Structural stability of shelf probe cards

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Presentation Outline

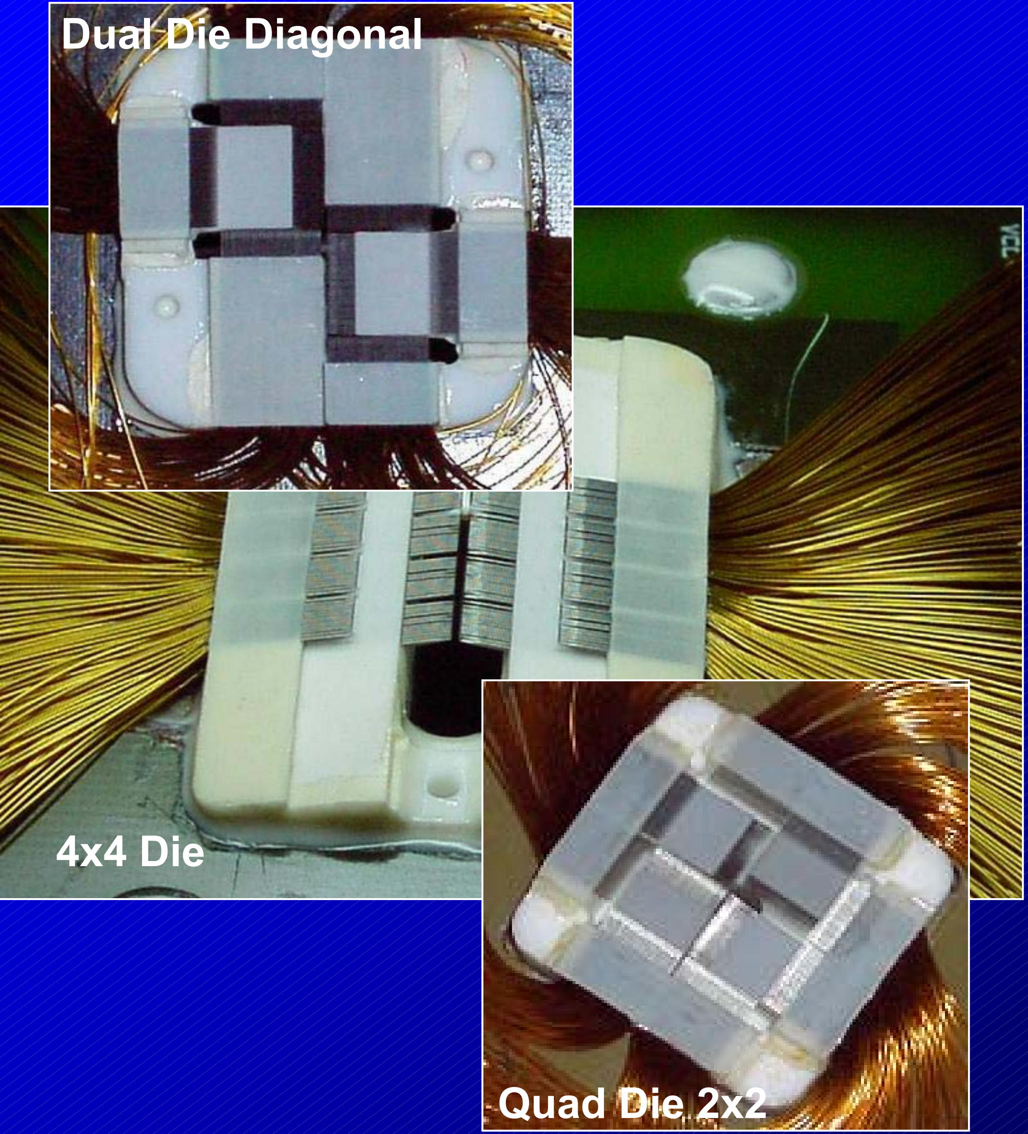
- **Introduction**
  - Objectives
  - Multi die applications
  - Structural system
- **FE Model Development**
  - Shelf probe card design
  - Three approaches of model development
  - Dual die model, stress and displacement
  - Recommended design changes
- **Validation Test**
  - Shelf probe card deflection experiments
  - Results evaluation
- **Conclusions**

Objectives

- 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

Shelf Probe Cards

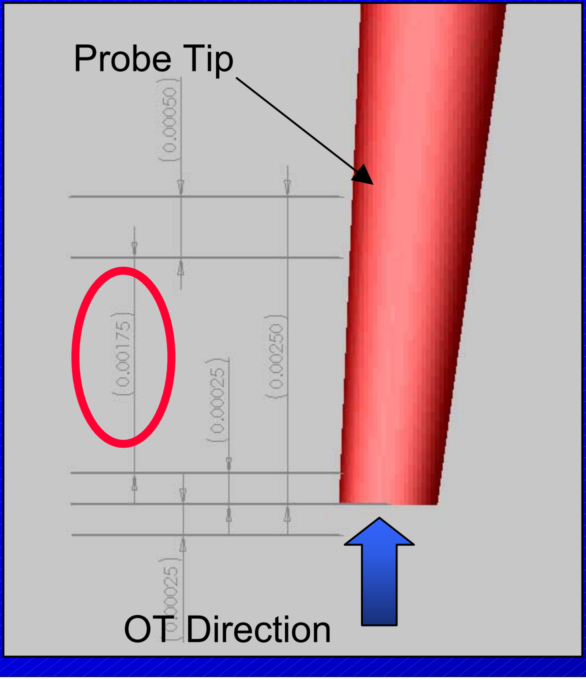
Introduction

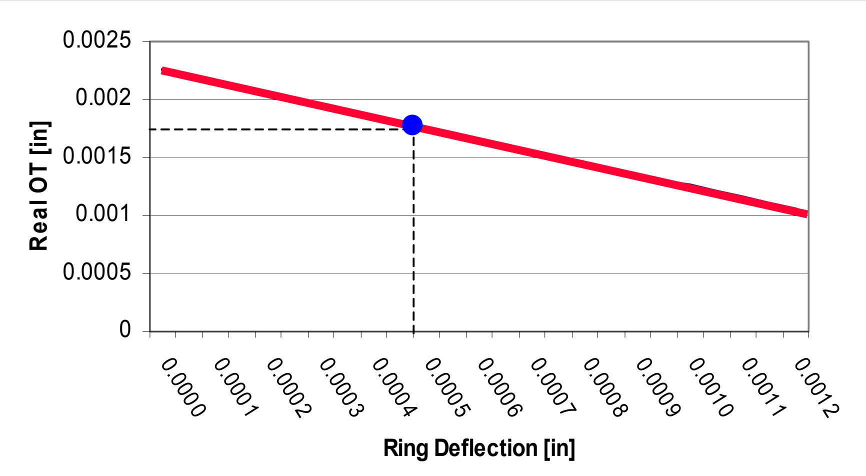


- A flat structure composed of a rigid material (ceramic) used to hold cantilevered probes
- Multi-die applications (dual die diagonal, quad (2x2), (1x4) or 1x8, or 4x4
- Straight probe layout inside the ring to accommodate fine pad pitch
- Complex shape of the probe ring fully covering a top view of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

Why structural stability is important?

