Thermal Considerations in Testing Very High Performance Devices

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BiTS 2006

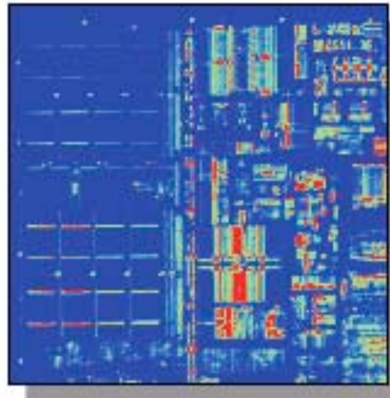
Thermal Considerations …

What's New ?

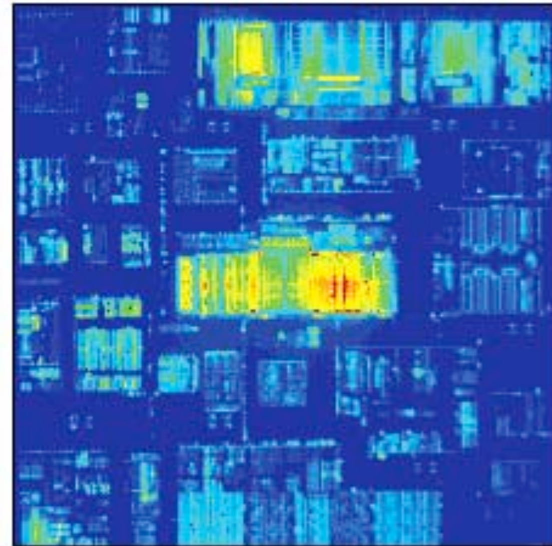
- More Thermal Gradients (Hot Spots)*
- Higher Power Densities
- Increased Testing of Bare Flip-Chips

* Dave Gardell, Thermal Characterization and Specification for Test and Burn-in, BiTS 2005

- Hot spots can be >300 W/cm2.

