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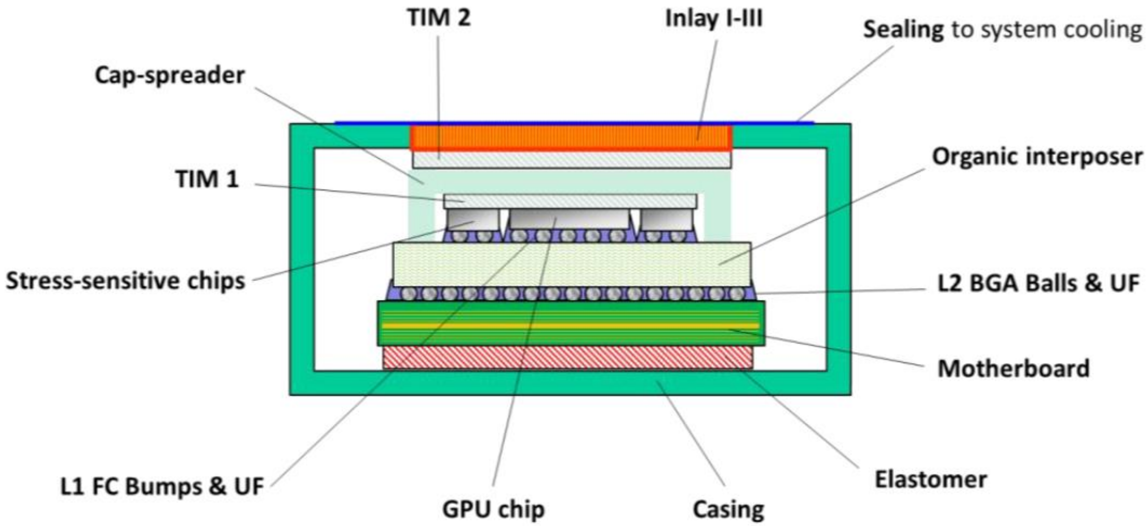
A novel liquid-based heat sink for thermal management of high-performance processors

Package arrangement of layers



Different proposed cooling concepts

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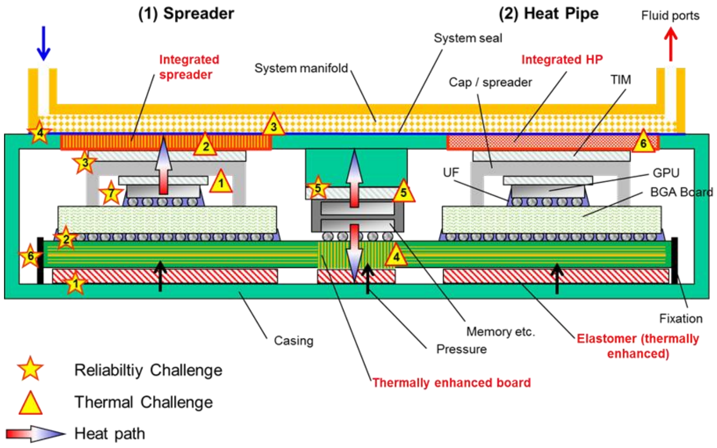

