel method using the coupled CFD and structural analysis is used to predict the die shift behavior under these different conditions.

In this paper, the finite element model of the wafer level molding process was built based on the design for single die embedded micro wafer level package (Figure 1a). A series of parametric studies are performed by changing the die thickness, die array arrangement, die pitch distance, and mold compression velocity. The paper focus on the die shift behavior of the worst case chip under different parametric studies. The results obtained from the modeling are useful to form the design and optimization guidelines for the molding process of the embedded wafer level packaging.

2. Package description

The wafer level molding model was performed on a 5 x 5 mm² square chip, with different thickness (300 µm, 500 µm and 700 µm) placed on the molding tape.

3. Finite Element Modeling

Numerical modeling of the compression flow wafer level molding process is conducted using commercially available fluid flow software. POLYFLOW v. 3.11 is chosen because of its advanced compression flow analysis capabilities for polymeric materials. Modeling of this process is essentially the simulation of compression molding with a very complex boundary. Although there is another compression molding package available, POLYFLOW offers the flexibility needed in terms of simulating the complex chip geometry in the compression flow chip placement problem. Compression molding is a relatively new feature in POLYFLOW, and its use in this study of compression flow chip placement is a unique application. To the authors’ knowledge, no previous attempt to solve a compression flow problem in wafer level molding has been reported.

The finite element model (Figure 3) simulating the wafer level molding process has been established. Modeling is done using a quarter model to minimize computing time required by the simulation. The fluid flow is initially solved with POLYFLOW solver to obtain the fluid pressure profile on the die during wafer level molding. The highest pressure difference along the die is then identified and the fluid pressures acting on the die is translated into boundary condition in the structural finite element model (Figure 4) to solve for the displacement (die shift) using ANSYS.

The modeling consists of the following assumptions:

i) A two-dimensional, time-dependent analysis will be performed on a axisymmetrical model of a 8 die arrangements;
ii) The mold surface boundary is assumed to be adiabatic;
iii) Perfect adhesion is assumed between the die and molding tape interface; and
iv) The mold compound is modeled with a shear-rate dependent viscosity obeying the Power Law,

\[ \eta = K (\dot{\gamma})^{n-1} \]

where \( \eta \) is the shear rate dependent viscosity and \( \dot{\gamma} \) is the shear rate. [5, 6]

The mold compound rheological properties are determined through material testing using a slit die rheometer (Figure 5), and the material behavior of viscosity changing with respect to shear rate is plotted out on a graph (Figure 8). The material parameters K, \( \lambda \) and \( n \) are determined from the plot using POLYMAT module in POLYFLOW. The other material properties are shown in Table 1.
Table 1: Material properties used in the finite element modeling

<table>
<thead>
<tr>
<th>Materials</th>
<th>CTE (below Tg)</th>
<th>CTE (above Tg)</th>
<th>Young modulus, E</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMC</td>
<td>8 ppm/°C</td>
<td>49 ppm/°C</td>
<td>30 GPa</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>(below Tg 150°C)</td>
<td>(above Tg 150°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon Die</td>
<td>2.7 ppm/°C</td>
<td></td>
<td>155 GPa</td>
<td>0.25</td>
</tr>
<tr>
<td>Molding Tape</td>
<td>126 ppm/°C</td>
<td></td>
<td>400 MPa</td>
<td>0.30</td>
</tr>
</tbody>
</table>

3.1 Finite Element Mesh and Boundary Conditions

Mesh topology is divided into faces, edges, and vertices for the two-dimensional cases studied. Figure 3 is an example of one of the finite element mesh models generated for the compression flow wafer level molding study. A mesh consists of three sub-domains and six boundary sets. Two sub-domains represent the top mold chaste and bottom mold chaste, while the remaining sub-domain (i.e., the fluid subdomain) model the epoxy molded compound material. The total number of elements for each mesh ranges from 35000 to 45000 elements.

