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Supplemental Papers

"Sources Of Variation And Error In Finite Element Analysis"
Mike Gedeon — Brush Wellman, Inc.

"Cost & Performance Optimization Of Air-cooled Burn-in Socket Thermal Design"
Hongfei Yan — Intel Corporation

Sources of Variation and Error in Finite Element Analysis

2006 Burn-in and Test Socket Workshop

March 12 - 15, 2006

Mike Gedeon
Brush Wellman Inc.

What is FEA?

- Analysis involving complicated geometry & boundary conditions
  - Gives clues about design problems
  - Changes in electronic model are cheaper than changes in physical tooling
  - Reduces number of prototype models and tooling changes

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Types of Modeling

- Mechanical (Stress)
- Electromagnetic (High/Low Frequency)
- Thermal (Heat Transfer)
- Dynamic (Frequency Response, Vibration)
- Fluid Dynamics
- Fatigue
- Design Optimization
- Combination

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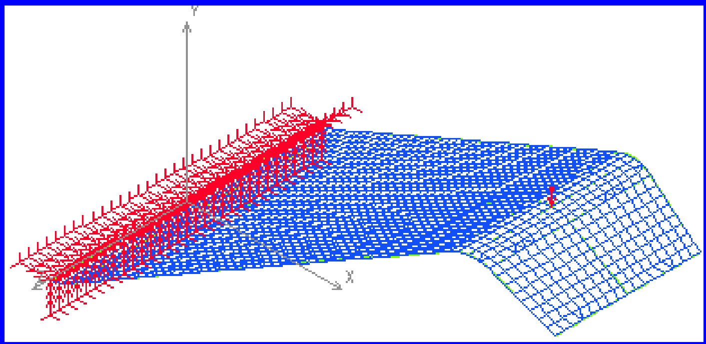
How does FEA work?

- Meshing - complicated part is divided into many smaller, simply shaped elements intersecting at points called nodes



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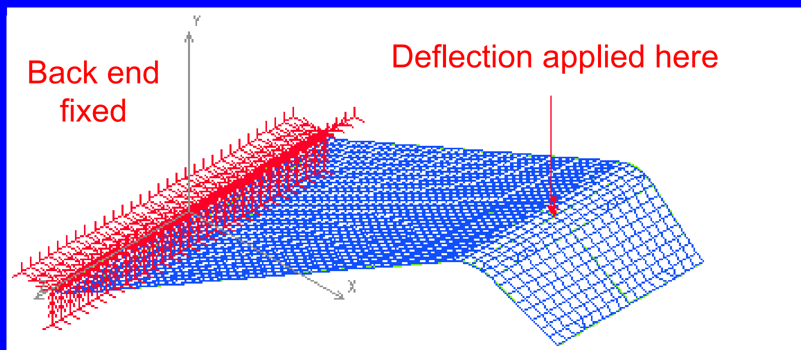
Loads & Boundary Conditions

- Describe model interaction with environment



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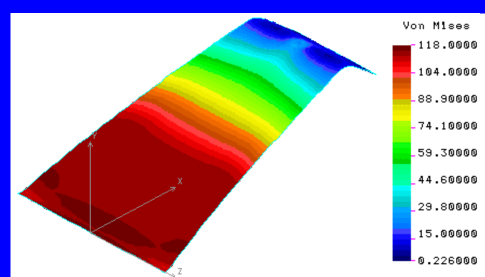
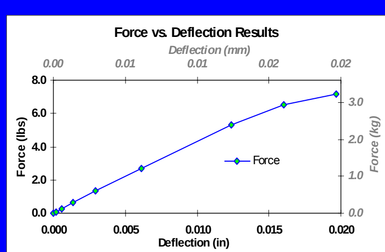
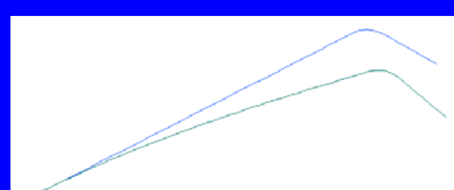
Typical Mechanical FEA Results

- Stress Distribution Plots





- Force-Deflection Curves



- Permanent Set Plots

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FEA Models v. Reality

- FEA is only a model
- Accuracy depends on assumptions
- Accuracy, solution time ∝ element type, size
- Interpolated results ≈ actual behavior

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Sources of Variation

- – Oversimplification of model
- – Element type/size
- – Nonlinearities
- – Definition of boundary/initial conditions
- – Frictional effects
- – Stiffness singularities
- – Dimensional tolerances
- – Property variation
- – Residual stresses
- – Edge condition/cross-section uniformity

