Thermal challenges in IC’s: Hot spots — passive cooling and beyond

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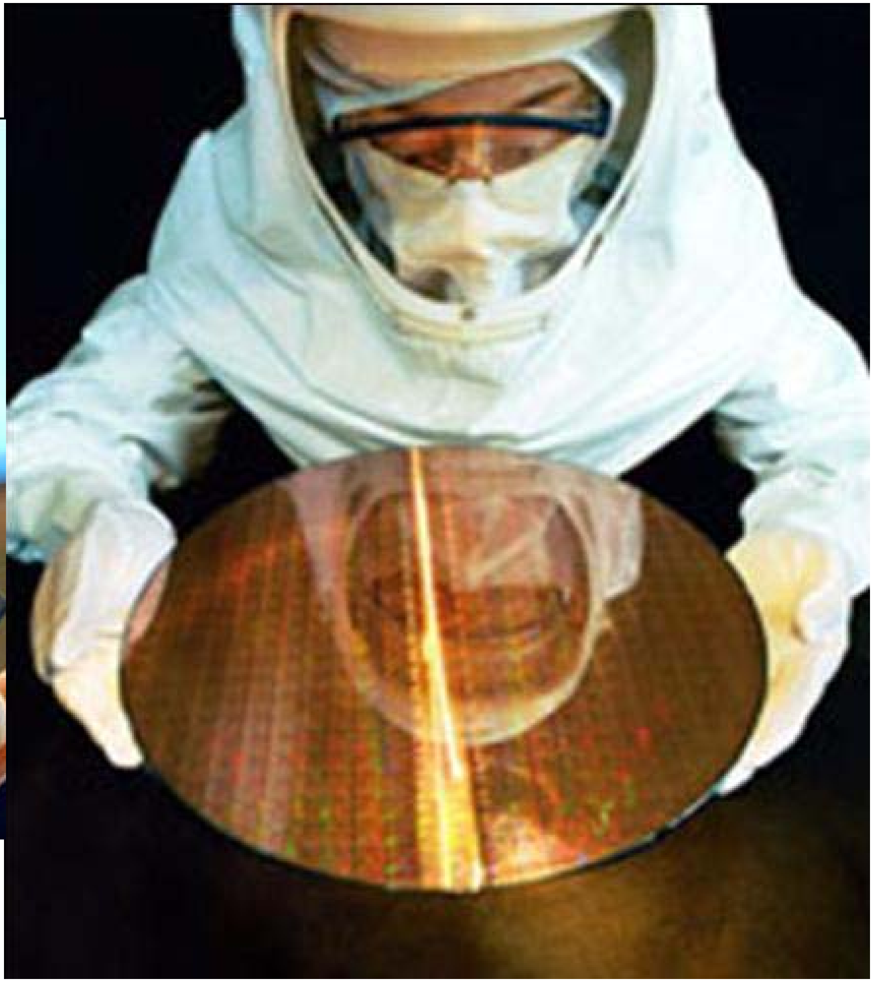
Overview

- **Motivation**
- **Where are the thermally challenged IC's?**
- **Cooling IC's today**
- **Cooling IC's in the future**
- **How do we get there?**
- **Conclusions**

Microprocessor Applications

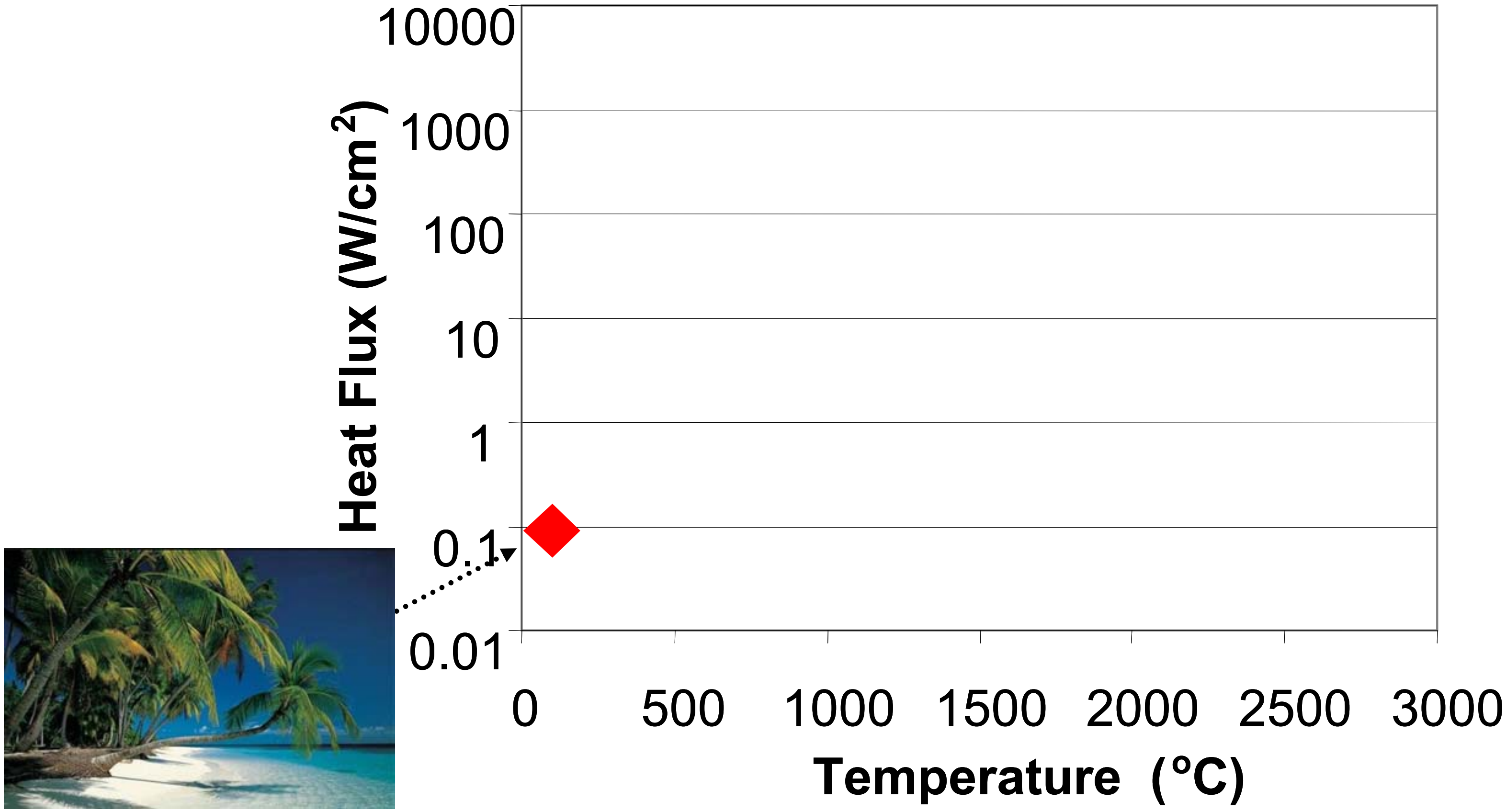
IC's are pervasive in various applications

All Rely on Chips



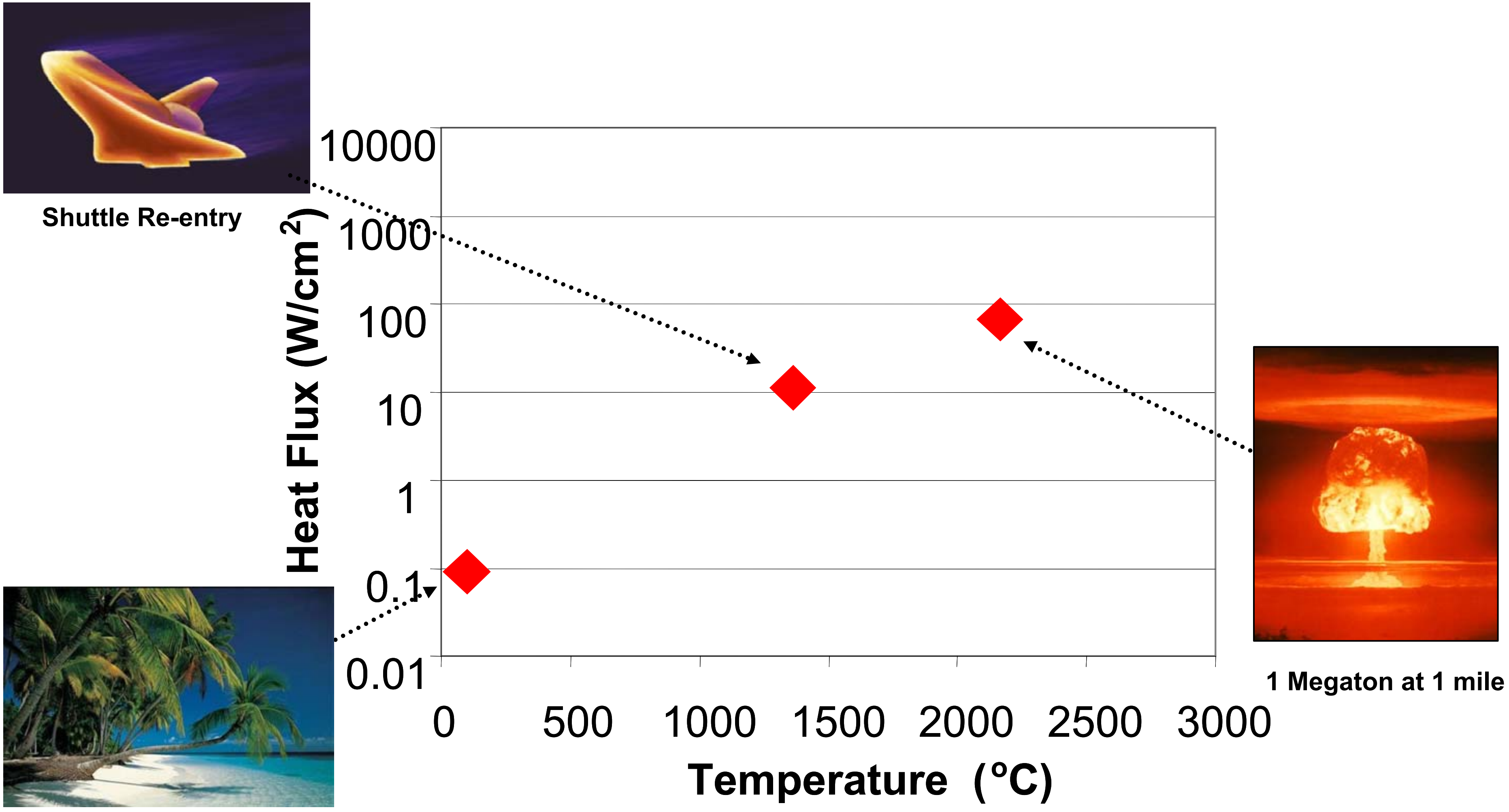
10 billion square inches of silicon forecast for 2009

