A future for Thermal Engineering

Not just a stand-alone profession anymore

Jerry Bartley – IBM Global Engineering Solutions

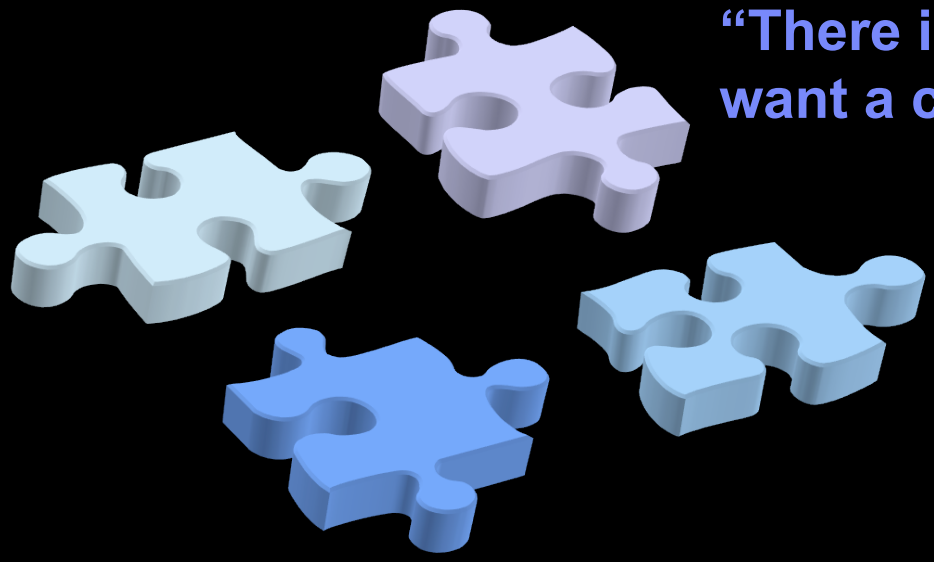
Quotes to remind you of your perceived limits

"I think there is a world market
for maybe five computers."

Thomas Watson, chairman of IBM, 1943

"Computers in the future may weigh
no more than 1.5 tons. "

Popular Mechanics, 1949



"There is no reason anyone would
want a computer in their home. "

Ken Olsen, founder of DEC, 1977

"640K ought to be enough
for anybody. "

Bill Gates, 1981

"Prediction is difficult, especially
about the future"

Yogi Berra

My dad

Understood the importance of looking at designs and processes from a multi-discipline perspective.

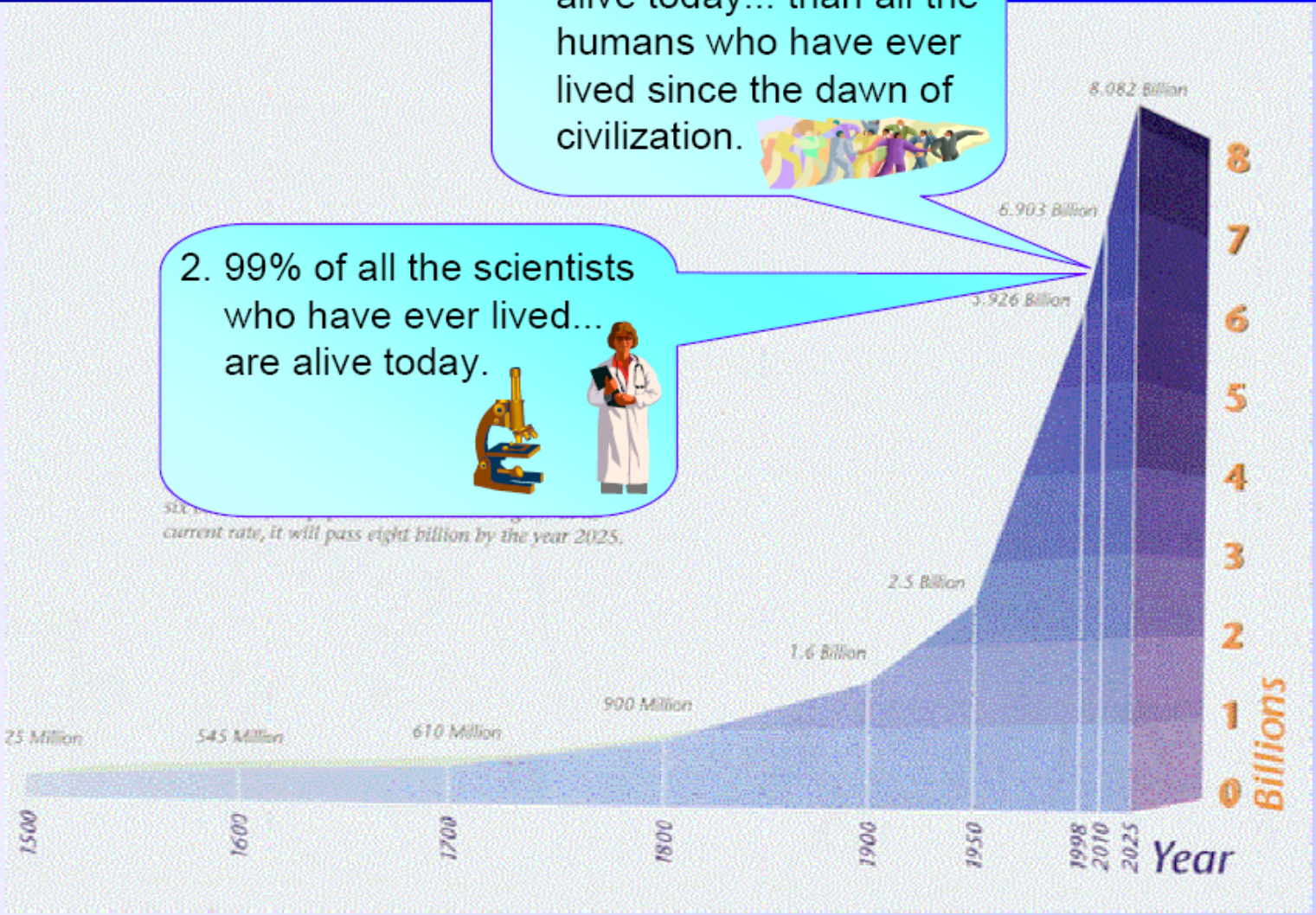
Defined his own profession as a Mechanical Engineer as "Hammer to form, File to fit, and Paint to cover"…

