Comparison of Advanced Package Warpage Measurement Metrologies
(Warpage Characteristics of Organic Packages Phase 3)

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Disclaimers

• This project was part of iNEMI effort in bringing key dynamic warpage metrology suppliers together to provide un-bias demonstration of dynamic warpage measurement performance.
• It is no way comprehensive and apple to apple comparison at the time of writing.
• Metrology, innovation and best known method evolve with time and knowledge.
• iNEMI is not endorsing any metrology but present the data and observation obtained from metrology suppliers who participated in this project.
Contents

• Introduction
• Dynamic Warpage Metrology and Characteristic
• Evaluation results and observations
• Summary
Dropped from further evaluation. Technique faced some challenge in getting absolute warpage.
## Dynamic Warpage Metrology Under Consideration

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Shadow Moiré</th>
<th>Digital Fringe Projection (DFP)</th>
<th>Confocal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool Considered</td>
<td>Akrometrix (AXP)</td>
<td>Insidix TDM TT &amp; LS</td>
<td>Takaoka HVI-8000-RC</td>
</tr>
<tr>
<td>Field of View (FOV in mm): pixel/mm²</td>
<td>(60x60): 144 pixels/mm²; (136 x 315): 25 pixels/mm²</td>
<td>(60x60): 1089 pixels/mm²; (90x90): 484 pixels/mm²; (210x210): 90 pixels/mm²</td>
<td>(13.3x13.3): 15,625 pixels/mm² with stitching</td>
</tr>
<tr>
<td>Theoretical Z Resolution per FOV:</td>
<td>0.85µm: &lt; 250 sq. mm FOV with 300LPI 1.27µm: 250 to 400 sq. mm FOV with 200LPI</td>
<td>~1.5µm: 30 to 150 sq. mm FOV 3µm: 150 to 400 sq. mm FOV</td>
<td>0.1µm</td>
</tr>
<tr>
<td>Oven Size</td>
<td>400x400mm (AXP) 70mm diameter (CRE6)</td>
<td>75x75mm (TDM TT) 400x400mm (TDM LS)</td>
<td>323x136mm</td>
</tr>
<tr>
<td>Heater Setup and Ramp Rate*</td>
<td>Radiation heating by one-sided NIR lamps or convection heating (CRE6) Max 3°C/sec (depends on sample)</td>
<td>Radiation heating by dual-sided and dual-controlled NIR lamps Max 4°C/sec (depends on sample)</td>
<td>Convection heating Max 2°C/s (depends on sample)</td>
</tr>
<tr>
<td>Sample Preparation Used</td>
<td>White paint</td>
<td>No paint applied except for the lens</td>
<td>Not required</td>
</tr>
<tr>
<td>Measurement of Package with BGAs intact</td>
<td>Need to deball</td>
<td>Yes (additional post processing needed)</td>
<td>Yes</td>
</tr>
<tr>
<td>Data Acquisition Rate</td>
<td>2 seconds/FOV</td>
<td>4 seconds/FOV</td>
<td>0.5 to 1 second/FOV</td>
</tr>
<tr>
<td>Post Processing Capability (see supplier for specifics)</td>
<td>Automated part tracking, batch analysis and reporting</td>
<td>Automated part tracking, batch analysis and reporting</td>
<td>3D contour; minimal post processing</td>
</tr>
</tbody>
</table>

Different measurement technique used for each metrology. Hence not an apple to apple comparison.

* IPC9641 – High Temperature Printed Board Flatness Guideline – June 2013
**FOV (Field of View)**

- **Variable FOV used in DFP and shadow moiré**
- **Fixed FOV used in confocal technique**

- Sample sizes: ~10x10mm to 90x90mm or even greater surface like PCBs
- FOV: function of
  - height of camera,
  - X-Y size of the thermal chamber
  - the view angle of the samples in it.
- For fix camera resolution:
  - A smaller FOV = greater X-Y resolution and vice versa.
  - A larger FOV can be suited for measurement of multiple units or a larger area of interest at once
  - Fixed Small FOV requires additional measurements in predefined x-y scans to complete a unit measurement by stitching the images together.
**Theoretical Z-Resolution per FOV**

**Thermal Shadow Moiré**

- Ronchi ruled grating made from low CTE glass. Ronchi ruled grating has 50 to 300 LPI.
- It does depend on the camera pixels density too to discretize the moiré fringes (x,y) and data density.
- Continuous surface only

\[
W = \frac{P}{\tan \alpha + \tan \beta}
\]

- \( W \) = resolution per fringe (Fringe Value)
- \( P \) = Grating pitch = 1/LPI
- \( \alpha \) = Angle of illumination
- \( \beta \) = Angle of observation

**Digital Fringe Projection (DFP)**

- Five phase shifting structured light patterns
- Processing the distorted structured light as function of elevation changes
- Continuous or discontinuous surface.
- Higher FOV can reduce the data density and resolution

**Confocal**

- Surface height is calculated by the peak output of the intensity response curve at focus point
- Objective lens NA (Numerical Aperture), which determines the width of the focus response curve, and peak position calculating method.
- The z-resolution can be attained at 0.1um
- Took ~0.5s to 1s per FOV.
Heating Chamber

- **Thermal Shadow Moiré**
  - Grating
  - Sample
  - IR Heaters
  - Servo motor & Stage

- **AXP Chamber**

- **Digital Fringe Projection (DFP)**

- **CRE6 Chamber**

- **Confocal**
  - Tray + Samples
  - Confocal objective
  - Glass Window
  - Duct (Exhaust heat)
  - Hot air
  - Factory air
  - Hot air Heater
Typical Sample Preparation and Arrangement

• Sample Preparation
  • Depending on sample condition, fringe contrast, shiny reflection and protrusion can add noise to the measurement. Particular true for shadow moire and DFP technique.
  • No sample preparation for Confocal technique.