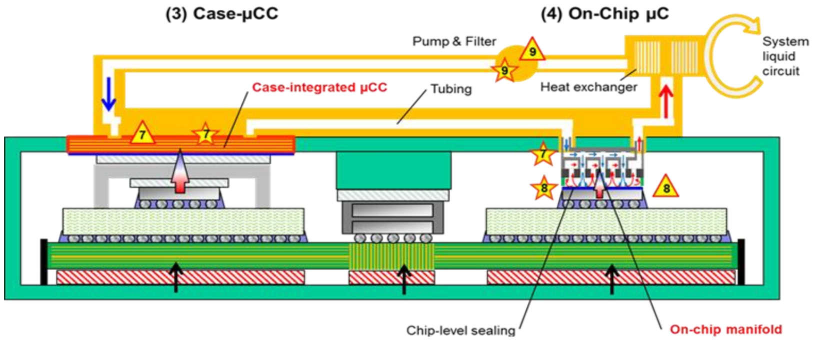

Objective

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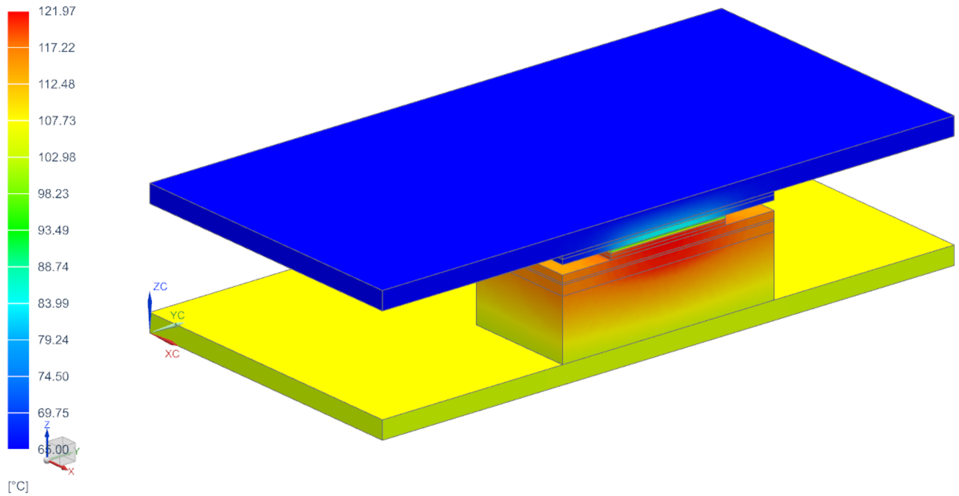
- Design a cooler to achieve maximum chip temp of 90°C While:
  - Flow rate < 5 lit/min
  - Cooling fluid = water/glycol @ 65°C
  - Pressure drop < 250 mbar
  - Ambient temperature = 85°C

Ideal cooler with default configuration



Conductive Adhesive and Grease

$$\begin{cases} K_{TIM_1} = 5 \\ K_{TIM_2} = 1 \end{cases}$$

$$T_{chip} = 122℃$$

Ideal cooler without adhesive and lid

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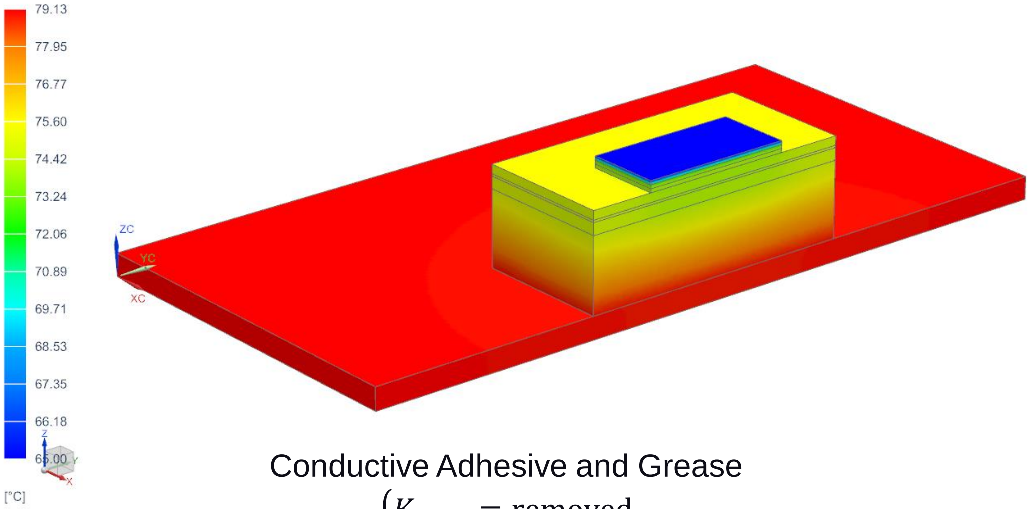
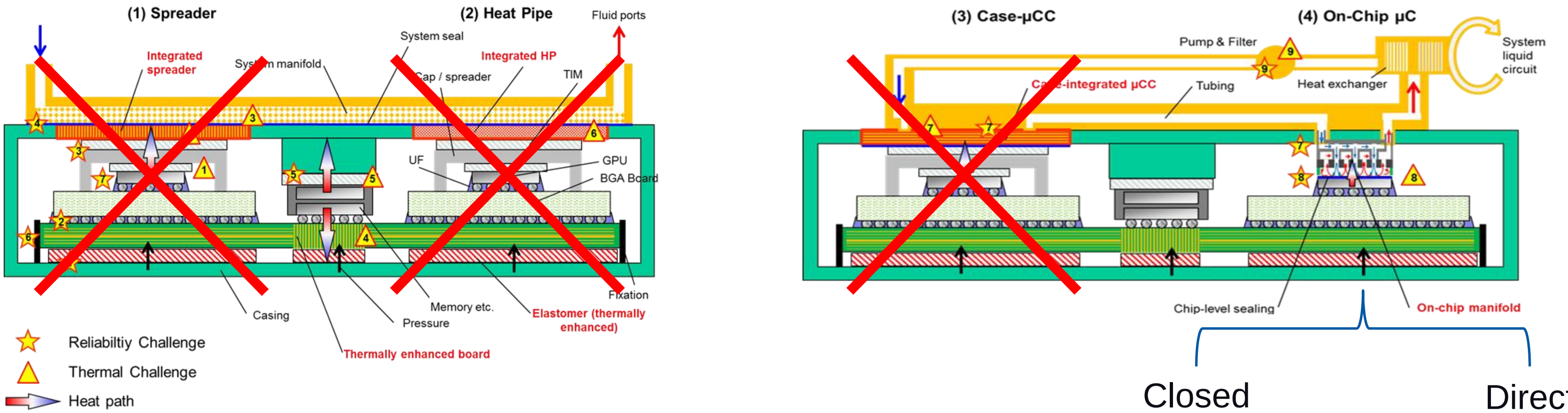