Putting the Heat Flux Challenge into Perspective



Sunlight on a Tropical Beach

Putting the Heat Flux Challenge into Perspective



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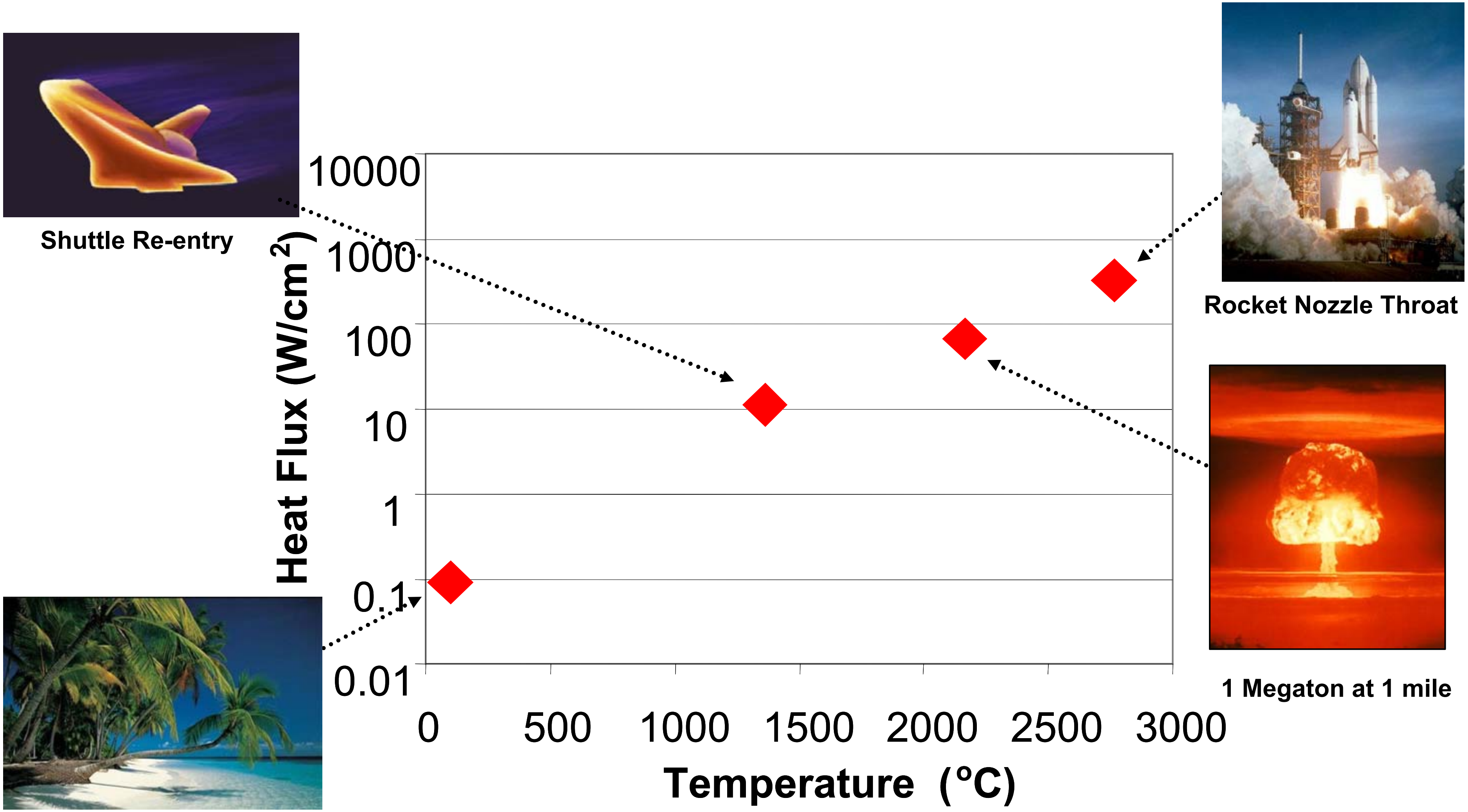

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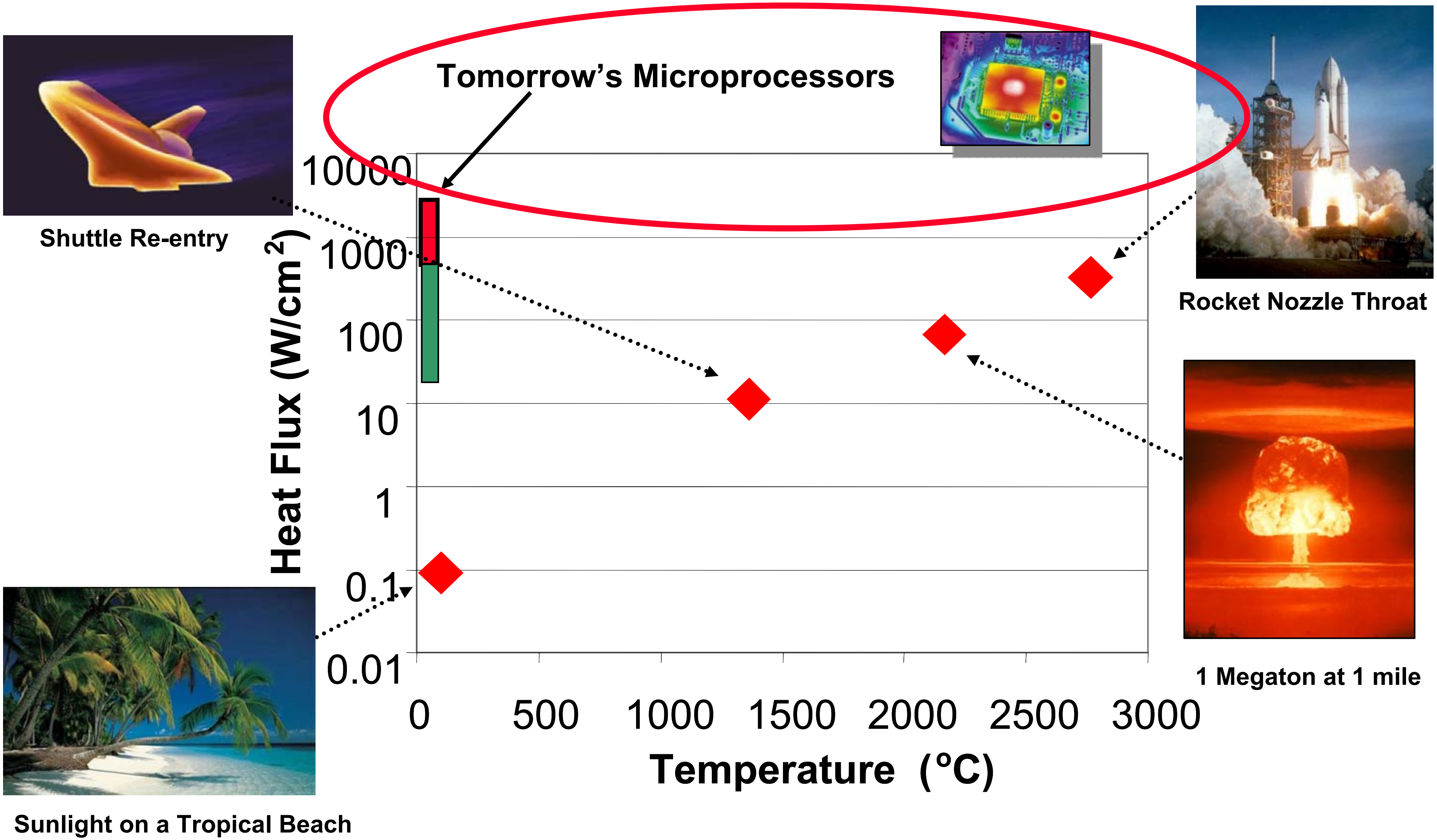
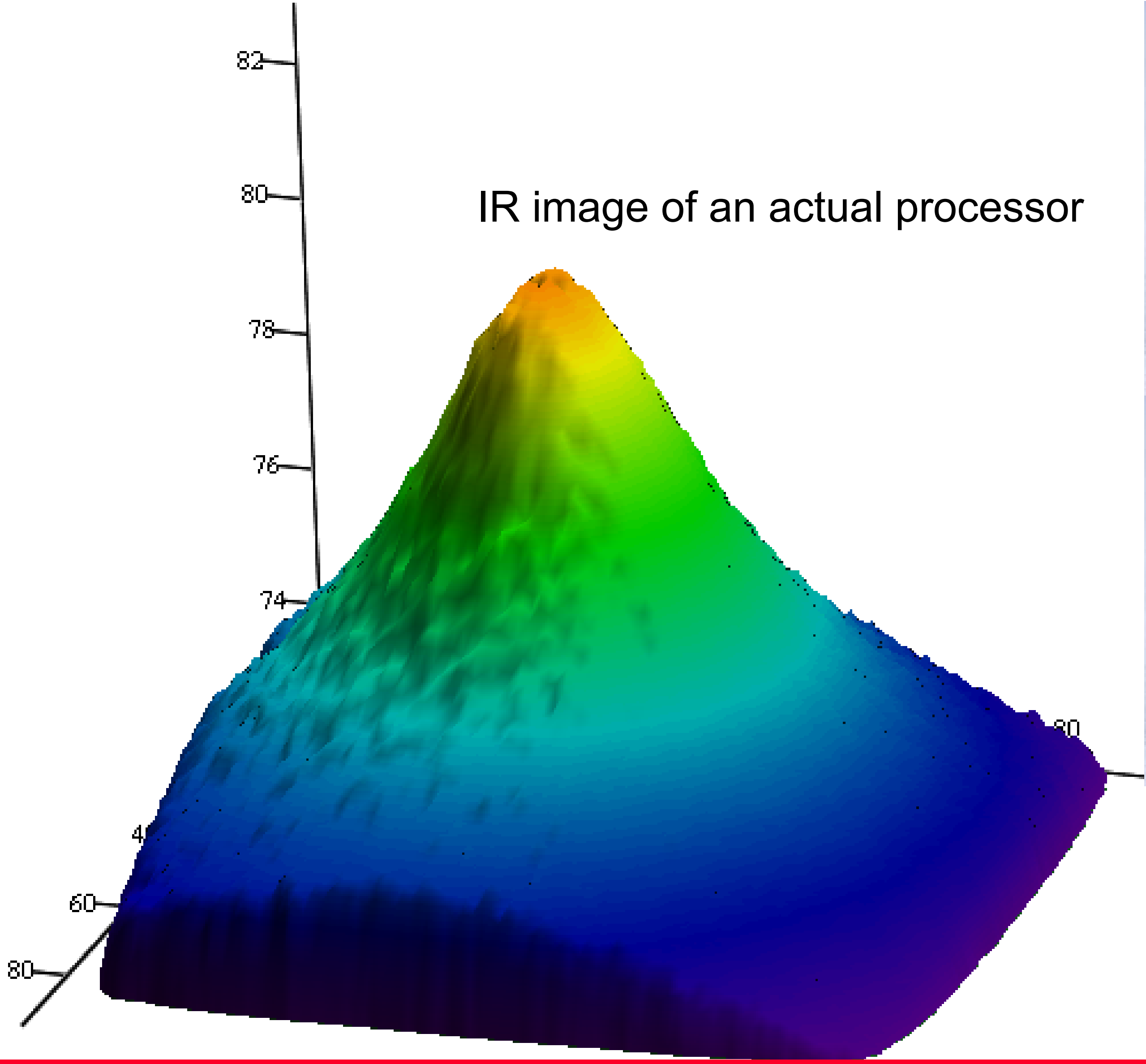
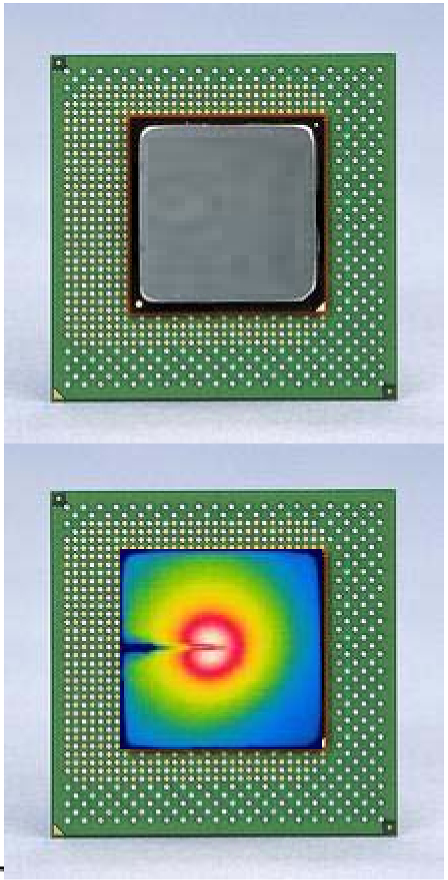