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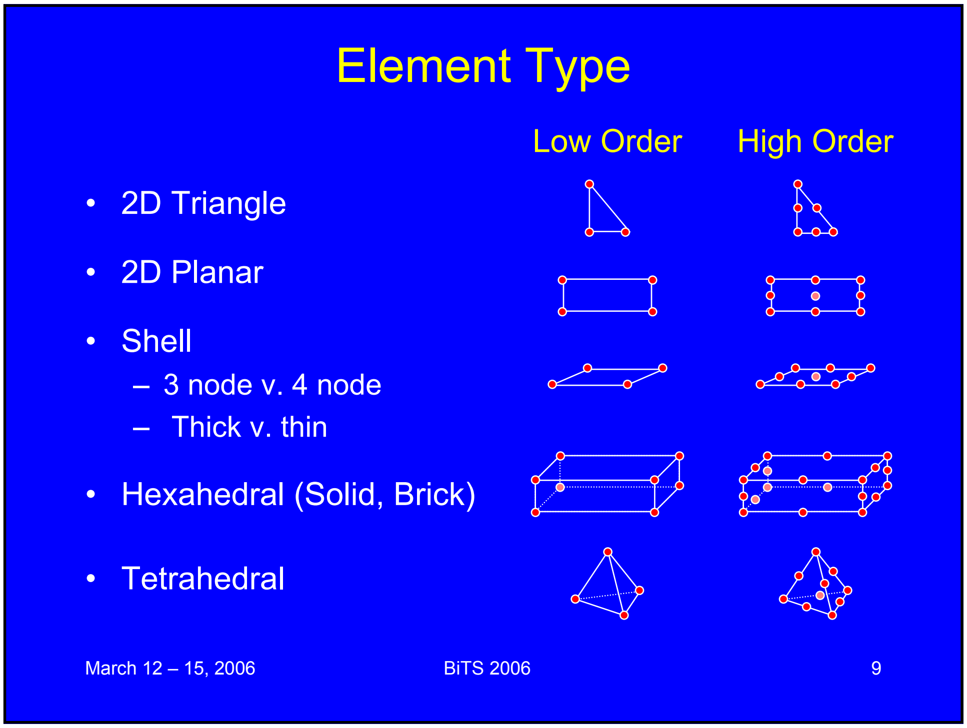
Element Type
Low Order
High Order
• 2D Triangle
• 2D Planar
• Shell
– 3 node v. 4 node
– Thick v. thin
• Hexahedral (Solid, Brick)
• Tetrahedral
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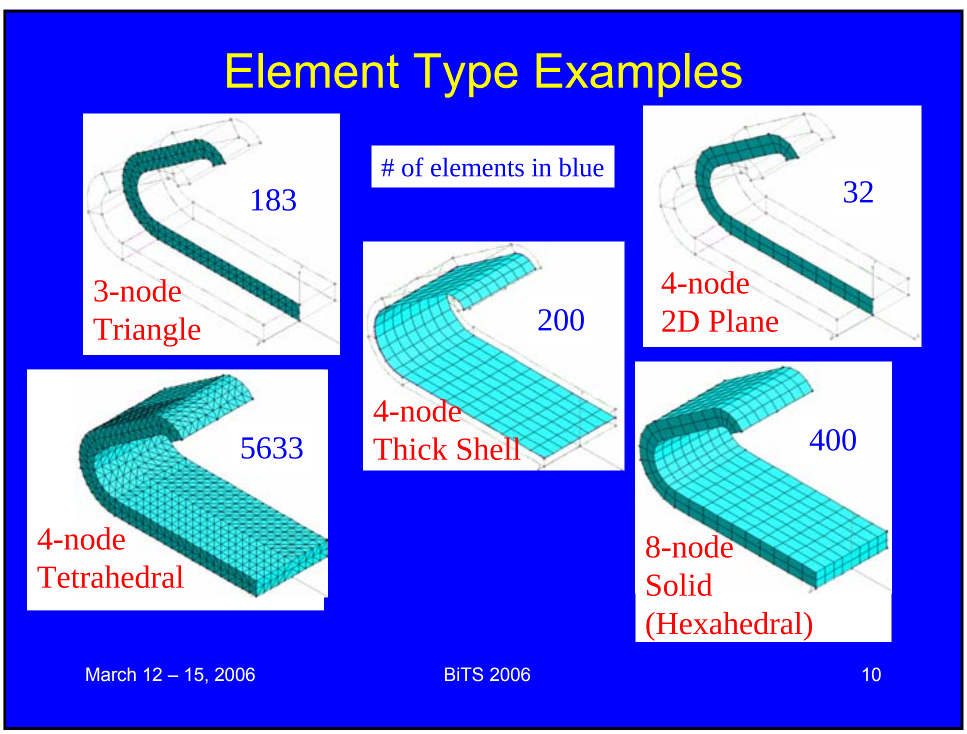
Element Type Examples
# of elements in blue
183
3-node Triangle
200
4-node Thick Shell
32
4-node 2D Plane
5633
4-node Tetrahedral
400
8-node Solid (Hexahedral)
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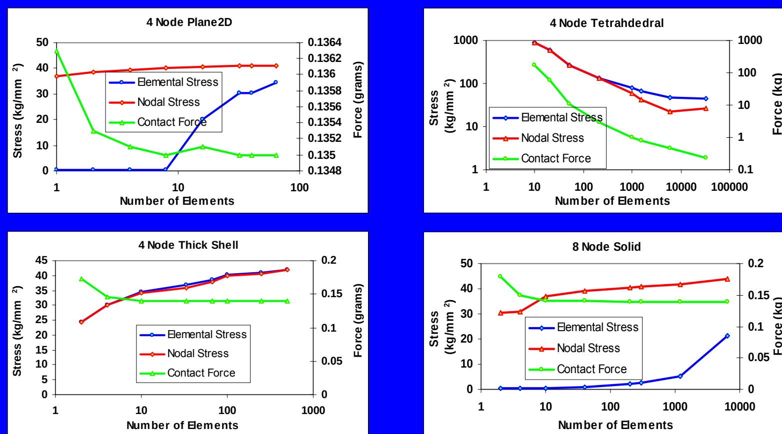
Effect of Mesh Size