The mesh of the epoxy molded compound fluid sub-domain is very fine as shown in Figure 3. A finer mesh is selected to provide more accurate results for the large deformations, especially in the regions of the complex die geometry. The fluid sub-domain has two different boundary conditions applied to its four boundaries. Boundary 1 defined along the horizontal and vertical center axis of the wafer is a symmetry condition that allows for the simulation of the axisymmetric geometry. It is defined as having a tangential force and normal velocity equal to zero. Boundary 2, the top, bottom and outer edge of the epoxy mold compound fluid free surfaces, are defined as free surfaces with contact detection. A free surface is essentially a condition where a vanishing surface force is imposed and the fluid cannot cross the free surface. The position of the boundary is not known in advance, and is therefore a part of the solution. Eight mesh models are created for the simulations performed in this work. These models represent different die thicknesses, die pitch distances and die arrangements. Each simulation problems include the density and inertial terms of the epoxy mold compound material during compression flow. By defining a value for the density, an incompressible fluid is specified. The inclusion of inertial terms in the momentum equation makes the analysis more realistic and comprehensive with respect to fluid motion during rapid compression cycles [4].

4. Parametric Study

There are a number of control parameters in the parametric studies. The chip thickness used in obtaining the data points are: 300 μm, 500 μm and 700 μm. The material properties of the silicon die remain unchanged throughout the simulations and the die size is fixed at 5 x 5 mm². The die pitch distance is also fixed at 10.1 mm except for parameter study in effect of die pitch distance. For parametric studies, we will look at the die shift of the chip under different conditions. There are a total of four effects studies presented in this paper. It included a comprehensive analysis to look into the effects of die thickness, die array arrangement, top mold chaste compression velocity, and die pitch distance that is affecting the die shift after molding.

Fig. 5: A typical slit die rheometer setup used for measuring the mold compound viscosity changes [3]

Fig. 6: Pressure profile in the molded wafer across the die top surface for 500 μm die thickness

Fig. 7: Local shear rate across the die top surface for 500 μm die thickness

Overall, the results of the compression flow simulations provide valuable information on the local shear rates,
pressure distributions, and velocity profiles of the various die configurations and mold materials studied. The results also provide critical insights into the potential formation of voids and die shift during next generation embedded micro wafer level packaging using compression molding which can be a reliability concern.

From the POLYFLOW simulation, the results show that the rate of change of epoxy mold compound fluid pressure is not constant across the die top surfaces. The trend line shows that it reduces from the centre of highest pressure to the low pressure region at the outermost die, approximating a second order polynomial equation as seen in Figure 6. The pressure distribution assumes a parabolic curve with centre being the highest pressure peak, if we extrapolate the full length of the wafer to the left. From Figure 7, the local shear rate across the top die top surfaces also increases in a linear behaviour with peaks indicating the top surfaces of the die and valleys being the spacing between each die. Figure 9 shows the behaviour of the fluid flow for t = 0.01 sec, t = 2.5 sec, t = 5 sec, t = 7.5 sec and t = 10 sec.

4.1 Effect of Die Thickness

The die size is fixed at 5 x 5 mm² and the fluid flow along surface of the die and molding tape is assumed to be having a slipless condition. Figure 10 shows the simulated die shift result at the peripheral location for different die thickness 300 µm, 500 µm and 700 µm. It is observed that the die shift decreases as the die thickness is increased. This is due to the effect of reduced fluid pressure acting of the chip surfaces as the die thickness is increased. The die shift has increased by 8% when the die is thinned down from 700 µm to 300 µm. The epoxy mold compound fluid velocity on the die top surface has increased but the pressure difference has reduced. This cause the irregular flow pattern on the die walls and contributes to the die shift. Figure 11 showed that the local shear rate is highest at the outermost die. The fluid flow velocity in the x-direction is also highest at this point.

4.2 Effect of Array Population

The arrangement of the dies on the molding tape affecting the die shift is studied. The die thickness and size is fixed at 500 µm and 5 x 5 mm², respectively. Figure 13 shows that there is no change in the die shift for fully populated and alternate populated array (Figure 12). The pressure difference has increased from 13 MPa to 14.2 MPa when the array switches from alternate populated array to fully populated array. From the simulation result, the effect of the die array population does not have an impact to the die shift after molding.

4.3 Effect of Top Mold Chaste Compression Velocity

The effect of top mold chaste compression velocity affecting the die shift during wafer molding was looked into. The top mold chaste velocity in the finite element model was tuned down and the pressure difference across the outermost die was extracted from the simulation result.
It was found that the die shift has decreased by 28% when the velocity of the top mold chaste has reduced by half from 100 \( \mu \text{m/sec} \) to 50 \( \mu \text{m/sec} \) (see Figure 14). The reason behind this is because the local shear rate and pressure difference across the outermost die have reduced. A pressure difference drop of 30\% from 9.1 MPa to 6.4 MPa was seen at the outermost die. Thus it is recommended to opt for a low top mold chaste compression velocity in order to reduce the die shift during wafer level molding.