Introduction





- **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%

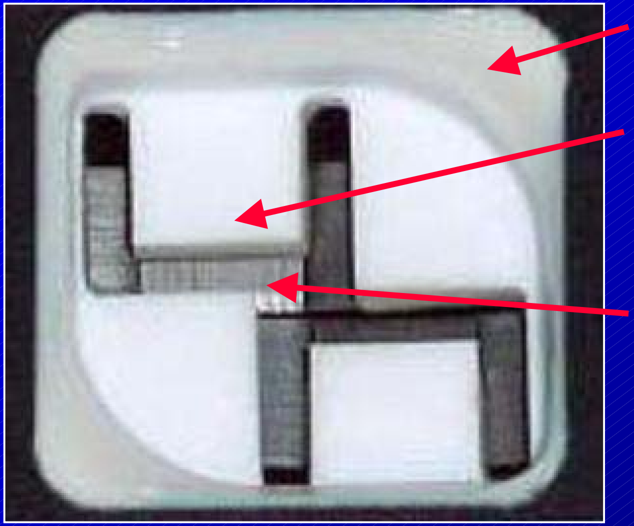
Min force per mil OT = 1.4 G

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

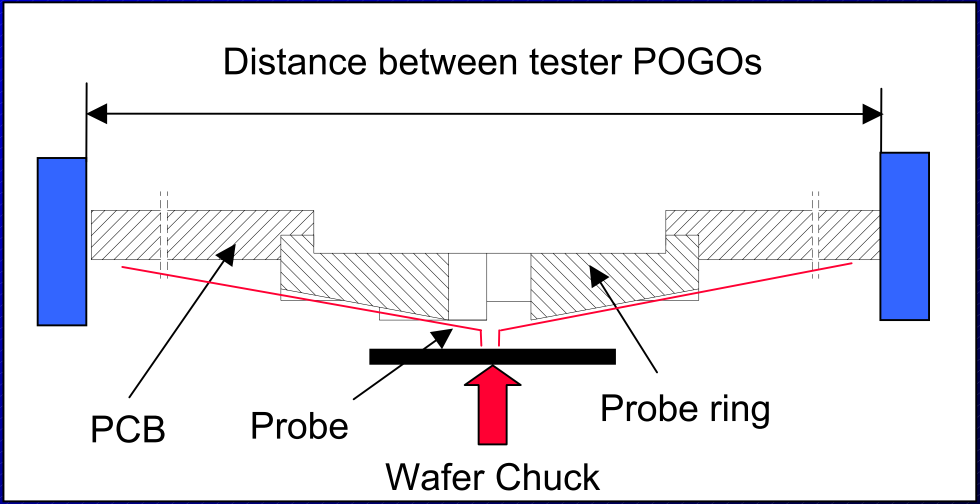
Close-up of Dual Die Ring

Introduction

Top view of the ring

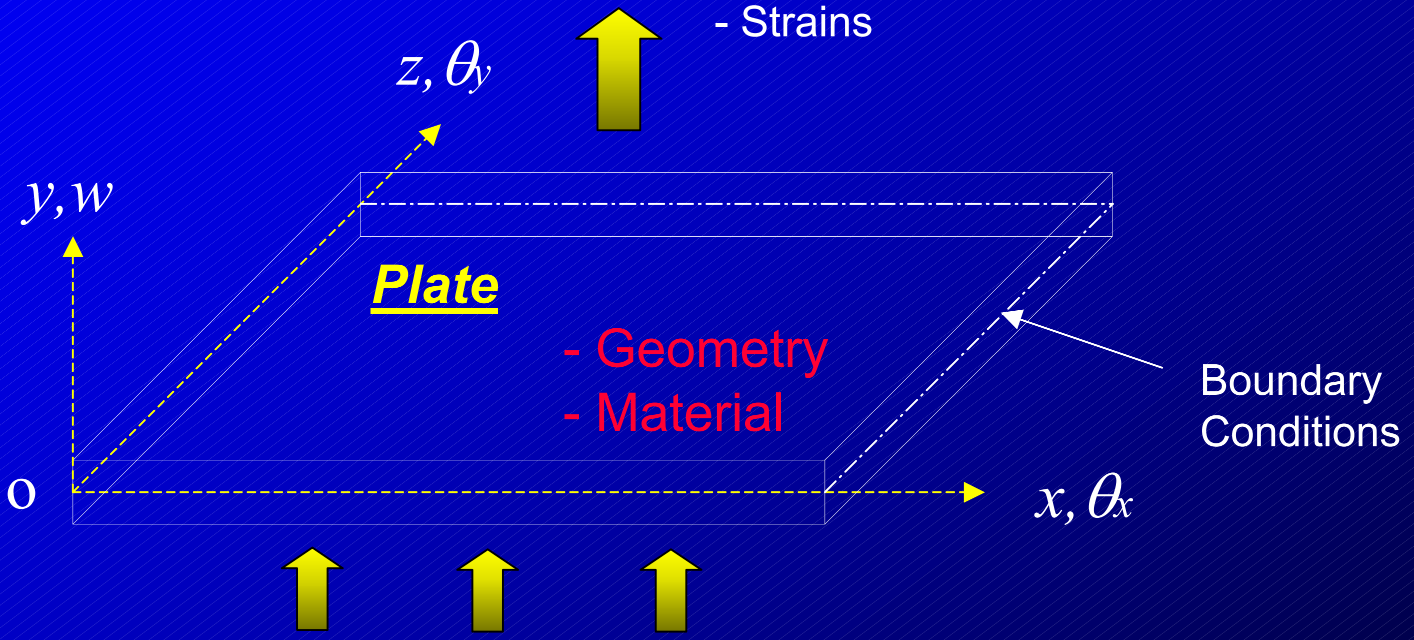


Probe card profile



Structural System

Introduction



Response

- Deflection
- Stress
- Strains

Plate

- Geometry
- Material

Action

- Loads
- Vibrations
- Thermal changes

General Analytical Solution

First Approach

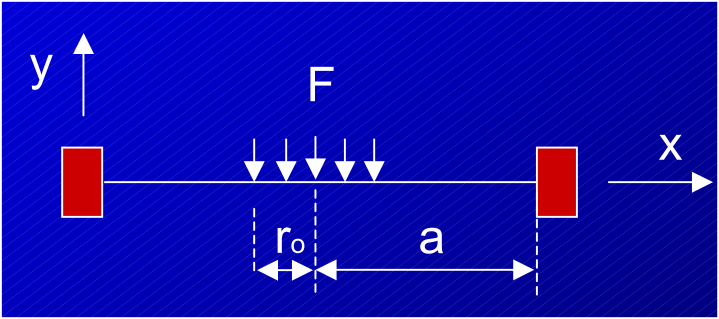
Deflection, d, of a clamped circular plate under a uniform load *F* applied over a small circular area is given by equation*:

$$d_{max} = \frac{-F\,[a^2 - r^2\,(1+2\ln\frac{a}{r})]}{16\,\Pi\,D}$$

Where *r*, *a* radial location of evaluated quantity and plate radius, respectively

$$D = \frac{E\,t^3}{12(1 - n^2)}$$ - plate flexural rigidity

E, n and t are Young's modulus, Poisson's ratio and plate thickness, respectively