- Accuracy inversely proportional to mesh size



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Nonlinearities

- Large deflection
- Material nonlinearities
- Contact

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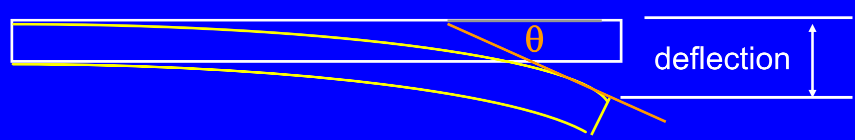
Large Displacement

- Many FEA calculations rely on small angle assumptions (e.g., sine θ ≈ θ, cosine θ ≈ 1)
- The large displacement option should be selected if the deflection is greater than the material thickness



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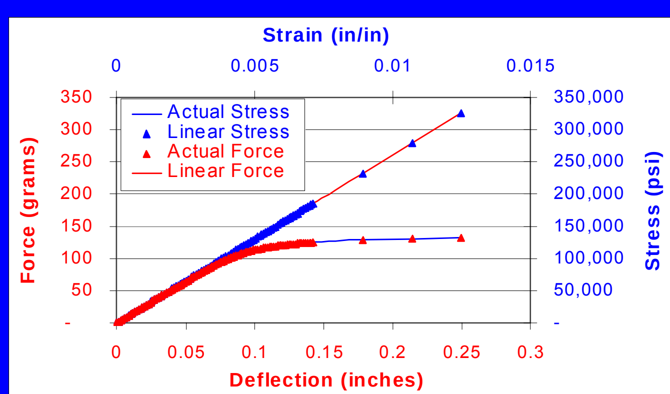
Material Nonlinearities

- Force-Deflection curve ≈ Stress-Strain curve)



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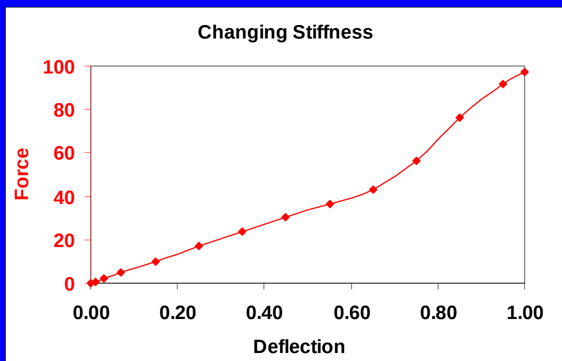
Contact

- Contact = change in model stiffness

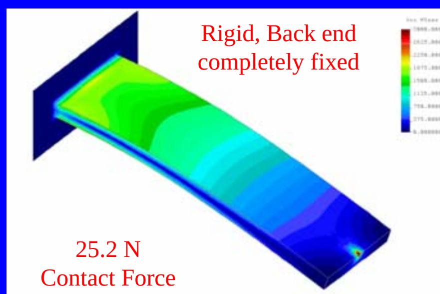


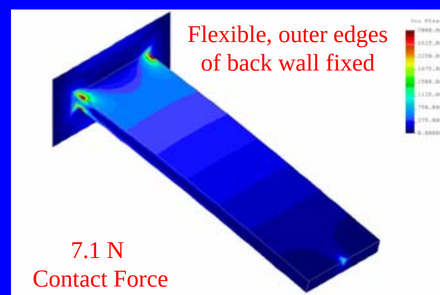
Boundary Conditions

- Rigid v. flexible
- Applied deflection/force v. contact elements
- Contact boundary condition v. fixity
- Friction neglected/included

Rigid v. flexible BC's

- FEA models often assume completely fixed boundary conditions
- In reality, plastic housing that holds contacts in place may be somewhat flexible