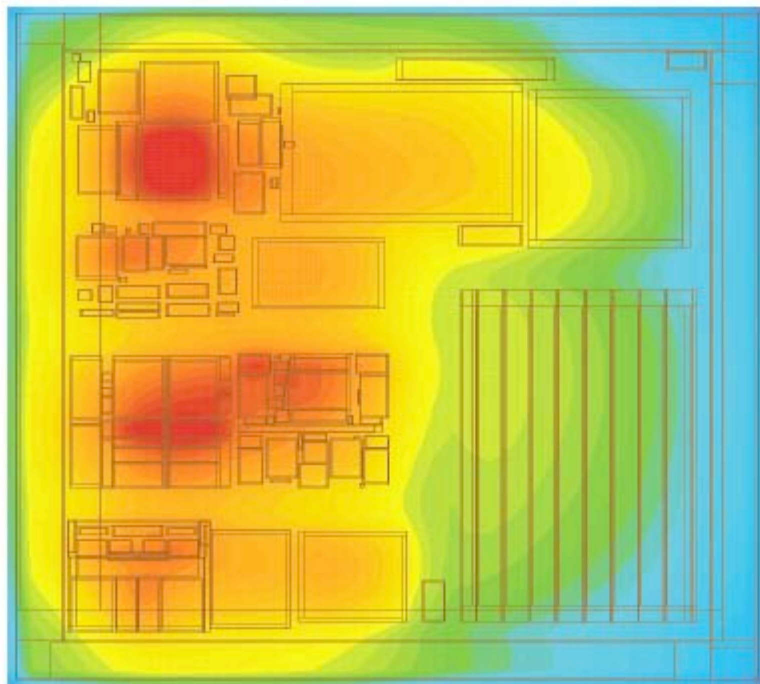


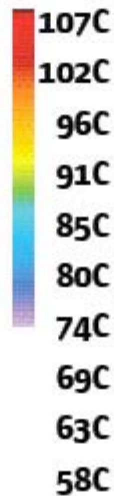
Intel Pentium® III Processor

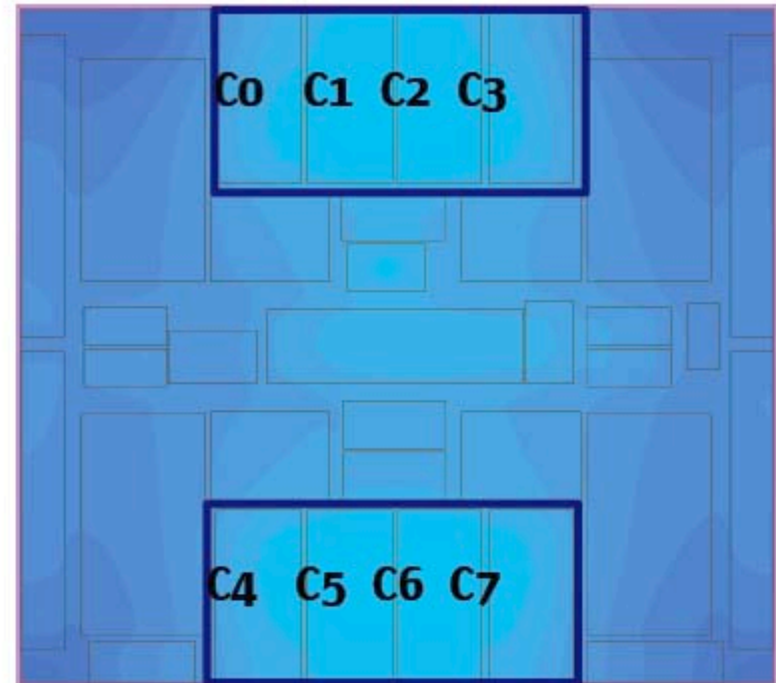


Intel Itanium® Processor

Debendra Malek, Thermal Issues from ITRS Perspective, MEPTEC The Heat is On 2006







Bidyut Sen & Jim Jones, Thermal Challenges for Sparc Based Microprocessors, MEPTEC The Heat is On 2006

Thermal Considerations …

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Thermal Considerations …

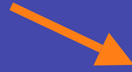
State of the Art

- TIM Materials   Θ ~ 0.15 ºC-cm² / W
- Temperature Control   ! 2 ºC average

Emerging Problem – “Hot Spots”

- Thermal Error Yield Loss
- Increased Re-test Rates

Hot Spots



Reduced IC Performance

Thermal Error Yield Loss

Local Heating:

- Degrades Switching Time of Critical Nets,
- Reduces Performance ~ 0.5 % per ºC at 25 ºC
- Leads to Unnecessary Yield Loss

Yield Loss due to Hot Spots

"Every 15ºC increase locally causes a delay or skew to increase roughly 10 to 15%"

