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# Measuring Current Carrying Capability (CCC) of Vertical Probes

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# Presentation Overview

- Current Carrying Capability
- Resistive Heating
- Probe Loading
- Experimental Set Up & Results
- Multi-physics Model Build-up
- Model Results
- Summary & Conclusions
- Future Work

# Current Carrying Capability

- Current carrying capability (CCC) of a probe is defined as the maximum current which it can carry with reliable contact.
- Factors Affecting CCC:
  - Ambient Temperature
  - Contact Resistance
  - Probe Material
  - Probe Geometry
  - Wafer Temperature

# Effect of Applied Current (Resistive Heating)

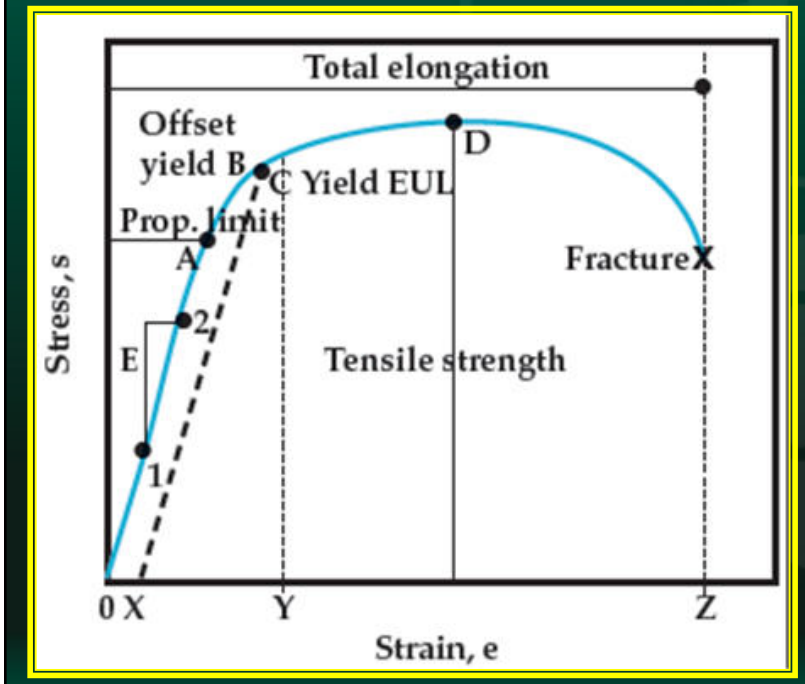
- Resistive heating (Joule heating) is a phenomenon during which heat is generated by passing electric current through a conductor. The heat released causes a significant rise in temperature in the conductor.

$$Q_{in} \propto I^2 R \quad (I = \text{Applied Current}, R = \text{Resistance})$$

- Some of this heat is stored in the body of the probe as internal energy due to rise in temperature and the rest is dissipated to the surroundings through conduction, convection and radiation.

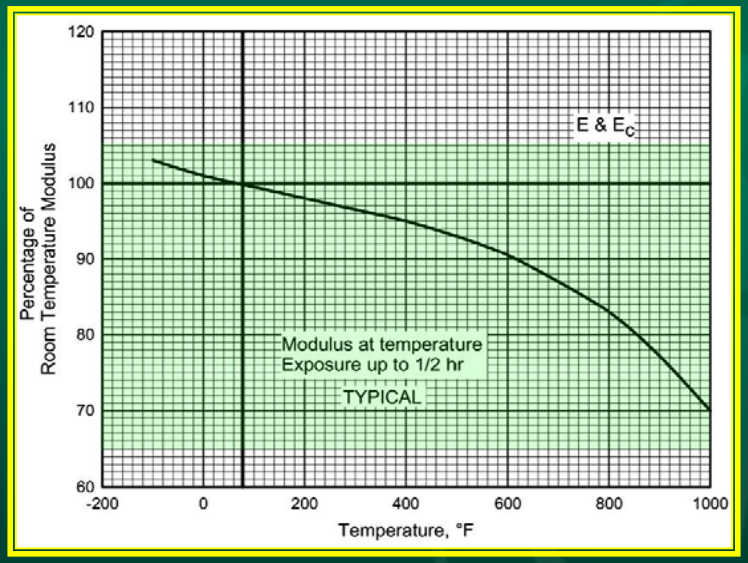
# Probe Loading at Room Temperature

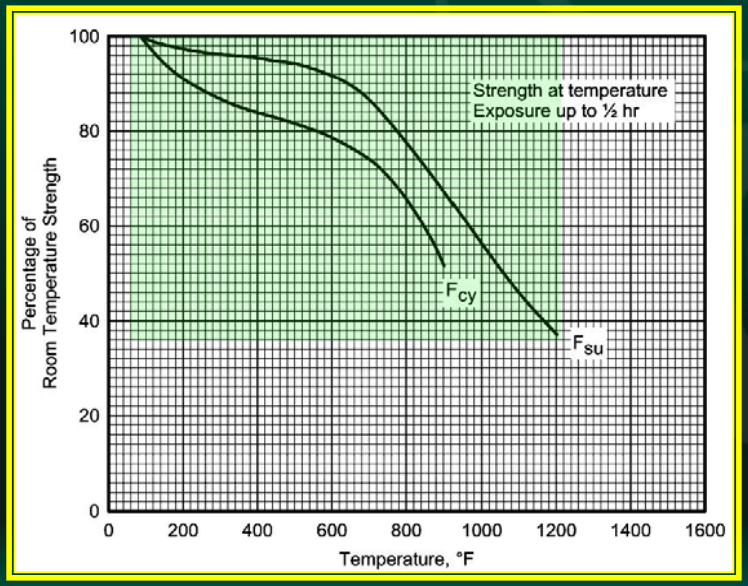
- Before Current is Applied to the Probe, it is Overdriven to a Specified Amount
- This Overdrive Causes a Rise in Stress in the Probe ( $\sigma \propto \mathrm{OD}$ )
- Probes are Designed to Remain in the Elastic/Recoverable Region to get Multiple Touchdowns (TDs)




***Any time this rule is violated, the probe will deform permanently, causing severe life reduction & loss in probe height!***

