Structural stability of shelf probe cards

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Presentation Outline

- **Introduction**
  - Objectives
  - Multi die applications
  - Structural system

- **FE Model Development**
  - Shelf probe card design
  - Three approaches of model development
  - Dual die model, stress and displacement
  - Recommended design changes

- **Validation Test**
  - Shelf probe card deflection experiments
  - Results evaluation

- **Conclusions**
Objectives

Introduction

- Understand the behavior of shelf card under load
- Develop and validate a parametric finite element model for shelf probe cards
- Improve a structural firmness and mechanical performance of the multi-die probe cards
- Compare and verify FEA results with experimental data
Introduction

Shelf Probe Cards

- A flat structure composed of a rigid material (ceramic) used to hold cantilevered probes
- Multi-die applications (dual die diagonal, quad (2x2), (1x4) or 1x8, or 4x4
- Straight probe layout inside the ring to accommodate fine pad pitch
- Complex shape of the probe ring fully covering a top view of wafer dice
- High pin count per device, 200 to 500 probes per die
Why structural stability is important?

- Probe spec over travel = 0.0025 inch
- Probe planarity tolerance = +/- 0.00025 inch

and if ring-board deflection is 0.0005 inch

then real probe OT (some) is 0.00175 inch

Contact force specification per mil OT = 1.75G +/-20%

Min force per mil OT = 1.4 G

Min force per total OT – 1.4 G x 1.75 mil OT = 2.45 G
Introduction

Top view of the ring

Probe card profile

Close-up of Dual Die Ring

Epoxy Bonding
Cantilevered Shelf
Probe Support
Probes

Distance between tester POGOs

PCB  Probe  Probe ring
Wafer Chuck

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Introduction

**Response**
- Deflection
- Stress
- Strains

**Action**
- Loads
- Vibrations
- Thermal changes

**Plate**
- Geometry
- Material

Structural System
Deflection, \( d \), of a clamped circular plate under a uniform load \( F \) applied over a small circular area is given by equation*:

\[
\begin{align*}
    d_{\text{max}} &= \frac{-F \left[ a^2 - r^2 (1 + 2\ln \frac{a}{r}) \right]}{16 \pi D} \\
    D &= \frac{E t^3}{12(1 - n^2)} \quad \text{- plate flexural rigidity}
\end{align*}
\]

Where \( r \), a radial location of evaluated quantity and plate radius, respectively.

- the equation is based on assumptions of flat plate with uniform thickness and of homogeneous isotropic material
- load distributed over a small area at the center of the plate
- lack of answer how a probe ring will react under load
- hard to identify a ring places with the high stress concentration

\* Source: Roark's Formulas for Stress and Strain, Sixth Edition, p 433

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Partial Finite Element Model

Second Approach

Concerns:
- unknown reaction from PCB supporting a ring (model assumed that base of the ring is fixed)
- lack of answer if and how PCB will deflect under load
- hard to identify places with the high stress concentration with correlation to the rest of ring and board parts
- no clear interaction between cantilevered shelf part and rest of the ring (no symmetries)
- a diverse shelf side geometry
Third Approach

Benefits:

- Less guessing, less assumption and less simplification
- A geometrical similarity of probe card design
- Composite material, stack up of different sort of materials
- Quick engineering evaluation for new applications
Full Scale FE Model

Third Approach

Model Conditions:
- Board geometry:
  - board diameter 8.0 in
  - board thickness 0.155
  - board cut-out 0.89 x 0.89 inch
- Board annular constraints diameter 4.1 inch
- Ring size 1.100, 1.050 inch
- Force applied 6.0 lbf
- Solid elements, first order tetrahedron (Terta4)

Material Properties*:

<table>
<thead>
<tr>
<th>Property</th>
<th>Ceramic</th>
<th>Copper</th>
<th>FR4</th>
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<tbody>
<tr>
<td>Young's Modulus</td>
<td>psi</td>
<td>9.70E+06</td>
<td>1.85E+07</td>
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<tr>
<td>Poisson's Ratio</td>
<td></td>
<td>0.29</td>
<td>0.36</td>
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<tr>
<td>CTE</td>
<td>ppm/C</td>
<td>9.3</td>
<td>17</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>psi</td>
<td>13600</td>
<td>50000</td>
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</table>
Simulation of Model Deflection

Dual Die

Scale x100
Deflection Curve Predicted by FE Model

- Charts are showing a board-ring deflection in two perpendicular x and z directions
- Cantilevered shelf part of the ring deflects greater than other parts
- A deflection peak occurred on the end of shelf support
- Deflection of the PCB (short off the ring) - 0.00028 inch (7 microns)
Dashed circles are showing the regions with highest stresses in the ceramic ring.