- Andrew Yang, TSMC EDN Sept /2005

Hot Spots Cause Performance Degradation

– Reduction of Surface Channel Mobility

$\neq\mu \,/\, \neq T = -\,K\mu_0 \,/\, T$ $\quad K \sim 1.5$ to 2.5

– Increased RC Delays

$\neq RC \,/\, \neq T = 0.0038\,RC$

Thermal Error Yield Loss

Simplified Model Assumptions*

- Switching time is temperature dependent

$$\tau \sim 1.13 \times 10^{-4} \tau_0 T^{1.6} \quad (T \text{ in } ^\circ K)$$

- Worst case performance is determined by hot spot δT

$\delta\tau / \delta T = 0.0055 \tau_0$ Delay Time

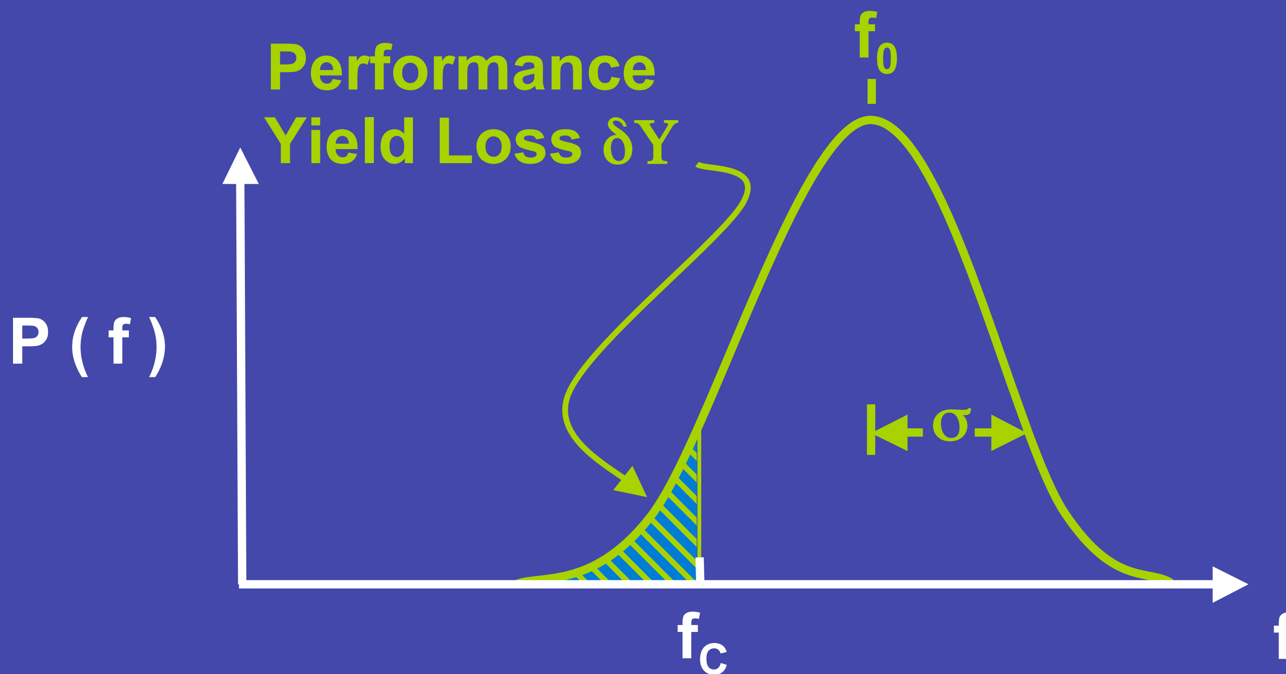
$\delta f / \delta T = - 0.0055 f_0$ Frequency

