3D Numerical Analysis of Two-Phase Immersion Cooling for Electronic Components

Xudong An, Manish Arora, Wei Huang, William C. Brantley, Joseph L. Greathouse

AMD Research
Advanced Micro Devices, Inc.

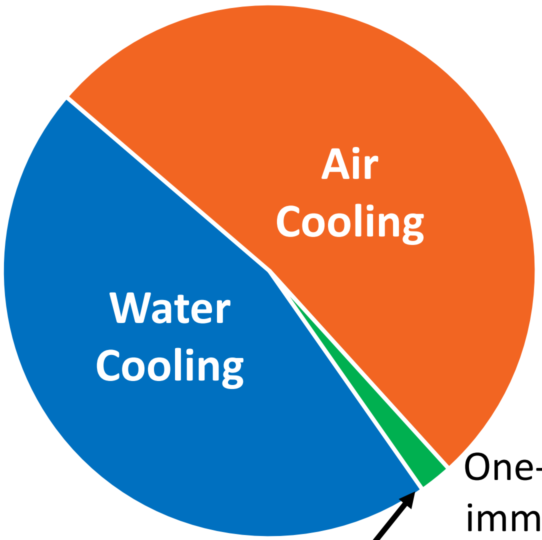
ITherm
SAN DIEGO, CA 2018

MOTIVATION

Cooling solutions for supercomputers

- Air cooling
- Water cooling
- One-phase immersion cooling
- Two-phase immersion cooling

Cooling solutions applied in Top50 Supercomputing systems [1]



Where is two-phase immersion cooling?

[1] "Top 500 supercomputers," Top 500 list for November 2017. www.top500.org

INTRODUCTION

Two phase immersion cooling

Heat release

Power source (CPU, GPU)

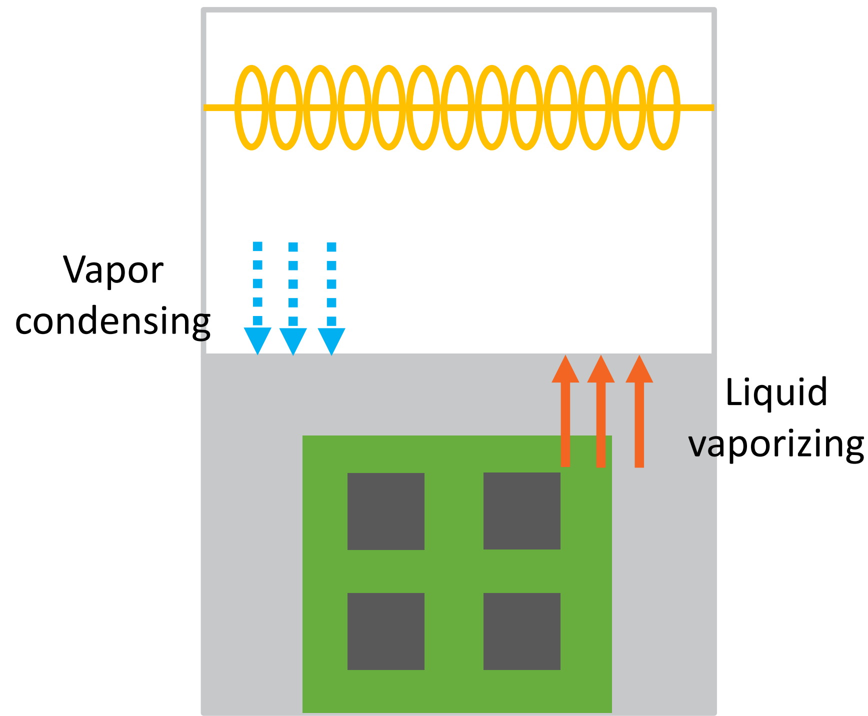
Liquid vaporization

Condensing pipe

Chilling facility

Main advantages

- High latent heat in liquid vaporization
- Less space for heat sink / cold plate
- Less cooling energy



