Abstract—This paper presents an analysis on panel warpage as the growth of the panel exceeds beyond current wafer sizes. This work is a part of iNemi working group “Wafer/Panel Level Package Flowability and Warpage Project”. The aim of the project is to understand material, process and design factors that impact on flowability and warpage. This paper focuses on warpage measurement aspect: method and results.

Keywords— Panel; thermo-mechanical Warpage; Flowability; wafer/panel level assembly molding; Compression Molding; Numerical Simulation; Measurement.

I. INTRODUCTION

Wafer Level Packaging (WLP) and the movement to Panel Level Packaging (PLP) have gained industry attention as more cost-effective packaging technology for certain applications. In both cases, the molding poses technical challenges in terms of understanding the optimum mold compound behavior in terms of flowability and warpage aspects, so as to limit process failure [6]. The increased size adaptation (panel larger than 300mmx300mm) expands the assembly molding challenges even further [1]. Better understanding the flowability fundamentals of mold compound and its impacts on quality and potentially warpage of the wafer/panel for subsequent processes is needed.

To identify key processing factors that impact flowability, warpage and also the complex relationship between the two, a project was set up among iNemi members. Identifying the material factors and key process parameters is also important to achieve higher yield in flow and warpage control for mold first WLP/PLP assembly processes.

In this paper, iNemi PLP project and TDM technology for WLP and PLP application will be introduced. Warpage variation during thermal process and impact of panel sitting points on warpage shape and values will be discussed from both an experimental and numerical point of view.

II. iNEMI PLP PROJECT

A. Project and difficulties

The project focus on the mold first process up to the de-bonding step. There is a need to identify main processing factors that impact flowability, warpage and also their relationship. Identifying the material factors and key process parameters is also important to achieve higher yield in flow and warpage control for mold first WLP/PLP assembly processes. So the first working axes was to evaluate material types for assembly molding processes and determine the processing window from both experiment and simulation prediction/visualization. The second one was to identify key factors for post mold assembly warpage on metal carrier and the working range acceptable for subsequent assembly steps.

An additional focus will be on determining the influence of chemical shrinkage, and the experimental/simulation techniques to represent them. With regards to warpage aspects, the deformation of the WLP or PLP function of the temperature are in mm-scale, and due to panel flexibility we realized that there is a gravity effect.

The other difficulty was to correlate and adapt simulation tools with gravity effect and with experimental results – since curvature are rather complex and not uncomplicated to model.

B. Samples description

For simplicity, 300x300mm panels used in this study consist of 10x10mmx0.2mm bare silicon dies and epoxy mold compound (EMC) of 500um thickness. There are 4 panels with varying silicon die density and EMC thickness as shown in Table I below:

<table>
<thead>
<tr>
<th>Panel Type</th>
<th>Die Density</th>
<th>Support Layer</th>
<th>EMC Thickness(um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDOE#1</td>
<td>196</td>
<td>No</td>
<td>500</td>
</tr>
<tr>
<td>MDOE#2</td>
<td>529</td>
<td>No</td>
<td>500</td>
</tr>
<tr>
<td>MDOE#4</td>
<td>529</td>
<td>Yes (118um)</td>
<td>500</td>
</tr>
<tr>
<td>MDOE#5</td>
<td>229</td>
<td>No</td>
<td>300</td>
</tr>
</tbody>
</table>

The molded panels went through post mold cure (PMC), carrier de-bonding and mold film separation [5] as shown in Fig. 1 below.

![Fig. 1. Panel molding process.](image)

C. Samples warpage and issues for manufacturing

After manufacturing, panels have warpages from tens mm to forty mm. They are convex curvature with variable symmetric aspects, eg. cylindrical tunnel shape or sphere with corners warping down in steeper gradient, as shown in Fig. 2.
The measurement technique should be capable to measure either some tens mm of warpage at room temperature and during heating processes, and surface with dark and shiny areas. Thus, warpage experimental measurements were performed using the fringe projection technology TDM by Insidix - (Topography and Deformation Measurement).

III. WARPAGE RESULTS AND DISCUSSION

A. Introduction to TDM Technology

TDM (Topography and Deformation Measurement) is a patented technology designed to the 3D warpage and strain measurements of complex objects under thermal stress. The operating system combines a heating/cooling sequence with an optical set-up for multiscale 3D topography and strain analysis under thermal stress (range -65°C to 400°C) – see fig. 3.

3D Strain and warpage of objects having a surface from 1x1 mm² to 300 x 375 mm² can be characterized simultaneously on the same system from -65°C to 400°C.

The 3D Sensor is based on Projection Moire and has some unique characteristics:

- Based on Phase Shifting Structured Light Illumination, known for high accuracy and robustness
- Outstanding resolution / measurement volume ratio, using high resolution projector and camera and a special Extended Depth Of Field algorithm
- Full frame measurement technique, measures the topography of a surface in a few seconds
- High point density, 5 million 3D points per acquisition
- Scalable, measurement volumes range from 10x12x3 [mm] to 400x500x50 [mm] as a standard, and could be customized

Thanks to unique design, multiscale analysis allows to perform several acquisition of the same object using various magnification, in one thermal profile. Therefore the effect of various scale in the deformation can be studied [2] – eg. WLP level and center/periphery dies at the same time.