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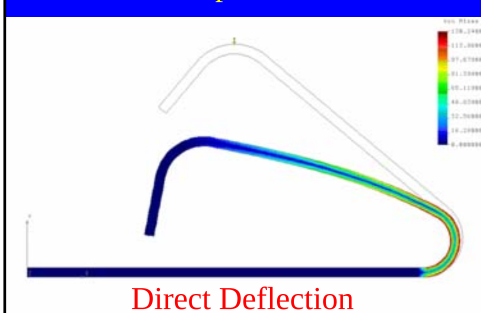
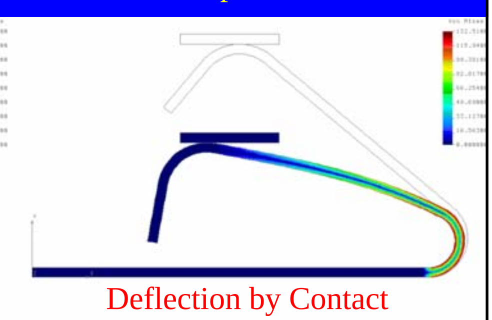
Applied load v. contact surface

- Deflection can be applied directly to a node, or 2nd object can be used to deflect the first.

230 grams contact force
0.06 mm permanent set

265 grams contact force
0.18 mm permanent set





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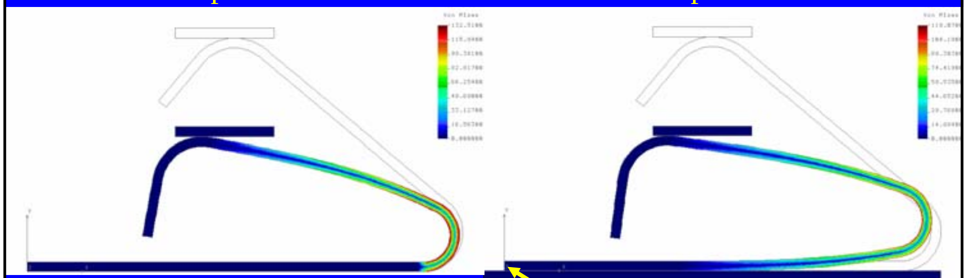
Contact BC v. fixity

- Is the entire bottom leg of the contact really fixed as the drawing may indicate, or is it just resting on another surface?

265 grams contact force
0.18 mm permanent set

202 grams contact force
0.00 mm permanent set



Entire Bottom Fixed

Only Back Edge Fixed

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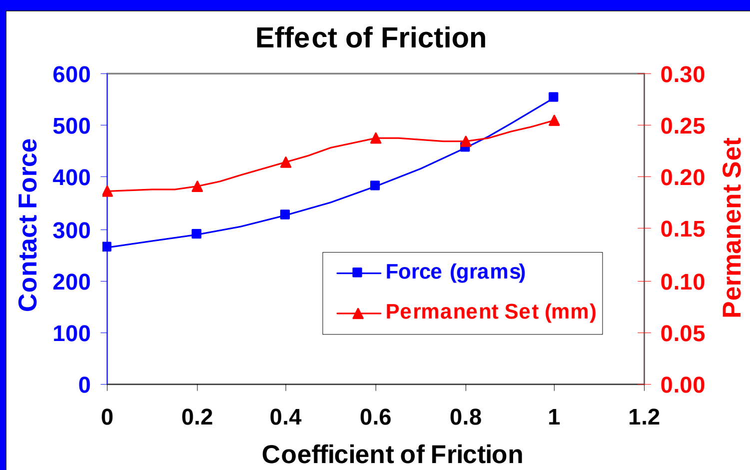
Friction Effects



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Paper #1

Stiffness Singularities

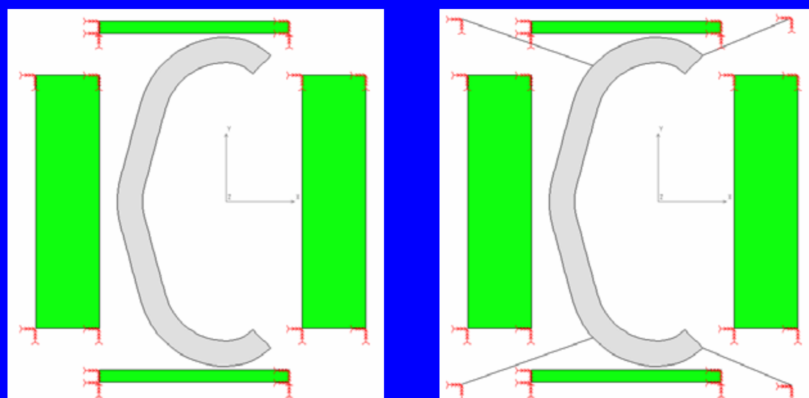
- Insufficiently constrained models
- Snap-through action
- Buckling/instability

Stiffness Singularities

- Insufficiently constrained models
  - In the real world, friction and gravity are enough to hold a part in a stable configuration, without specifically holding it rigidly in place
  - In FEA, the model must be constrained somewhere, or the stiffness matrix will be singular and the analysis will not run