• Shadow Moire and DFP
  • Sample arrangement in the heating chamber can be altered to get better results based on FOV needed.

• Takaoka Confocal
  • It requires proper arrangement of samples within JEDEC Tray size and allow proper indexing.
In general, post processing depends very much on the level of automation programmed into the accompanied software. Hence there is no clear apple to apple comparison.

Shadow moiré and DFP

- Requires cropping of area of interest for further processing
- Employed data filtering or smoothing during measurement over the area of interest.
- Subject to human interaction

Confocal

- Data obtained directly without cropping once recipe being setup (requires coordinate of interest)
- Fairly automated but structured.
Each metrology supplier were given electronic packages randomly. It was impossible to run round robin measurement because
• sample preparation needed is different
• metrology requirement is no similar and
• resource needed is limited.
Fused Silica:
- SPC037 and KPC064 concave lenses were chosen as thermally stable and precisely contoured elements
- The coefficient of thermal expansion is ~0.55ppm/ºC.

<table>
<thead>
<tr>
<th>Metrology</th>
<th>Lens code</th>
<th>Measurement (um)</th>
<th>Theoretical Flatness (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confocal</td>
<td>SPC037</td>
<td>670.3</td>
<td>668</td>
</tr>
<tr>
<td>DFP</td>
<td>KPC064</td>
<td>1024.6</td>
<td>1025.6</td>
</tr>
<tr>
<td>Shadow moiré</td>
<td>SPC037</td>
<td>661</td>
<td>662</td>
</tr>
</tbody>
</table>

- Confocal tool (highest resolution, accuracy and repeatability shows steady increase of lens flatness
- DFP and Shadow Moiré showed more like a saw tooth trend behavior – could be due to paint applied and relatively lower repeatability.
Confocal
- Scanning nature - less data point needed for high ramp rate.
- Significant longer measurement time
- Minimal temperature different.

DFP
- No dwell time – capturing multiple samples at once
- Fast heating chamber.
- Can further optimize heating profile to reduce temperature different.

Shadow moiré
- No dwell time – capturing multiple samples at once
- Very fast heating and cooling chamber (CRE6)
- Can further optimize heating profile to reduce temperature different.
FCBGA – Fast Ramp and Typical SMT Reflow

All metrologies able to produce the expected dynamic warpage characteristic of a given package. Fast ramp and slow ramp heating profiles used did not modulate the dynamic warpage of the package significantly.
Typical SMT Reflow and Higher Unit Counts

Confocal
- Scanning nature – stepped temperature profile.
- Significant longer measurement time
- Minimal temperature difference

DFP
- No dwell time – capturing multiple samples at once
- Employed top and bottom heating.
- Fast heating chamber.

Shadow moiré
- No dwell time – capturing multiple samples at once
- Very fast heating and cooling chamber AXP
- Higher temperature difference between top and bottom.
- Lack of top side heating or heating profile was too aggressive.
Typical SMT Reflow and Higher Unit Counts

- All metrologies able to produce the expected dynamic warpage characteristic of a given package.
- High sample to sample variation.
- Confocal’s dynamic warpage seems smoother.
- DFP and Shadow Moire demonstrated more of a saw tooth curve. This could be attributed to the repeatability of the tool.
Dynamic Warpage Measurement on Package w/ BGAs

Confocal
- No sample preparation needed.
- Design to measure package with balls

DFP
- Can measure discontinuous surface.
- Employed data processing technique to extract required data.
- Subjected to noises like shadow from protruded feature can be cast on the sample.
Time taken for pre and post processing of the data were obtained from each metrology. (not apple to apple comparison)
Confocal – no sample preparation needed. Requires initial setup time but repeat measurement requires minimal time.
DFP and Shadow Moire
  - Debballing process can be time consuming when dealing with lots of units.
  - Painting the sample was used for shadow moire to obtain optimum result.
  - Analysis time can be subjected to computing power and software automation as well as operator skill.
Summary

• The findings here are limited to the scope of evaluation that was implemented with existing capabilities. All these dynamic warpage metrologies which include shadow moiré, DFP and confocal technique, were able to generate the expected results and provide sub-mil resolution or finer.

• Shadow moiré
  – Variable FOV able to measure multiple sample at once with minimal impact to through put time. Resolution is impacted by FOV.
  – Employed smaller heating chamber (CRE6) for faster ramp rate
  – Lack of top heating in bigger chamber (AXP) can be a challenge for high ramp rate and high thermal mass measurement requirement but can be addressed with different heating profile.
  – Sample preparation was required which involve de-balling and painting.

• DFP
  – Variable FOV able to measure multiple sample at once with minimal impact to through put time. Resolution is impacted by FOV.
  – Can measure discontinuous surface but care needed to ensure shadow casted is not impacting the measurement.
  – Good heating camber with top and bottom heating elements.

• Confocal
  – Small FOV with high resolution and repeatability.
  – Longer measurement time needed when multiple interval measurement and sample needed.
  – No sample preparation needed. This can be useful for delicate samples.
Thank you!