Conductive Adhesive and Grease

$$\begin{cases} K_{TIM_1} = \text{removed} \\ K_{TIM_2} = 5 \end{cases}$$

$$T_{max} = 74°\text{C}$$

Different proposed cooling concepts



Closed system

Direct impingement

Traditional approach

- Generate a new design (first iteration)
- Print the design (expensive)
- Do experiments to measure the performance (expensive)
- Get feedback to improve the design
- Hundreds of iterations considering tens of design parameters

Computational Fluid Dynamics (CFD)

- Numerical schemes to solve conservation equations (momentum, mass, and energy) over a domain

$$Mass: \quad \frac{\partial \rho}{\partial t} + div(\rho\,\mathbf{u}) = 0$$

$$x-momentum: \quad \frac{\partial(\rho u)}{\partial t} + div(\rho u \mathbf{u}) = -\frac{\partial p}{\partial x} + div(\mu\ grad\ u) + S_{Mx}$$

$$y-momentum: \quad \frac{\partial(\rho v)}{\partial t} + div(\rho v \mathbf{u}) = -\frac{\partial p}{\partial y} + div(\mu\ grad\ v) + S_{My}$$

$$z-momentum: \quad \frac{\partial(\rho w)}{\partial t} + div(\rho w \mathbf{u}) = -\frac{\partial p}{\partial z} + div(\mu\ grad\ w) + S_{Mz}$$

$$Internal\ energy: \quad \frac{\partial(\rho i)}{\partial t} + div(\rho i \mathbf{u}) = -p\ div\ \mathbf{u} + div(k\ grad\ T) + \Phi + S_i$$

Computational Fluid Dynamics (CFD)

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- A bunch of numerical schemes to solve conservation equations (momentum, mass, and energy) over a domain
- Input:
  - Geometry (domain)
  - Material properties (thermal, fluid, …)
  - Flow regime (laminar or turbulent)
  - Boundary conditions

Computational Fluid Dynamics (CFD)

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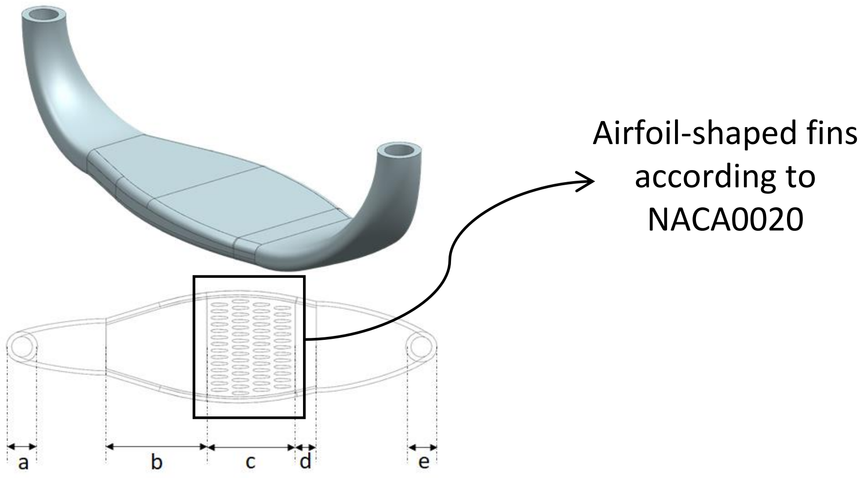
- A bunch of numerical schemes to solve conservation equations (momentum, mass, and energy) over a domain
- Output:
  - Velocity field
  - Spatiotemporal distribution of pressure
  - Spatiotemporal distribution of temperature