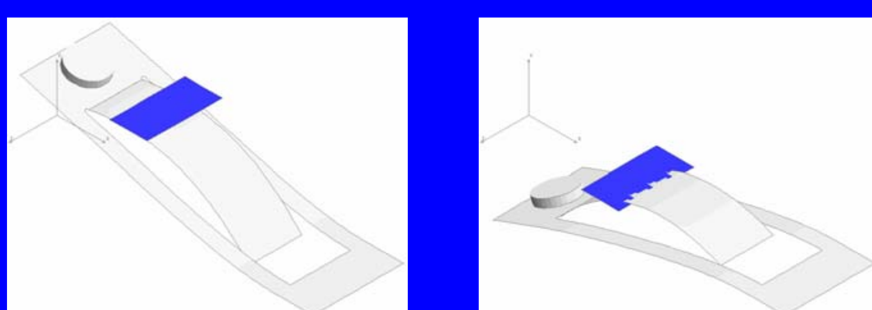
Stiffness Singularities

- Example: Loose LGA Contact
  - Contacting surfaces are fixed, but LGA contact is not
  - Soft springs provide fixity with minimal impact on solution



Stiffness Singularities

- Snap action
  - Abrupt change from one equilibrium position to another



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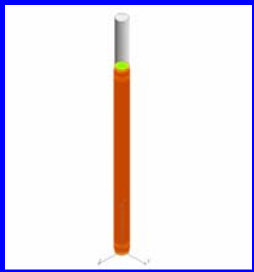
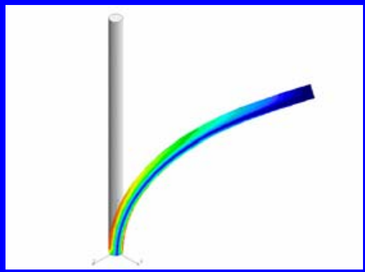
Stiffness Singularities

- Buckling
  - Tall, thin columns with axial compression
  - Occurs at stresses below yield strength
  - Abrupt transition to rapidly accelerating failure

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Dimensional Tolerances

- FEA assumes all dimensions are at the nominal value specified on the drawing
- Actual part dimensions will vary from nominal due to
  - Springback
  - Heat treating distortion
  - Tool wear

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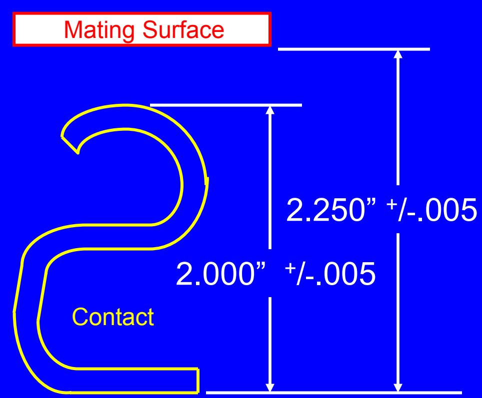
Tolerance Stack-up Example



Initial Gap =
0.250" +/- 0.010"

Gap tolerance is double the individual tolerances

Mating surface to travel 0.500"+/- 0.005 downward for actuation

Nominal deflection = 0.250"
Minimum deflection = 0.235"
Maximum deflection = 0.265"

All initial tolerances are 0.005" but deflection tolerance is 0.015", 3X greater.

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Material Property Variation

- Tolerances: nominal v. min. / max.
- Directionality: longitudinal v. transverse
- Homogeneous solid v. actual microstructure
- Edge condition from manufacturing processes
- Residual stress & the Bauschinger effect

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Property Tolerances

- Every coil of strip material produced is unique
- Important properties like strength, elongation, and modulus will vary from coil to coil and from point to point within a single coil
- FEA will usually assume nominal or average properties for the material

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Property Directionality

- Many materials show anisotropic properties
  - Data sheets usually based on longitudinal properties
  - Transverse properties of Cu alloys are typically 5% higher than longitudinal
  - Compression stress-strain curve may not equal tensile stress-strain curve
- Largest differences show mostly in heavily cold worked materials

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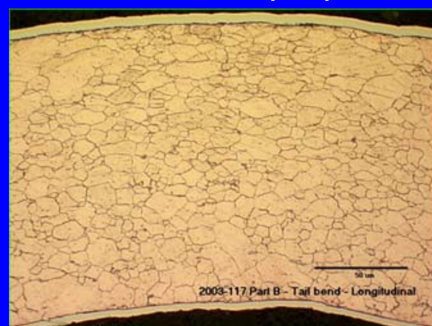
Microstructure

- FEA assumes a homogenous structure with continuous properties (OK in large parts)
- In very small parts, microstructural variations can result in non-uniform properties