Concerns:

- 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

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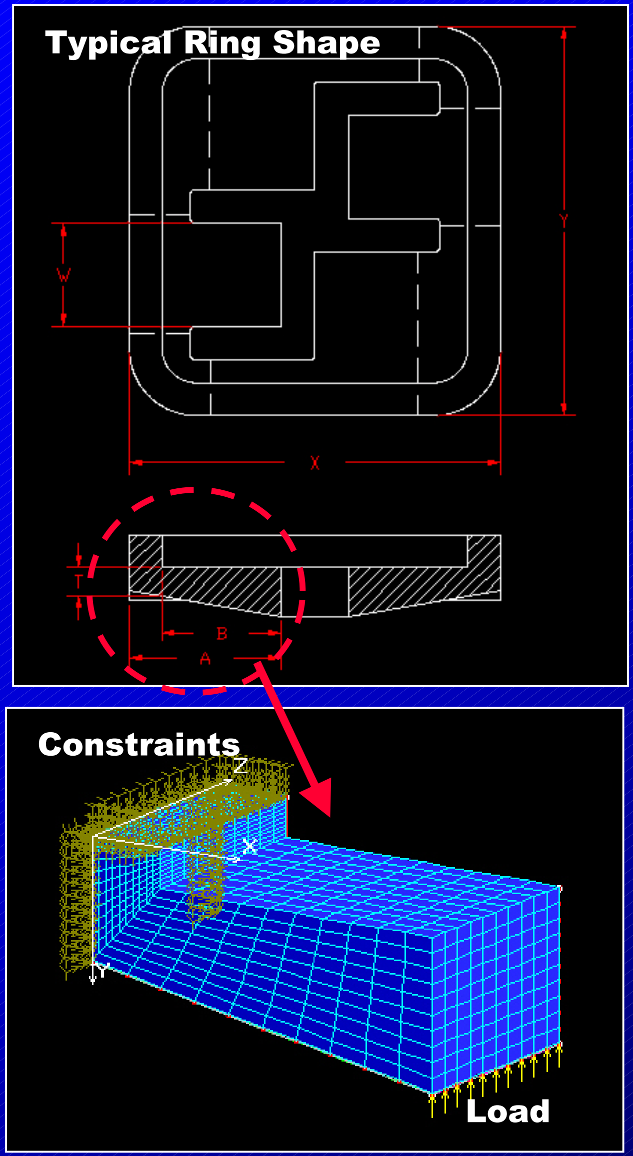
* Source: Roark's Formulas for Stress and Strain, Sixth Edition, p 433

Partial Finite Element Model

Second Approach

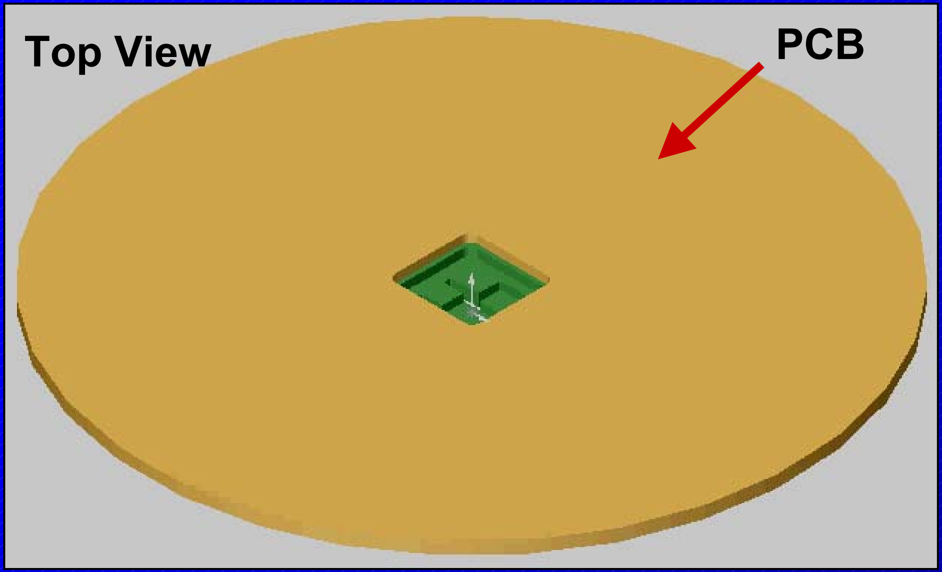


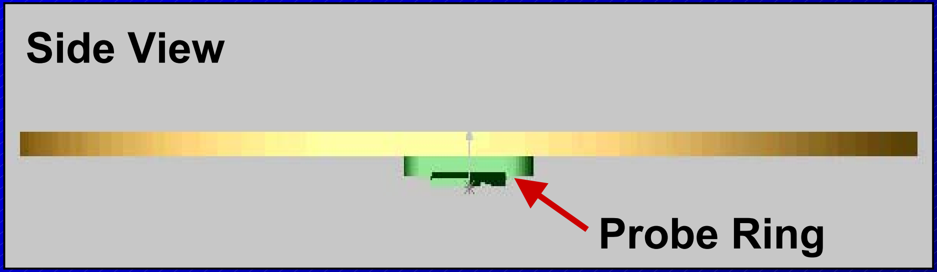
Concerns:

- 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

Full Scale Model

Third Approach



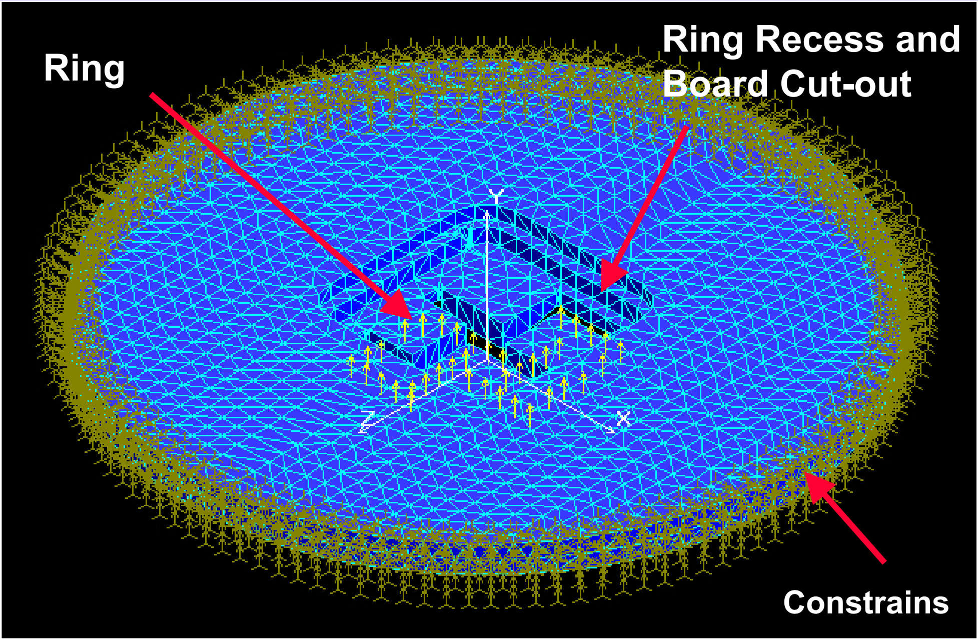


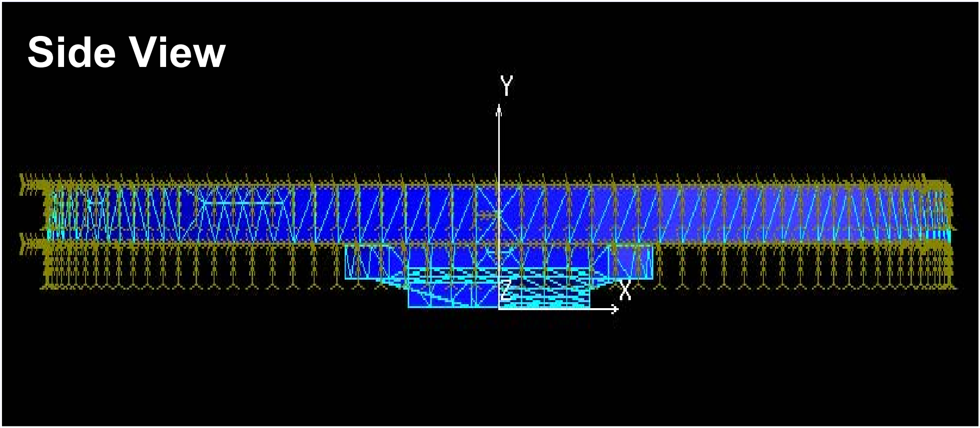
Benefits:

- 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)

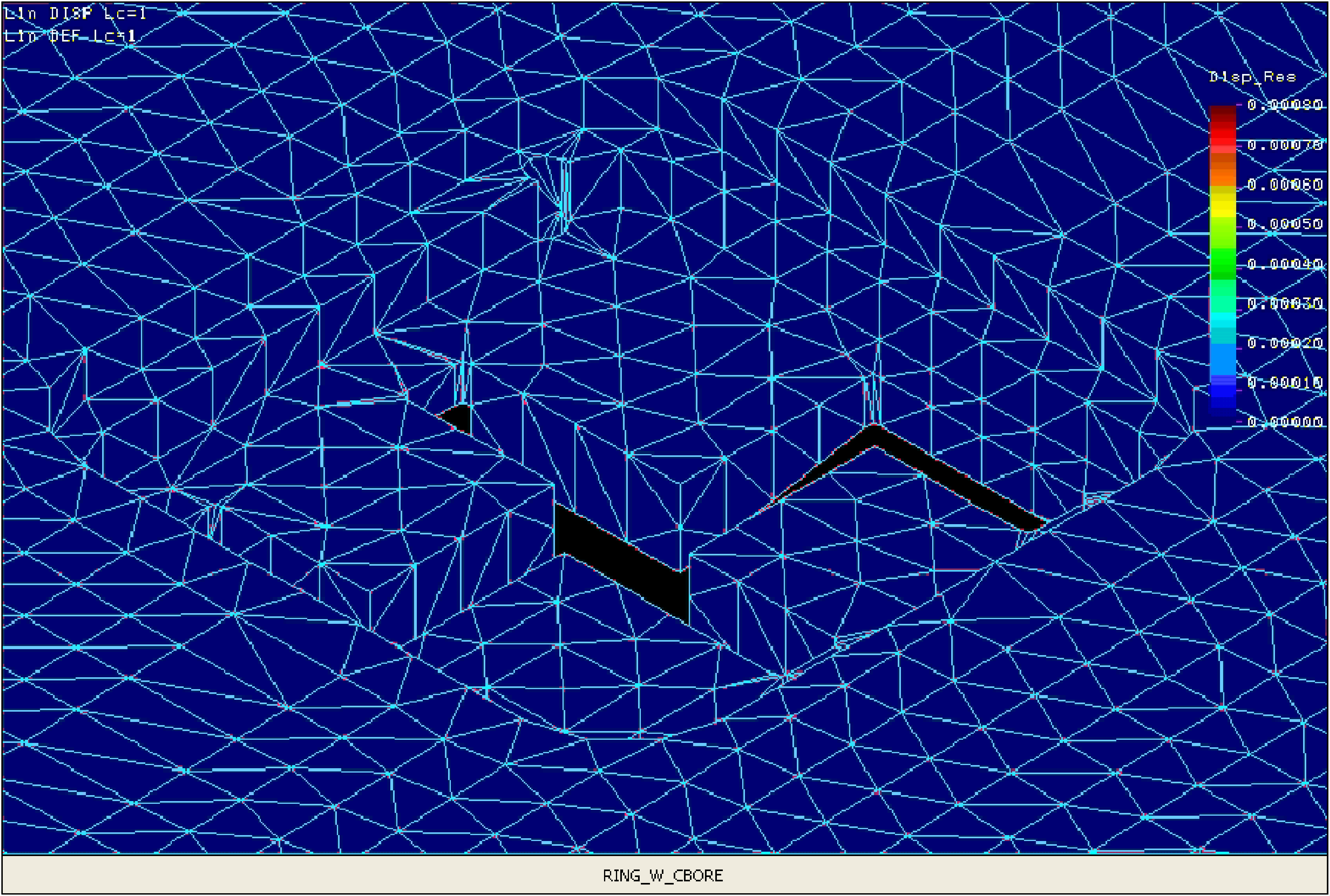
Material Properties*

		Ceramic	Copper	FR4
Young's Modulus	psi	9.70E+06	1.85E+07	3.50E+06
Poisson's Ratio		0.29	0.36	0.13
CTE	ppm/C	9.3	17	12
Flexural Strength	psi	13600	50000	60000