Max calculated stress - 2600 psi

Any micro-crack propagation, material defects or material fatigue could cause a brittle fracture of the ceramic.
Dual Die Deflection Test

- **Test Equipment**
  - Probe Card Analyzer
  - Mitutoya dial gauge with low contact pressure (~38g)

- **Spec Overtravel**
  - probes overtravel 0.0025 inch (60 um)

- **Test Locations**
  1 - the tip cantilevered shelf
  2 – the base of cantilevered shelf
  3 – in the corner of shelf
  4 – on the top of PCB
Registered Deflection at Point 1

Validation Test
Experimental Data

Validation Test

Chart shows a recorded deflection at dedicated locations during multiply touchdowns.

Deflection level is not acceptable at all tested points.

Ring and board require more constraints to reduce deflection and to maintain the stability.

Statistical Summary

<table>
<thead>
<tr>
<th></th>
<th>Shelf #1</th>
<th>Shelf #2</th>
<th>Shelf #3</th>
<th>Board #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>0.00095</td>
<td>0.00065</td>
<td>0.00065</td>
<td>0.00040</td>
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<tr>
<td>Min</td>
<td>0.00060</td>
<td>0.00045</td>
<td>0.00045</td>
<td>0.00025</td>
</tr>
<tr>
<td>Mean</td>
<td>0.00072</td>
<td>0.00057</td>
<td>0.00059</td>
<td>0.00034</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.00009</td>
<td>0.00006</td>
<td>0.00005</td>
<td>0.00003</td>
</tr>
</tbody>
</table>
Recommended Changes

- Eliminate the ring recess
- Eliminate PCB cutout and fully support ceramic ring by board
- Minimize PCB counter bore
- Add a stiffener on the top of PCB and cover as much as possible allowed area between tester pogo
An Improved FE Model

Dual Die

Board Constrains

Top View

Stiffener

PCB

Side View

Ring

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New Model Simulation

Dual Die
Post-Processing Analysis

Max ring deflection has been reduced to 0.00015 inch at total over travel 2.5 mils (60 um)

- Very uniform the ring deflection across ring area (D displacement = 0.00003 inch)
- Max calculated stress at critical regions has been reduced to 835 psi
Validation Test

Experimental Data - Improved Design

Summary Results

<table>
<thead>
<tr>
<th></th>
<th>Top Stiffner #1</th>
<th>Top Stiffner #2</th>
<th>PCB #3</th>
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</thead>
<tbody>
<tr>
<td>Max</td>
<td>0.00035</td>
<td>0.00030</td>
<td>0.00025</td>
</tr>
<tr>
<td>Min</td>
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<td>0.00020</td>
<td>0.00010</td>
</tr>
<tr>
<td>Mean</td>
<td>0.00029</td>
<td>0.00027</td>
<td>0.00016</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.00004</td>
<td>0.00003</td>
<td>0.00004</td>
</tr>
</tbody>
</table>

- Chart shows a deflection at marked test locations (#1, #2, #3) during multiply touchdowns
- Measured deflection has been significantly reduced at all tested points
Discussion of Results

Validation Test

**Deflection before changes**

<table>
<thead>
<tr>
<th></th>
<th>FEA</th>
<th>TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelf #1</td>
<td>0.00066</td>
<td>0.00072</td>
</tr>
<tr>
<td>Shelf #2</td>
<td>0.00042</td>
<td>0.00057</td>
</tr>
<tr>
<td>Shelf #3</td>
<td>0.00046</td>
<td>0.00059</td>
</tr>
<tr>
<td>Board #1</td>
<td>0.00025</td>
<td>0.00034</td>
</tr>
</tbody>
</table>

**Deflection after changes**

<table>
<thead>
<tr>
<th></th>
<th>FEA</th>
<th>TEST</th>
<th>Max Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelf #1</td>
<td>0.00013</td>
<td>0.00029</td>
<td>2600</td>
</tr>
<tr>
<td>Top Stif #1</td>
<td>0.00013</td>
<td>0.00029</td>
<td>835</td>
</tr>
<tr>
<td>Top Stif #2</td>
<td>0.00011</td>
<td>0.00027</td>
<td></td>
</tr>
<tr>
<td>PCB #3</td>
<td>0.00009</td>
<td>0.00016</td>
<td></td>
</tr>
</tbody>
</table>

- An improved model and experimental data are showing diminish deflection.
- A deflection over entire ring area in both cases of improved design, FE model and test, is very uniform and has been significantly reduced.
- A fairly good correlation between FE models and test data.
- Some discrepancies of deflection between model and test card most likely are contributed by an idealization of bonding model parts (ring-board, board-stiffener) and assumption that a card holder mechanism is fixed.
Conclusions

Summary

- Structural analyses were performed on multi-die, shelf probe cards
- An effective modeling and simulation approach based on 3D structure computation has been used to take into account the ring-board deflection effect
- The test results shown that correct ring constrain can considerable improve a structural steadiness of the multi-die probe cards
- The study indicated that FEA can be used as a reasonably accurate assessment tool to analyze a complex probe card design