Offered **me career guidance… "A sparky that can't talk to the mechanical team is not very valuable"**

Encouraged me to consider different perspectives

- **Take Mechanical/Chemistry courses in college.**
- **Work in metal and plastics fabrication shops during summers.**

The Curve of Change



Source: The Gary Hilbert Letter
http://www.thegaryhilbertletter.com/newsletters/population.htm

Today's world

- Power-in and out among today's largest challenges
- Technology suppliers are working on "new" and "breakthrough" TIMS, Materials, different approaches, etc.
- Users benefit in many ways, but the gold is still out there. Working together with the other disciplines to optimize the technology usage.

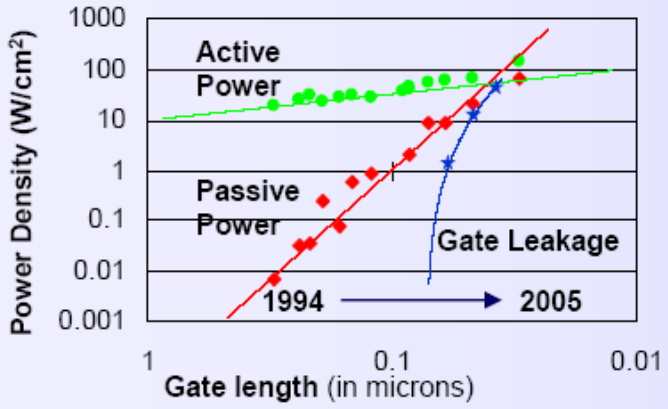
Chip designers are starting to understand, and the market wants more. Example, a mobile device includes a game system, music, camera, PDA, and oh yes, a cell phone, that lasts weeks on a single charge and weighs less, is smaller etc.

Now the throw away "gadget" has become a necessity

Power, Cooling and Frequency Limits

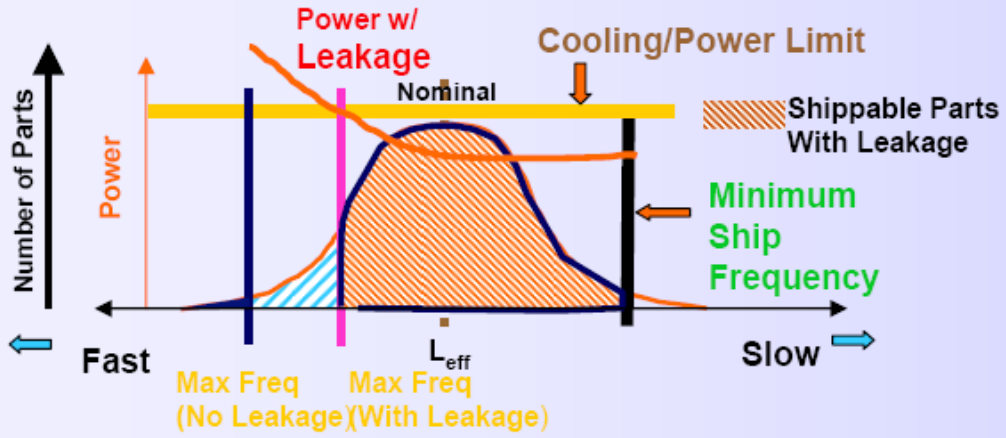
Server microprocessors cannot simultaneously utilize all their transistors due to power limitations

Active vs Passive Power

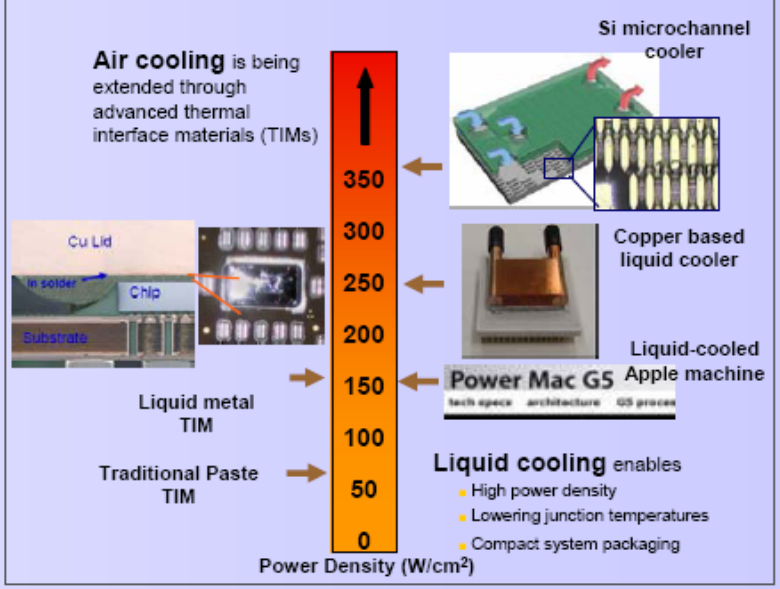


- **Moore's law is continuing with respect to transistor density, although at a reduced pace, because:**
- Passive Power (power leakage) approaches Active Power
- Air cooling is pushed to its limits
- To satisfy power, frequency, and cooling constraints - new materials and methods will be developed