Computing rack of two-phase immersion cooling

INTRODUCTION

Research goals

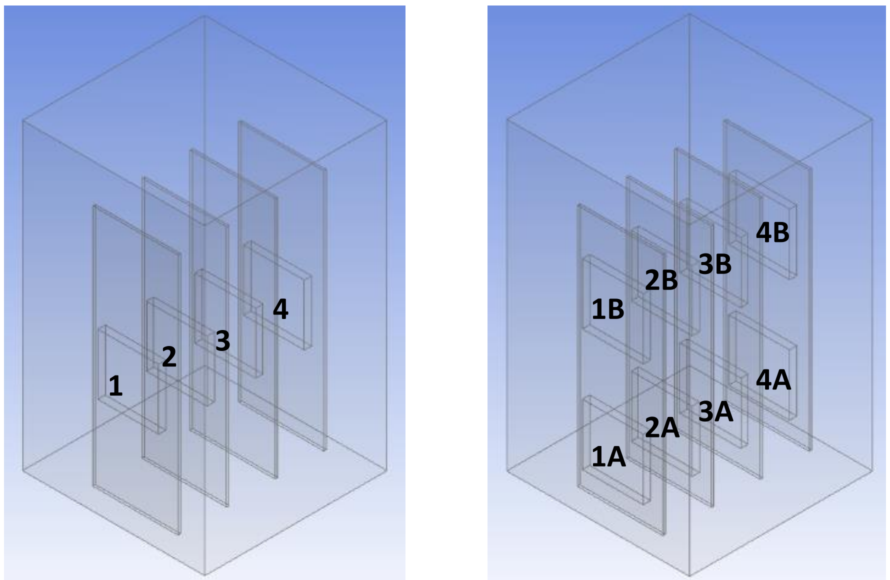
- Understand impact of two-phase immersion cooling on CPU/GPU processors
- Investigate thermal coupling between nearby processors
- Obtain capable processor power
- Analyze trade-offs in supercomputing system design

Research approaches

- Numerical study in ANSYS FLUENT (current work)
- Experiment testbed

MODEL CONFIGURATION

Modeling approach



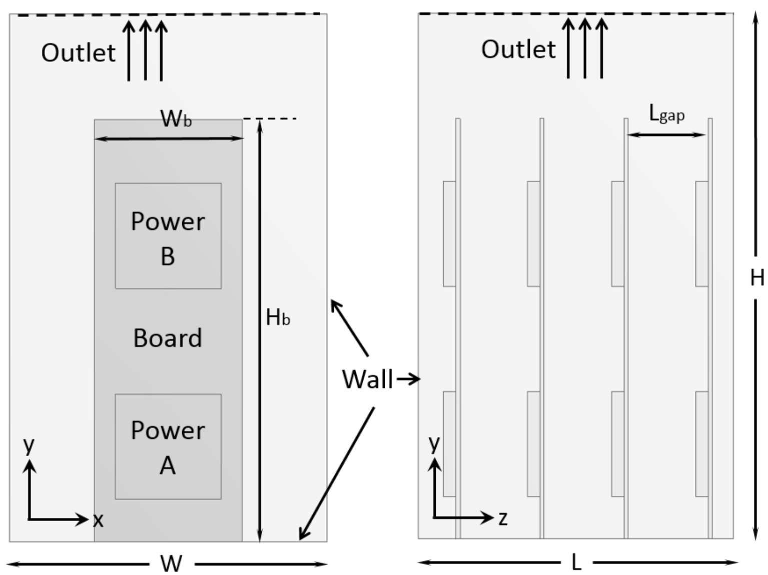
Simulation geometries in ANSYS FLUENT

Main features:

- Mimic structure in computing rack
- 4 boards, 4 or 8 processors
- Consider boiling, ignore condensing

MODEL CONFIGURATION

Dimensions and boundary conditions



Model configuration

Dimensions

Simulation zone:	15cm × 25cm × 15cm
Compute board:	7cm × 20cm
Board gap:	3.8cm
CPU package:	5cm × 5cm

Conditions

Cooling liquid:	Novec7000 & FC72
Boiling point:	34℃ & 56℃
Subcooling:	No
Package power:	50W – 300W
Top of domain:	Flow outlet

MODEL CONFIGURATION

Governing equations

Mass conservation: $$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

Momentum equation: $$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F}$$

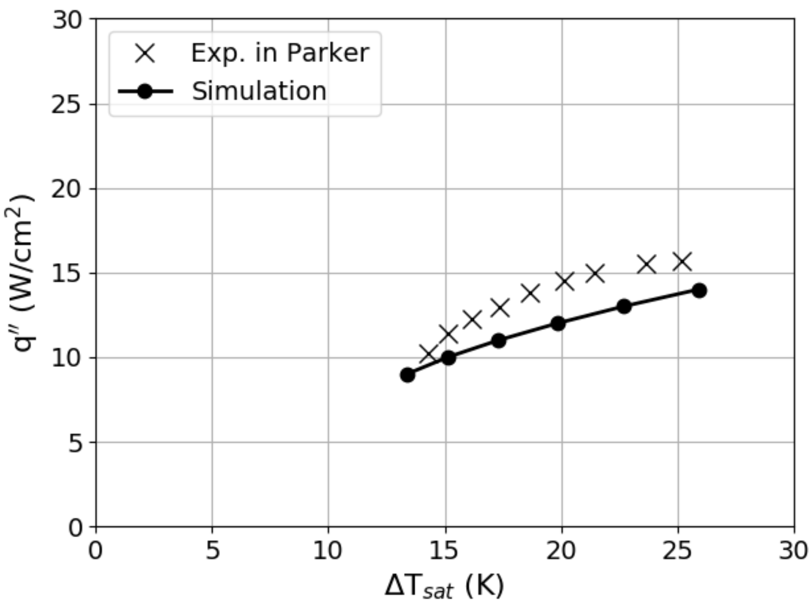
Energy conservation: $$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho h \vec{v}) = \nabla \cdot [(k + k_t)\nabla T] + S_h$$