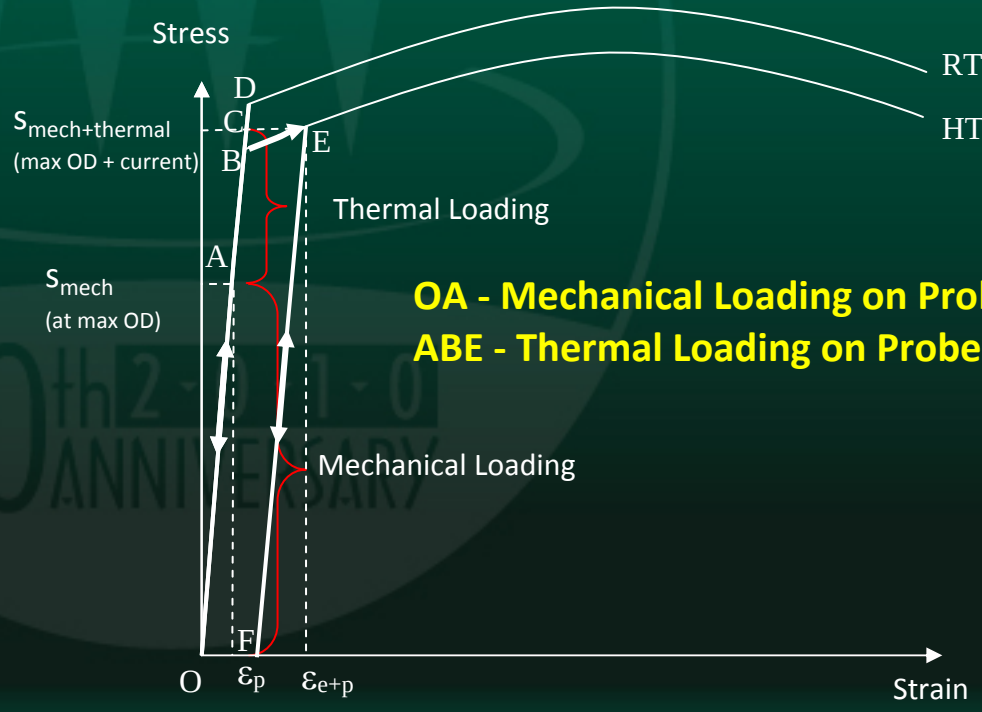
# Mechanical Properties & Probe Loading at High Temperature




*Ref: Military Handbook - MIL-HDBK-5H*

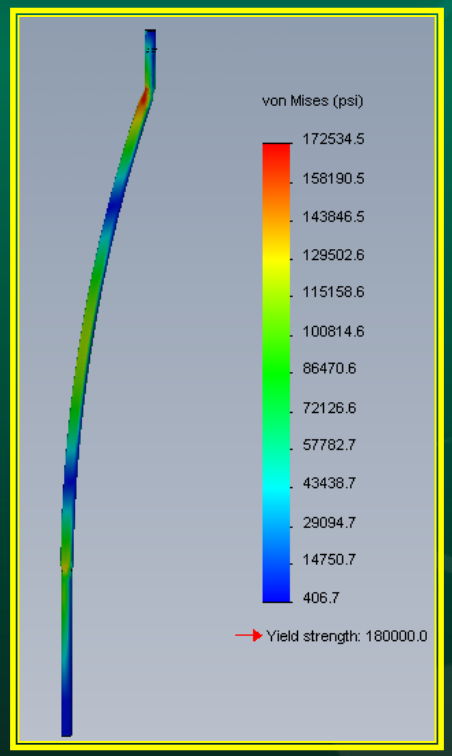
- **Modulus (E) & Yield ($F_{cy}$) are both Functions of Temperature**
- **Both *E* & $F_{cy}$ Decrease when Current is Applied (due to Resistive Heating)**
- **Drop in Yield Strength is more Significant than Modulus**



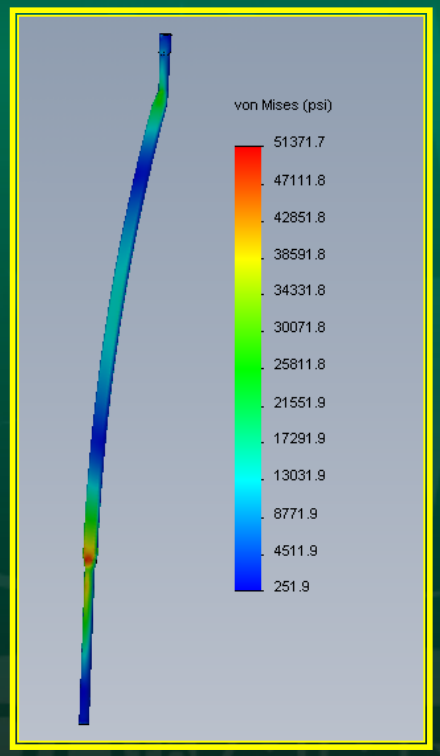

**OA - Mechanical Loading on Probe**
**ABE - Thermal Loading on Probe**

*** Total Stress = Mechanical Stress + Thermal Stress**

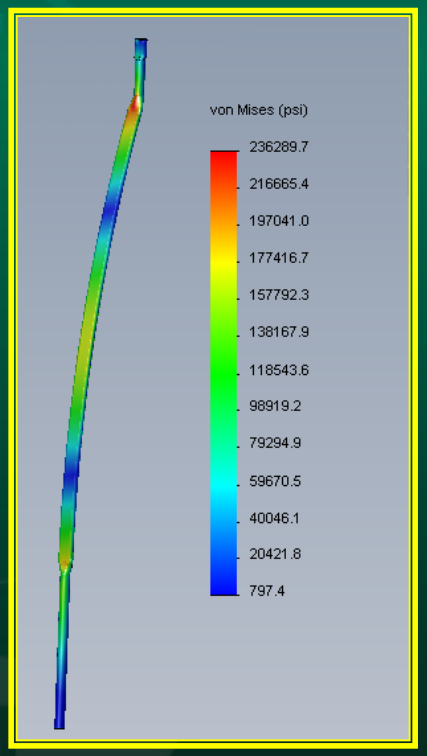
# Effect of Temperature on Probe Loading




- **Boundary Conditions**
  - Temp = 27°C
  - OD = max
  - Max Stress= 172 Ksi
- **Probe does not yield!**




- **Boundary Conditions**
  - Temp = 250°C
  - OD = 0 mils
  - Max Stress= 51 Ksi
- **Probe does not yield!**




- **Boundary Conditions**
  - Temp= 250°C
  - OD = max
  - Max Stress= 236 Ksi
- ***Probe yielded!***

