SWTEST

PROBE TODAY, FOR TOMORROW

2023 CONFERENCE

High Heat Dissipation: Facing New Challenges with High-Power Testing at the Wafer Level

Micron®

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Overview

- Background
- Industry capability with high-heat dissipation
- Additional considerations
- Conclusions

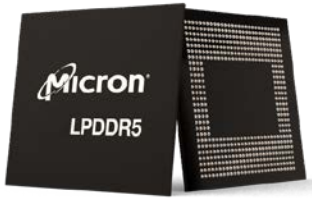
Background

The Micron Memory Market

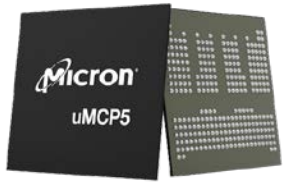
Memory

Storage

Graphics and ultra-bandwidth solutions



DRAM



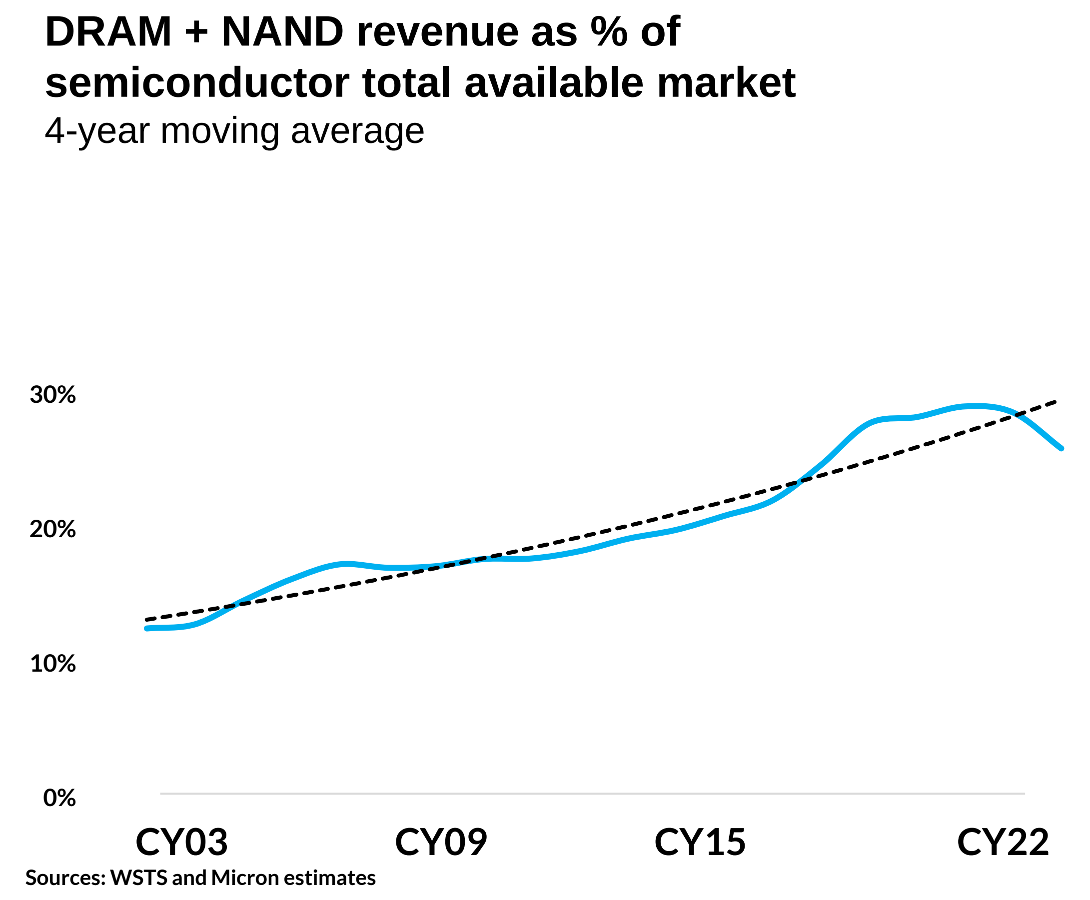
Multichip packages (DRAM + NAND)

Solid-state drives

Flash storage (NAND and NOR)

- Micron’s product portfolio requires a high variety of testing requirements & conditions.

Memory Market Growth


DRAM + NAND revenue as % of semiconductor total available market

4-year moving average

Sources: WSTS and Micron estimates

- **Record memory & storage market growth by CY25 and beyond.**

How do these trends affect Probe?