Turbulence model: Standard k - ε model

Boiling model: RPI model

MODEL VALIDATION

Comparison of FLUENT model and experiment data [1]



Conditions

Cooling liquid: FC72

Boiling point: 56℃

Power source: 1cm × 1cm

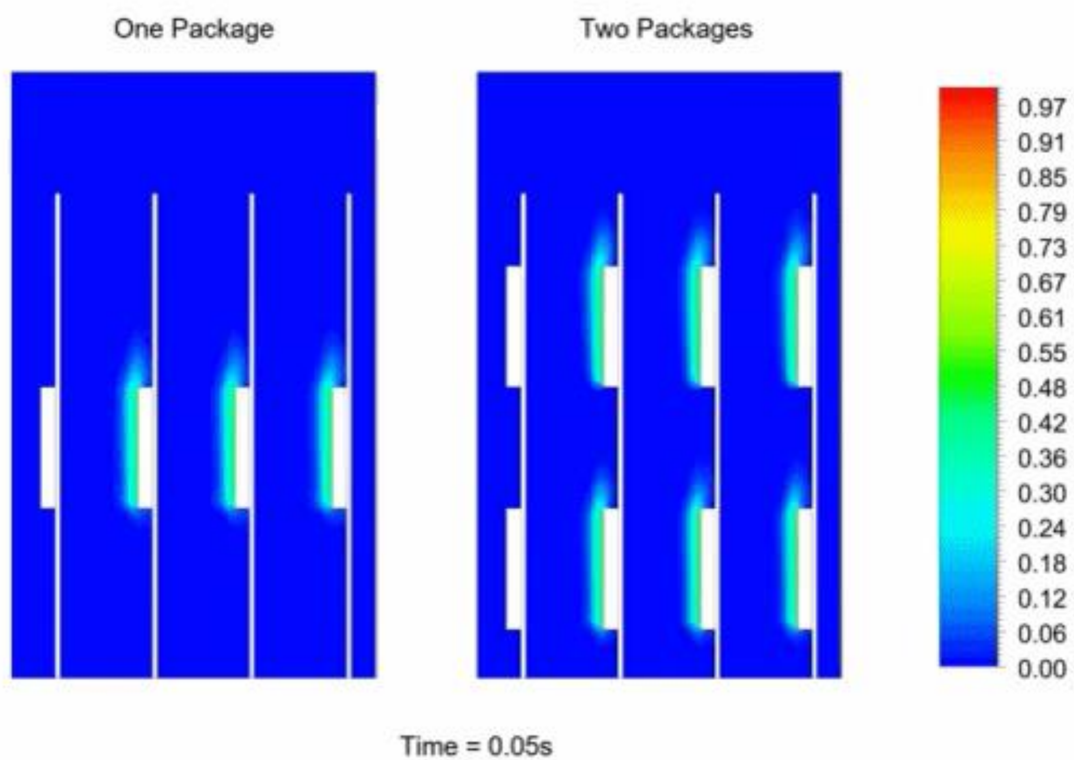
Comparison data points near CHF

	q'' (W/cm^2)	ΔT_{sat} (K)
Experiment	15.7	25.2
FLUENT	14	25.9
error	10%	3%

[1] Jack L. Parker, and Mohamed S. El-Genk. "Effect of surface orientation on nucleate boiling of FC-72 on porous graphite." Journal of heat transfer 128.11: 1159-1175, 2006.