CFD packages

- Ansys CFX
- Comsol multiphysics
- Siemens FLoEFD
- Cradle
- …

The design



a cross-section through the cooler with a) Inlet, b) distribution zone, c) cooling zone, d) collection zone, and e) outlet.

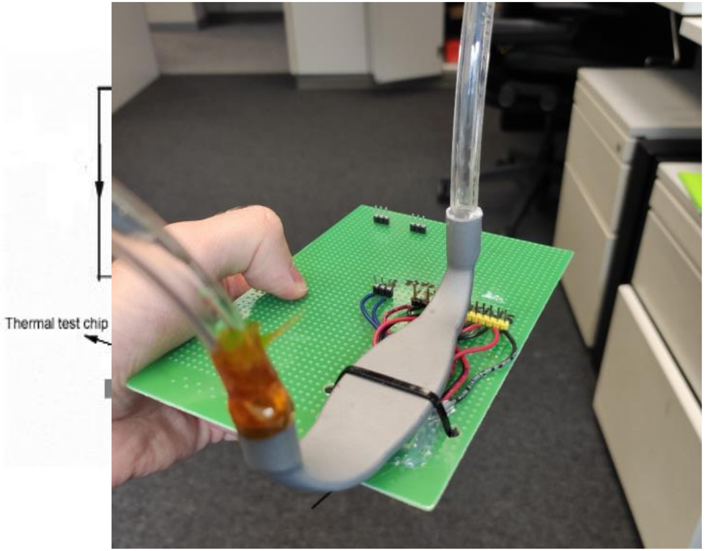
Experimental setup

Thermal test vehicle to mimic an actual processor

- 9.8×9.8×0.675mm^3 test chip
  - Controllable resistive heaters
  - Integrated temperature sensor
- 25×20×1.6mm^3 substrate
- thermal joint compound

The hydraulic circuit

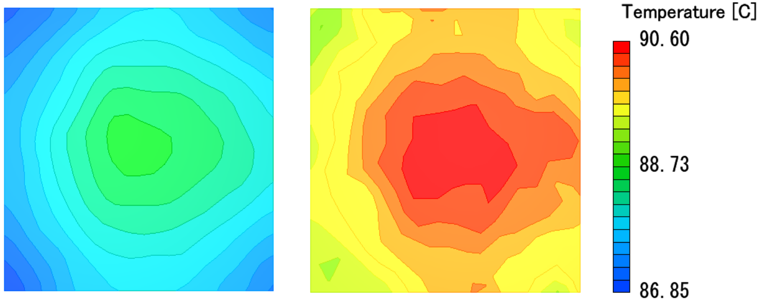
- Differential pressure
- Flow meter
- Heat exchanger and reservoir



Experimenting conditions

- Testing conditions:
  - Ambient temperature = 22 ± 1℃
  - Cooling fluid temperature = 20℃
  - Cooling flow mass flow rate = 2.55 L/min
  - Generating 50W in the mock-up chip