* Precise model depends upon specific details

Thermal Error Yield Loss

Simplified Model Assumptions*

- IC performance is a normal distribution around f_0



* Precise model depends upon specific details

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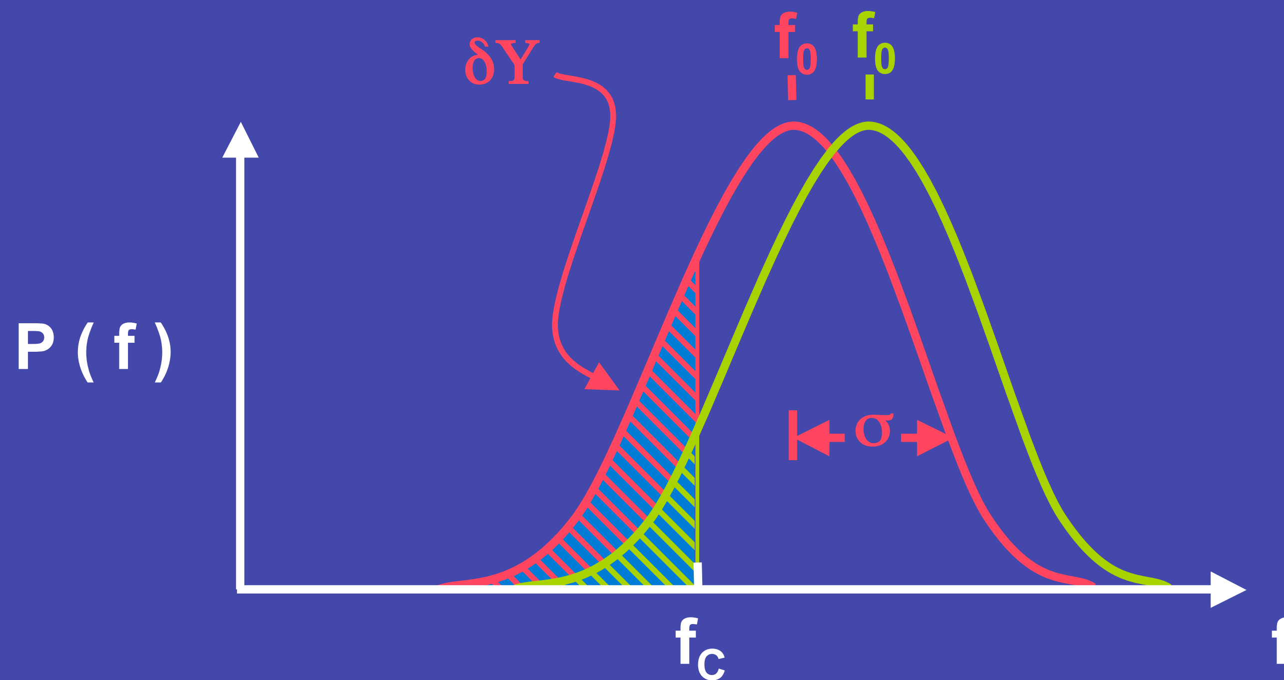
Thermal Error Yield Loss

Simplified Model Assumptions*

- Performance yield curve is shifted by hot spot



* Precise model depends upon specific details

Thermal Error Yield Loss

Simplified Model*

- Performance yield curve is shifted by hot spot

$$Y = \tfrac{1}{2} + \tfrac{1}{2}\,\mathrm{erf}\left\{ (f_0(T) - f_C) / (\sigma\sqrt{2}) \right\}$$