NUMERICAL SIMULATION

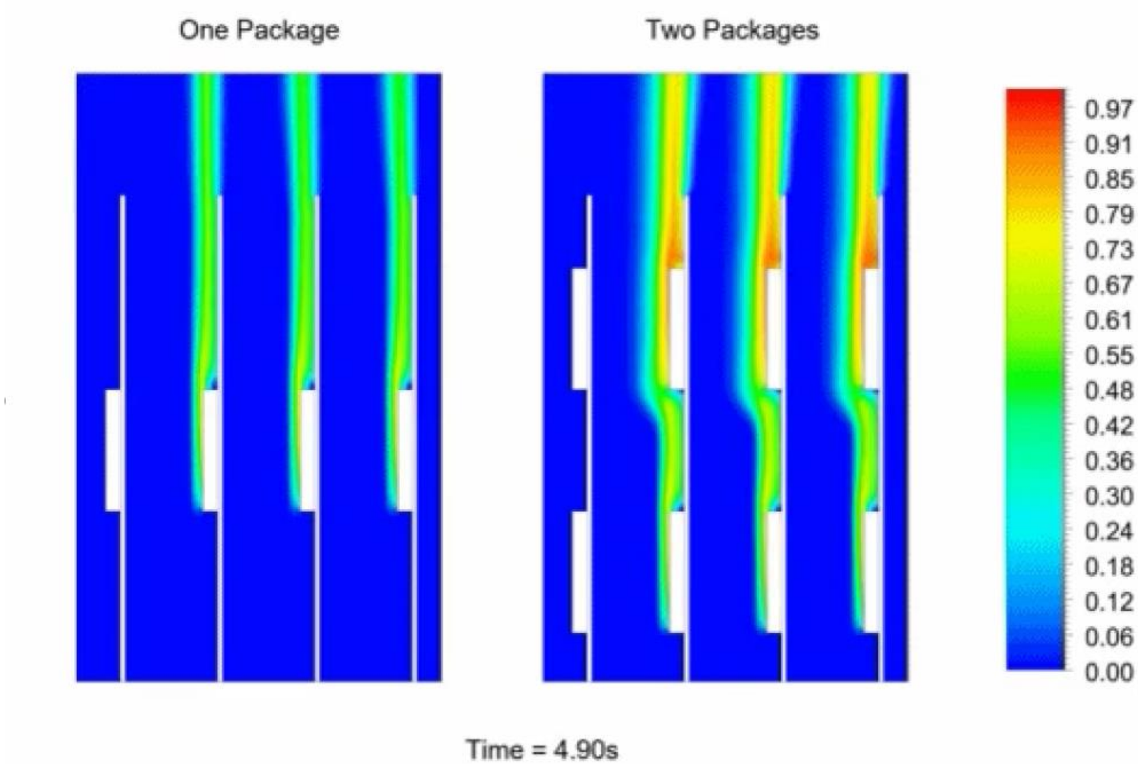
One package on board vs. two packages on board



Phenomenon of liquid vaporization in first 5 seconds when package power is 125W
(Blue is liquid phase, red is vapor phase)

NUMERICAL SIMULATION

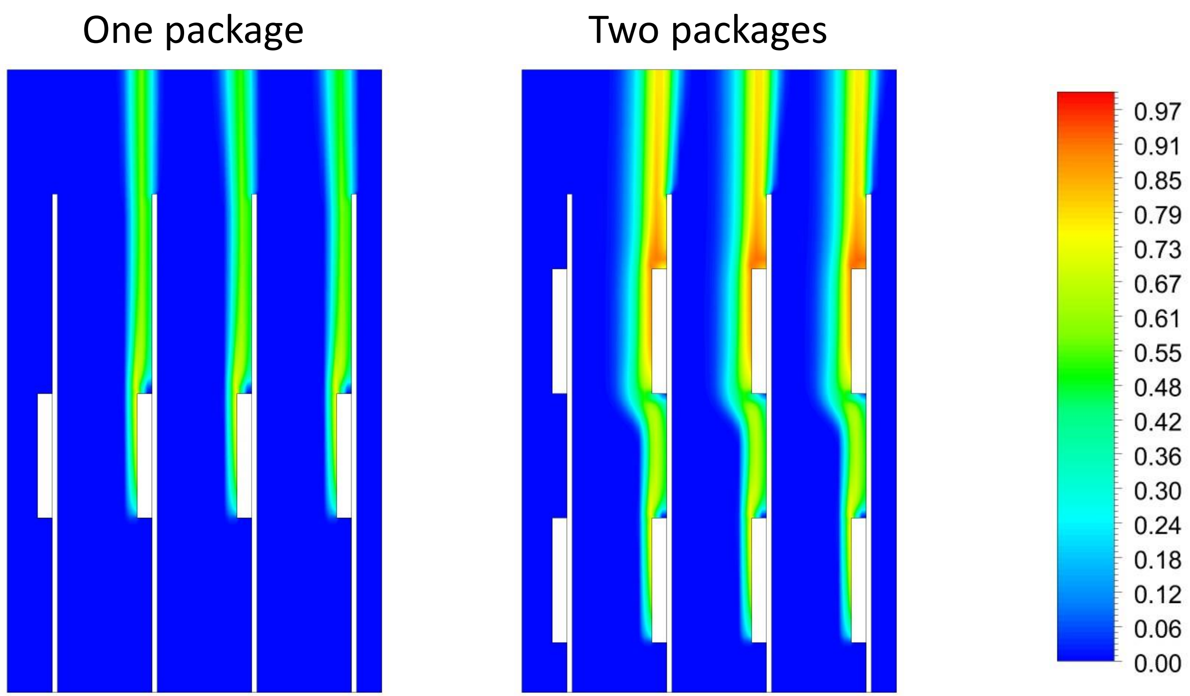
One package on board vs. two packages on board



Phenomenon of liquid vaporization in first 5 seconds when package power is 125W
(Blue is liquid phase, red is vapor phase)