Power, Frequency, Cooling Limits



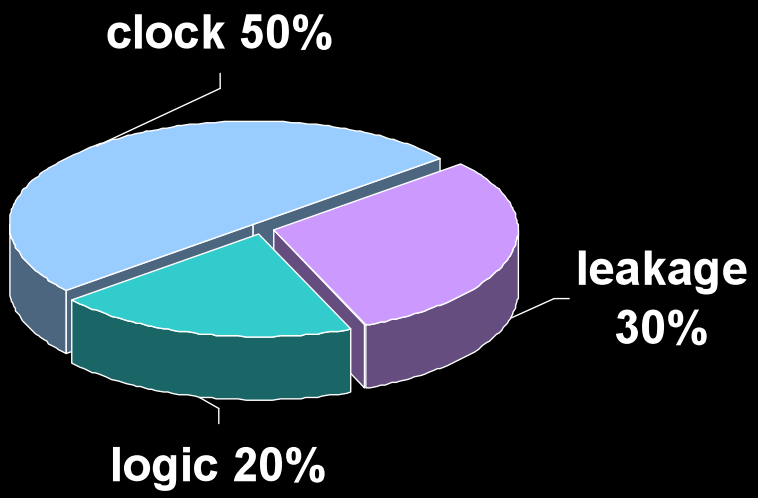
Advanced Cooling Techniques



Power in Server Class Processors

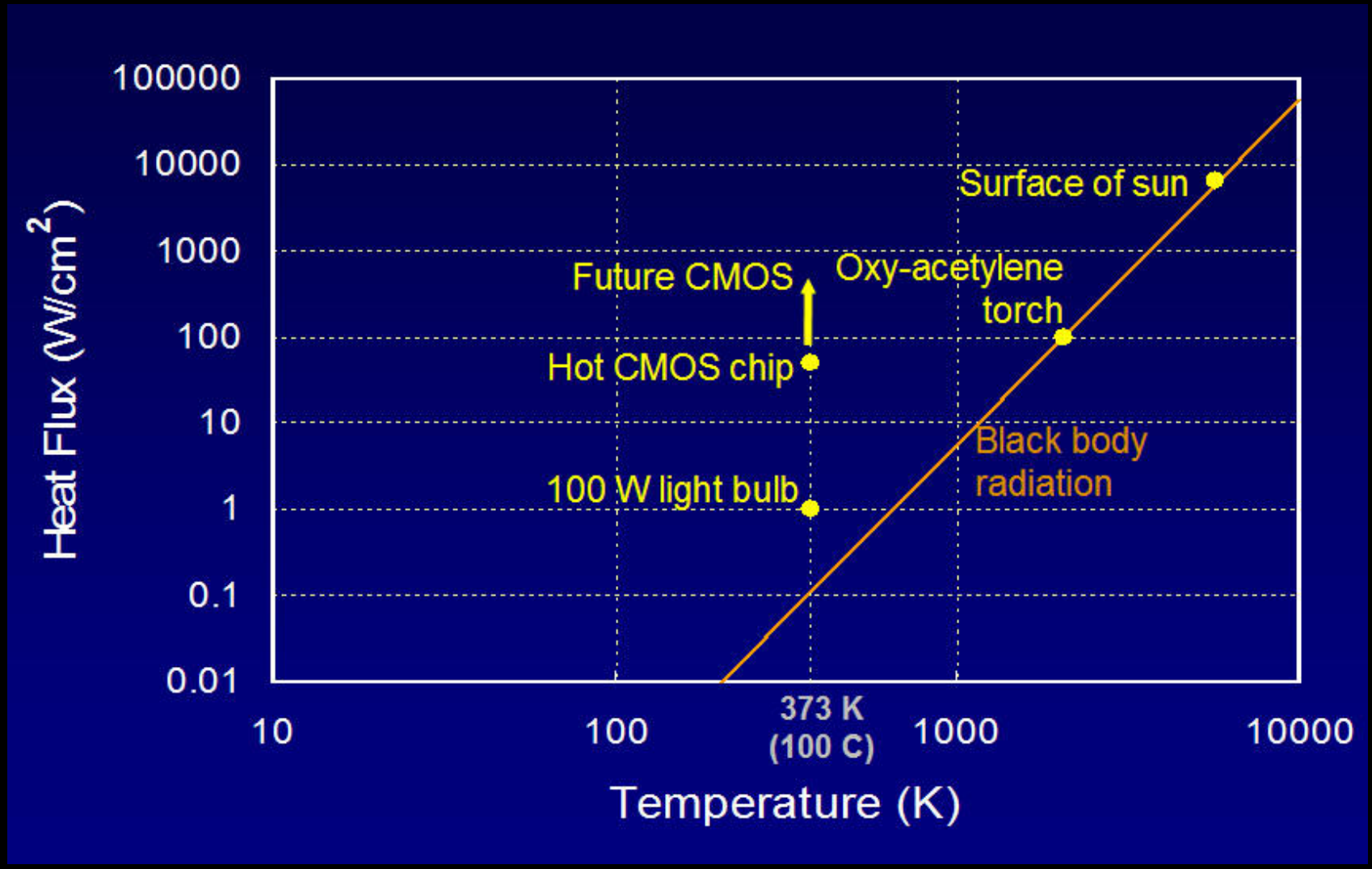
- Main focus on worst-case power
  - Processor must work at full speed under worst-case workloads
  - Power saving techniques should have minimal impact on IPC and frequency

- Traditional top power consumers
  - Clock power
    - 70% or more of dynamic power
    - 50% of total power
  - Static power
    - 30% of total power (limited)
  - Logic power
    - 20% of total power