* Source:Accuratus Corporation, Park/Nelco

Simulation of Model Deflection

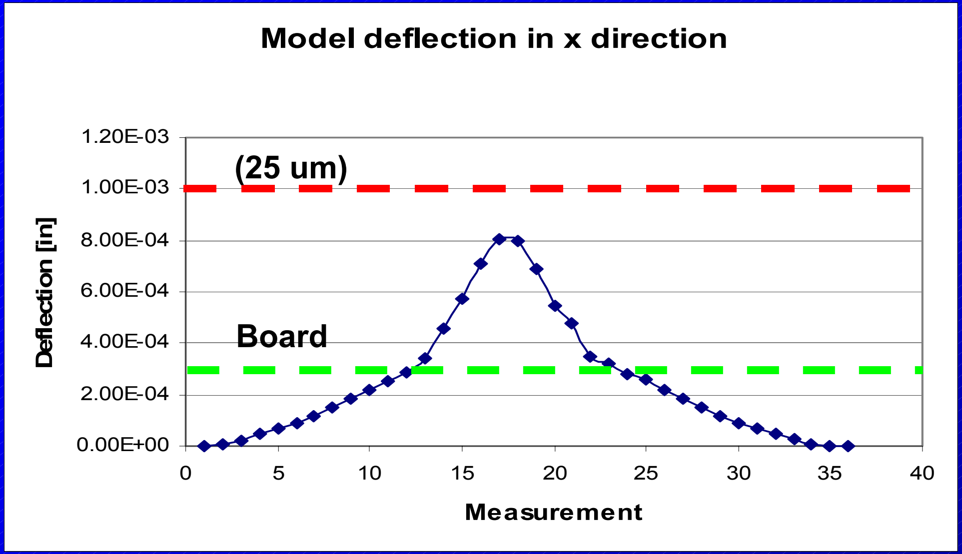
Dual Die

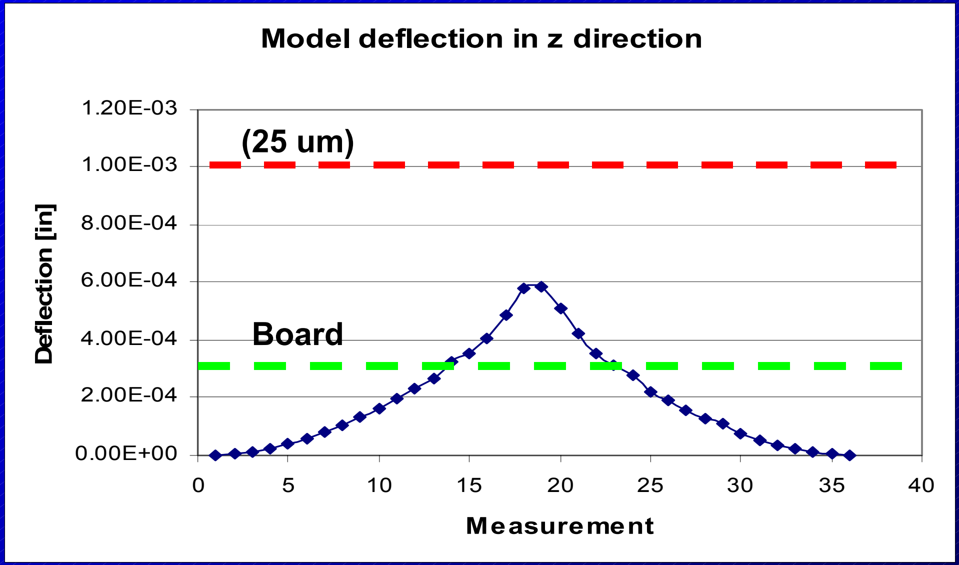


Scale x100

Dual Die

Deflection Curve Predicted by FE Model

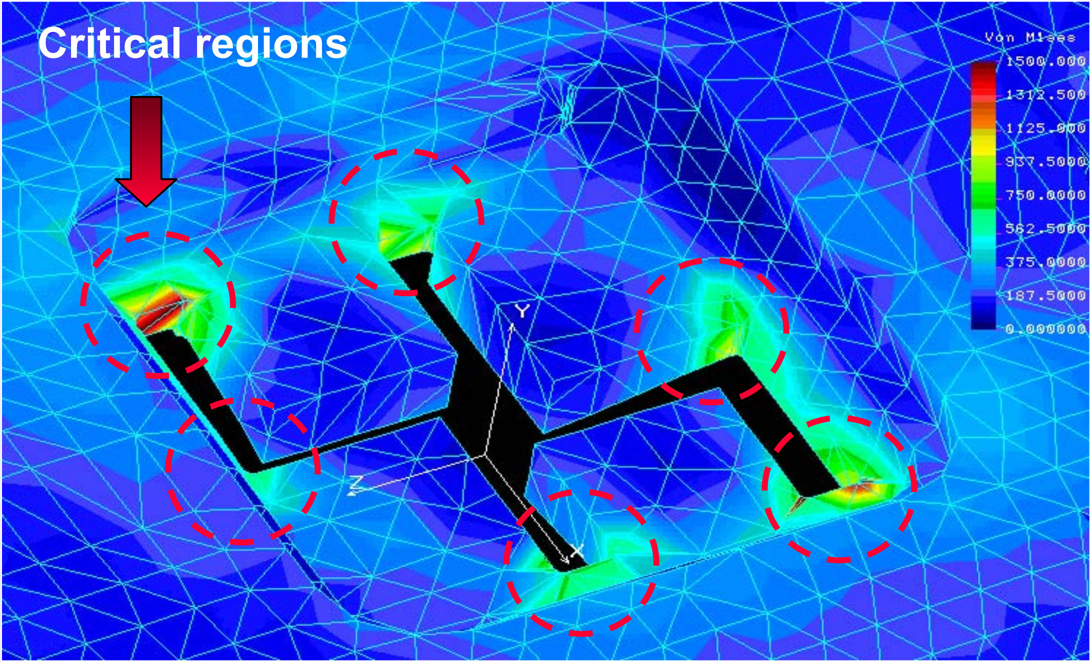




- Charts are showing a board-ring deflection in two perpendicular x and z directions
- Cantilevered shelf part of the ring deflects greater than other parts
- A deflection peak occurred on the end of shelf support
- Deflection of the PCB (short off the ring) - 0.00028 inch (7 microns)