*** Current Applied Increases the Stress on the Probe Significantly!**

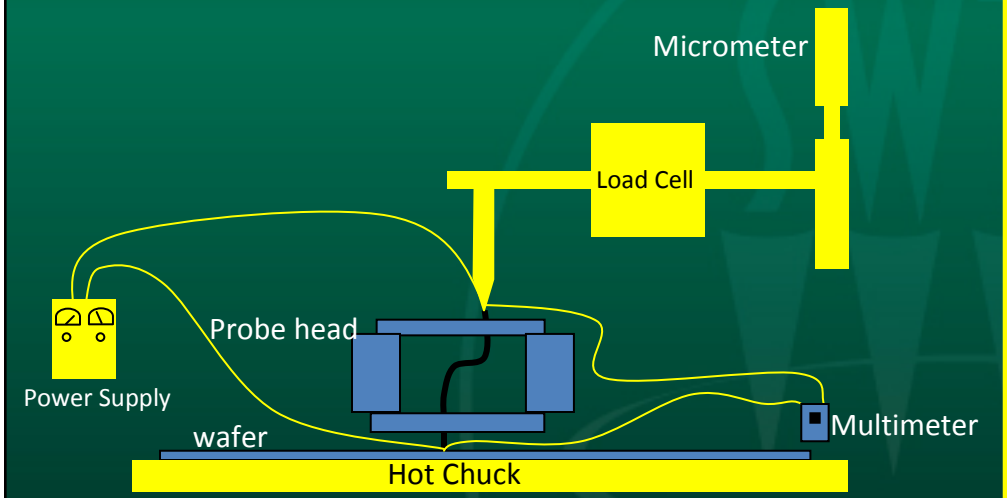
# CCC

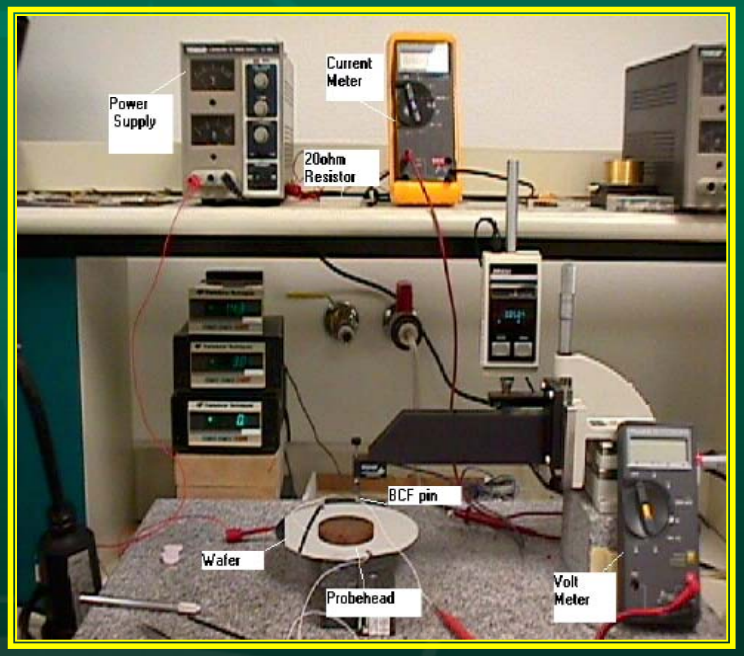
- **Based on the proposed theory, CCC can be re-defined as:**

  ***"The maximum current a probe can handle without permanently deforming (stresses remain below the yield strength) at its fully loaded state for repeated number of cycles."***

- **This definition ensures the probe never loses height or deforms permanently even with passage of max prescribed current.**
- **It also ensures the planarity of the card does not change with passage of current.**

# Experimental Set-up

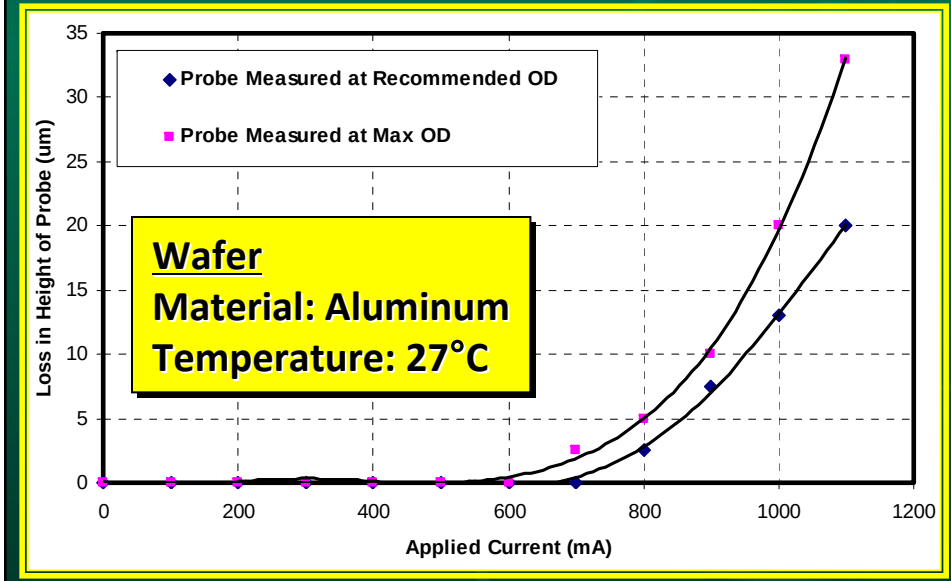


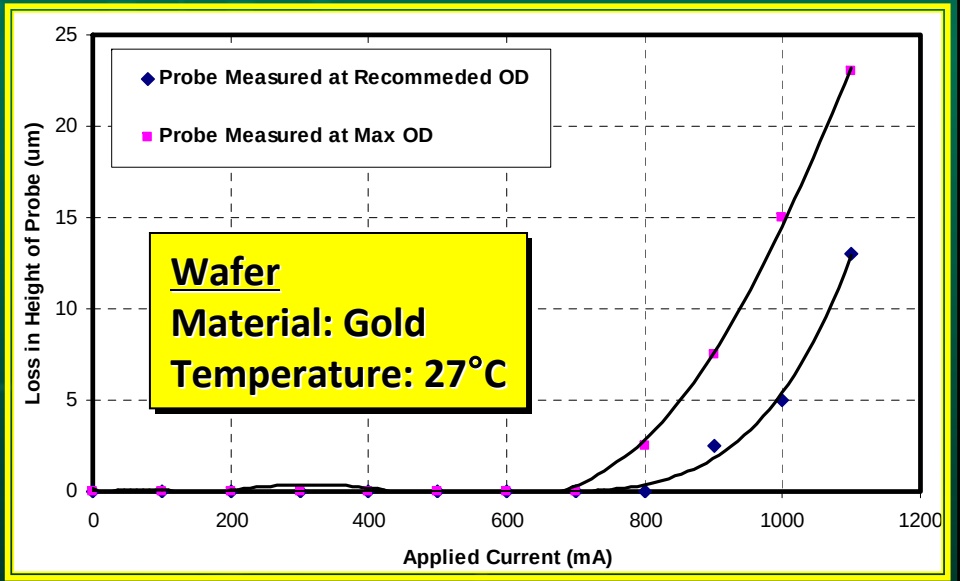

**Method:**

- **Load Probe at Recommended OD & Pump Current through the Probe for 1 Minute**
- **Turn Current OFF & Wait 1 Minute to Allow the Probe to Cool**
- **Measure Height of Probe at the End of Each Current Input Using Micrometer**
- **Repeat Loading with 100mA Current Increments until Probe Loses Height**
- **Record CCC (Highest Current Value at which Probe does not Lose Height)**
- **Repeat Test on Another Probe at Max OD**
- **Record CCC (Highest Current Value at which Probe does not Lose Height)**