High-Level Breakdown of Processor Power

Trends in Heat flux



Blue Gene/L Supercomputer

64 Racks, 64x32x32

Rack

32 Node Cards

180/360 TF/s
32 TB

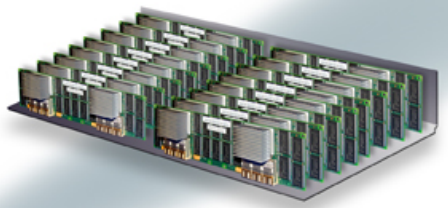
Node Card

(32 chips 4x4x2)
16 compute, 0-2 IO cards

2.8/5.6 TF/s
512 GB

Compute Card

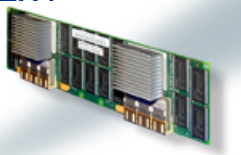
2 chips, 1x2x1



90/180 GF/s
16 GB

Chip

2 processors



5.6/11.2 GF/s
1.0 GB

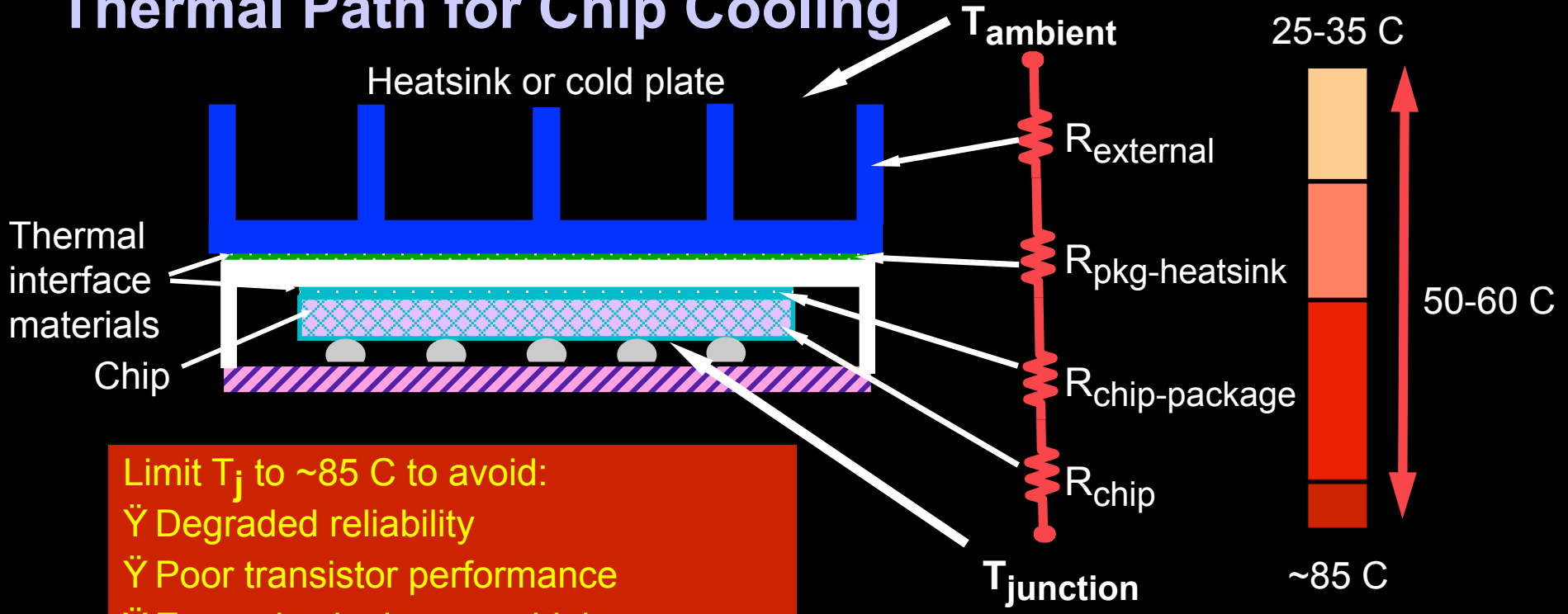
2.8/5.6 GF/s
4 MB

Chimp off the old block

0.6% Really does make a difference !!!!!

DETAILS REALLY MATTER !!!!!!!!

Thermal Path for Chip Cooling



Limit T_j to ~85 C to avoid:

- Degraded reliability
- Poor transistor performance
- Excessive leakage --> higher power

$T_j = T_a + P\ R_{ja}$ where R_{ja} = sum of thermal resistances from junction to ambient, T_j and T_a are junction and ambient temperatures, P = chip power

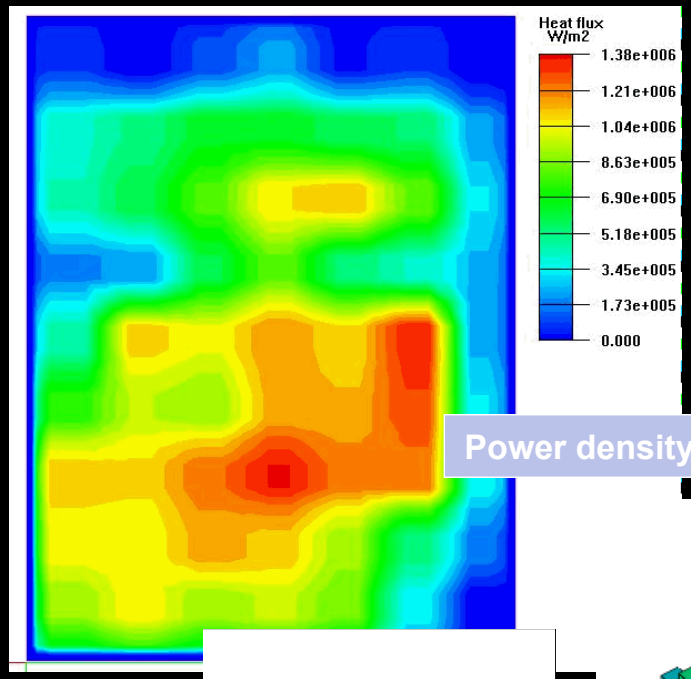
- Typically 40-70% of internal heat drop is across the thermal interface material (TIM)