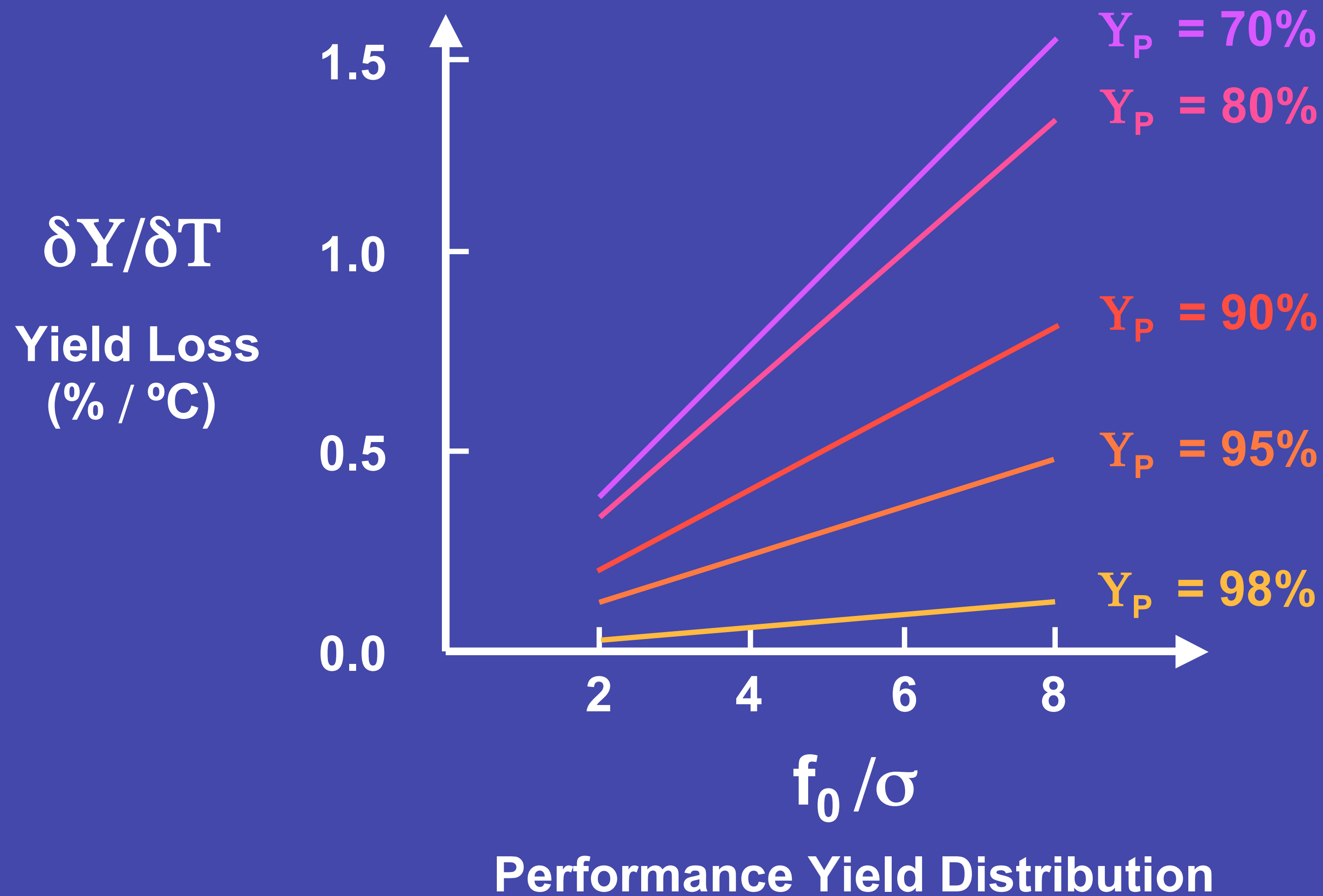
- Yield loss due to hot spot

$$\delta Y/\delta T = -\,0.00242\,(f_0/\sigma)\left\{ 1 - 1.03\,(Y_0 - 0.5) - \dots \right\}$$