![Fig. 11: Local shear rate (1/sec) contour for 5 x 5 mm\(^2\) with 500\( \mu \text{m}\) thickness, top mold chaste velocity = 0.1 mm/sec](image)

4.4 Effect of Die Pitch Distance

The effect of die pitch distance is discussed in this section. The pitch distance is reduced from 10.1 mm to 6.1 mm to see the effect of die shift and fluid pressure distribution after the distance between each die is reduced. A 0.1 mm clearance between every package was taken into account for the dicing lane. From the simulation, it is observed that the pressure difference has increased from 12.7 MPa to 14.2 MPa when the die pitch distance increases. The die shift is 1.51 \( \mu \text{m} \) for 10.1 mm pitch distance and 1.35 \( \mu \text{m} \) for 6.1 mm pitch distance as seen in Figure 15. The magnitude of increment is 12\%. Therefore it is advisable to keep the die pitch distance at its minimum to reduce the die shift caused by molding.

![Fig. 14: Effect of top mold chaste compression velocity affecting the die shift](image)

4.5 Correlation with Experimental Measurements

The concept and results obtained from section 4.1 to 4.4 were used to verify in an experiment. It attempts to explain the physics behind the die shift in the wafer during molding. It is to take note that the experiment discussed here also take into consideration of the molding tape expansion and warpage during molding. The results from the simulation correlates with the experimental measurement for die shift shown in Figure 17. The die shift at the outermost die in all four directions is about 100 \( \mu \text{m} \) – 630 \( \mu \text{m} \), whereas the innermost die is about 0 \( \mu \text{m} \) – 60 \( \mu \text{m} \).
The experiment results showed that the die shift is highest at the outermost die which correlates with the simulation result. Due to the high local shear rate at the outermost die, the pressure difference along the surfaces of the chips increase. The higher pressure from the innermost of the wafer pushes the epoxy mold compound fluid to move outward away from the centre. The pressure distribution contour from simulation (Figure 16) also showed that the pressure at the centre of the wafer (extreme left due to axisymmetry model) is high but pressure difference is not significant across the die surface.

![Fig. 16: Pressure distribution of the epoxy mold compound for 500µm die thickness across the wafer after molding](image)

The effect of different fluid pressure acting on the die side surfaces cause the die to shift during molding. This phenomenon causes the chip to have more shift at the outer wafer diameter. The die shift is also not proportional in all directions from the experiment. The die shift is ranked in order of increasing magnitude: directions A, B, D and C respectively, as shown in Figure 17.

5. Conclusions

Some basic design and optimization guidelines for the molding process of the embedded wafer level packaging have been obtained in this study. Some important results and recommendations are summarized in the followings:

(i) The die shifting is predicted with the coupled CFD and structural analysis, which is verified (in good accuracy) by experimental measurement.

(ii) The die shift increases by a factor of 8% when the die thickness is decreases from 700 µm to 300 µm. This is due to the reduction of the pressure difference and irregular flow pattern on the die walls. The die shift will affect the misalignment errors in the subsequent RDL lithography process. Process engineers should take note of this when they are processing for thin die design in the embedded micro wafer level packages.

(iii) There is no change in the die shift between a fully populated array and alternate populated array after molding. But the pressure difference across the die increases when the alternate populated array switches to fully populated array.

(iv) By increasing the compression velocity of the top mold chaste, the mold compound fluid travel velocity increases and aggravates the die shifting.

(v) Die shift is directly proportional to the pitch between each die on the molding tape. This is due to the reduction of pressure difference and local shear rate effect of fluid force acting against the surface of the die.

(vi) Based on results from (iii) and (v), engineers should try to avoid to keep the distance between each die too far apart. The benefit is the process can achieve a higher throughput as a result of more dies being able to populate close to each other on the molding tape.

(vii) The simulated result in an 8-inch compression flow wafer level molding model correlates very well with the experimental measurements. Also, based on experimental results, the die shift is not proportional in all directions due to expansion of the molding tape and epoxy mold compound fluid flow.

These findings will form the basic design and optimization guidelines for the molding process of the embedded wafer level packaging.

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References