More Thermal Reality

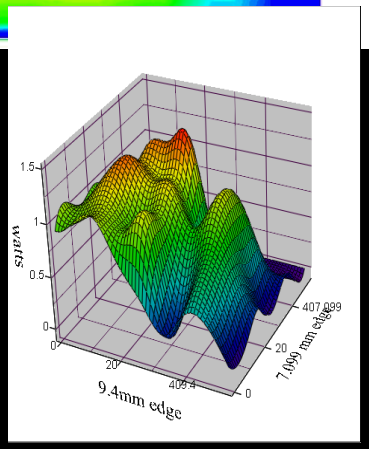
Detailed knowledge is important

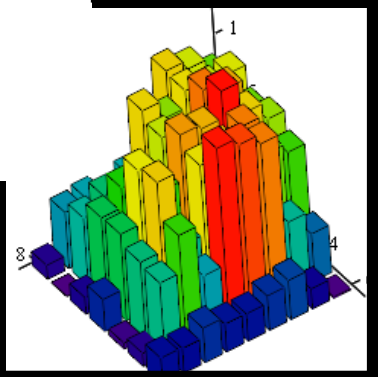
- Understanding the power density
- Understanding the impact of higher Temperatures
- Having the ability to bring the appropriate amount of technology to the application.

Tambient	Tj_nom	effective hot-spot R	fin base HTC	TIM1 interface condition
C	C	C/W	W/m**2K	
25	57.5	0	755	uniformly heated chip
25	64.1	0.15	755	best can-do grease
25	91.9	0.76	755	2 mil PCM interface



Power density maps



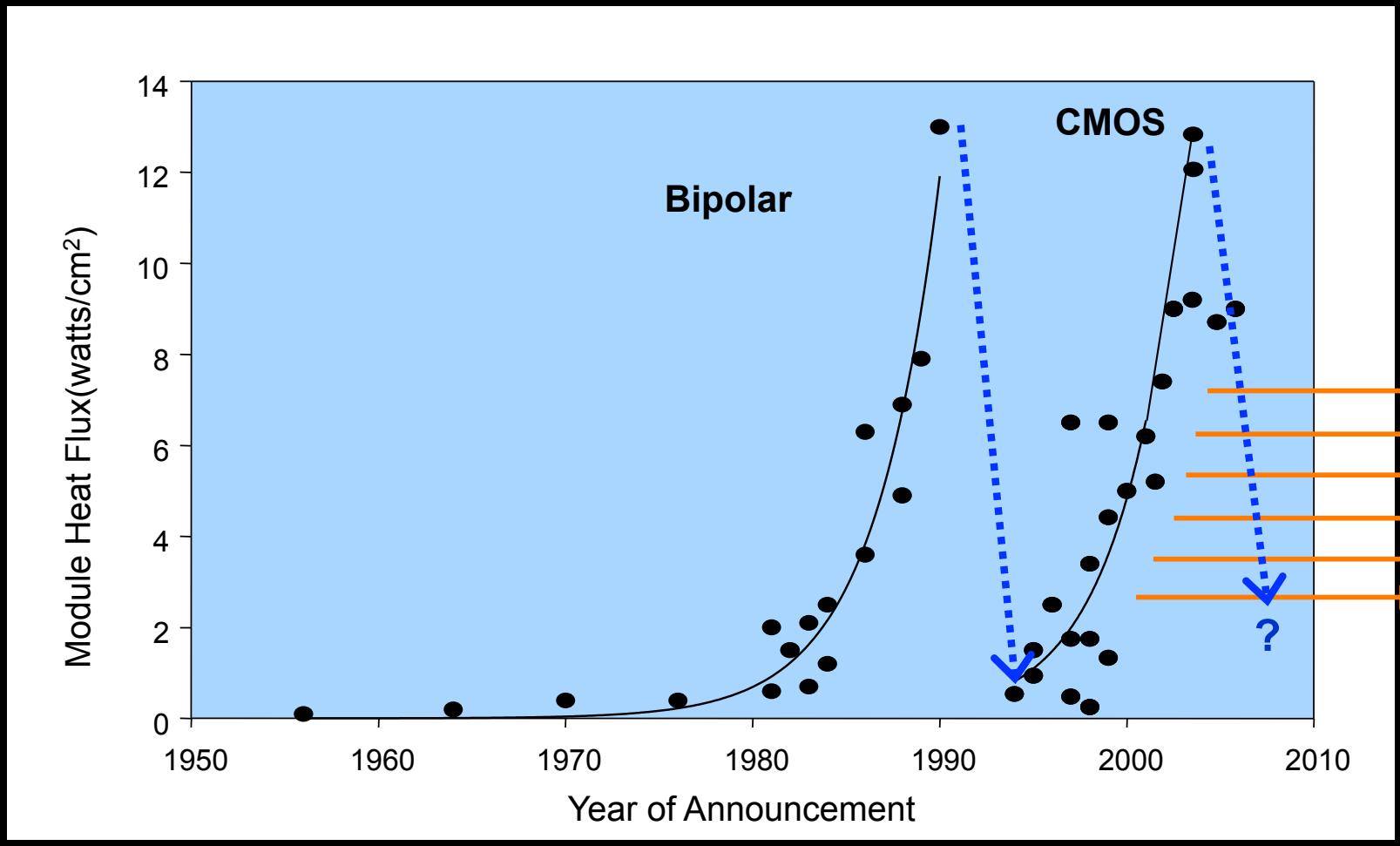


Observations

- 1 dimensional analysis, has known limitations, but still in demand from the chip/system teams.
- Transient thermal analysis becoming more important
- In the past, a different set of “Special” cases were pushing technology
- Limitations starting to engage broader teams and disciplines
  - Silicon process, Chemists, etc.
  - System and micro-architecture
  - Device/transistor designers
- Reliability pressure growing dramatically
- Circuit designs, chip materials…. Timing, reliability, yield all pressuring our analysis capability.
- More and more analysis necessary with much more detail, trade-offs required to achieve success.