δT = Hot Spot Temperature above T_0

* Precise model depends upon specific details

Thermal Error Yield Loss



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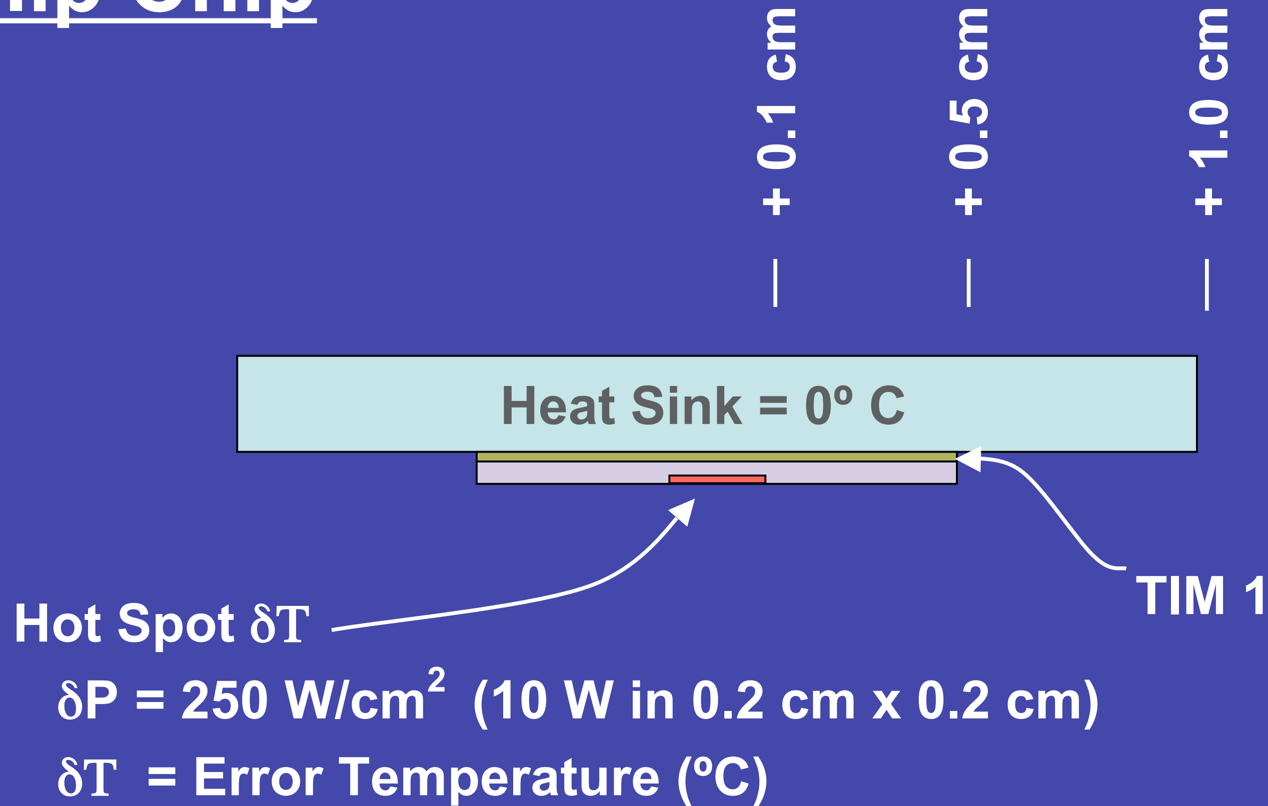
Test Methods can Introduce Thermal Errors :

- Insufficient Thermal Conductivity in TIM
- Errors due to Single Point Sensing
- Temperature Non-Uniformities on Heat Sink