# Experimental Results (27°C)



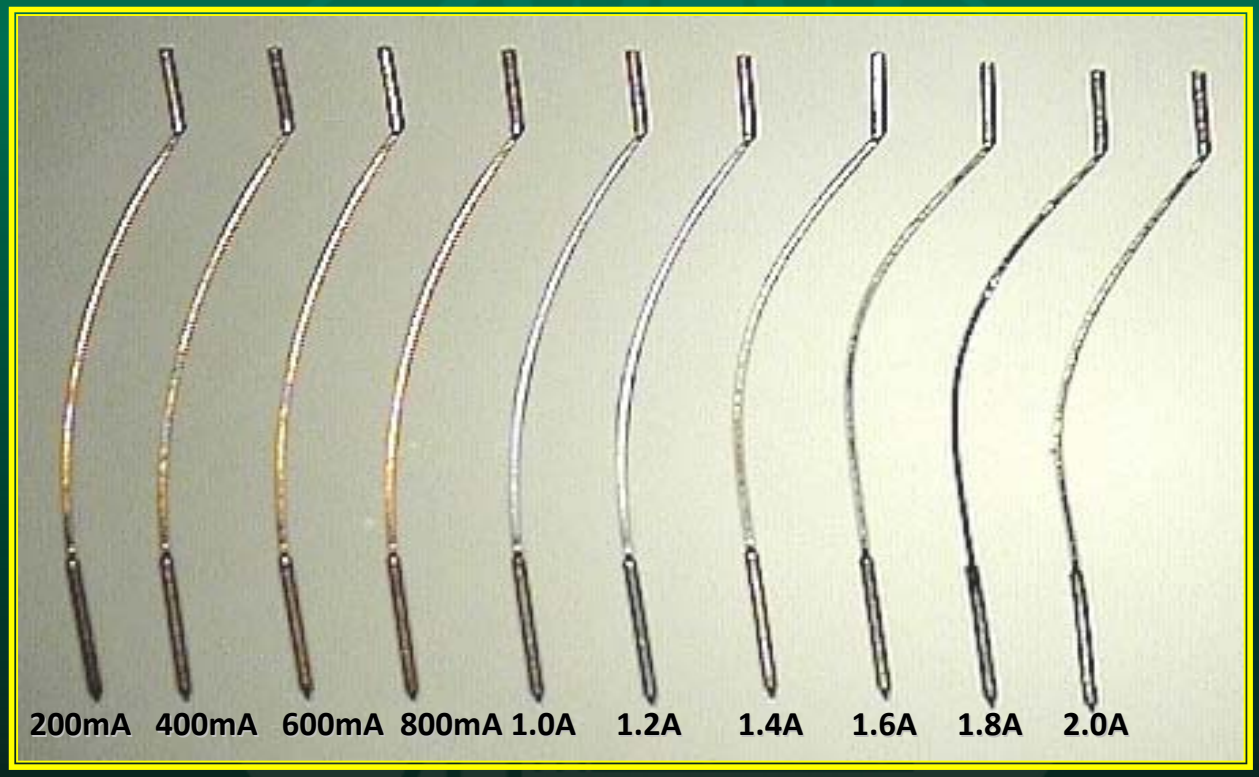

CCC of Probe (Measured)
@ Recommended OD= 700mA
@ Max OD = 600mA




CCC of Probe (Measured)
@ Recommended OD= 800mA
@ Max OD = 700mA

- Experimental Results Clearly Show a Reduced CCC with Higher Mechanical Stress (Higher OD) in the Probe
- Stress in the Probe is a Function of both Thermal (Resistive Heating) & Mechanical Loading
- CCC is a Function of the Wafer Material (Contact Resistance)