Effect on wafer fabrication

- Bit density ↑
- Die per wafer ↑
- Die stacking & CoW +

→

Subsequent effect on probe

- Test time ↑
- Power requirements for DUTs ↑
- Parallelism ↑

How do these trends affect Probe?

Affect on wafer fabrication

Subsequent effect on probe

What do these effects on Probe lead to?

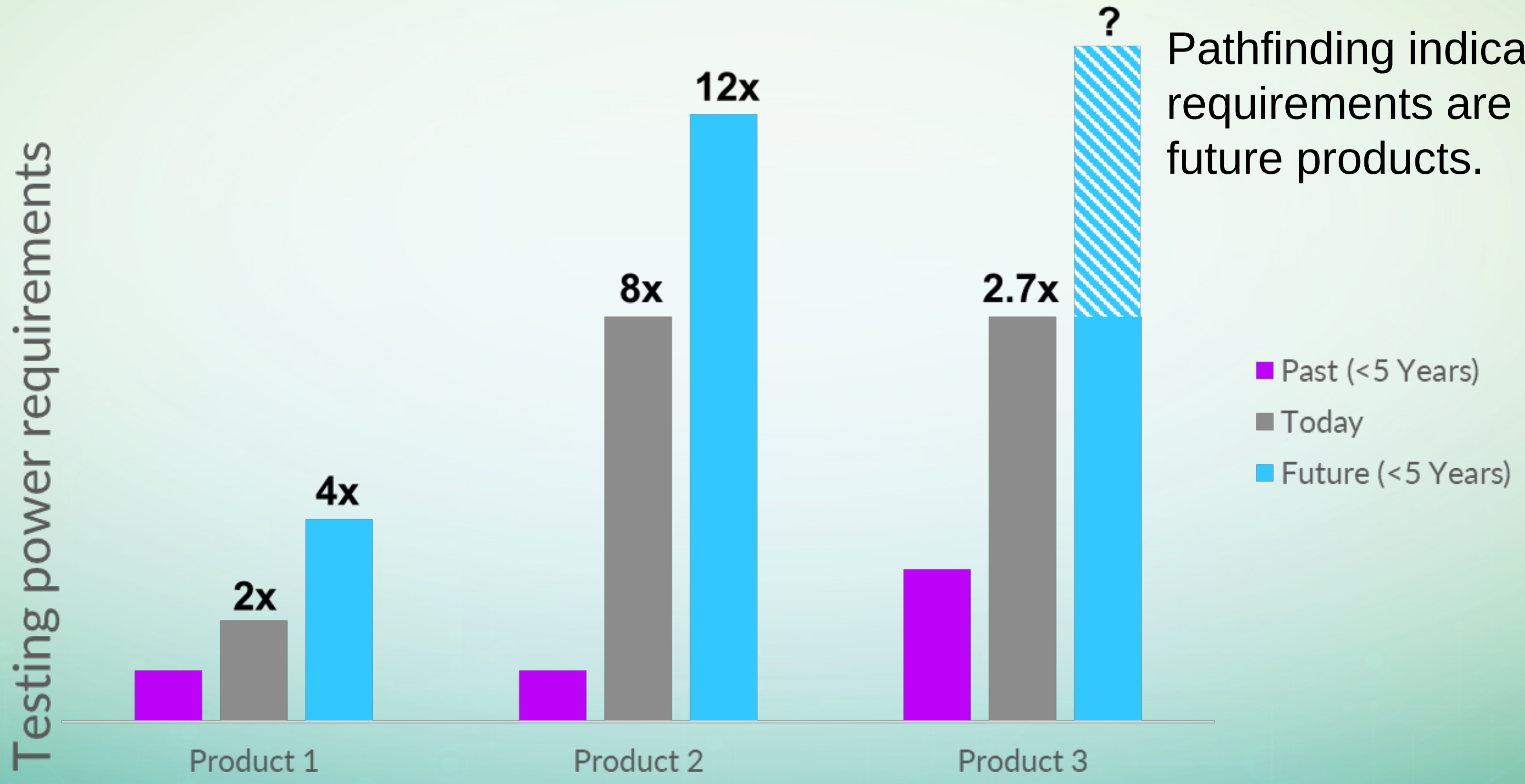
Heat dissipation requirements ↑

& CoW

rements ↑

Micron power requirement forecast

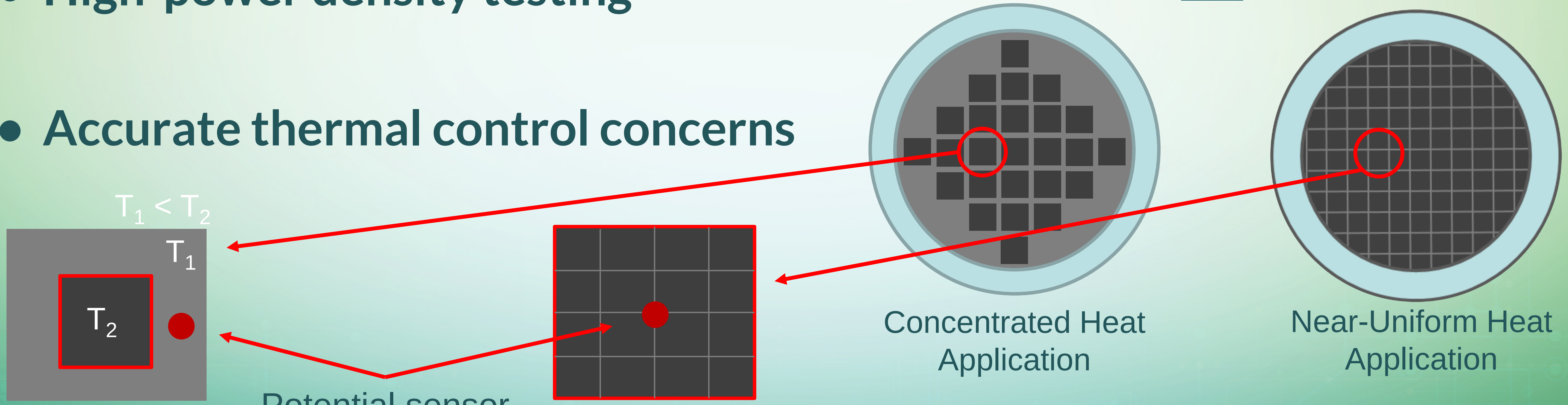
- **Expect to see continued increases in required testing power.**



Pathfinding indicates power requirements are increasing for future products.

What makes memory different?

- **Explosion in memory testing conditions & requirements**
- **High-power density testing**
- **Accurate thermal control concerns**



Maximum power applied to (per touchdown)

1α W = **1α** W

Concentrated Heat Application

Near-Uniform Heat Application

$T_1 < T_2$

T_1

T_2

~10β W/mm^2

Potential sensor positions?

β W/mm^2

Industry advancements needed

- Prober thermal control methods for high-heat dissipation must improve to meet the predicted testing power requirements.
  - Improved transient temperature response to high-power testing.
  - Decreased reliance on HTF’s or creative alternative solutions.

- Investigations into removing excess probe card heat, either generated or added from the surrounding environment.