NUMERICAL SIMULATION

One package on board vs. two packages on board

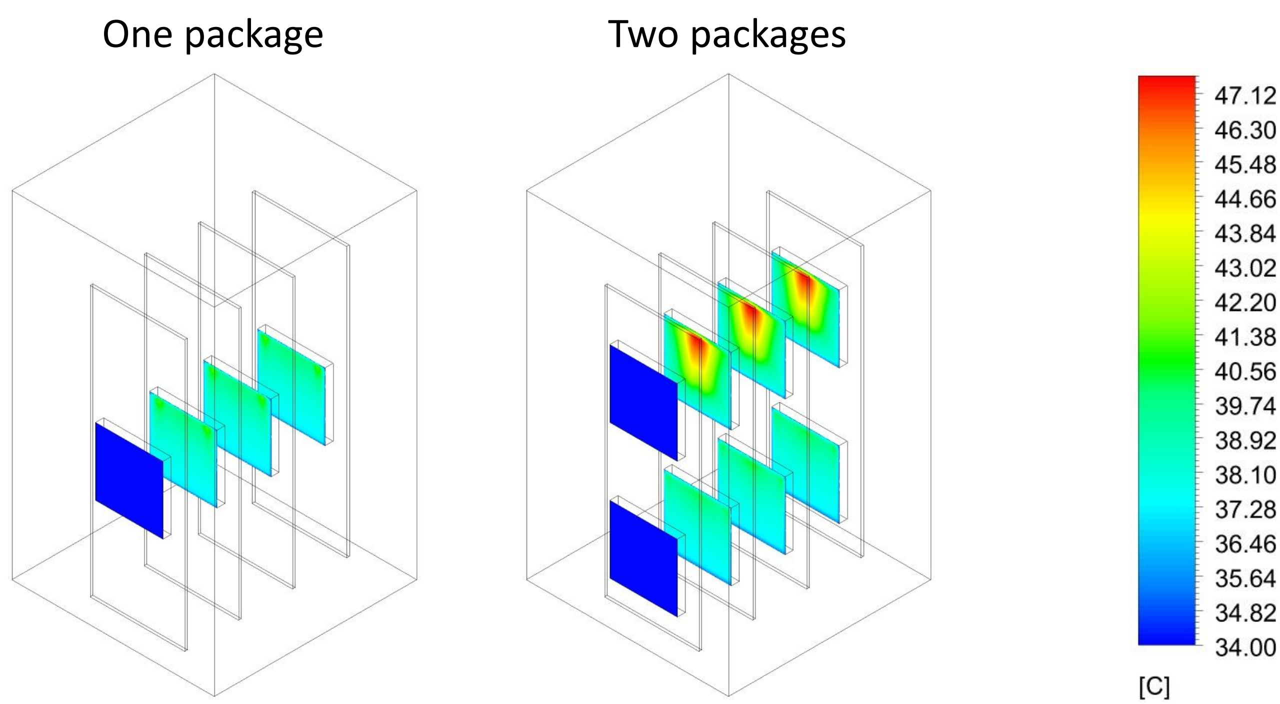


Volume fraction contour when package power is 125W
(Blue is liquid phase, red is vapor phase)

- Upper packages are covered by thicker vapor
- Lower packages in “two packages” test and all packages in “one package“ test are covered by thinner vapor and those thicknesses are similar

NUMERICAL SIMULATION

One package on board vs. two packages on board



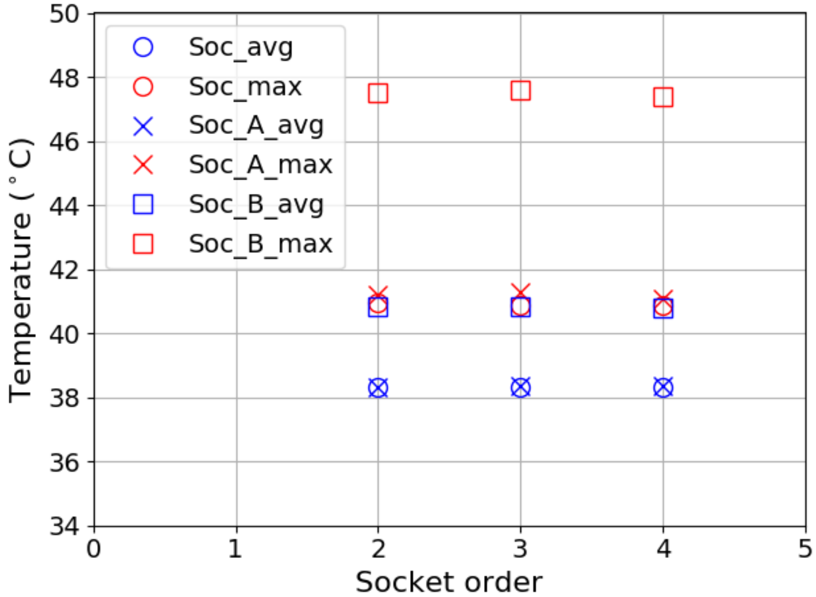
Lid temperature contour

- Hot zones appear on top central area due to insufficient liquid contact
- Temperature maps on “related” packages are similar