The thermal challenge in an IC is a truly daunting problem

Motivation: CPU Heat Flux is High



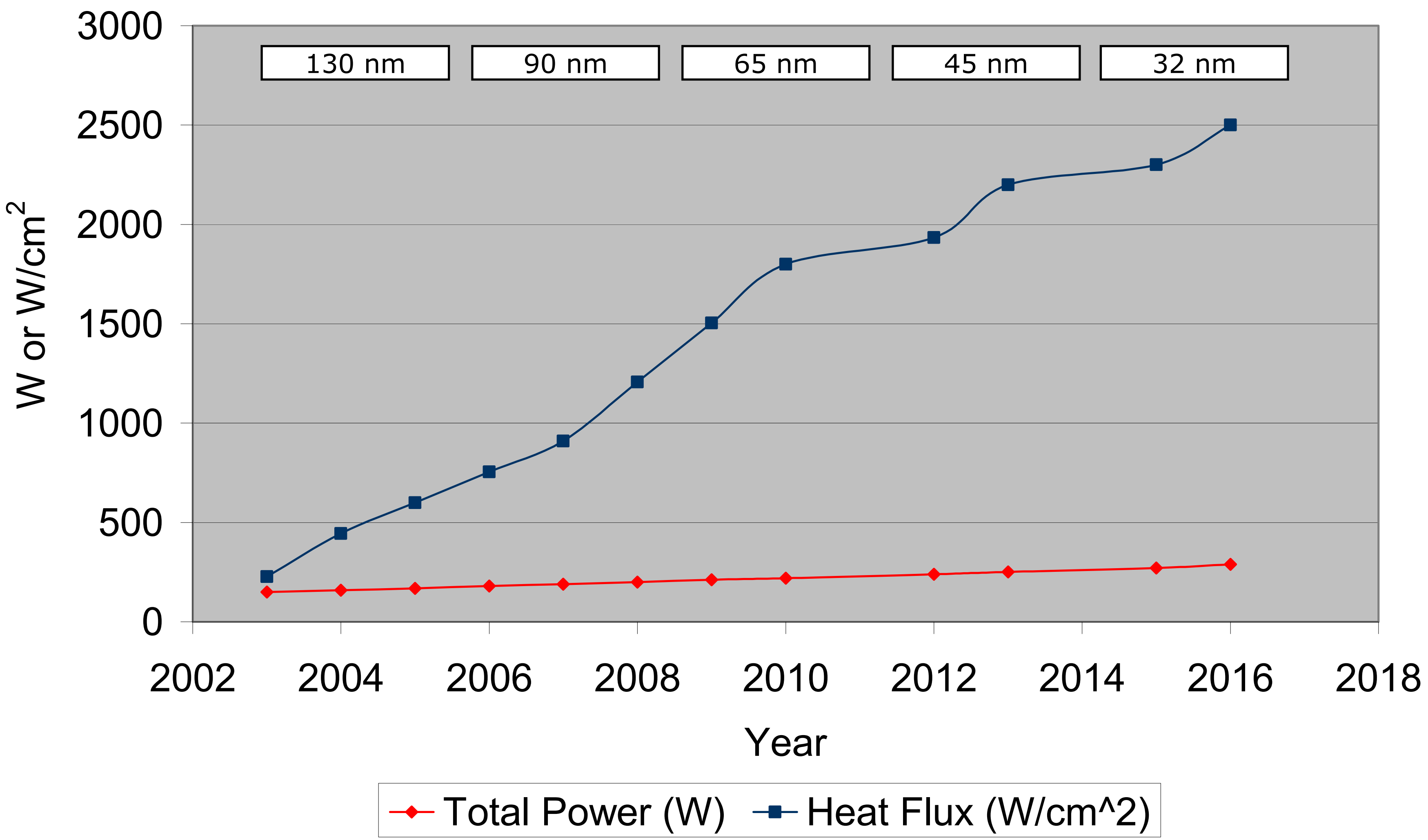
IR image of an actual processor



Most heat leaves through center 15% of the spreader's surface area

Motivation: CPU Power is Steadily Increasing

ITRS Power Predictions



Flux at the core continues to rise despite design innovation

Where are the thermally challenged IC's?

