iNEMI Statement of Work (SOW)

Packaging TIG

Warpage Characterization and Management Program,
Package Warpage Prediction and Characterization Project
Phase 6

Version # 1.0
Date: November 16, 2022

Project Leader: Kang Eu Ong, Intel
Co-Project Leader: TBD
iNEMI Project Manager: Haley Fu

Project Overview:
Dynamic warpage characterization of electronic packages is critical to enable high yielding board assembly. One of the challenges is to predict the dynamic warpage behavior of the new packages accurately through simulation before having the real physical article, helping to optimize design for assembly & reliability and reduce product development time. Current package warpage modeling capabilities are not adequate to satisfy this need.

This project will build on earlier iNEMI project work, in tracking the dynamic warpage of advanced packaging technologies by:

1) Conducting dynamic warpage characterization of latest advanced packaging material
2) Deriving a reliable modelling framework to predict new package dynamic warpage

Project Motivation
Electronic packaging technology is aggressively evolving to meet new user demands and application requirements. One of the challenges for developing new electronic packages is to understand the dynamic warpage behavior of the completed package before having the real physical article available. Dynamic warpage characterization of electronic packages is critical to enable high yield board assembly. The industry relies on the use of simulation tools, such as finite element model and analytical equation, to refine the design options to obtain a high confident prediction. Current package warpage modeling techniques are not adequate to satisfy the future needs of more complex and larger package constructions. Predicting package warpage is not straightforward. It requires significant consideration of properties, multi-physics and boundary conditions. The use of different simulation tools may help understand the different physics assumptions. More work is needed to derive a reliable modelling framework for electronic industry.

Based on the modeling framework gap analysis and simulation case study in earlier iNEMI warpage project work (see Previous Related Work section), in phase 5, the team further investigated organic substrate-based packages, conducted material properties
characterization, including that of the mold compound and substrate raw material to help understand the impact of curing process on eventual package warpage. In this phase - Phase 6, this project will focus on the panel level packaging with organic/inorganic material on a substrate/carrier.

**Project Purpose**

- Characterization of the warpage of advanced latest packaging technologies from real samples to track the typical range of warpage and the trend.
- Package warpage prediction – establish a reliable modelling framework to optimize package warpage simulation.

**Project Scope**

This project is divided into two separate parts:

1) Dynamic warpage characterization of latest packaging technology
   - Characterize emerging electronic packaging technology dynamic warpage behavior to develop a better understanding of the impact of current package construction and material development. Example packages include:
     - Use of inorganic material in wafer/panel level packaging
     - Inorganic material such as glass substrate or glass carrier

2) Package Warpage Prediction Framework
   - Derive a reliable modelling framework (model generation, model material parameters, simulation capabilities) to predict future package
     - Material properties characterization – especially modulus and thermal expansion of inorganic material used in packaging – this will help understanding the impact of the assembly process on eventual raw material warpage (e.g. substrate).
     - Derive the material parameters and other non-linear properties needed for material models, which are currently lacking due to the complexity and software capability.
     - Provide opportunity for simulation software provider to validate or develop material model for further electronic packaging capability needs.
     - Conduct experimentation to quantify how warpage evolves during the assembly (substrate or package).
IS / IS NOT Analysis

<table>
<thead>
<tr>
<th>This Project IS:</th>
<th>This Project IS NOT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>To characterize warpage behavior of the latest inorganic material package</td>
<td>To develop a specific standard(s)</td>
</tr>
<tr>
<td>technologies available in industry and track the warpage roadmap</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>To provide data, input, and make recommendations to identified standards</td>
<td>To repeat prior or existing work (required extensive</td>
</tr>
<tr>
<td>for modifications / improvements to the standards</td>
<td>literature survey)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>To provide package suppliers with dynamic warpage characterization data on the</td>
<td>To be biased towards specific suppliers, geographies, or</td>
</tr>
<tr>
<td>packages donated to the study.</td>
<td>market segments (impartial)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>To focus the simulation on inorganic material in packaging</td>
<td>To include evaluation of first level interconnects (C4</td>
</tr>
<tr>
<td></td>
<td>joins)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>To conduct a reliability study</td>
</tr>
</tbody>
</table>

Business Impact

- Improve confidence levels of package warpage prediction for inorganic material.
- Earlier, more accurate prediction of package warpage behavior can minimize risk of new package technology introduction and result in cost savings.
- Understanding package warpage and minimizing it can improve assembly yield and reliability performance.
- Accelerate the improvement of the simulation and modeling capability through the close collaboration among IC designers/makers, assembly houses, material suppliers and simulation tool/service providers, which is helpful to achieve in-depth understanding and investigation and result in holistic solutions, especially in this multi-physics area.

Project Outcome

- Generate improved simulation model and framework and share the best practices through published report, paper and webinars.
- Provide recommendations and guidelines to the industry on material characterization and package warpage simulation, with an emphasis on:
  - Package warpage prediction with the influence of inorganic material

Previous Related Work

This project is the next in a continuous iNEMI project series addressing warpage issues for organic packages. Packaging technology is aggressively evolving to meet new user demands and requirements. Dynamic warpage characteristic of electronic package is critical for seamless board assembly. Hence this ongoing effort to understand the kind of dynamic warpage demonstrated by different package technologies available in industry. The project previously titled Warpage Characteristics of Organic Packages has completed 4 phases.
addressing metrology challenges, the recent trends of package warpage characteristics, as well as gaps in warpage simulation. The study and outputs of earlier phases can be found at iNEMI project webpage. The following table provides a highlight summary of the accomplishments of each phase.