NUMERICAL SIMULATION

One package on board vs. two packages on board

Temperature on each package when power is 125W

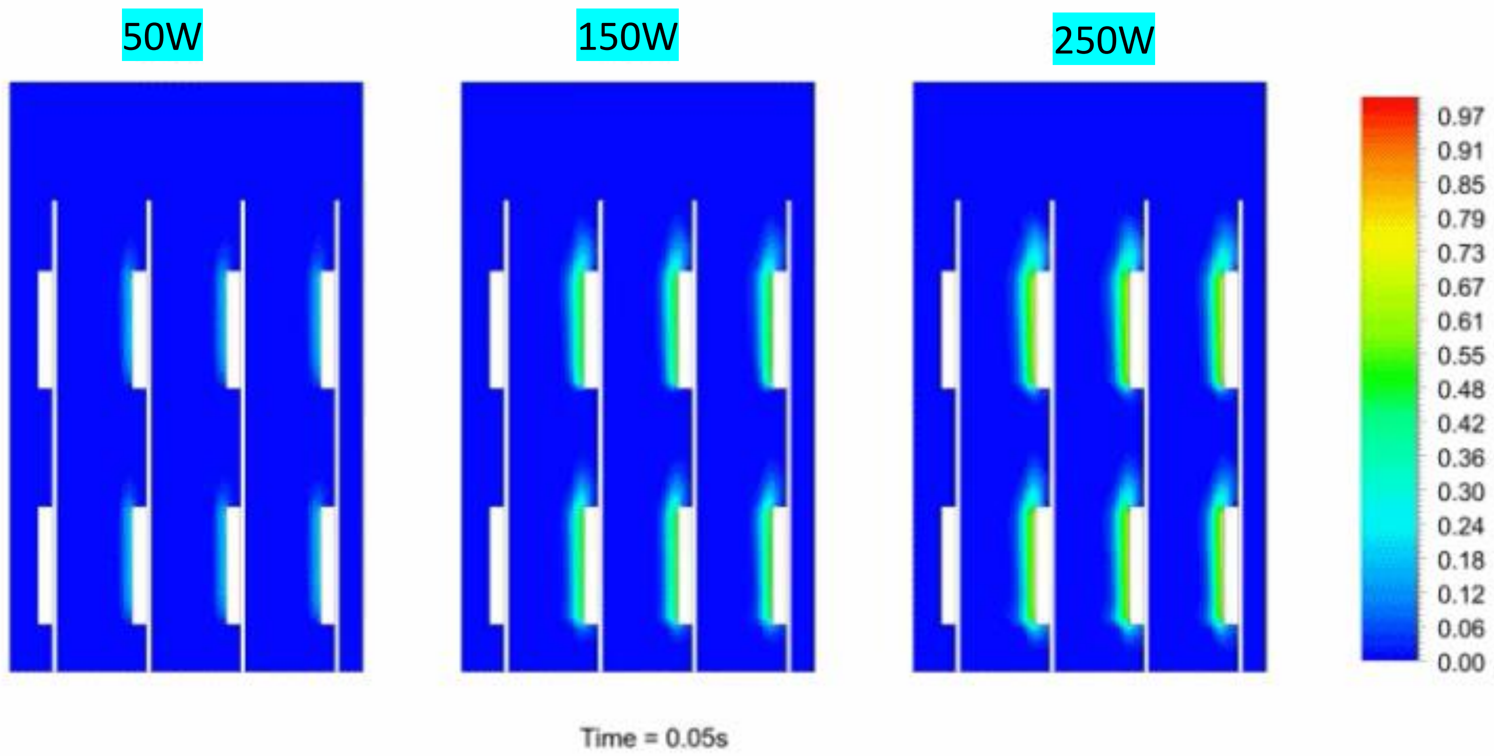


Summary

- Temperature situations on different boards are almost the same
- Lower packages in “two packages” test and all packages in “one package“: same temperature
- Upper packages are much hotter than lower packages

NUMERICAL SIMULATION

Two packages on board



Phenomenon of liquid vaporization in first 5 seconds, different power values (Blue is liquid phase, red is vapor phase)