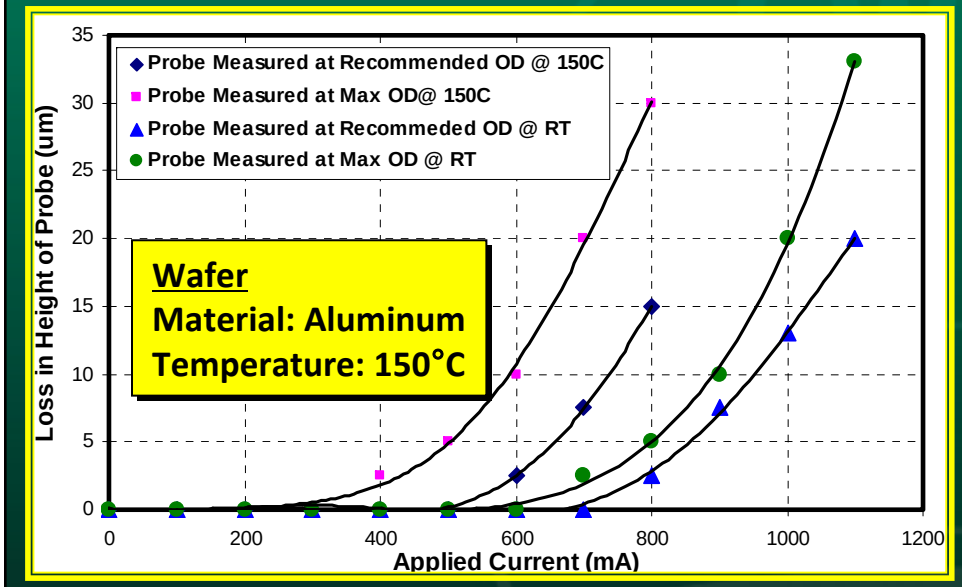
# Probe Deformation w/Current



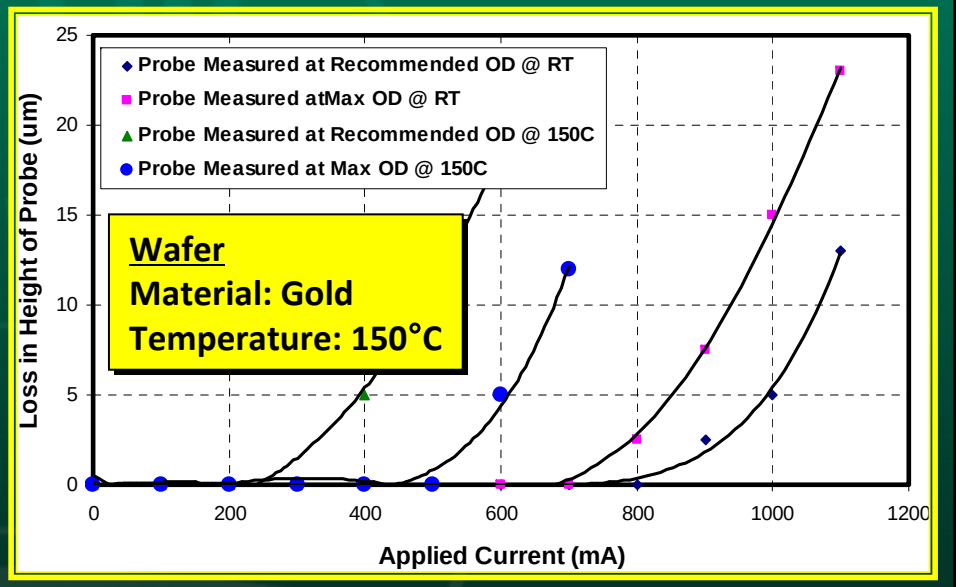

**3 mil BeCu @ Recommended OD (Room Temp Probing)**

- **Probes Undergo Plastic Deformation & Discoloration Beyond 0.8A**

# Experimental Results (150°C)




CCC of Probe Measured (150°C)
@ Recommended OD= 500mA
@ Max OD = 300mA




CCC of Probe Measured (150°C)
@ Recommended OD= 500mA
@ Max OD = 300mA

- **CCC Reduces with Increase in Wafer Temperature**

# Multi-Physics Model

- **To understand the temperature rise in the probe, a model is created based on Resistive or Joule heating & Energy Balance equation.**

$$Q_{input} = Q_{stored} + Q_{dissipated} \quad \textit{(Energy Balance Equation)}$$

$$Q_{input} = I^2 R \qquad R = \rho_0 \frac{l}{A}\left[1 + \alpha\left(T - T_{ref}\right)\right], \text{ where } \alpha = \text{Temperature Coefficient of Resistivity}$$

$$Q_{stored} = (\mu A l) c \frac{dT}{dt}$$

$\rho_0 =$ Resistivity at Reference Temperature

$\mu =$ Density $\quad c =$ Specific Heat Capacity

$$Q_{dissipated} = k\left(\pi d^2/4\right)\left(T - T_{ST}\right) + k\left(\pi d^2/4\right)\left(T - T_{wafer}\right) + h\pi dl\left(T - T_{ambient}\right) + \varepsilon\sigma\pi dl\left(T^4 - T_{ambient}^4\right)$$

where $k =$ Thermal Conductivity

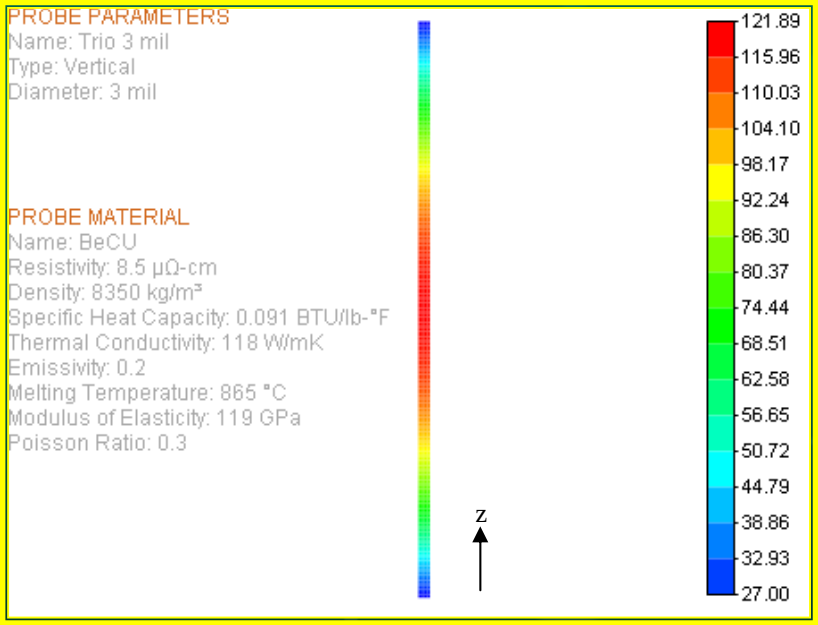
$h =$ Convective Heat Transfer Coefficient