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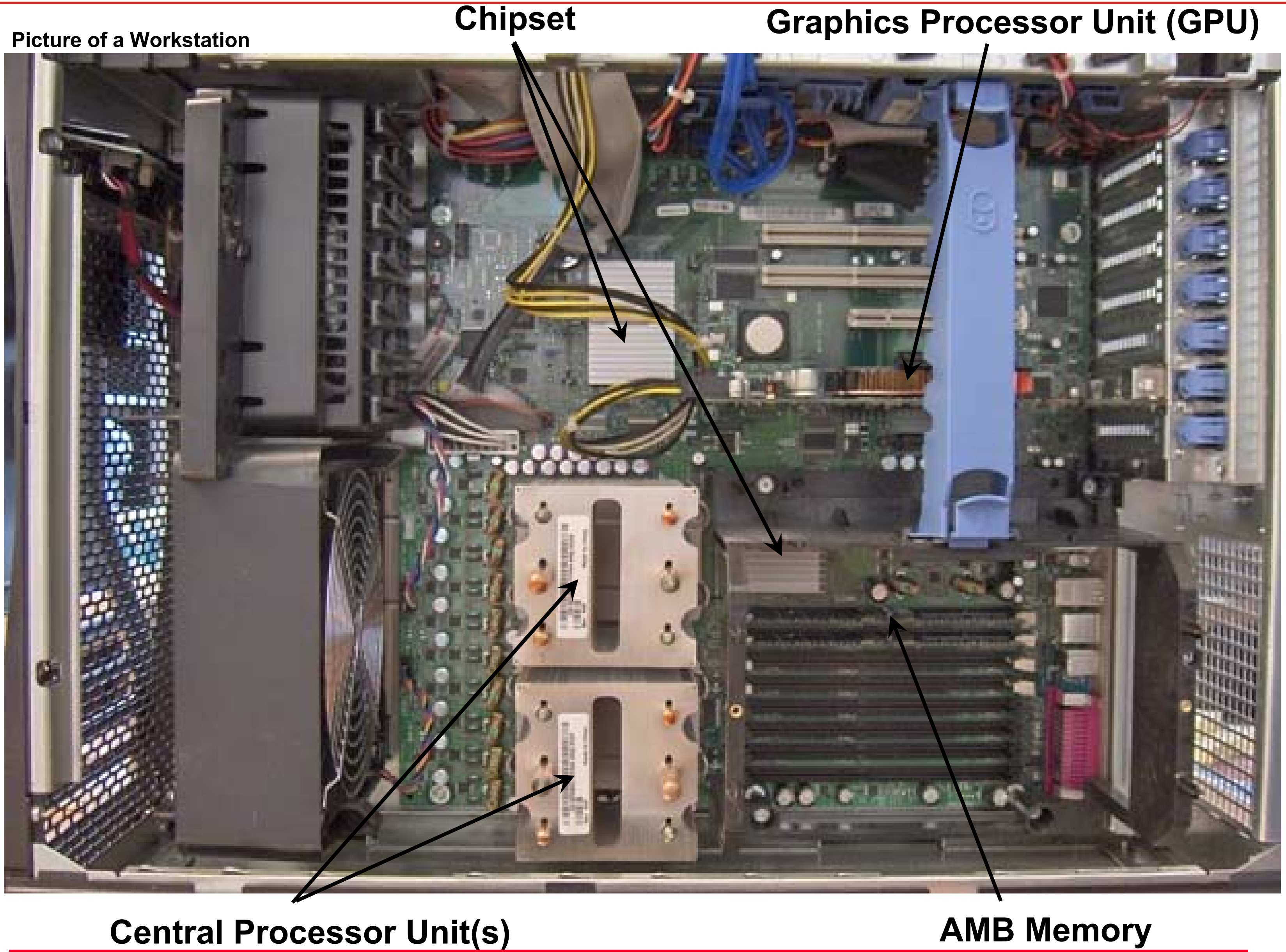
Picture of a Workstation

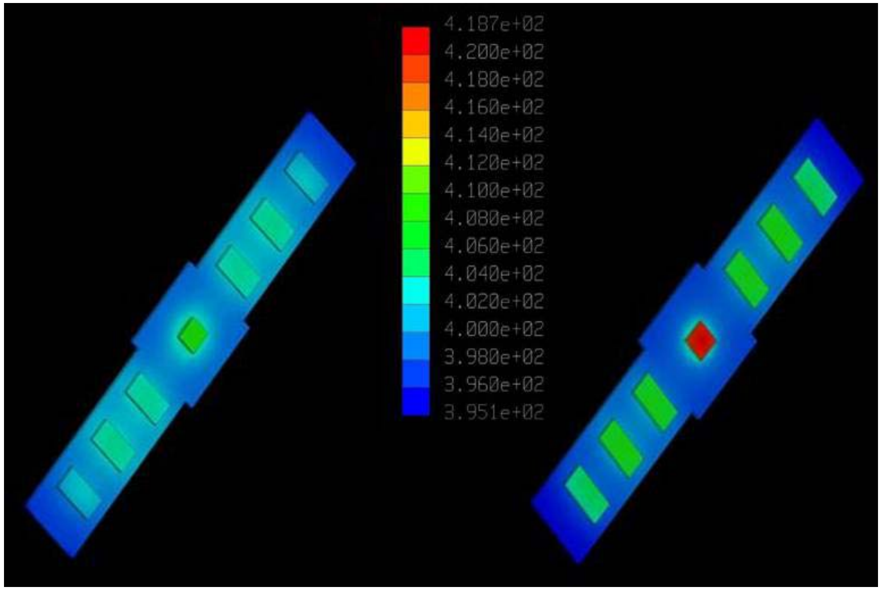


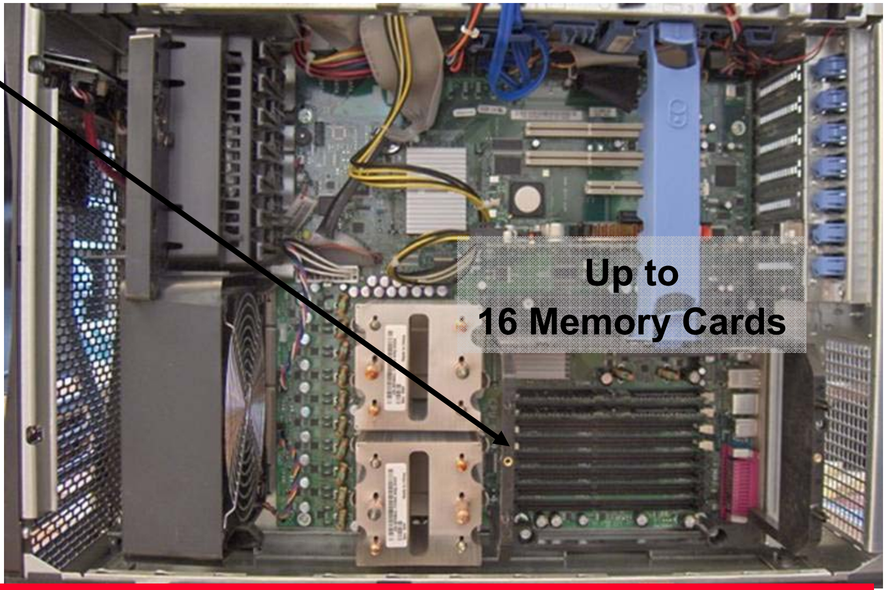
Thermal solutions are required for the CPU and ASIC's

Memory: AMB IC

- IC: Bare die
- Power: 4-8 Watts
- Airflow: System dependent, usually compromised
  - Sometimes cards are perpendicular to flow
  - In servers and workstations, many cards are packed densely together
- Thermal Solution: TIM and a heat spreader