<table>
<thead>
<tr>
<th>Previous Phases</th>
<th>Scope &amp; accomplishments</th>
</tr>
</thead>
</table>
| **Phase 1** (2011-13) | Literature survey  
Establish metrology correlation between sites and increase awareness  
Reach out to industry for component donation |
| **Phase 2** (2013-2014) | Establish current technology package dynamic warpage (POP, PBGA, FCBGA)  
Measurement protocol (effect of “As Is”, “Bake” and Moisture Exposure Time (MET)) and sample size needed. |
| **Phase 3** (2015-2016) | Continue establishing technology package dynamic warpage (all kind)  
Dynamic warpage measurement metrology assessment. |
| **Phase 4** (2017-2019) | Continue establishing technology package dynamic warpage of new package technology (all kinds)  
Leverage previous effort to study the impact of Low Temperature Solder on dynamic warpage requirement  
Collaborate with simulation software to derive modeling approach in better predict the dynamic warpage |
| **Phase 5** (2020-2022) | Collaborate with simulation software to derive modeling approach in better predict the dynamic warpage. Investigated organic substrate-based packages, demonstrated the impact of transient thermal structural analysis coupled with the effect of the visco-elastic and cure model implementation to warpage modeling. |

**Prospective Participants**

Warpage is a multi-physics and holistic issue which involves materials, design and manufacturing processes. Participation of researchers and engineers from package designers and manufacturers, EDA and simulation tool providers and equipment suppliers for warpage measurement, as well as industrial organizations and academic institutes is required.

**Participants in development of SOW**

We acknowledge the inputs and contributions from AGC, Akrometrix, Ansys, CoreTech (Moldex3D), IBM, Insidix, Intel, Flex, Fraunhofer IZM and Shinko in developing this project plan.

**Project Plan**

**Resource Requirement**

The project resources required are listed below: advanced package donation, warpage measurement equipment and effort, mold compound, raw substrate materials, material characterization, test vehicle design and fabrication, modeling & simulation. Potential

NOTE: All changes to SOW must be approved by the Technical Committee for version control
participants and in-kind contributions are identified during the project formation stage. After the project sign-up, the final project participating members will discuss and decide the details of the experiment design, including the variables (material options, strip, size, etc.), exact amount of the materials required and quantity of the organic package samples to be built, and detail the resource plan (e.g. quantity, who does what).

<table>
<thead>
<tr>
<th>Resource / Capability Needs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material / Components</strong></td>
<td>Inorganic material (full glass type)</td>
</tr>
<tr>
<td></td>
<td>Substrate raw material (glass core, build-up film, solder resist film etc.)</td>
</tr>
<tr>
<td></td>
<td>Die / silicon material</td>
</tr>
<tr>
<td><strong>Test Vehicle</strong></td>
<td>Assemble inorganic packages (e.g. 1-2-1 structure)</td>
</tr>
<tr>
<td></td>
<td>Assemble wafer (e.g. wafer/panel carrier with silicon)</td>
</tr>
<tr>
<td><strong>Measurement &amp; Test</strong></td>
<td>Materials properties of modulus &amp; thermal expansion with temperature dependent by DMA, TMA measurement</td>
</tr>
<tr>
<td></td>
<td>Room temp &amp; dynamic warpage measurement of TV</td>
</tr>
<tr>
<td><strong>Simulation Software</strong></td>
<td>Simulation software and analysis for warpage prediction</td>
</tr>
</tbody>
</table>

**Schedule with Milestones**

This timeline starts when the project opens for sign-up and participating team members are finalized. The overall project will take 12 months.

<table>
<thead>
<tr>
<th>Package Warpage Prediction and Characterization Project</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project sign up; Confirm the resource &amp; detail the plan</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Package warpage prediction framework
   1) Inorganic raw material selection   x x x
   2) Material characterization          x x
   3) Modeling & warpage prediction     x x x
   4) Report & summary                  x x x

2. Warpage measurement and validation
   1) TV design, donation                x x x
   2) Warpage measurement               x x x
   3) Report & summary                  x x

End-of-project webinar   x

**Scope 1 - Package Warpage Prediction Framework**

**Task 1 – Raw material selection**
- Identify Material partner volunteer to contribute raw material to the project.
- Finalize sample required by partner for material lab characterization.
• Design test coupon for model validation.
• Finalize variation of materials to be tested out. Detail the test/simulation plan.

Task 2 – Material characterization
• Obtain material sample from industry.
• Ship final samples to partner for lab testing and measurement.
• Characterize properties required to be measured for project.
• Publish measurement data.

Task 3 – Material model & warpage prediction
• Derive material model parameters from lab measurement data.
• Assemble TV with selected inorganic & other raw materials.
• Validate material model with simulation and measurement data.
• Share material model parameter with partner.
• Predict package warpage with the new material model.

Task 4 – Report and summary
• Compile and summarize all learnings generated from the project.
• Publish results.

Scope 2 - Warpage characterization of latest packaging technology

Task 1 – Package Donation
• Identify candidate packages and suppliers and prepare solicitation letter.
• Reach out to industry for component donation.
• Arrange shipment and allocate collected samples to member’s measurement labs.

Task 2 – Warpage Measurement
• Execute package warpage measurements.
• Leverage warpage measurement tool from partner labs and resources.
• Review measurement results.

Task 3 – Report and Summary
• Compile and analyze the warpage data together with the data accumulated from previous project phases.
• Summarize the learnings and publish the results.
• Communicate with the package donors about the measurement results.

General and Administrative
Guidelines for this project and all other iNEMI Projects are documented at http://thor.inemi.org/webdownload/join/gen_guidelines.pdf.