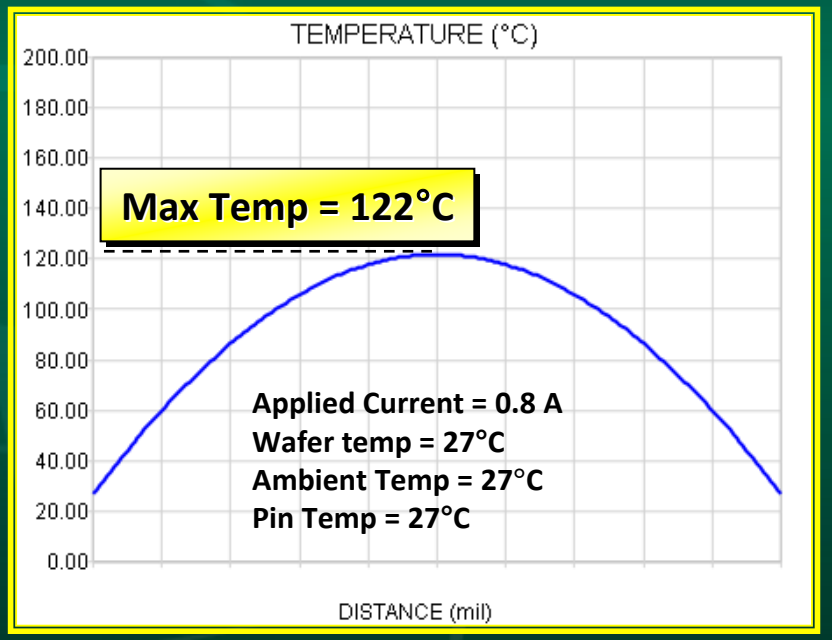
$\varepsilon =$ Emissivity

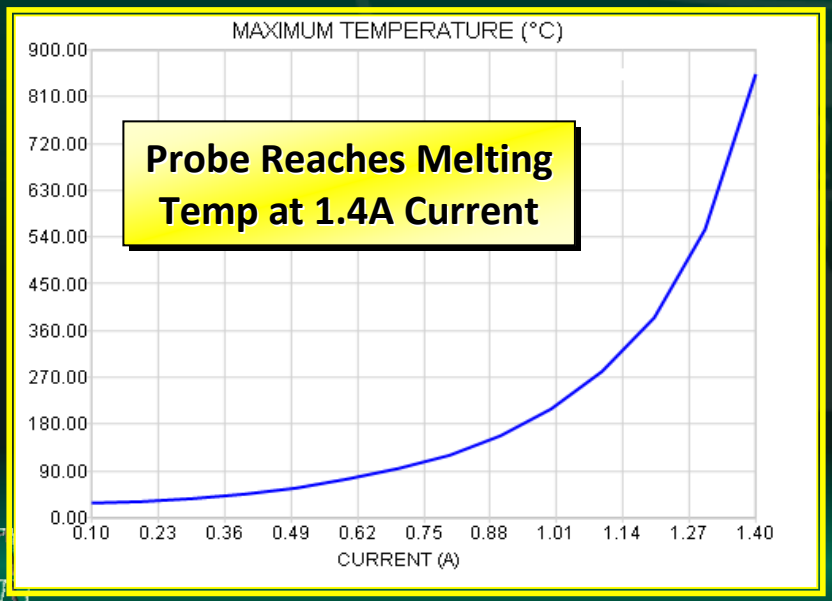
$\sigma =$ Stefan – Boltzmann Constant

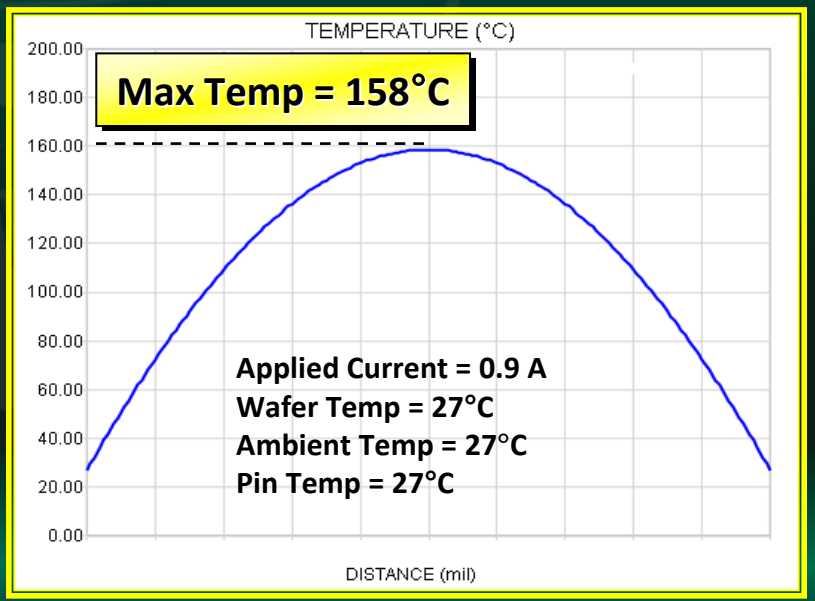
***The energy balance equation is integrated over time & solved to get the temperature rise in the probe.***

# Model Results for Room Temp Probing



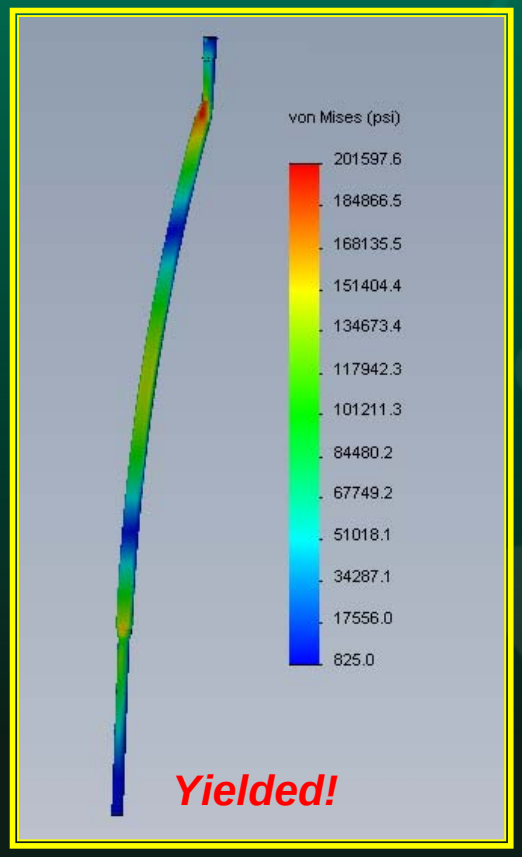



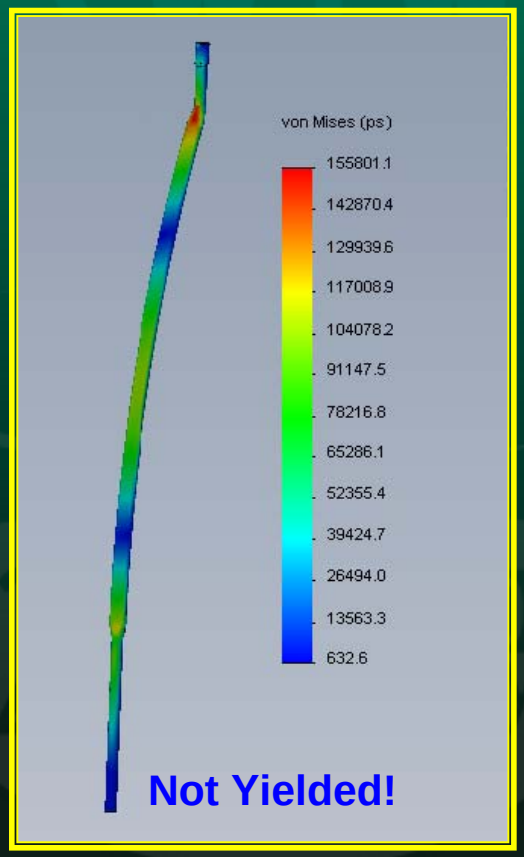



# Thermo-Mechanical Simulation

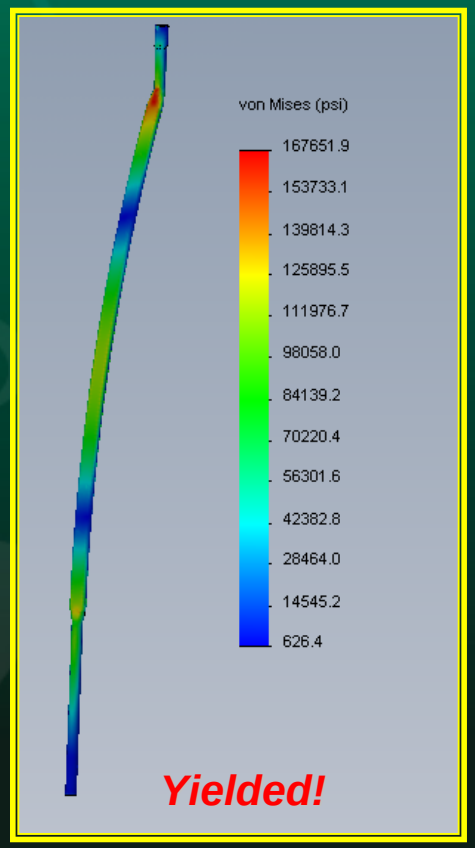
- The temperature output from the model is used as input in the thermo-mechanical simulation to estimate the CCC of any vertical probe.