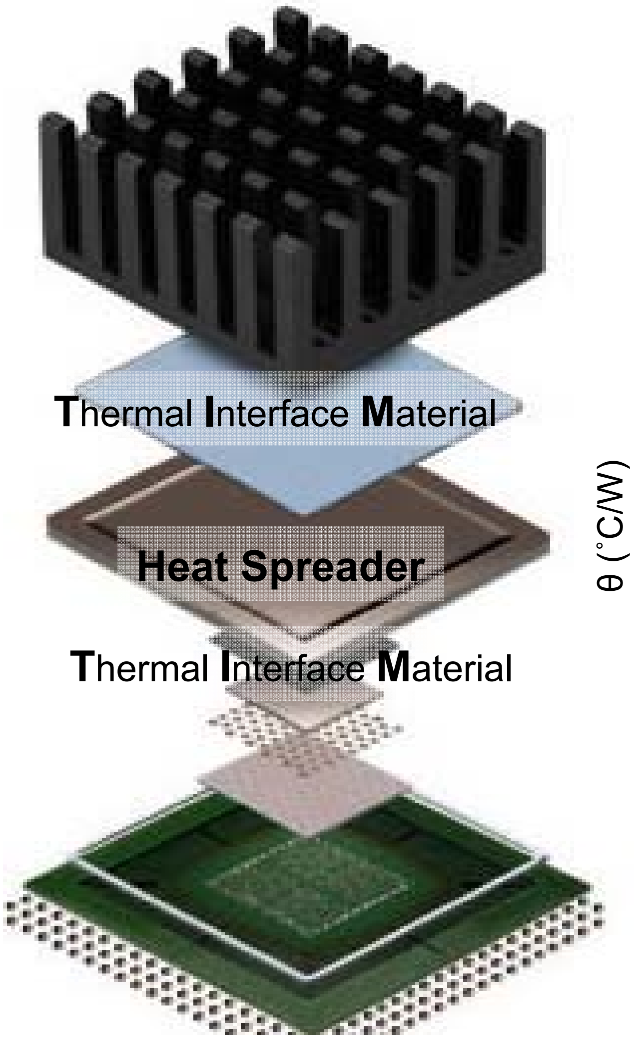
AMB IC is HOT

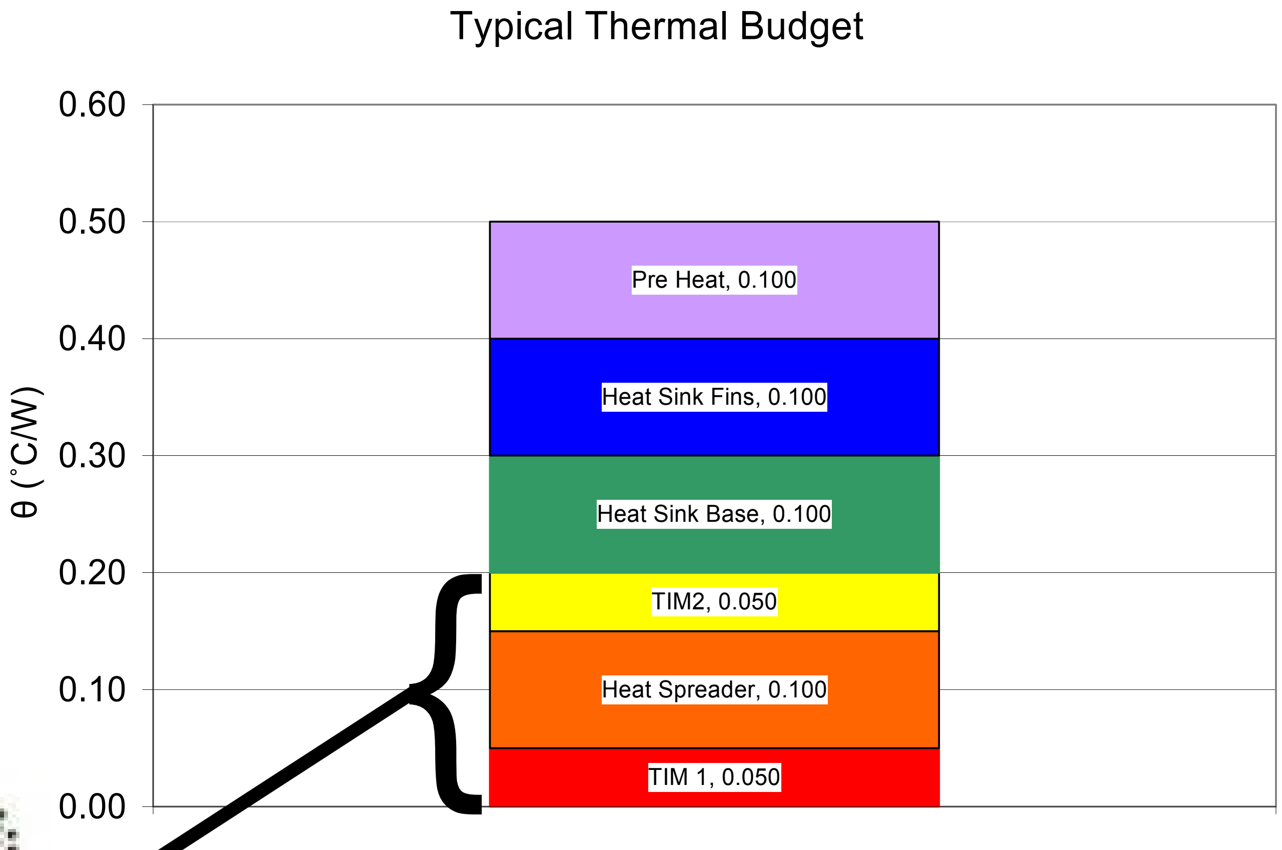




Memory cards require thermal solutions and system level attention

The Most Critical Heat Pathways

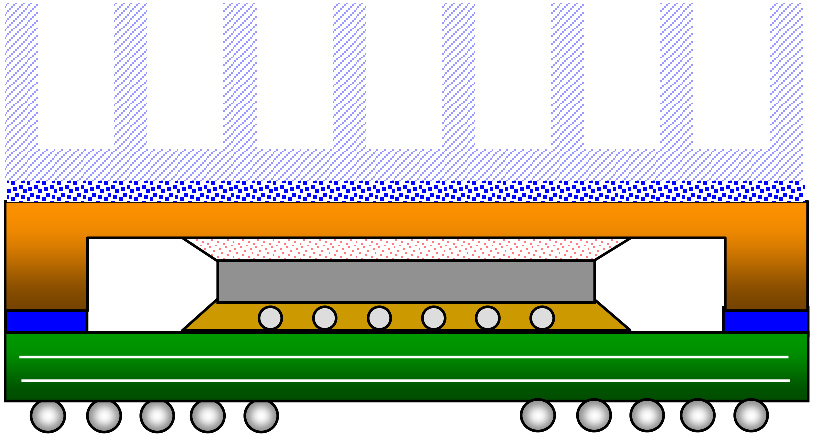


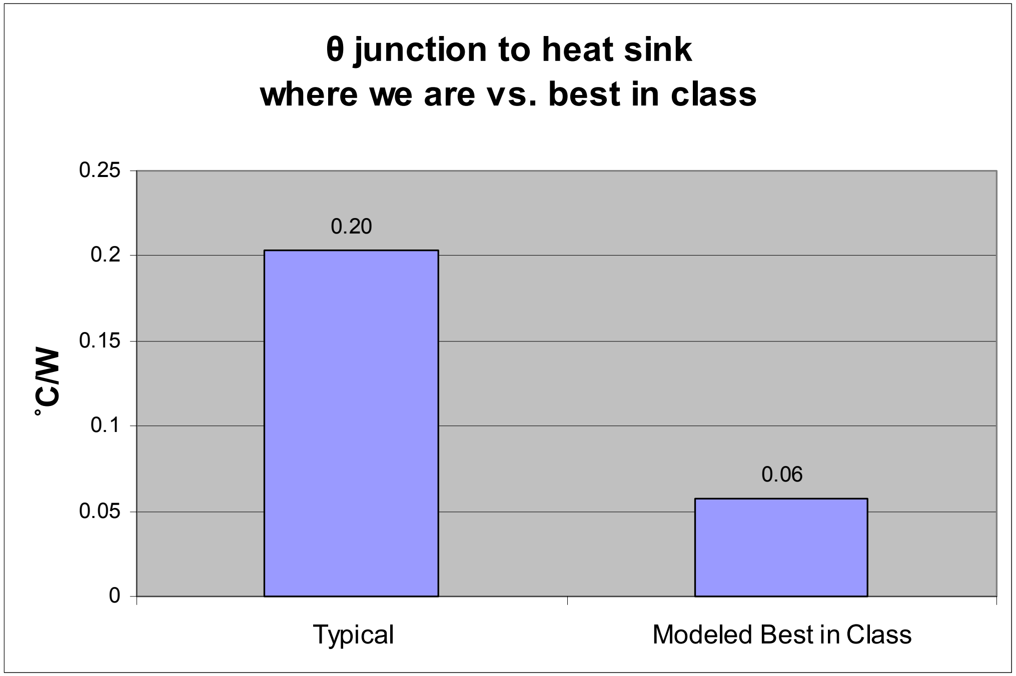


The highest heat fluxes travel through 0.20 C/W of the total budget

Classical Packaging Limits

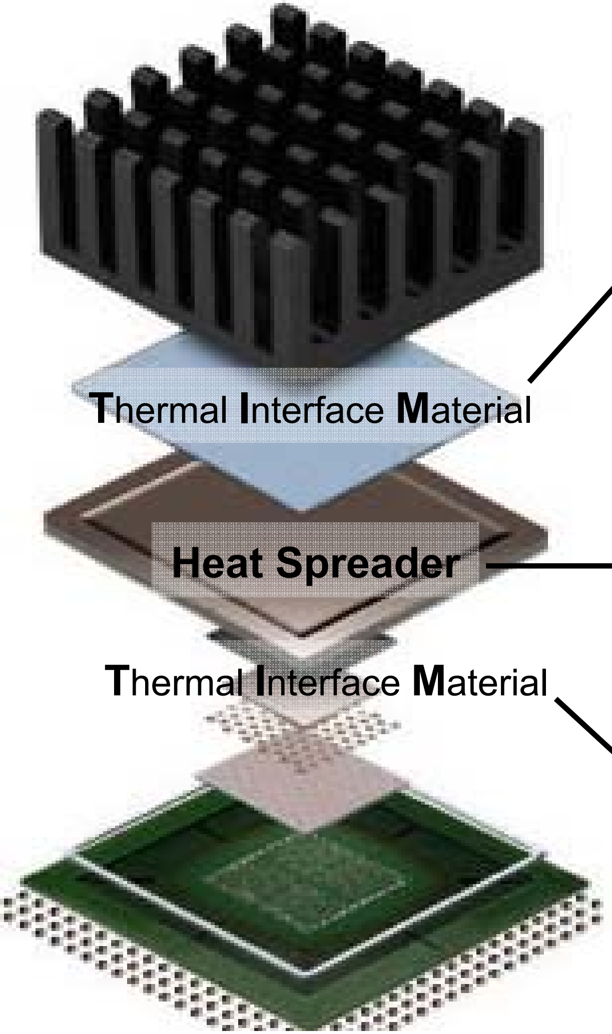
- Classical Package consists of:
  - TIM1
  - Heat Spreader
  - TIM2
- Typical limitations
  - TIM1
    - Heat Spreader Flatness
    - Heat Spreader Surface
  - Heat Spreader
    - Spreading Resistance
    - CTE mismatch
  - TIM2
    - Heat Spreader Flatness
    - Heat Spreader Surface



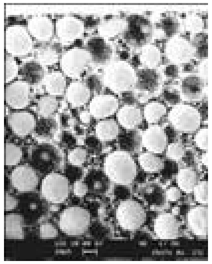


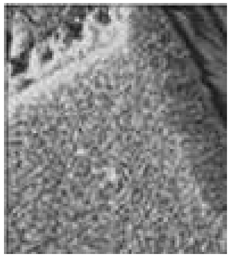
Room to improve classical package with improved technology

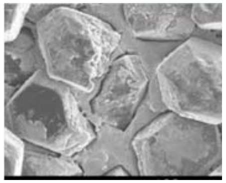
Materials Roadmap for Critical Heat Pathways

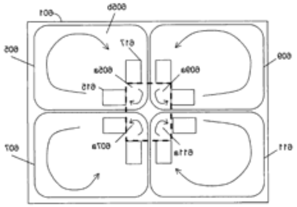


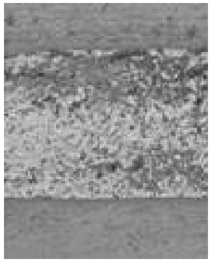
-2004------------------------ 2006---------------------------2008+