Stress Distribution

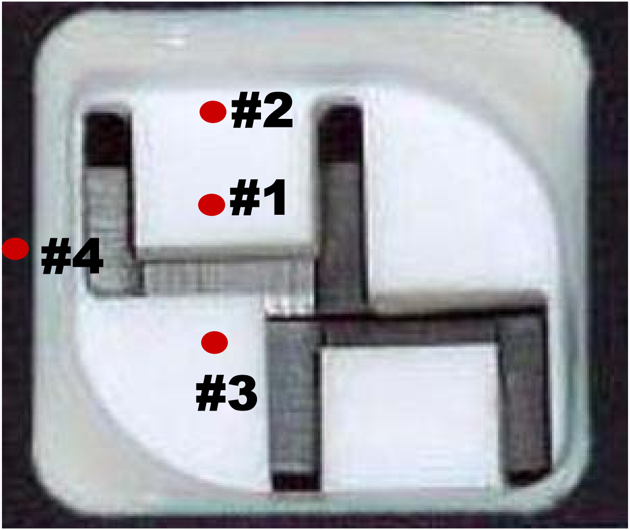
Dual Die



- 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

Validation 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

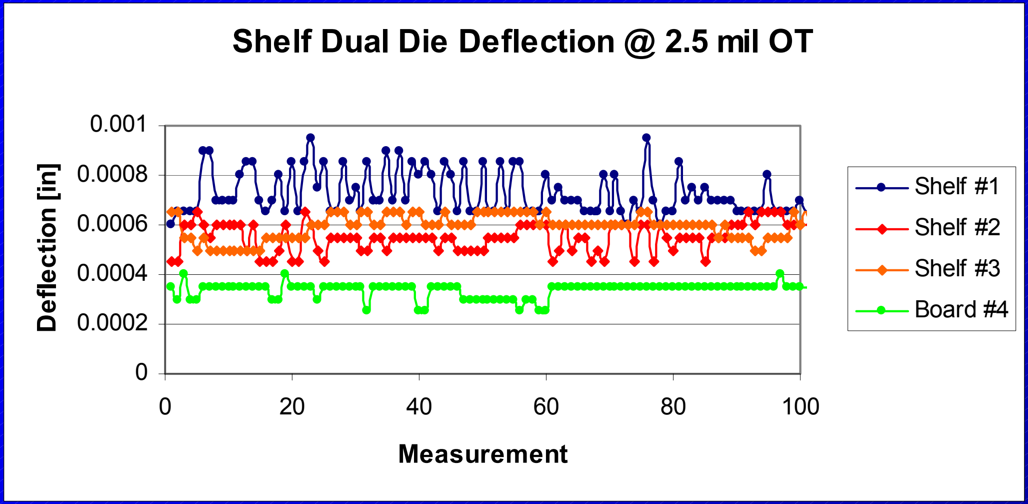
Registered Deflection at Point 1

Validation Test

Shelf_DualDie

Experimental Data

Validation Test



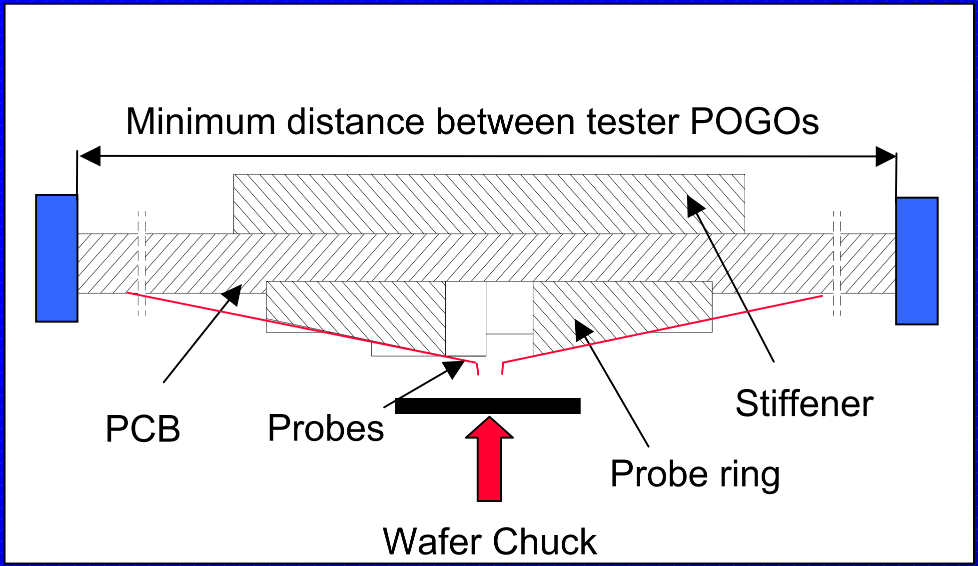
Statistical Summary

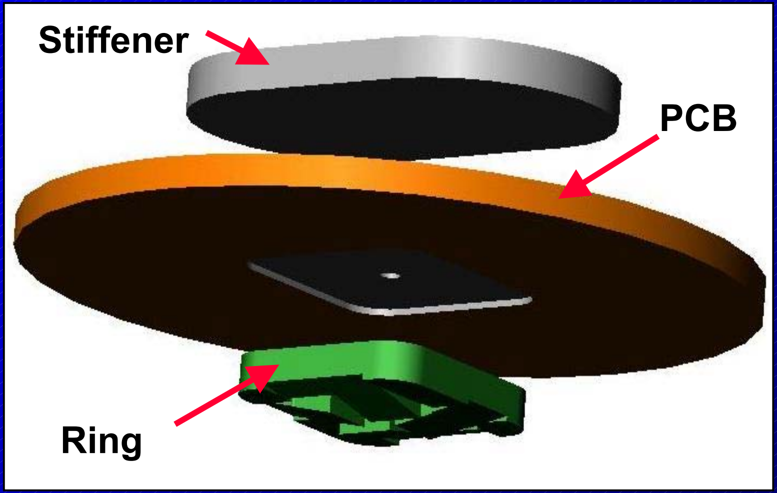
	Shelf #1	Shelf #2	Shelf #3	Board #4
	in	in	in	in
Max	0.00095	0.00065	0.00065	0.00040
Min	0.00060	0.00045	0.00045	0.00025
Mean	0.00072	0.00057	0.00059	0.00034
Std Dev	0.00009	0.00006	0.00005	0.00003