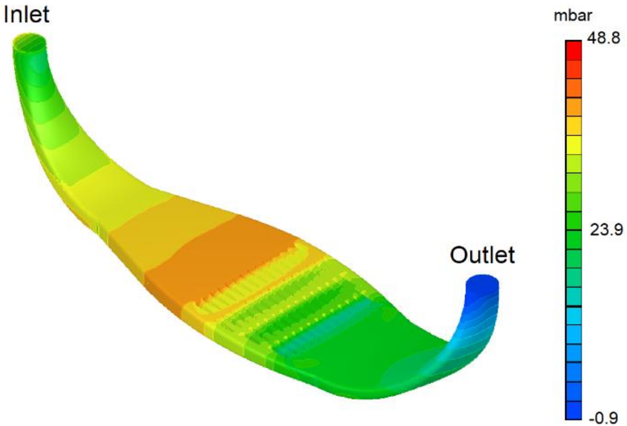
Simulation results



Facing the cooler

Facing the substrate

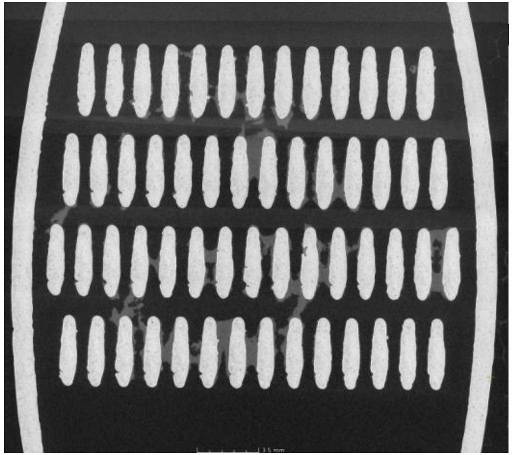
Predicted 89℃ VS measured 81.9℃



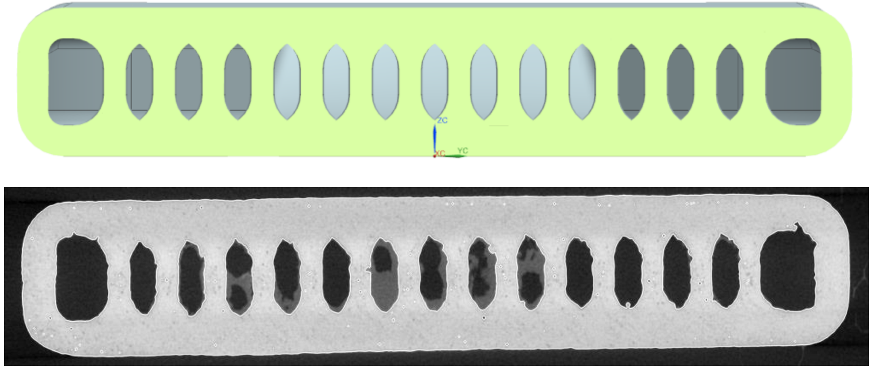
Predicted 24mbar VS measured 106mbar

Discrepancy between measured and predicted values

- Pressure drop:



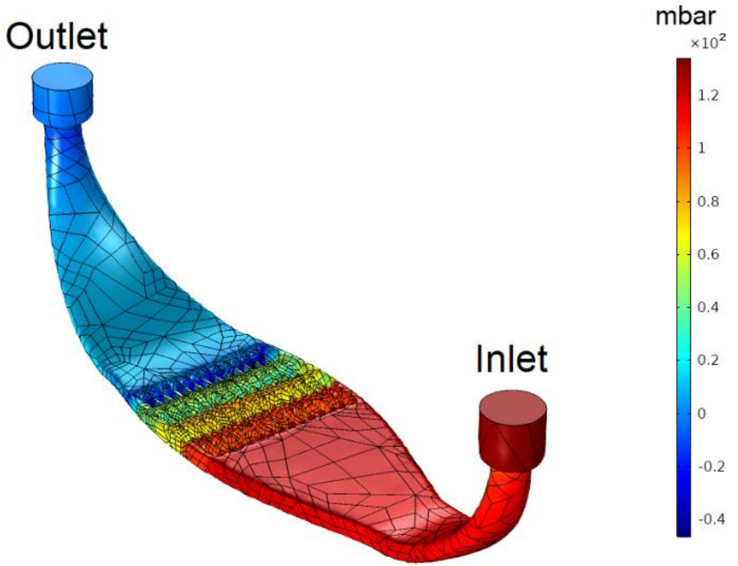
Trapped powder



Geometric deviations

Discrepancy between measured and predicted values

- Pressure drop:
  - Geometric deviations
    - CT scanning of the component
    - Creating a STL surface out of the fluid cavity
    - Repairing the created surface
    - Generating a CAD model out of the surface
    - Creating a solid object out of the watertight surface



Predicted 125mbar vs measured 106mbar

Future plans

- Accounting for the actual geometry
- Separate research to improve the conductivity of TIM