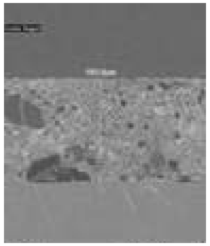












HEM produces and develops products for critical heat pathways

The products control at least 0.20 C/W of the total budget

Memory Module Heat Sink: Thermal Modeling

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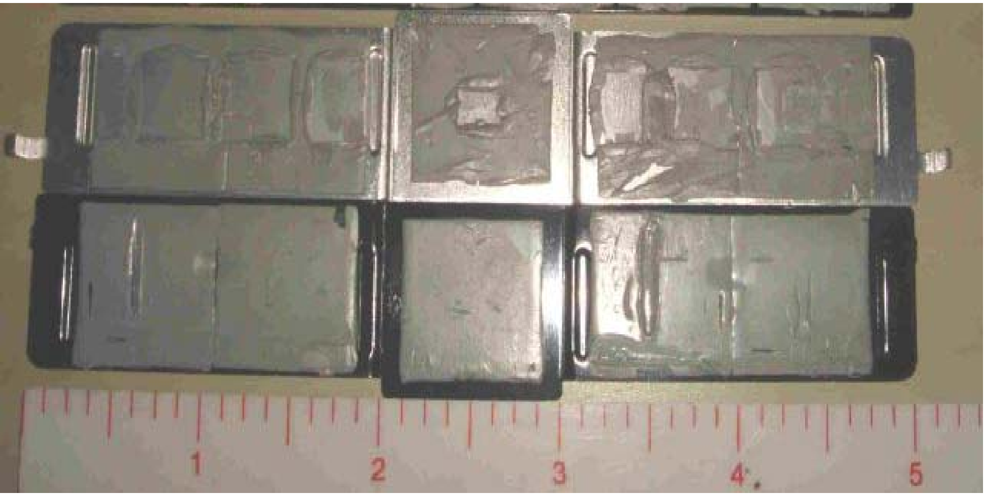
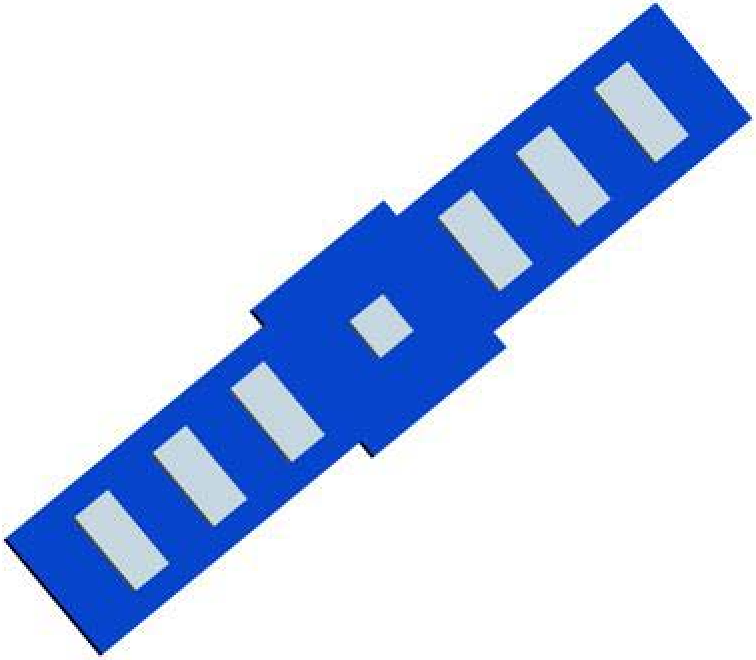
Actual Memory Heat Sink





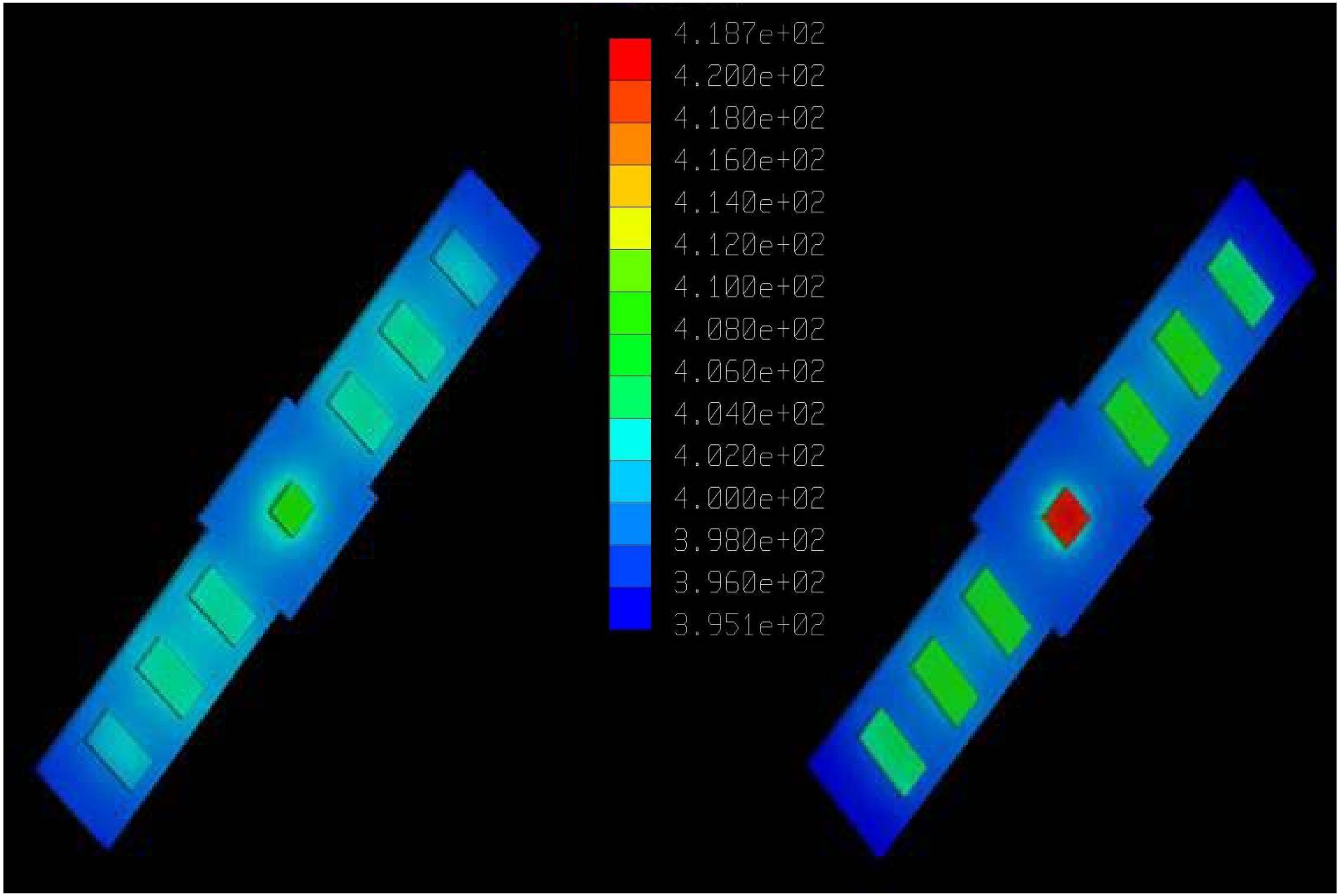
3D CAD Model for Mechanical FEA Analysis

Is TIM1 important to the AMB?