- 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

Recommended Changes

Dual Die

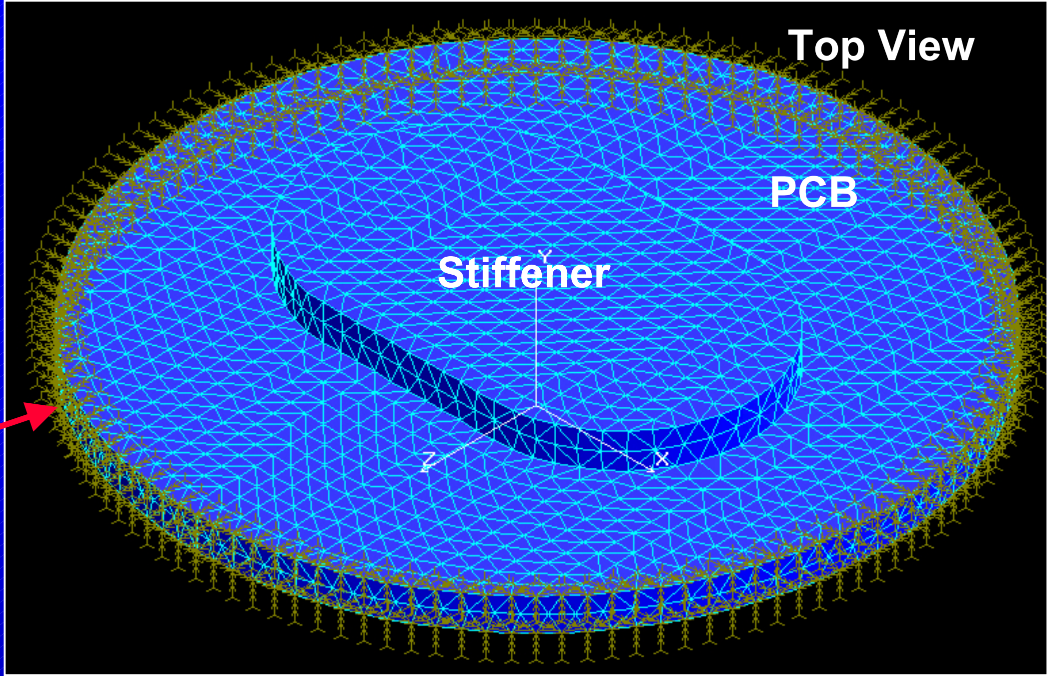




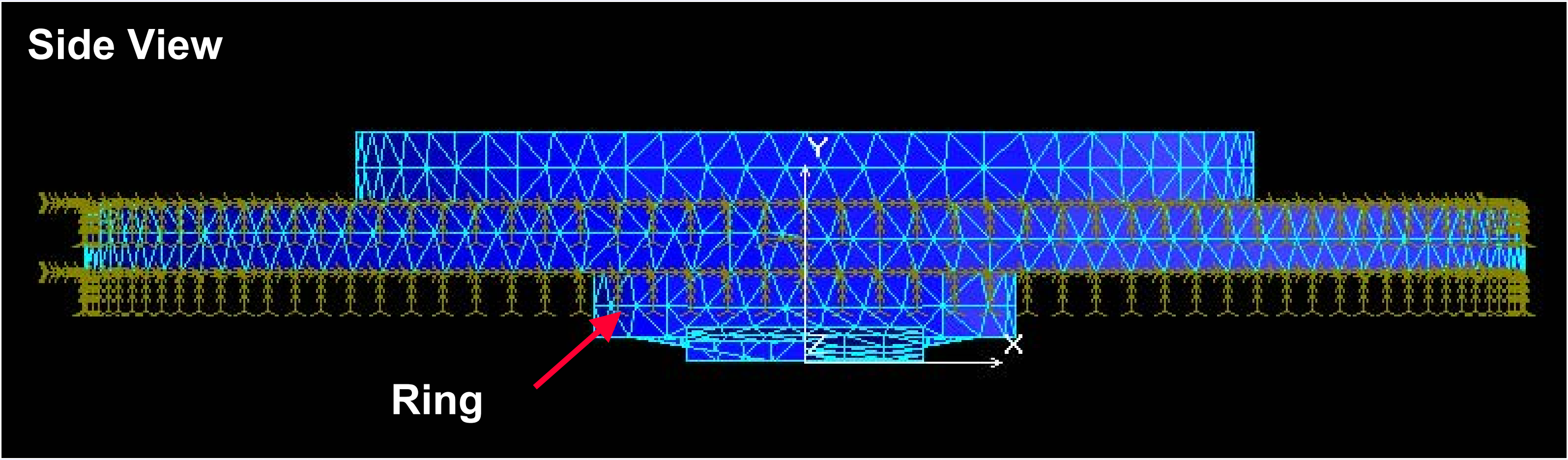
- Eliminate the ring recess
- Eliminate PCB cutout and fully support ceramic ring by board
- Minimize PCB counter bore
- Add a stiffener on the top of PCB and cover as much as possible allowed area between tester pogo