Max OD @ 122°C (800mA)



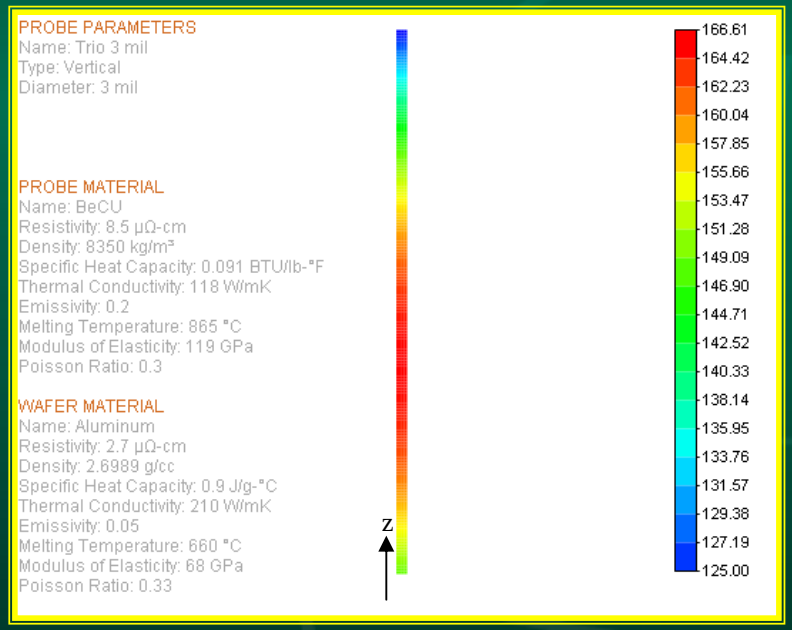

Recommended OD @ 122°C (800mA)

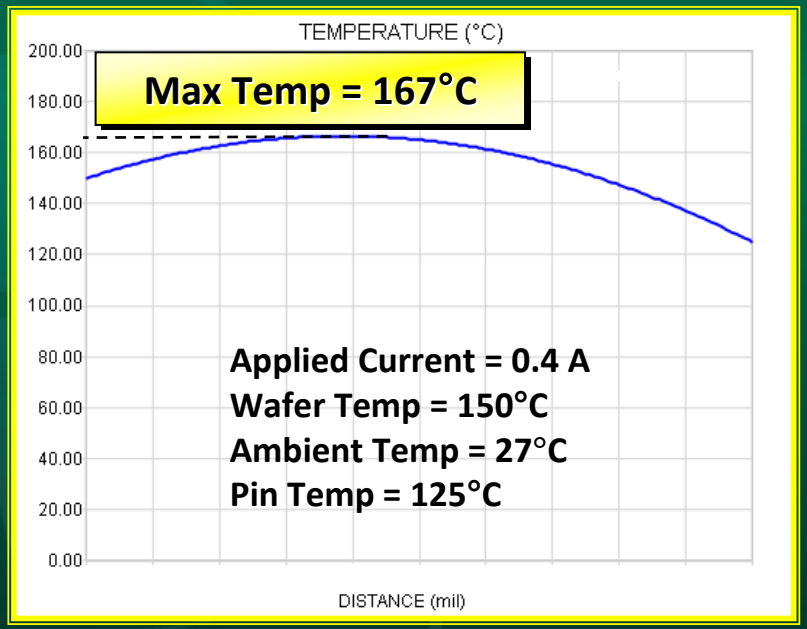


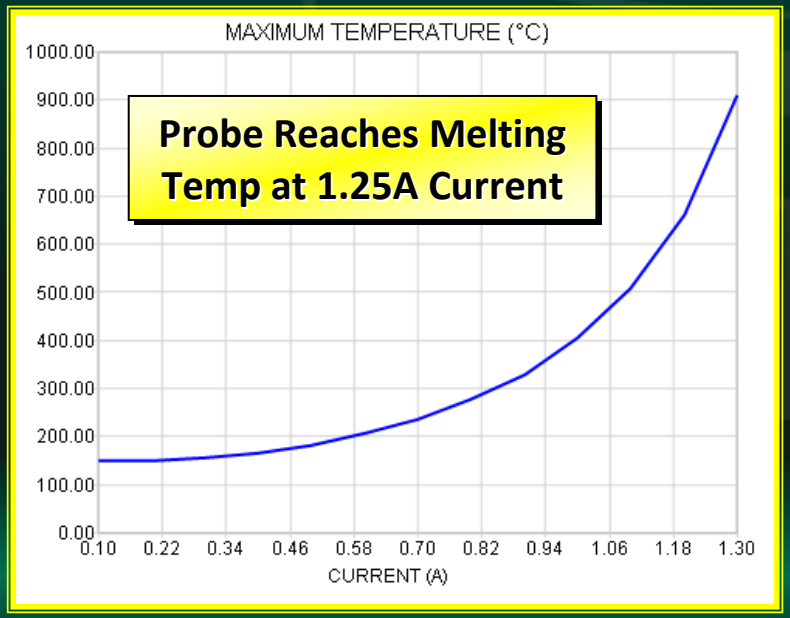

Recommended OD @ 158°C (900mA)