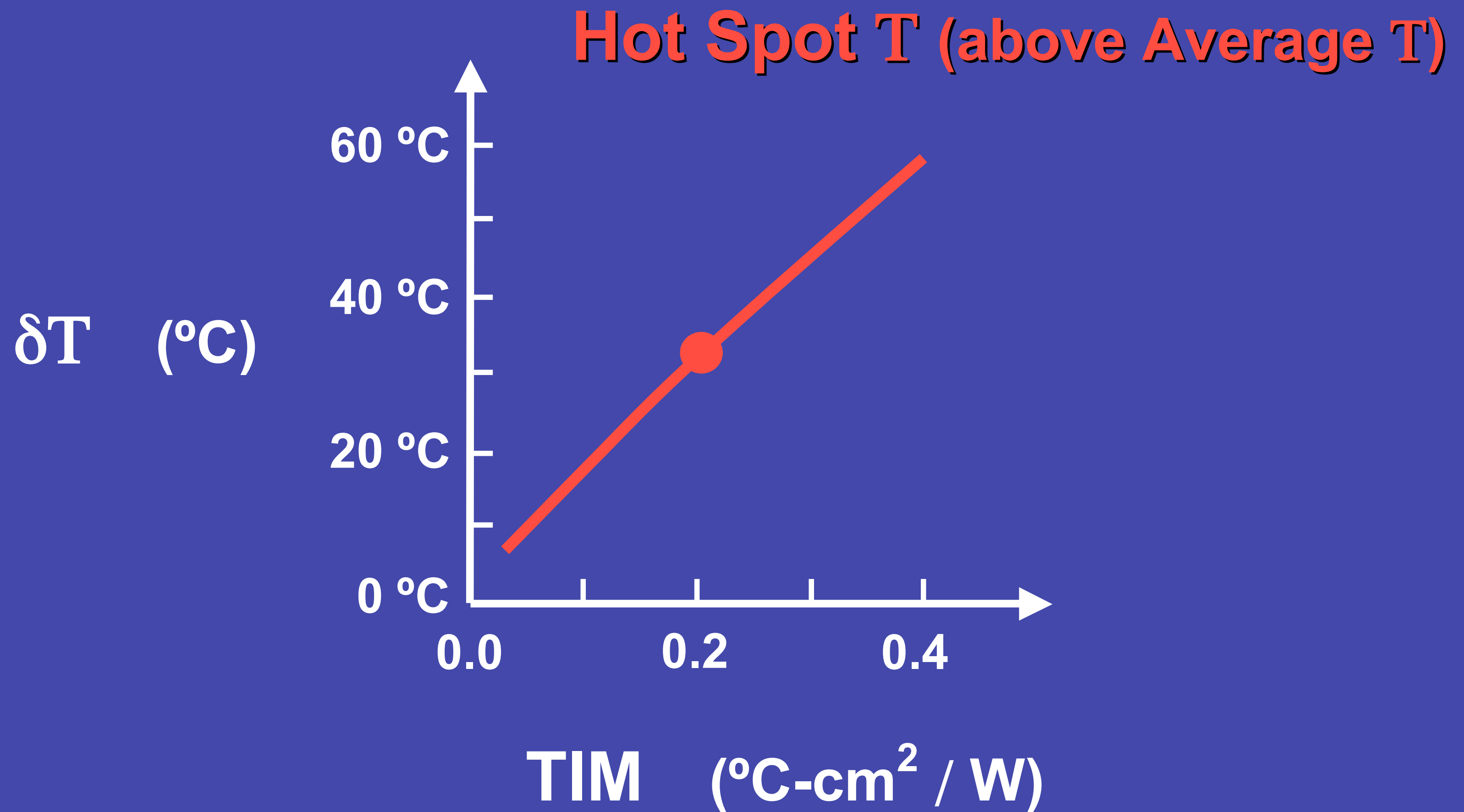
Illustrative Model #1

Flip Chip



Illustrative Model #1

Flip Chip



Illustrative Model #1

Flip Chip Parameters

Hot Spot	10 W in 0.2 x 0.2 cm area
Performance Yield	Y_P = 95 %
Yield Distribution	σ = 0.33 f_0
TIM Material	0.2 ºC-cm2 / W