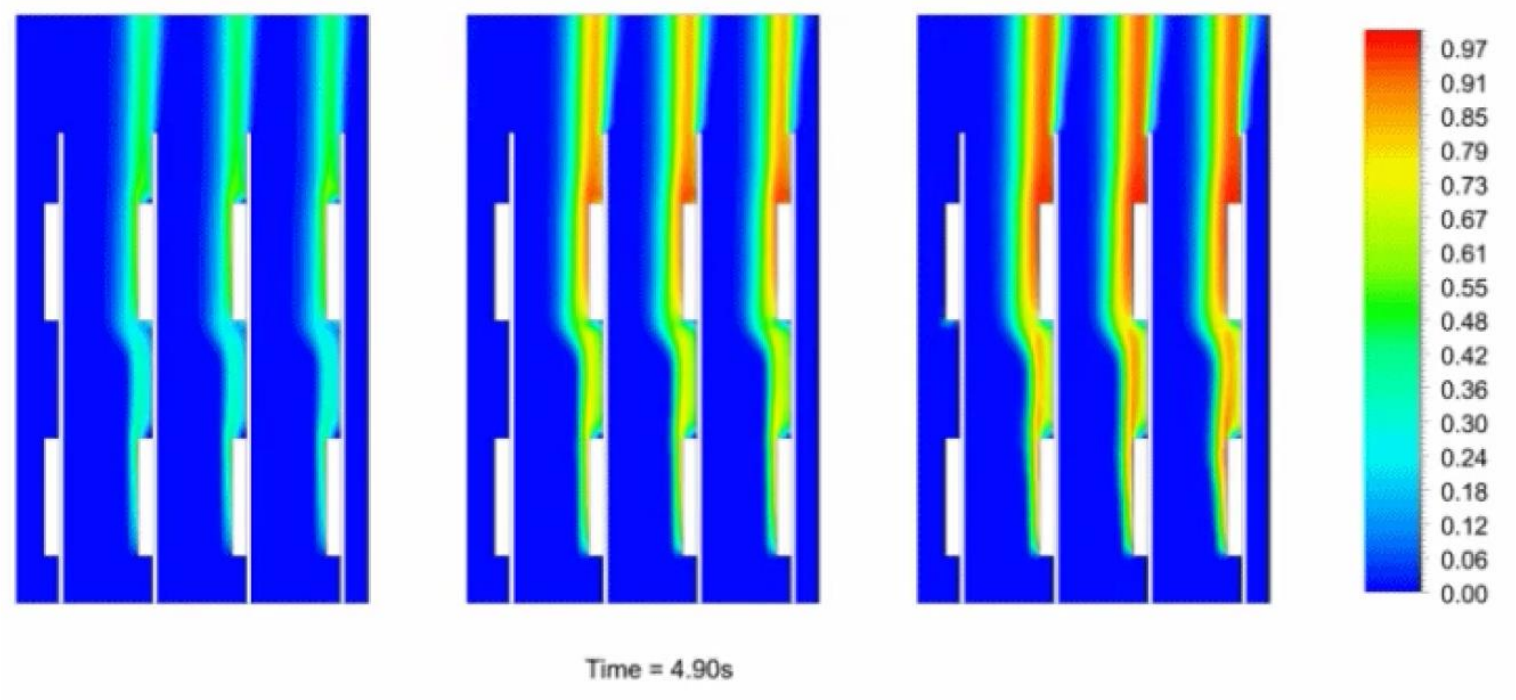
NUMERICAL SIMULATION

Two packages on board

50W

150W

250W

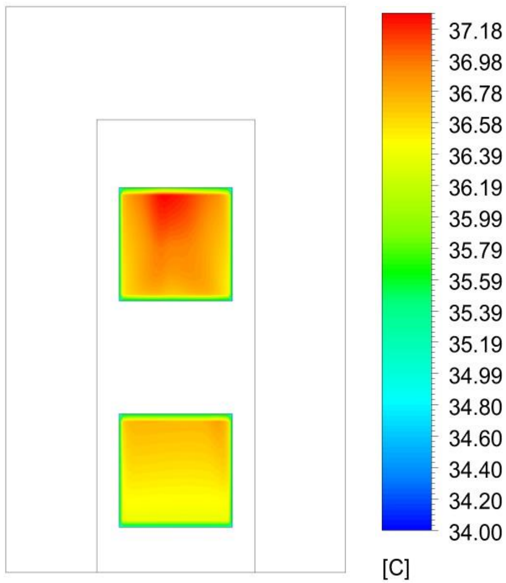


Phenomenon of liquid vaporization in first 5 seconds, different power values
(Blue is liquid phase, red is vapor phase)