Therefore, TDM technology has been identified as an adapted tool to perform PLP warpage measurements: at room temperature, during thermal profile, to study gravity effect.

B. Warpage measurements during thermal profile

Warpage measurements were lead at room temperature to analyze the influence of process and design parameters (see fig. 4).

As a first analyse of results, die density does not seem to impact warpage. Support layer and EMC thickness have a more significant influence on warpage (table II).

<table>
<thead>
<tr>
<th>Panel Type</th>
<th>Die Density</th>
<th>Support Layer</th>
<th>EMC Thickness(um)</th>
<th>Warpage (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDOE#1</td>
<td>196</td>
<td>No</td>
<td>500</td>
<td>32.5</td>
</tr>
<tr>
<td>MDOE#2</td>
<td>529</td>
<td>No</td>
<td>500</td>
<td>34.5</td>
</tr>
<tr>
<td>MDOE#4</td>
<td>529</td>
<td>Yes (118um)</td>
<td>500</td>
<td>6.8</td>
</tr>
<tr>
<td>MDOE#5</td>
<td>529</td>
<td>No</td>
<td>300</td>
<td>14.9</td>
</tr>
</tbody>
</table>

Measurements of warpage variation with temperature aim to analyze thermal behavior, and to determine when the panel is almost flat, here around 150°C (Fig. 5).
The data will help to implement and adjust models, most of all due to non-symmetrical shape and the significant warpage values.

On another hand, during the experiments, some issues regarding curvature stability were pointed out. Thus the team has lead an additional work on gravity effect for these new type of products.

C. Warpage and Gravity Effect Measurement

In order to separate out the effect of gravity, the panels were placed on two different support setup, as shown in Fig 6.

\[
\begin{align*}
    h_g &= (h_2 - h_1)/2 \\
    h_n &= (h_2 + h_1)/2
\end{align*}
\]

The molded panels were let cooled down to room temperature, and then measure the warpage profile using projection moiré technique. The panel warpage is determined from the peak to valley (P-V) value within the measurement profile (eg. of one panel Fig 7).

![Fig. 5: Warpage of panel #1 during thermal profile](image)
![Fig. 6: Warpage support setup for gravity effect separation.](image)
![Fig. 7: Panel warpage measurement from projection moiré technique.](image)

Results show that gravity influences not only warpage values but also the shape: fig. 7 the two diagonals are similar for meas. 1, and for meas. 2 one diagonal has half-value warpage than the other one. For some samples, a slight mechanical change induces a shape change. These measurements also point out certain instability of warpage.

Additionally, results from 2 panels with same die density and different EMC thicknesses are compared in Table III below, with calculated gravity influence, \(h_g\), using equations (1) and (2).

<table>
<thead>
<tr>
<th>Panel Type</th>
<th>(h_1)</th>
<th>(h_2)</th>
<th>(h_n)</th>
<th>(h_g)</th>
<th>Gravity Influence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDOE#2</td>
<td>1.000</td>
<td>1.101</td>
<td>0.051</td>
<td>1.051</td>
<td>4.83%</td>
</tr>
<tr>
<td>MDOE#5</td>
<td>0.432</td>
<td>0.725</td>
<td>0.146</td>
<td>0.578</td>
<td>25.31%</td>
</tr>
</tbody>
</table>

Gravity effect can be enabled and disabled easily in simulation models. Numerical models for MDOE#2 and MDOE#5 reported gravity influence of 4.2% and 26.5% respectively, which is close in comparison to calculated result in Table II.

From Table III, it was also observed that gravity plays a more significant role when the panel aspect ratio increases. MDOE#2 has a 600:1 edge to thickness ratio, where MDOE#5 has a 1000:1 ratio.

D. Numerical Predictions & Trends

Material properties of the EMC were first characterized before performing numerical simulations for flow and warpage prediction. The method and results are detailed in [3][4].

The ability of numerical technique to capture the trend of panel warpage trend or tendency with varying silicon die percentage, EMC thickness and presence of support layer is shown in Fig. 8 in a normalized warpage comparison.

![Fig. 8: Panel warpage measurements as a function of die density, mold thickness and presence of support layer.](image)

Discrepancies in absolute warpage value is expected between model and experiment due to tolerances and factors beyond process control. The normalized reporting provided an insight into ability of numerical approach in predicting the trend of panel warpage behaviour during early design phase for product optimizations.

However, adjustments should improve models accuracy for shape description. Indeed, non-linearity in warpage...
curvature measured is to understand and identify for fitting lifetime prediction.

SUMMARY

Panels with dummy silicon and EMC only were molded and warpages measured using projection moiré technique. Measurement setups and calculation demonstrated the ability to separate out the influence of gravity through semi-empirical approach. Numerical approach showed the ability to predict the panel warpage trend which is useful in early product and process design phases and reduction in empirical resources. Due to the high aspect ratio of panels, the current iNEMI consortium project proposed more focus in understanding and treating the non-linear geometric nature for numerical solving for such class of problems.

ACKNOWLEDGMENT

The project team also included simulation specialists, Autodesk and Moldex3D. We would like to thank and mention Franco Costa and Sejin Han from Autodesk Inc. USA & Australia, Goran Liu from CoreTech System Co. Ltd., Taiwan for their active participation and expertise.

REFERENCES