Temperature Error δT = 33ºC

Thermal Error Yield Loss = 5.9%

Illustrative Model #2

Thermal Spreader

- 10 mm
- 5 mm
- 1 mm
+ 1 mm
+ 5 mm
+ 10 mm

Heat Sink = 0º C

0.1 cm W-Cu Spreader

TIM 2

TIM 1 = 0.1 ºC-cm² / W

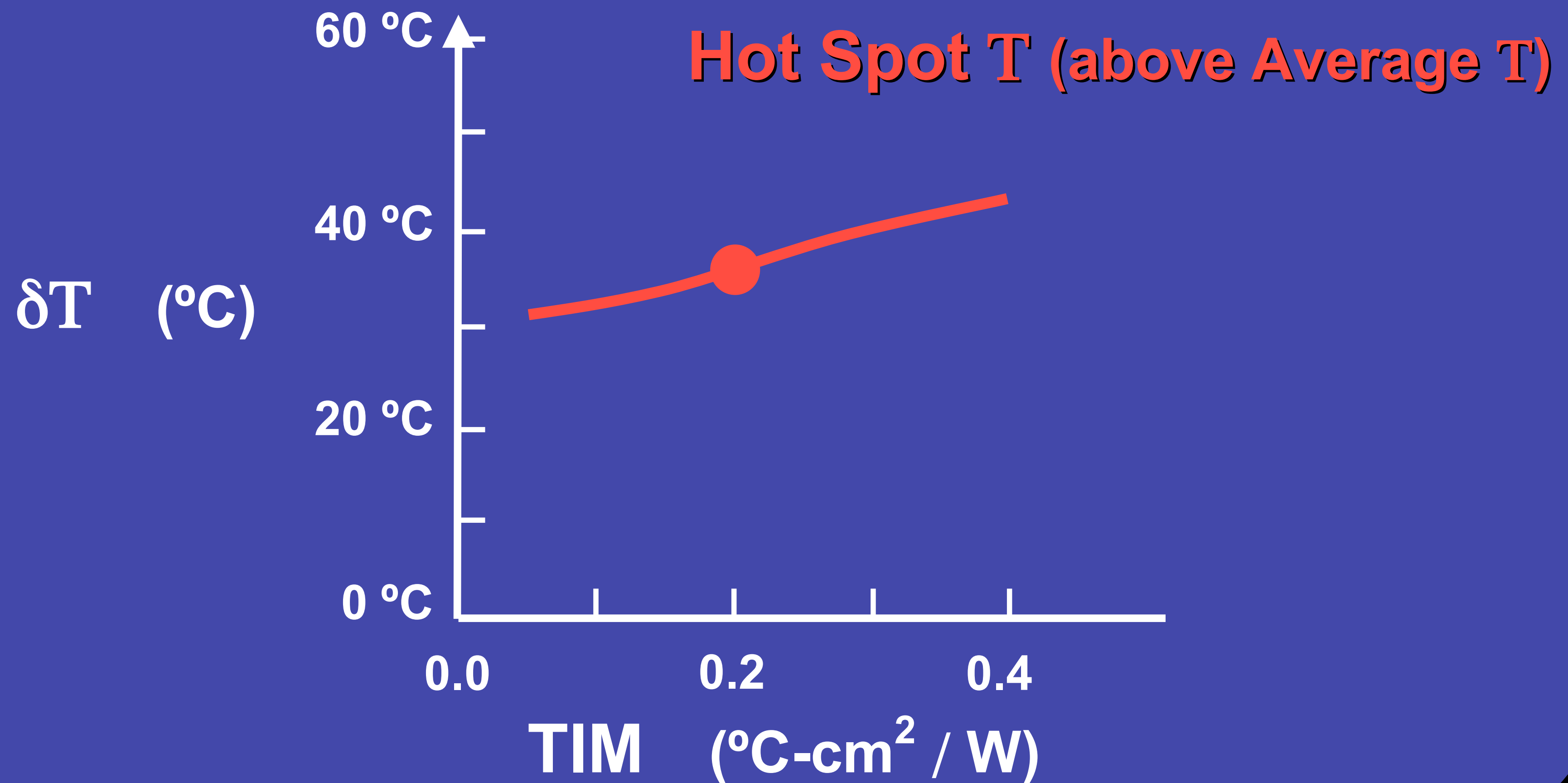
Hot Spot

δP = 250 W/cm^2 (10 W in 0.2 cm x 0.2 cm)

δT = Error Temperature (ºC)

Illustrative Model #2

Thermal Spreader



Illustrative Model #2

Thermal Spreader Parameters

Hot Spot	10 W in 0.2 x 0.2 cm area
Performance Yield	Y_P = 95 %
Yield Distribution	σ = 0.33 f_0
TIM Material	0.2 ºC-cm2 / W

Temperature Error δT = 36ºC

Thermal Error Yield Loss = 6.4 %

Caveat …

Thermal Error Yield Loss Model Must Take into Account the Actual:

- Impact of Temperature on IC Performance
- Thermal Properties of Materials
- IC Performance Yield

Thermal Considerations …

Local Heat Generation in IC

- Hot Spots Degrade Measured Chip Performance

Single Point Temperature Measurement

- Local Variations Induce Errors in Control Temperature

Thermal Gradients on Heat Sink

- Degrade Measured Chip Performance

Conclusions …

Improvements Needed to Avoid Unnecessary Thermal Error Yield Loss

- Thermal Head Performance
- Temperature Detection and Control
- Temperature Uniformity of Thermal Head