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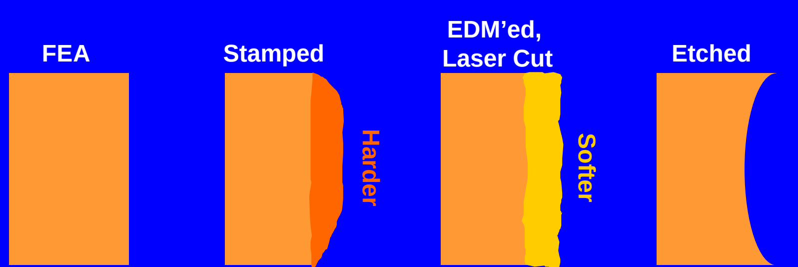
Edge condition

- Stamping - edges harder than nominal
- EDM, Laser cut - edges softer than nominal
- Photo / Chemical Etching - hourglass edges



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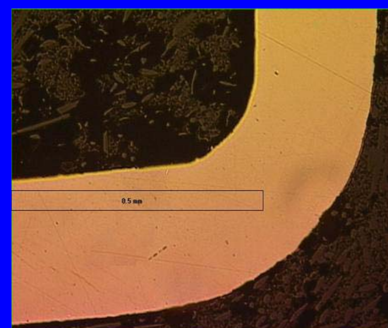
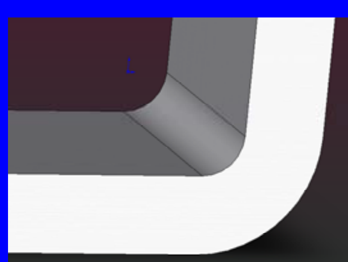
Thinning and Stretching

- Models assume uniform cross sections
  - Reality: materials thin and stretch in the die

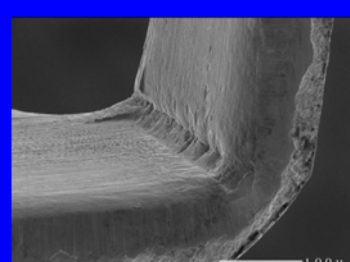


Stress risers

- Natural Stress Risers
  - Increase stress in surrounding areas
  - Burrs, scratches, tooling marks, fatigue cracks etc.



Model



Stamped Part

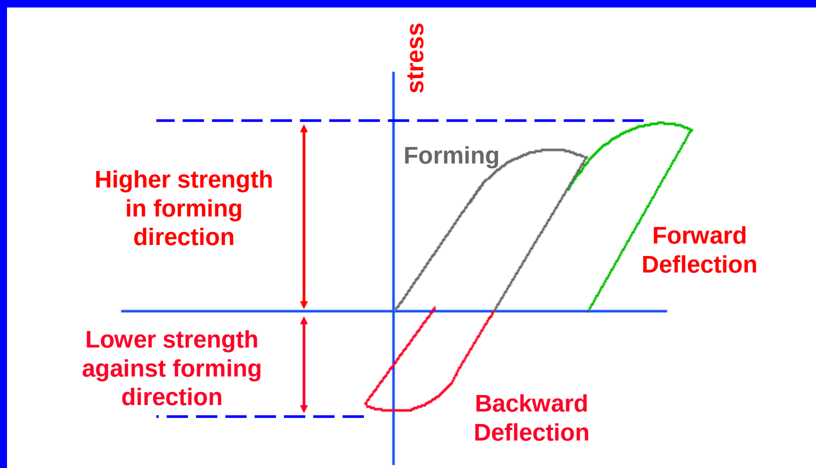
Residual Stresses

- Residual stress v. stress-free initial state
  - Created by forming, blanking, slitting etc.
  - Can be reduced by stress relieving or eliminated by age hardening after forming.
  - Can interact with the operational stresses
  - FEA typically assumes a stress-free initial state in the part; therefore the model can significantly underpredict stress and miss potential problems.

Bauschinger Effect

- Forming operations work harden the base metal and impart residual stress
  - Deflections in forming direction – residual stress effectively increases yield strength
  - Deflections against the forming direction – residual stress stress effectively decreases yield strength

Bauschinger Effect



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Model Validation

- FEA is an excellent predictor of stress, force, etc., within the limits of the boundary conditions
- Models are approximations – always validate by making and testing prototypes
- Other factors must also be considered when designing contacts (e.g. stress relaxation, formability, contact resistance, and operating environment).

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Cost & Performance Optimization of Air-cooled Burn-in Socket Thermal Design

2006 Burn-in and Test Socket Workshop

March 12 - 15, 2006

Hongfei Yan
Intel Corporation

Agenda

- Introduction
- BIS Thermal Resistance
- Factors Impacting BIS Thermal Performance
- Optimization of BIS Thermal Design
- Heat Sink Cost Consideration
- Summary