TIM 1 Performance: Memory Module

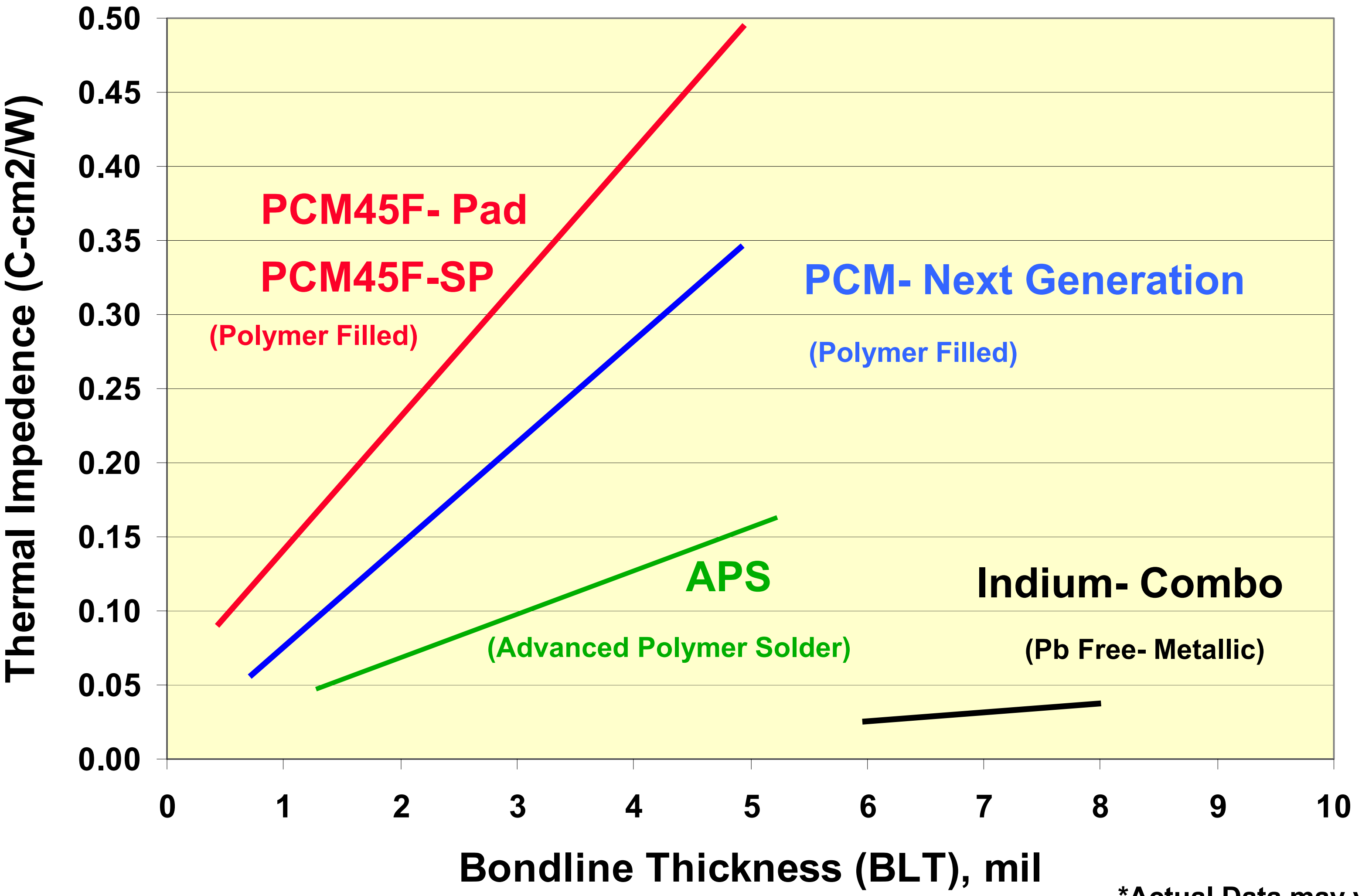
Honeywell PCM45

Competitor's Material



FEA results predict >10 ˚C reduction on AMB chip, allowing superior performance

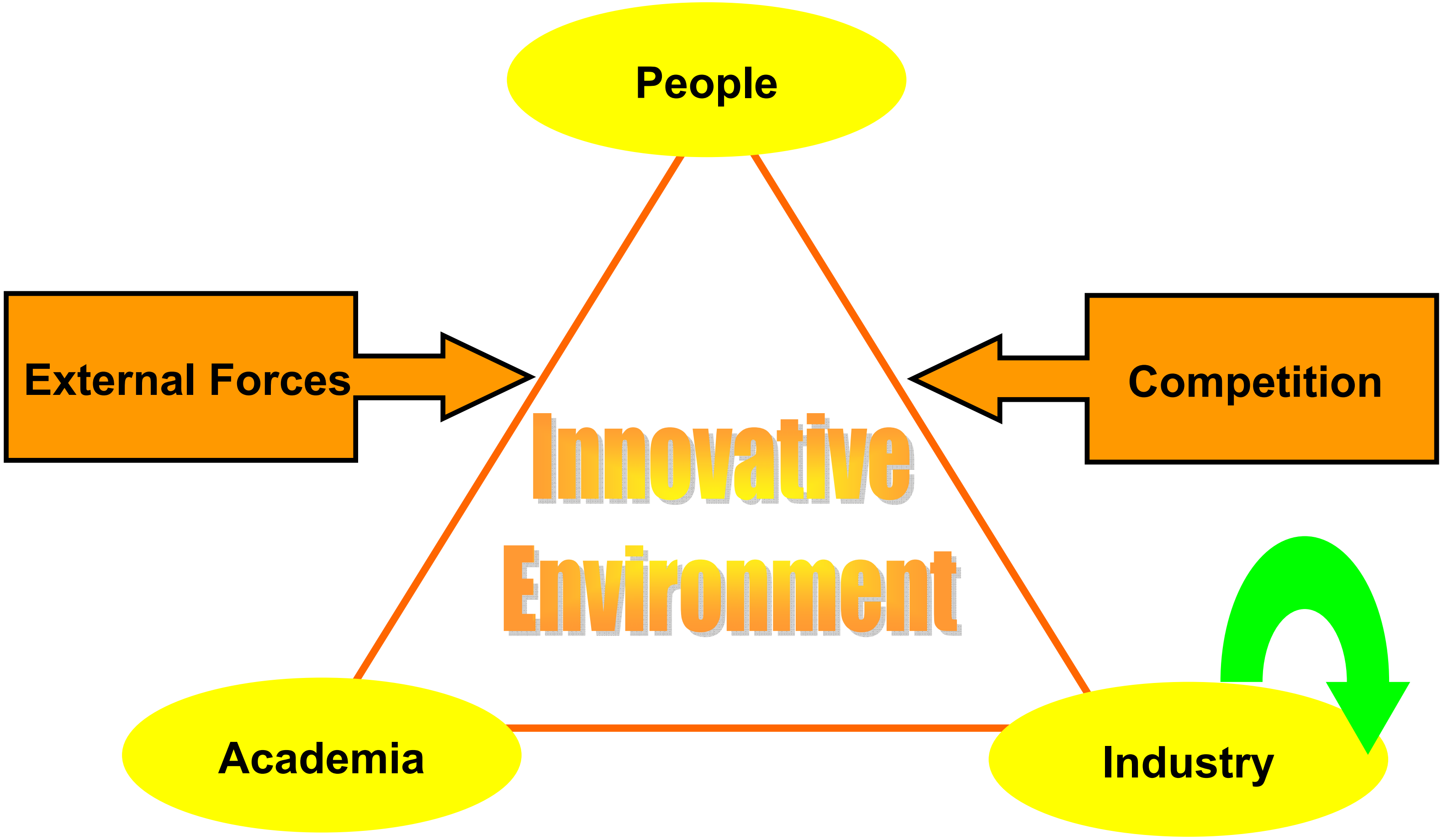
Honeywell's TIM's*



*Actual Data may vary in application. ASTM D-5470

HEM representative products cover a wide performance range to help address thermal challenges

Collaboration is key to Innovation



Rapid and fundamental innovation requires increased collaboration

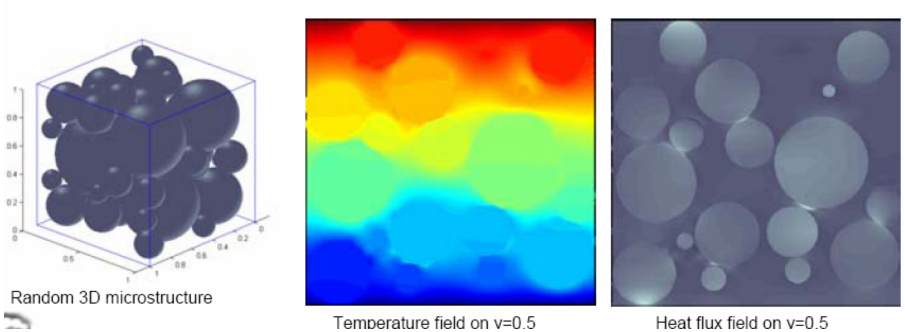
Collaboration: example CTRC

- Purpose: Long term research and development in the area of high-performance heat removal from compact spaces
  - NSF Industry/ University cooperative research center at Purdue University

- Path
  - Attend bi-annual CTRC meetings to review work
  - Determine and support relevant technologies
  - Productize

Cooling
Technologies
Research
Center

- Products
  - Optimized particle TIMS
  - CNT TIMS
  - Advanced Heat Spreaders



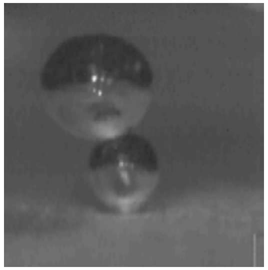
Random 3D microstructure

Temperature field on v=0.5

Heat flux field on v=0.5

Particulate TIM Models

- Progress
  - Member since 2002
  - Hired CTRC graduate



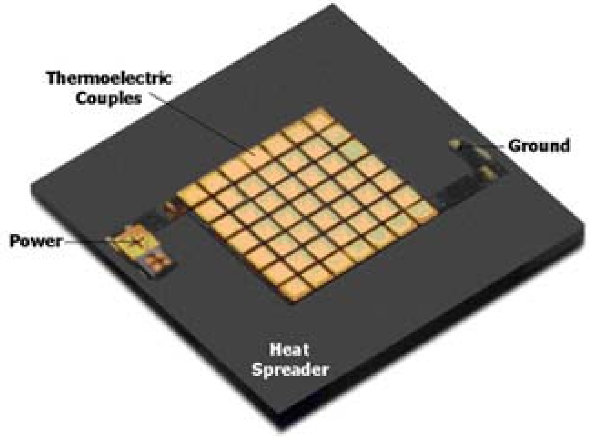
Boiling Research

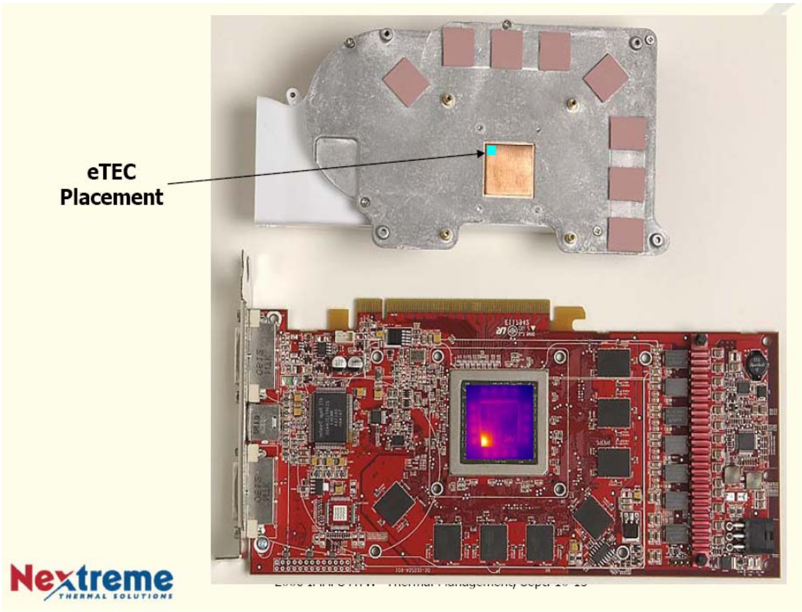
Source: CTRC, Purdue. Used with permission.

Industry issues worked on fundamentally to address challenges

Thermoelectrics: example Nextreme Active Cooling

- Thin film thermoelectric device operates between the heat spreader and IC
- Hot spots are addressed with refrigeration
  - Heat flux into heat spreader increases, however, hot spot temperature is reduced
  - Some additional power is required
- Challenges
  - Improving TE materials
  - Understanding Reliability





Source: Nextreme, used with permission.