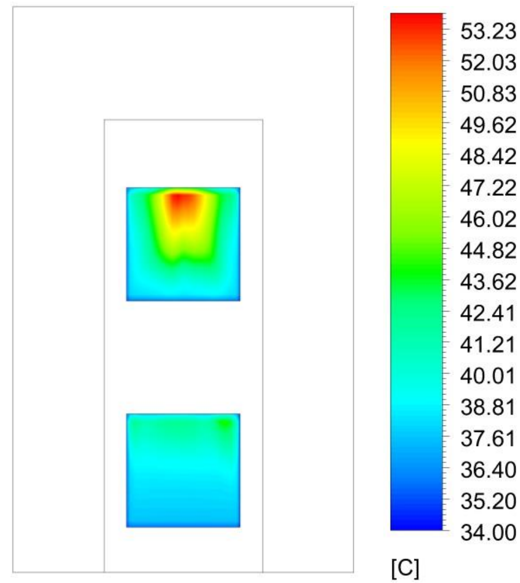
NUMERICAL SIMULATION

Two packages on board

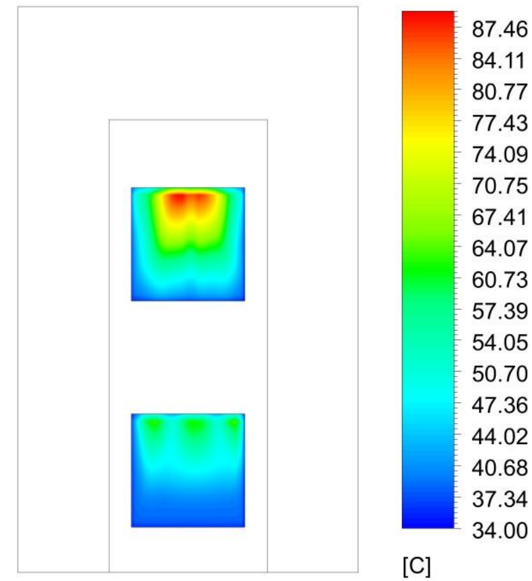
50W



150W



250W



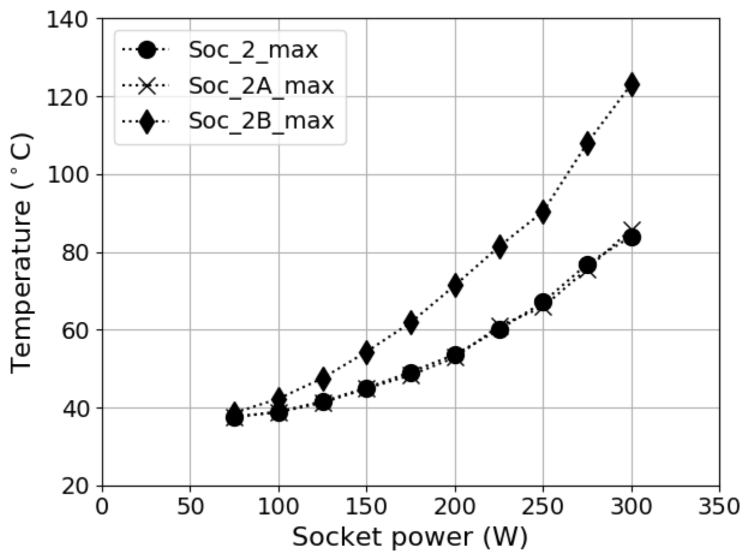
Lid temperature contour on 2nd board from left

- When power is higher, temperature gradient on lid is bigger
- Temperature gradient on lower package is smaller

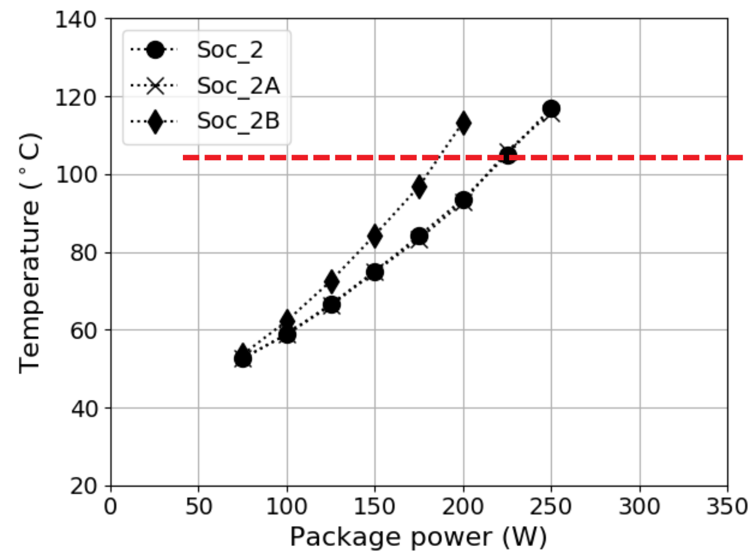
NUMERICAL SIMULATION

Two packages on board

Package power and lid temperature

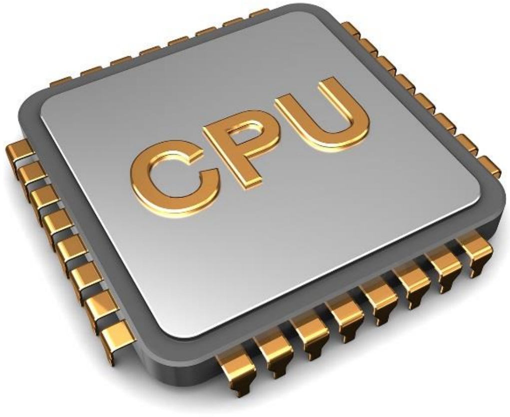


Package power and temperature on silicon (estimation)



- When power rises, temperature increases faster
- Assume package thermal resistance is 0.2℃/W (lid to silicon)
  - In "one package" test, highest capable package power is about 230W
  - In "two packages" test, highest capable package power is about 180W

SUMMARY



Macro scale: provide cooling solutions for computing center
Micro scale: provide thermal info for processor design

Thank You – Questions?

DISCLAIMER & ATTRIBUTION

ATTRIBUTION