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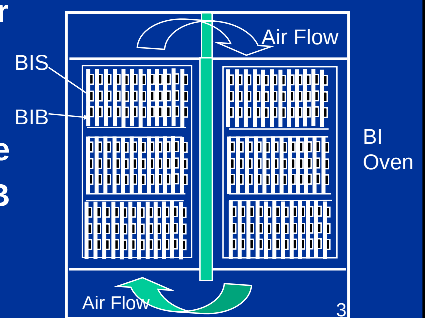
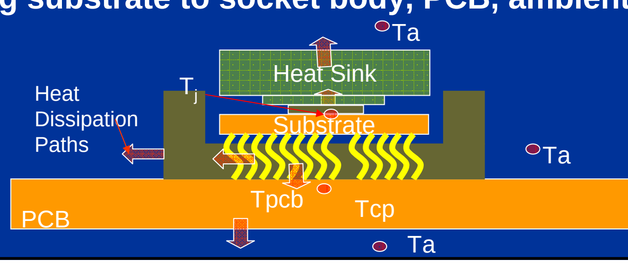
Introduction

- Burn-in "Ovens"
  - Convection Air Cooling
  - Liquid Cooling
  - Refrigeration
- Burn-in Board and Burn-in Socket
  - Built-in Heat Sink in BIS for Air-cooled Burn-in System
  - Limited Size of Heat Sink
    - Board to Board Distance
    - Number of DUTs per BIB
    - Handler Constraints



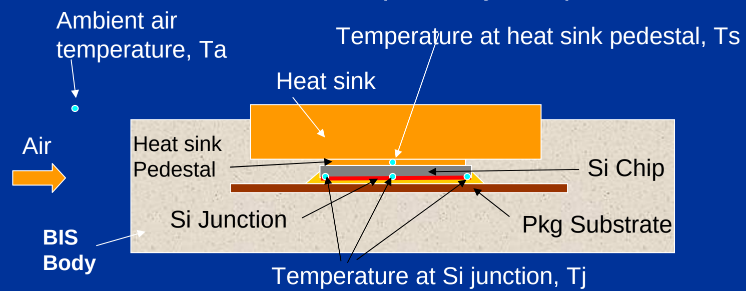
BIS Heat Dissipation Paths

- Primary Heat Dissipation Path:
  - Die junction to package surface
  - Package surface to heat sink pedestal
  - Heat sink pedestal to heat sink surface
  - Heat sink surface to ambient air
- Secondary Heat Dissipation Path
  - Die junction to package substrate
  - Pkg substrate to socket body, PCB, ambient air



BIS Thermal Resistance Budget (bare die example)

- **Only Primary Heat Dissipation Path Considered:**
  BIS thermal resistance = (Max. Tj – Ta) / Power to DUT



Typical Thermal Resistance Distributions:

Heat sink thermal contact resistance (TIM)	**~ 20%**
Conduction within heat sink	**~ 10%**
Convection from heat sink surface to air	**~ 70%**

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Key Factors Impacting Socket Thermal Performance

- **Air Flow to BIS**
  - **Flow Speed/Flow Pattern**
  - **Socket Body Blockage**
- **BIS Heat Sink**
  - **Heat Sink Size/Material**
  - **Heat Sink Pedestal Geometry**
  - **Contact Pressure to DUT**
  - **Thermal Interface Material**
- **DUT**
  - **Die size**
  - **With/without integrated Heat Spreader**

Focus of Performance and Cost Optimization

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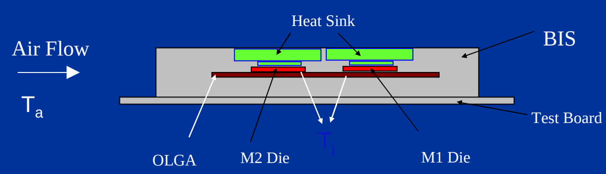
Paper #2

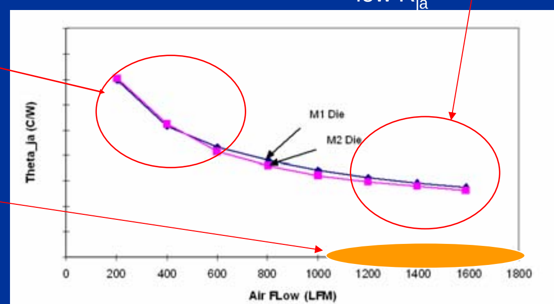
Air Speed Impact to BIS Thermal Performance



Setup for Wind Tunnel Testing

High Air Speed, low R_{ja}

Low Air Speed, high R_{ja}



Ensure air speed to socket heat sink in optimum performance range

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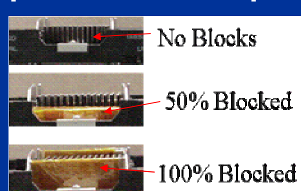
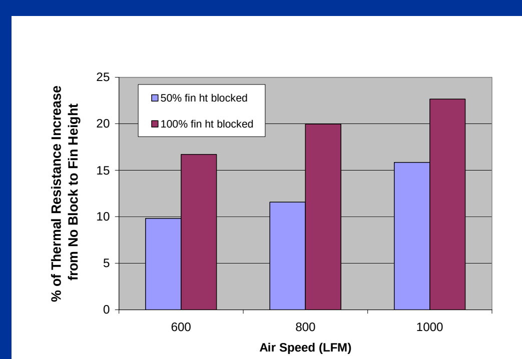
Impacts by Socket Body Blockage to Heat Sink Fins

- Design socket body to avoid blockage to air flow to heat sink as blockage has significant thermal performance Impact





- The impact increases as air speed increases.