Nextreme's eTEC for Hotspot Cooling

With improved materials and reliability, thermoelectric devices could revolutionize hot spot cooling

New: Honeywell’s Active Heat Spreader

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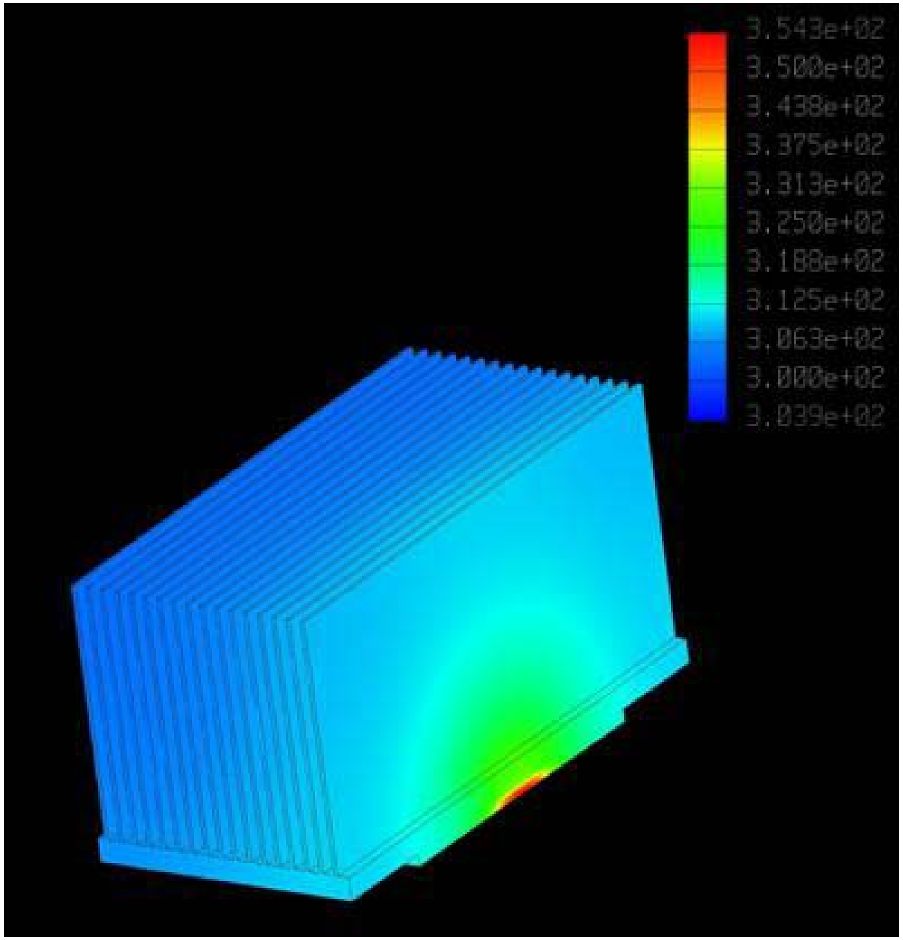
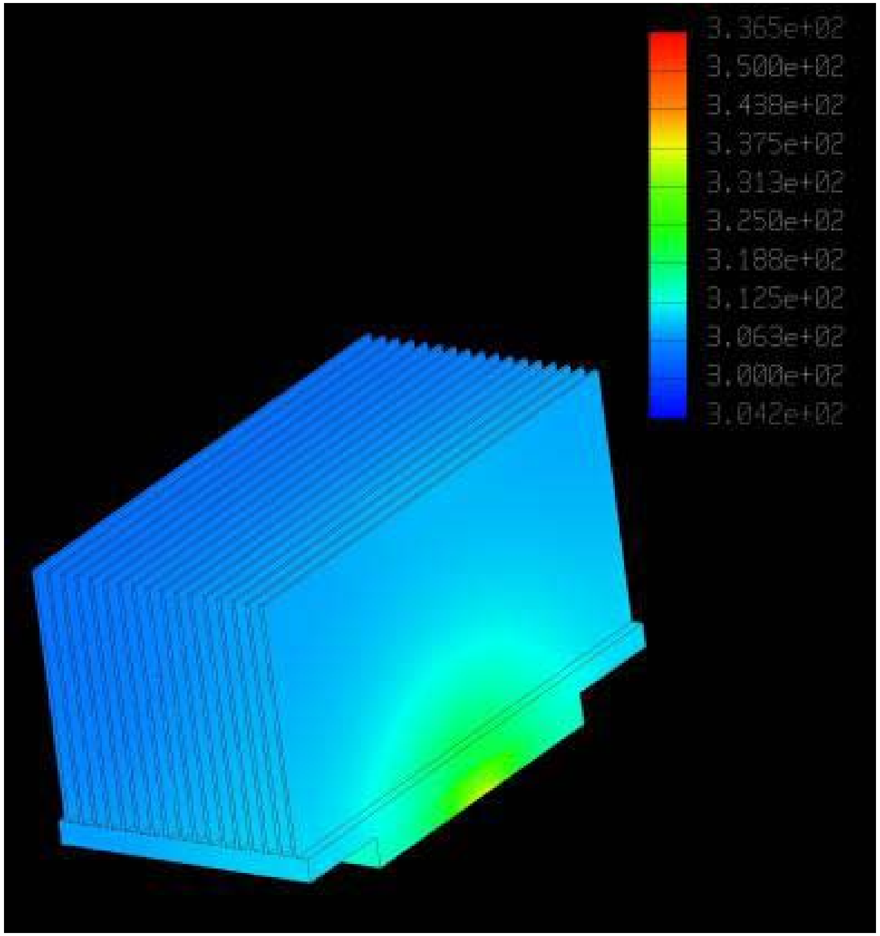
Improving the Heat Spreader Improves the performance of everything downstream



- **Standard Heat Spreader**
- **T_{max} = 81.2 ˚C**



- **Enhanced Heat Spreader**
- **T_{max} = 63.4 ˚C**

Significant (17.8°C) reduction over current technology

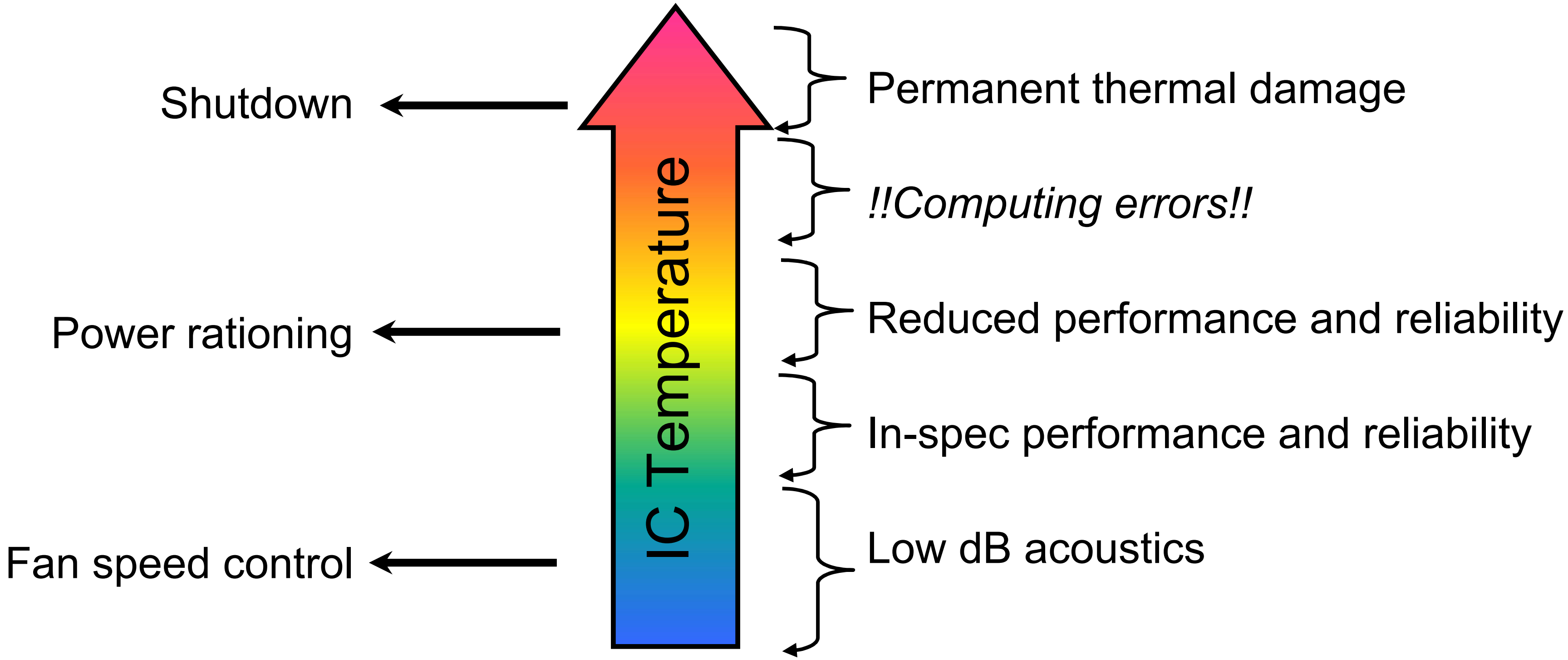
Other Innovations

- Power limitations for chip architects
- Software and threading innovation
- Data center power balancing
- Discrete device computing
- Multi die and multi core
- Feedback loops, throttling, and thermal shutdown

Smart chip & system design can also address thermal challenges

Thermal Management at the IC Level

- **This technique is currently used in:**
  - **mobile computers**
  - **CPU's**
  - **AMB's (DIMMs)**



Shutdown

Power rationing

Fan speed control

Permanent thermal damage

!!Computing errors!!

Reduced performance and reliability

In-spec performance and reliability

Low dB acoustics

Power management can improve thermals, but will reduce performance

Summary

- **Thermally Challenged IC's found throughout modern computers**
  - **CPU**
  - **ASIC's**
    - GPU
    - Memory
    - Chipsets

- **Overall Heat Flux and Hot Spots are pushing the limits of today's products**

- **Some of today's cutting-edge products address the thermal challenge today**

- **Next generation products offer hope. Collaboration is key.**

Innovation in thermal management will enable better performance

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