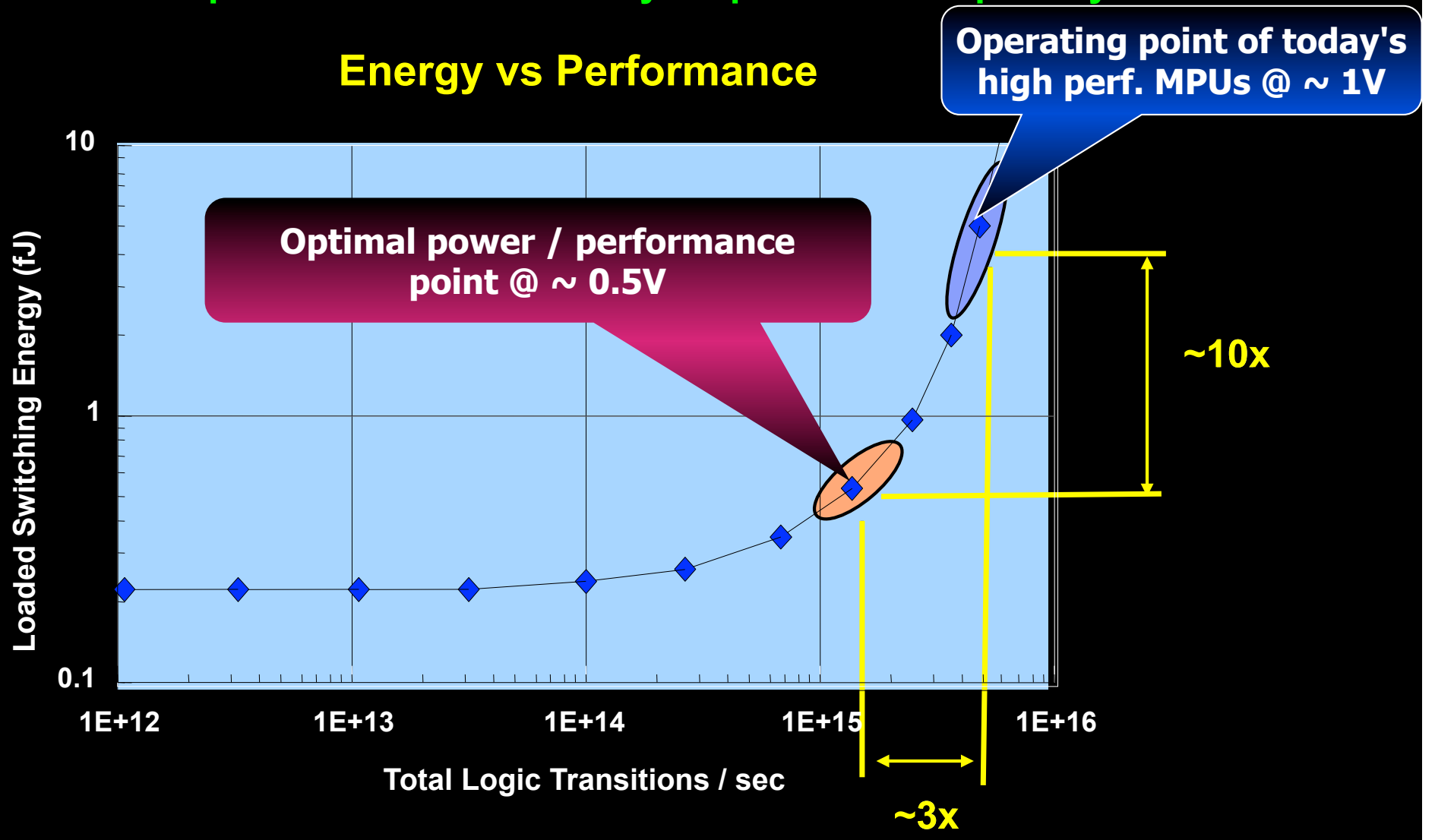
Net: Thermal engineering becoming involved much sooner.