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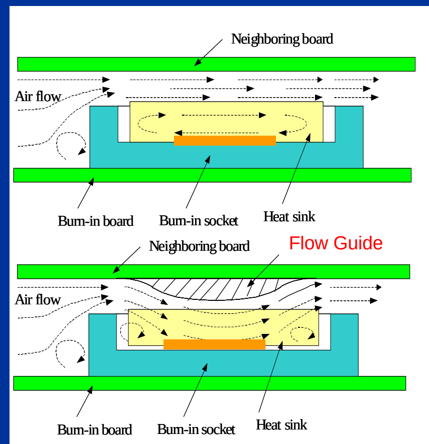
Performance Impact by Flow Pattern

- **Use Flow Guide to Improve Air Flow Pattern to BIS Heat Sink**
  - No change to BIS design
  - Significantly Increases the amount of cold air through the heat sink for more effective cooling.
  - Performance improves 10 to 20%



- **Consider Heat Sink Fin Geometry for Optimized Performance for Air Impinging or per-DUT Based Fan Speed Control Burn-in System**

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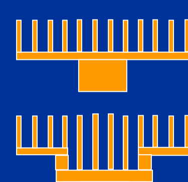
BIS Heat Sink Design Considerations

- **Heat Sink Base & Pedestal**
  - **Optimize the Thickness of Heat Sink Base**
  - **Avoid Tall and Small Pedestal**
- **Heat Sink Fin**
  - **Maximize size of heat sink**
  - **Maximize # of Fins**



- **Heat Sink Materials – the smallest pareto in thermal resistance stack ups. But it is a big cost driver.**
  - **Extruded Al**
  - **Die Cast Al**
  - **Copper**

} Select based on total cost & overall socket thermal performance

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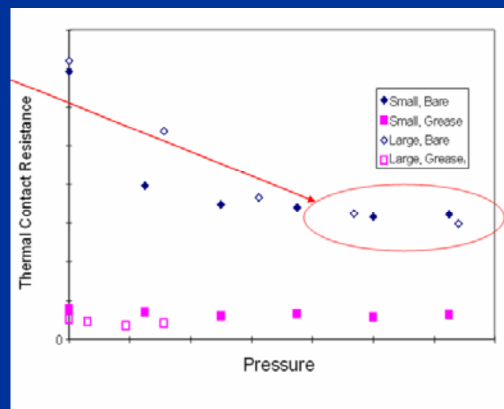
Heat Sink Contact Pressure to DUT with Bare Die

- Design heat sink contact pressure to bare die greater than a critical value for stable and minimum thermal contact resistance.
- Flatness of contact surface is critical.
- With thermal grease, thermal contact resistance is not sensitive to pressure and die size.

Contact Resistance between Heat Sink and Die



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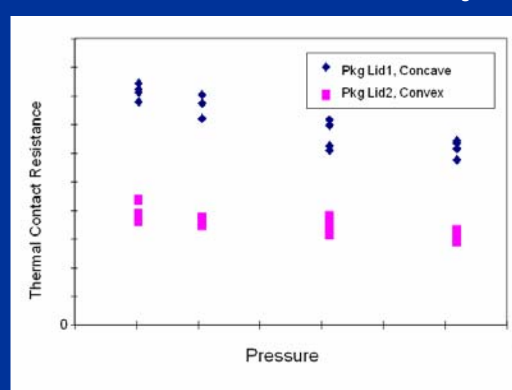
Heat Sink Contact Pressure to DUT with Integrated Heat Spreader

- Avoid heat sink pedestal surface conditions as concave shape for better thermal performance
- Thermal contact resistance (package lid to heat sink base) is less sensitive to pressure.

Contact Resistance between Heat Sink and Pkg Lid



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The Use of Thermal Interface Material

- Enable universal heat sink with cost benefits
  - Avoid die edge cracking & costly pedestal polishing
  - Remove die edge keep out zone – reduce heat flux
  - Single line item for different die sizes/products
  - Cost saving on re-tooling
- Reduce thermal resistance variation
  - Better process control, BIT reduction
- Residue on DUT after BI
  - Add clean process
  - Control residue via special coating
    - Trade off on thermal contact resistance
- As cost saving solution via integration with other thermal performance improvement measures

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Summary

- Air-cooled Burn-in is not going away
- BIS suppliers still need to design cost effective BIS for better thermal performance:
  - Design BIS/BIB for better air flow to BIS heat sink
  - Maximize heat sink fin areas
  - Use of TIM for optimum BI tooling cost
  - Consider alternative heat sink material (lower thermal conductivity) and more cost effective manufacturing process for overall performance and cost

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