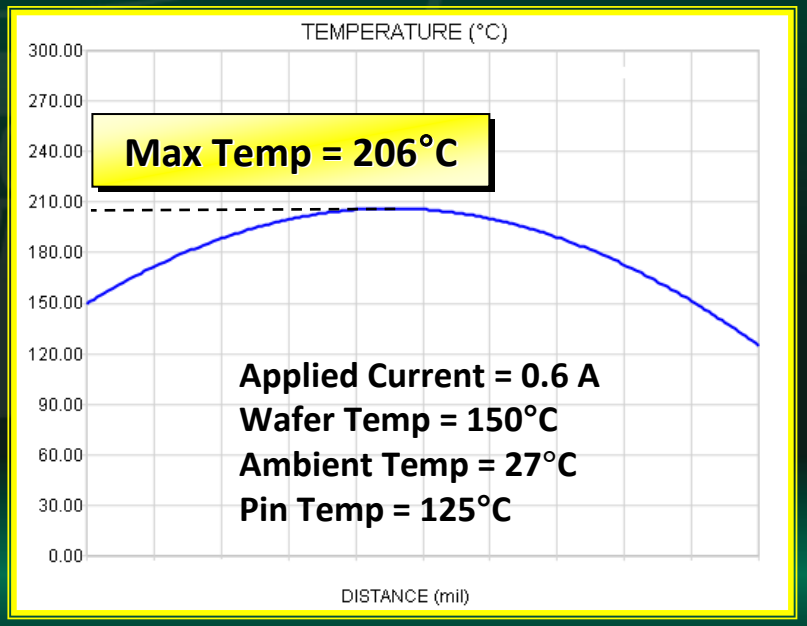
**(Ref Temp @ Zero Strain = 27°C)**

# Model Results for Hot Chuck Probing (150°C)

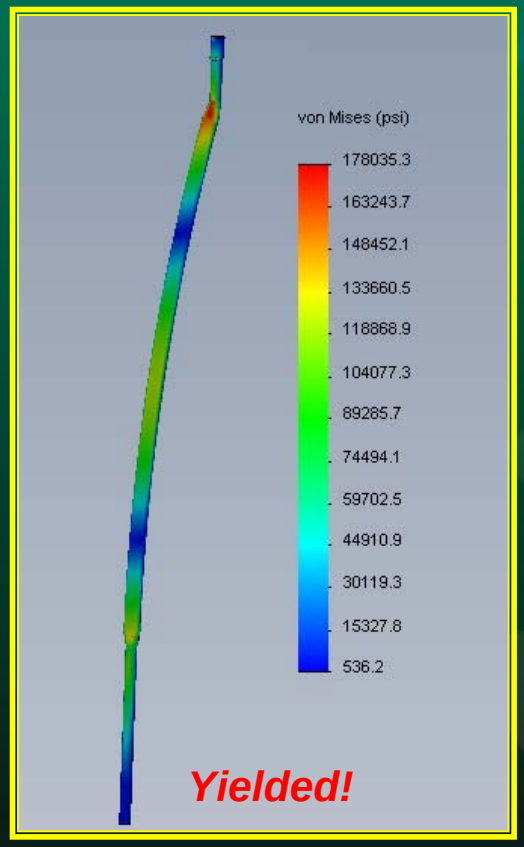


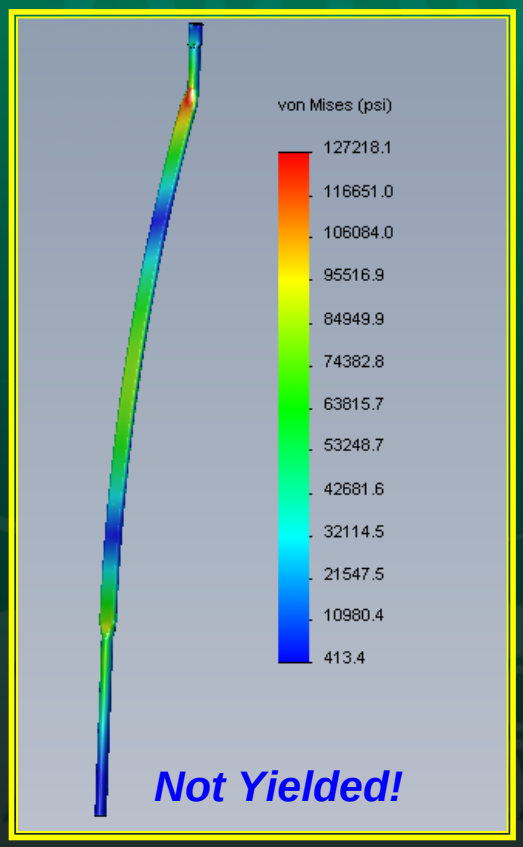



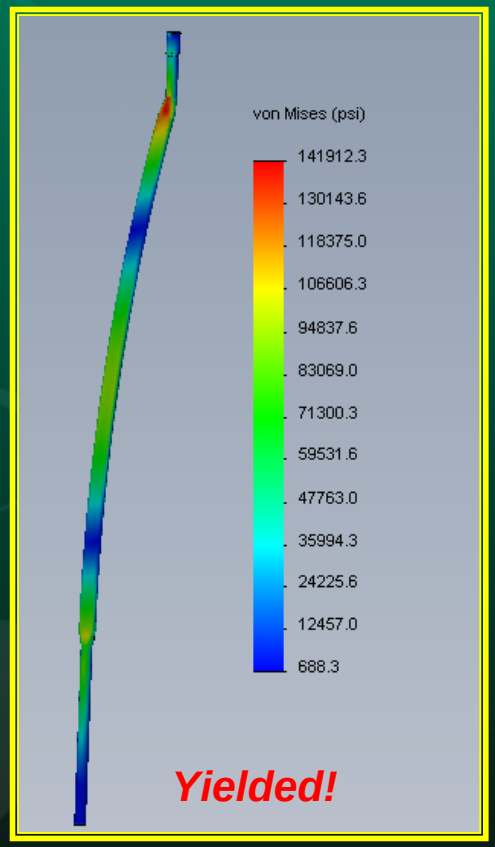
# Thermo-Mechanical Simulation (150°C)




Max OD @ 167°C(400 mA)




Recommended OD @ 167°C (400 mA)




Recommended OD @ 206°C (600mA)

**(Ref Temp @ Zero Strain = 150°C)**

# Results Table

| Probe Dia. | OD at which Current is Applied | Chuck Temp (°C) | Current @ loss in Probe Height (mA) | Temp from Model (°C) | Delta Temp (°C) | CCC (mA) |
|---|---|---|---|---|---|---|
| 3 mil | Max | 27°C | 800 mA | 122°C | 95°C | 700mA |
| 3 mil | Recommended | 27°C | 900 mA | 158°C | 131°C | 800mA |
| 3 mil | Max | 150°C | 400 mA | 167°C | 17°C | 300mA |
| 3 mil | Recommended | 150°C | 600 mA | 206°C | 56°C | 500mA |

- Recommended OD requires higher thermal loading (ΔT) than max OD to yield at any given temperature of wafer.
- High temperature probing requires less thermal loading (ΔT) than room temperature probing to yield (yield strength reduces with temperature).

# Summary

- A new criterion of measuring CCC is presented which ensures that the probe does not deform permanently upon application of max current.
- The governing equations of resistive heating & energy balance are applied in a multi-physics model to estimate the temperature rise in the probe.
- Thermo-mechanical FEA is performed to predict the stress in the probes at the temperature estimated by the multi-physics model.

# Conclusions

- The stress in the probe is a function of both mechanical and thermal loading.
- Lower mechanical stress in the probe increases the CCC of the probe.
- Understanding the temperature rise in the probe is very important to estimate the thermal loading.
- The proposed model gives the flexibility of predicting the CCC of vertical probes for any probe material at any sort temperature.

# Future Model Improvements

- Use advanced meshing techniques to perform simulations for any probe geometry.
- Incorporate contact resistance & thermal conductivity at contacts as boundary conditions to get more accurate results.
- Include time dependent algorithms to predict pulsed current loadings.