Transition to 3D CMOS

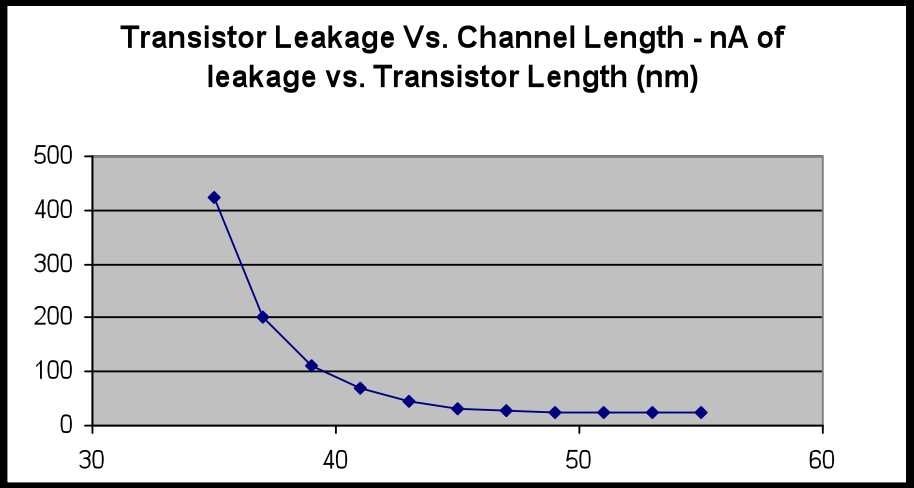


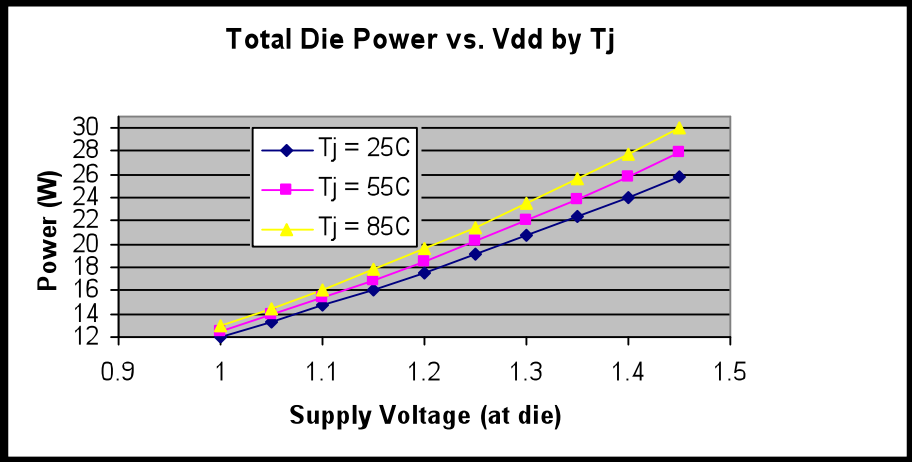
Moving to an Ultra-Low Voltage Operating Point

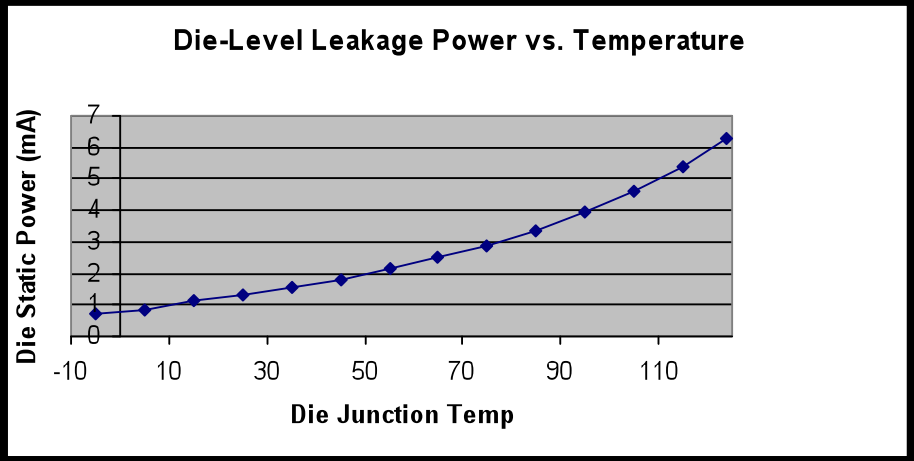
10X power reduction for only 3X performance penalty



Characteristics of today's Silicon

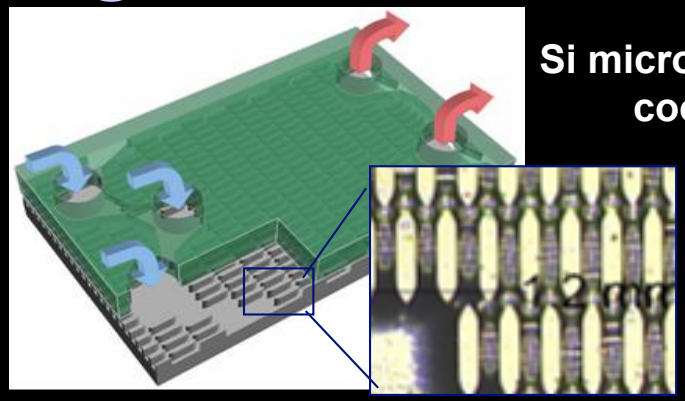




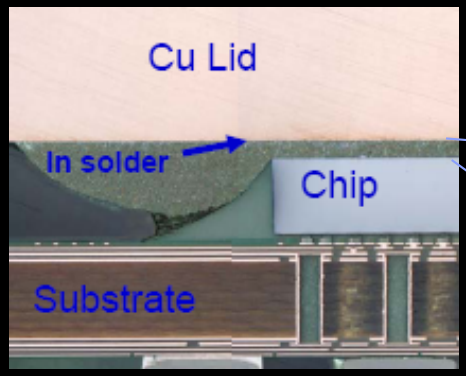


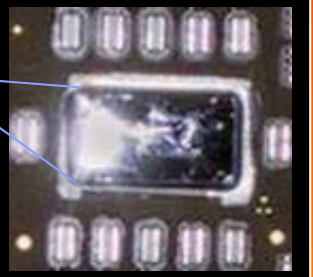
Advanced Cooling Technologies

- Air cooling is being extended through advanced thermal interface materials (TIMs)



Si microchannel cooler



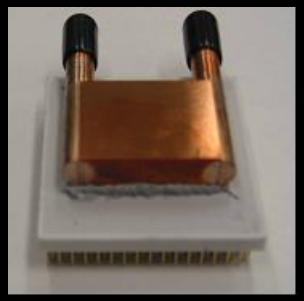


Liquid metal TIM

Traditional Paste TIM

350
300
250
200
150
100
50
0

Power Density (W/cm²)