An Improved FE Model

Dual Die

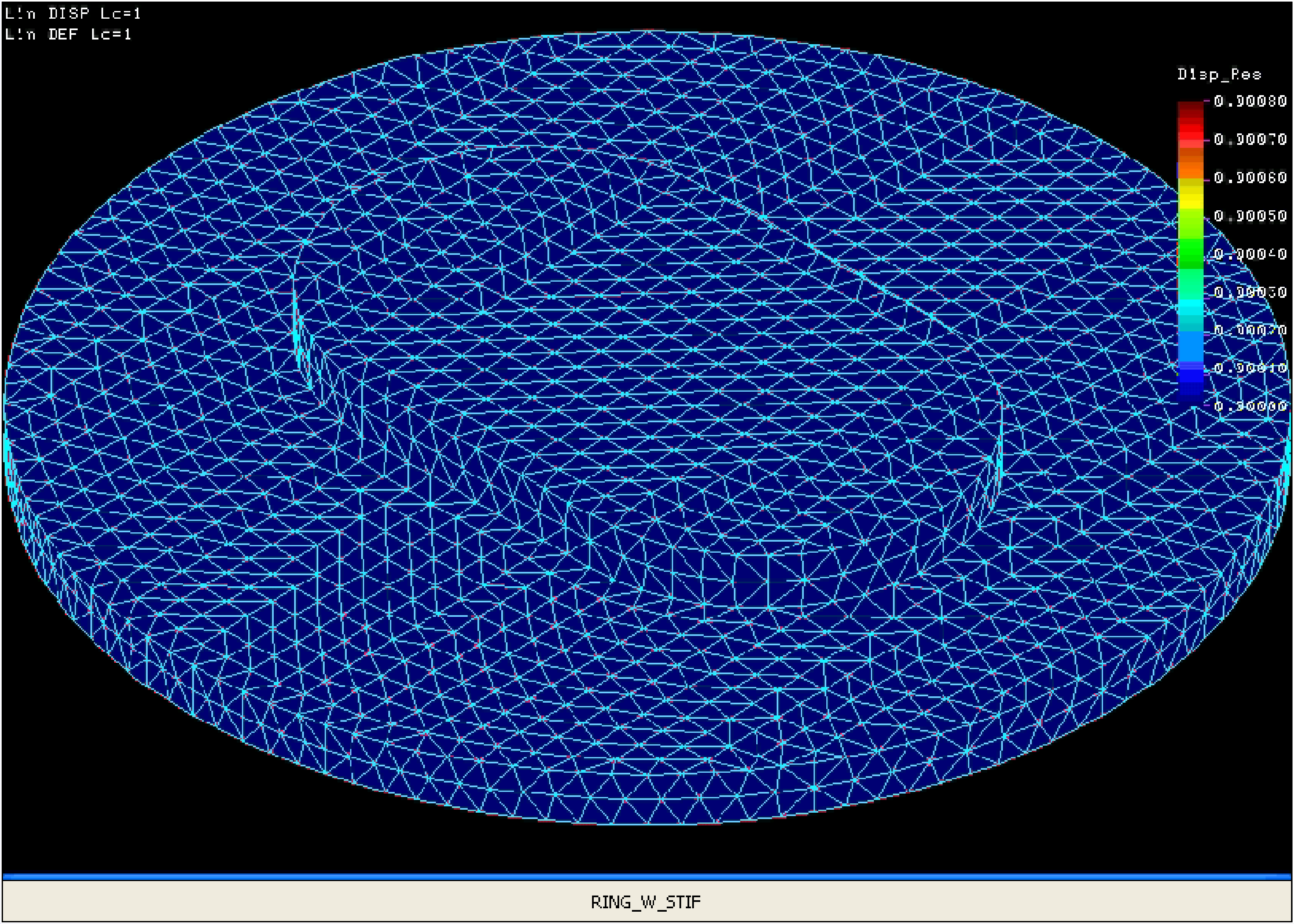


Board Constrains



New Model Simulation

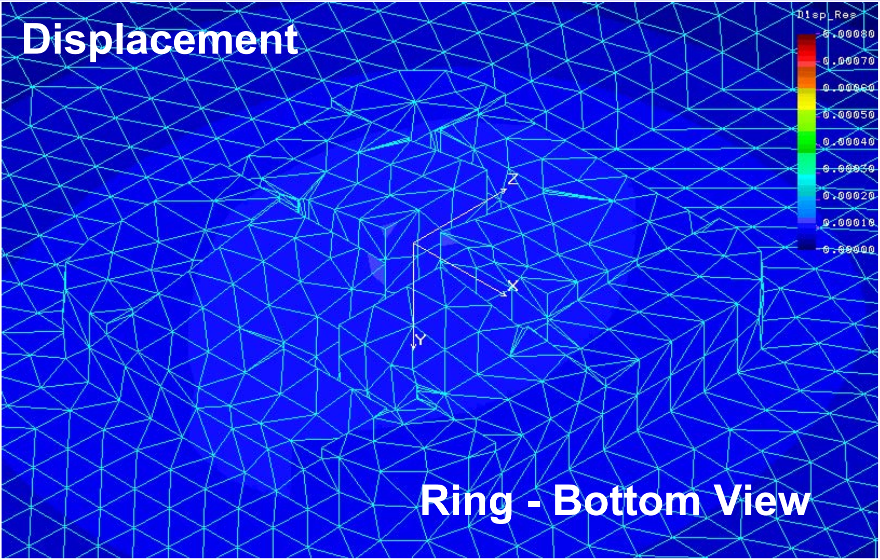
Dual Die

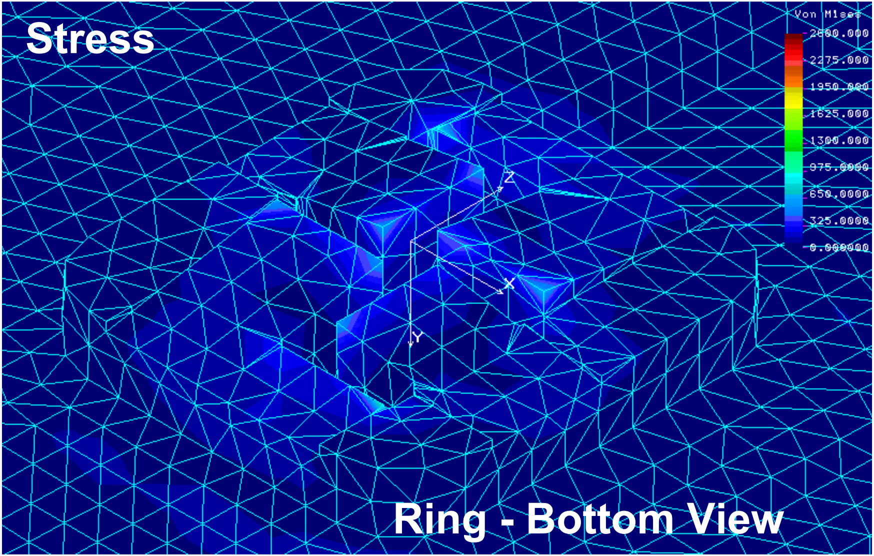


Scale x100

Post-Processing Analysis

Dual Die

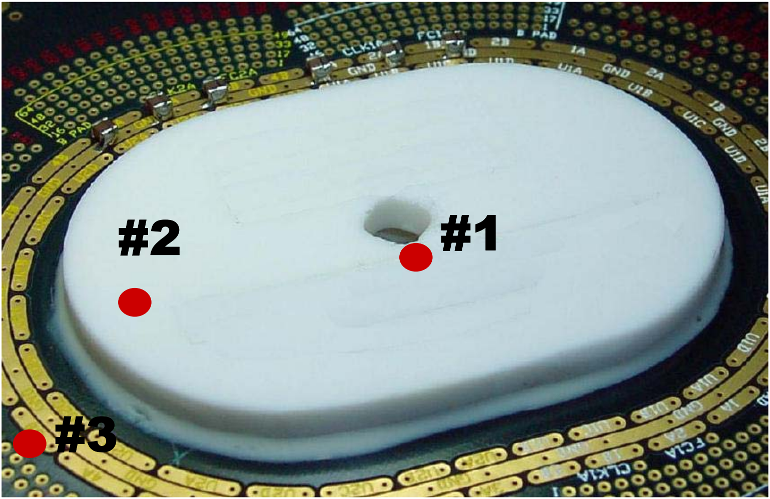


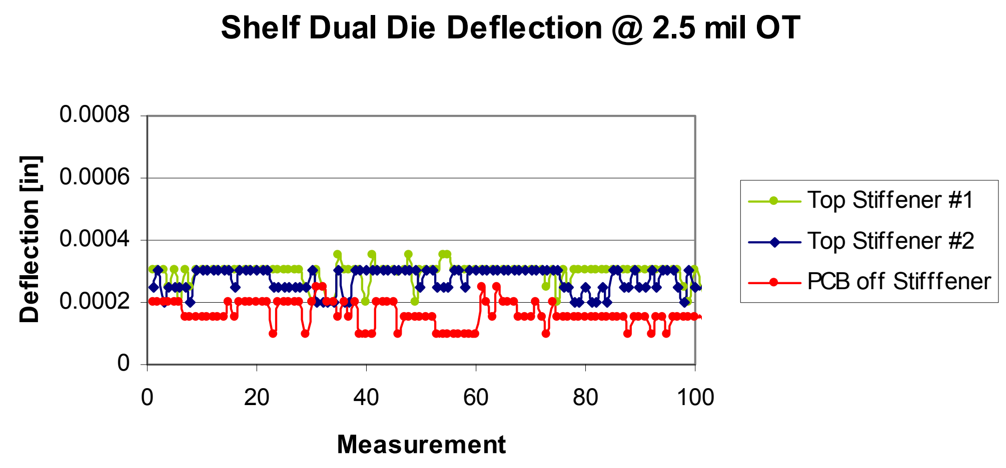


- Max ring deflection has been reduced to 0.00015 inch at total over travel 2.5 mils (60 um)
- Very uniform the ring deflection across ring area (D displacement = 0.00003 inch)
- Max calculated stress at critical regions has been reduced to 835 psi

Experimental Data - Improved Design

Validation Test





Summary Results

	Top Stiffner #1	Top Stiffner #2	PCB #3
	in	in	in
Max	0.00035	0.00030	0.00025
Min	0.00015	0.00020	0.00010
Mean	0.00029	0.00027	0.00016
Std Dev	0.00004	0.00003	0.00004

- 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

	FEA	TEST
	in	in
Shelf #1	0.00066	0.00072
Shelf #2	0.00042	0.00057
Shelf #3	0.00046	0.00059
Board #1	0.00025	0.00034

Max Stress
psi
2600

Deflection after changes

	FEA	TEST
	in	in
Top Stif #1	0.00013	0.00029
Top Stif #2	0.00011	0.00027
PCB #3	0.00009	0.00016

Max Stress
psi
835

- 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