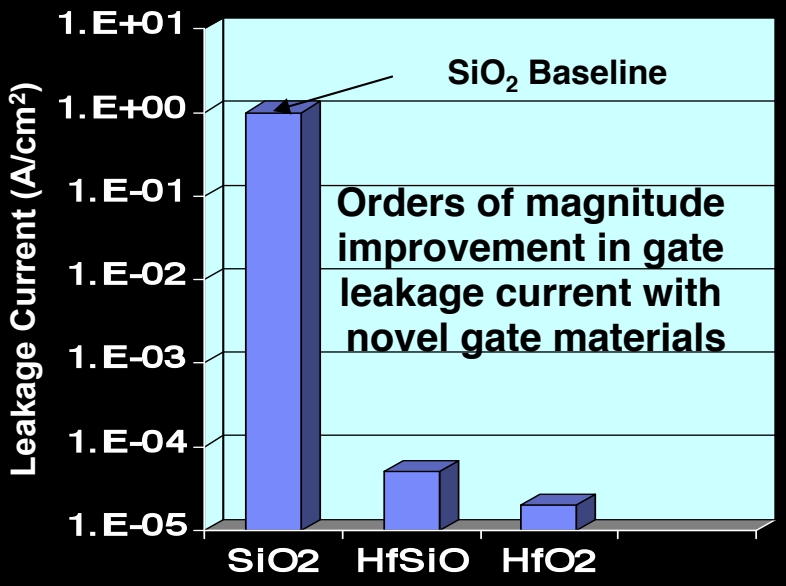
Copper based liquid cooler

Liquid-cooled Apple machine

- Liquid cooling enables
  - High power density
  - Lowering junction temperatures
  - Compact system packaging

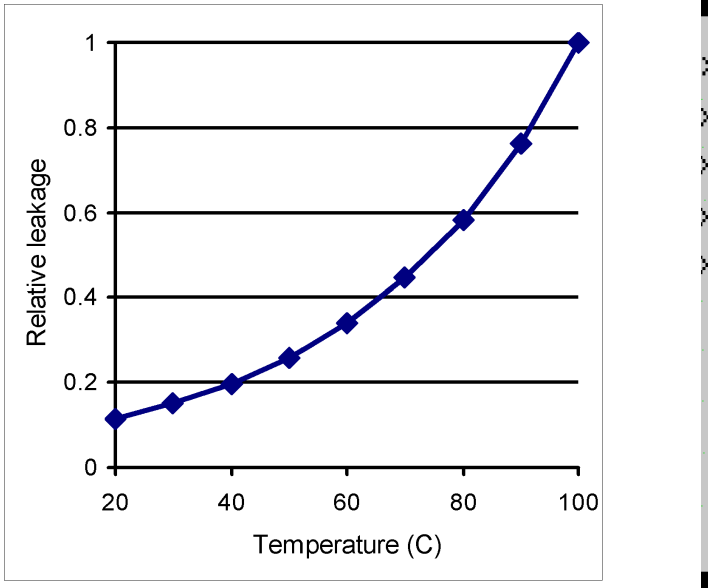
High-k Metal Gate

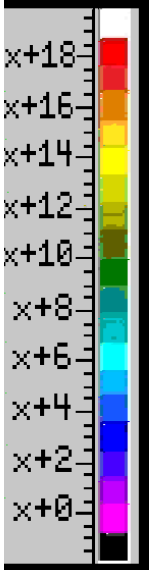
New materials can significantly reduce leakage currents

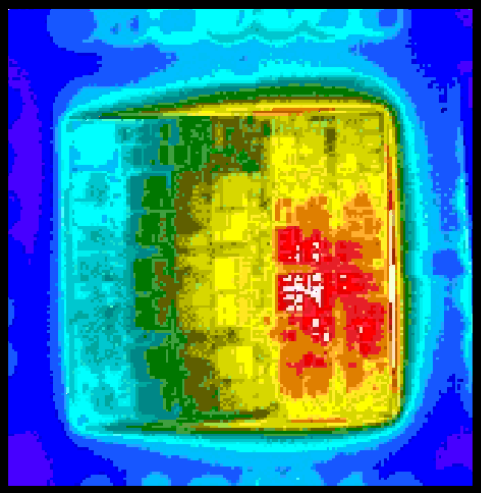


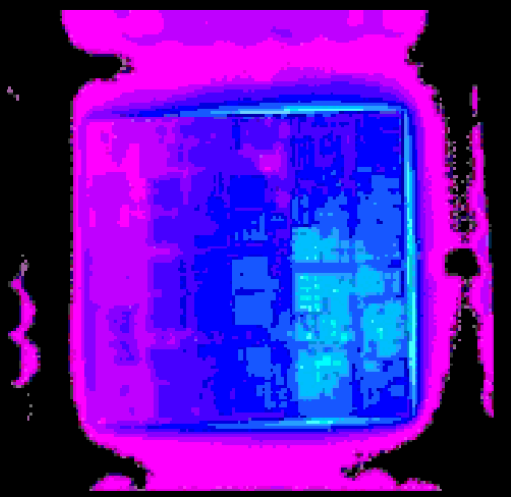
Clock Gating and Temperature

- Clock gating reduces temperature
  - Leakage exponentially dependent on temperature
  - Power 5 core measured temperature
    - About 10 C reduction when clock gating turned on
    - Results in about 10% leakage reduction at 80 C point









My Conclusion, Prediction, and Encouragement

- Thermal limitation awareness has become pervasive across all facets of the electronic industry and thus the opportunity for this group to influence the direction of the industry has clearly increased.
- More analytical capability will be required to provide the detail necessary to guide developers (including the other disciplines) toward Compute Pwr
- More interaction to close the gaps between the disciplines will provide large paybacks in the ability to integrate and deploy applications to the marketplace.
- Challenges exist at all levels, we must evolve to succeed. TheKnack