Industry capability with high-heat dissipation

Basic heat dissipation process in probe

- Energy transfer in a typical coolant-based probe system

1. Wafer to Chuck

$$Q_1 = \frac{k\,A_1(T_1 - T_2)}{d_1}$$

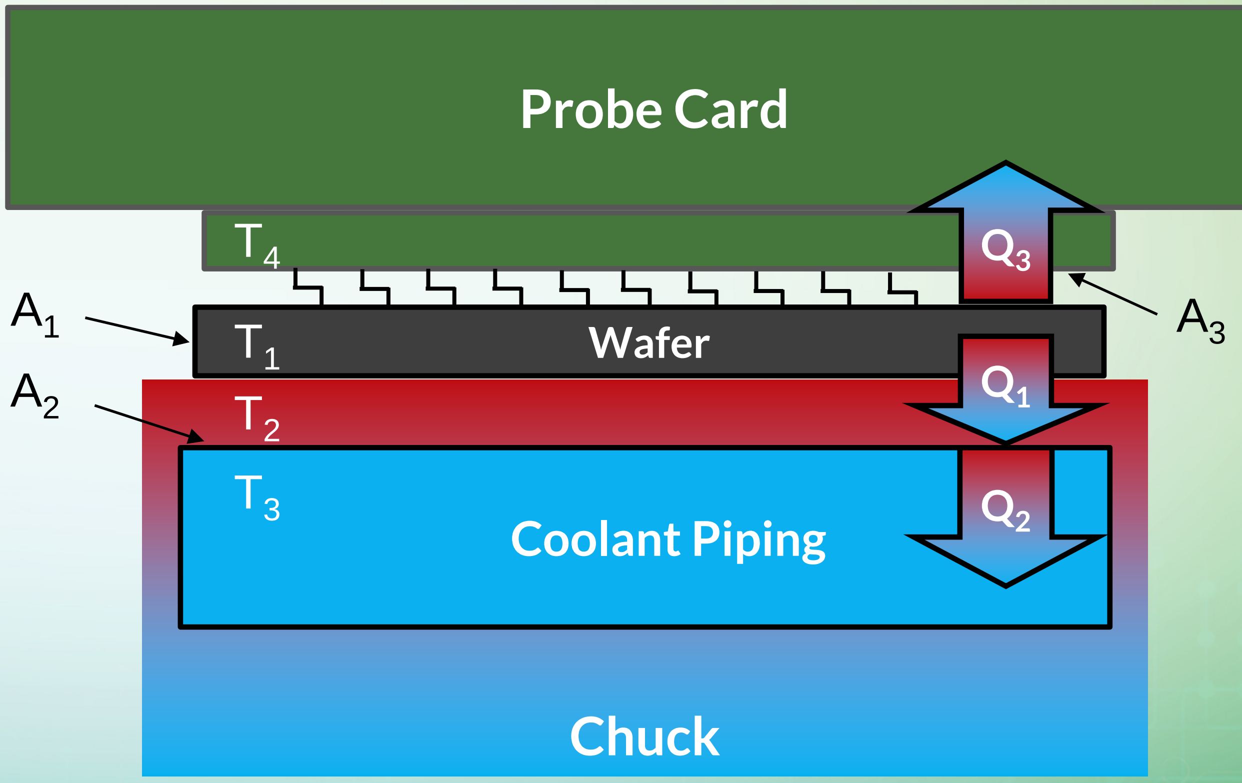
Primary HD driver → **2. Chuck to Coolant**

$$Q_2 = H_C A_2\,(T_2 - T_3)$$

3. Wafer to Probe Card

$$Q_3 = \frac{kA_3\,(T_1 - T_4)}{d_2}$$

Heat Transfer from DUTs



k = thermal conductivity
H_C = conv. heat transfer coeficient
d_1 = distance between wafer & coolant
d_2 = distance between wafer & PC

A_1 = surface area of wafer
A_2 = surface area of coolant piping
A_3 = surface area of probe card
T_x = Temperature

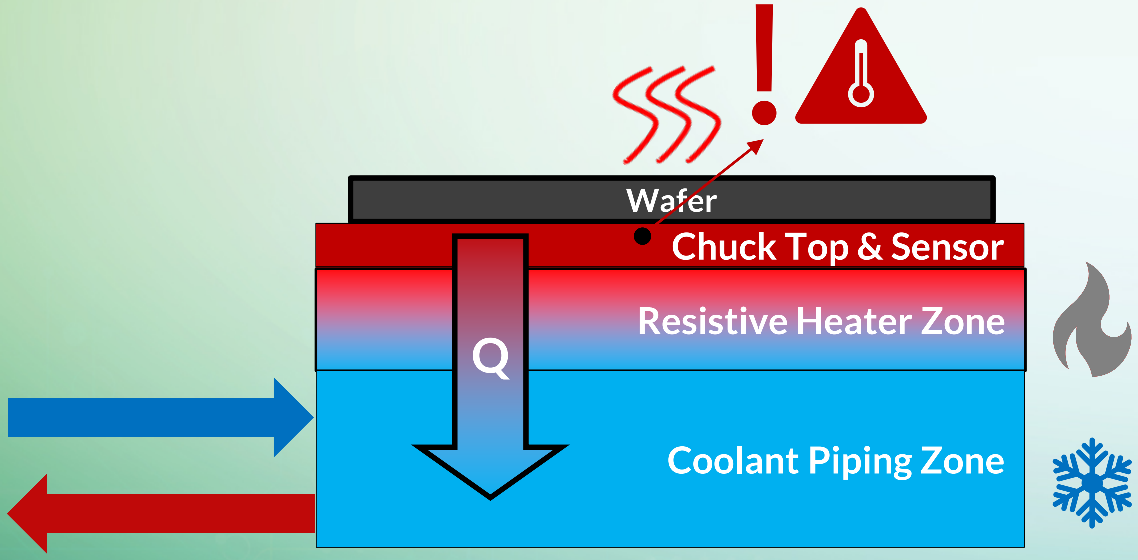
Industry thermal control systems

Continuous coolant flow

- Undercooling process
- Heater modulation for thermal control

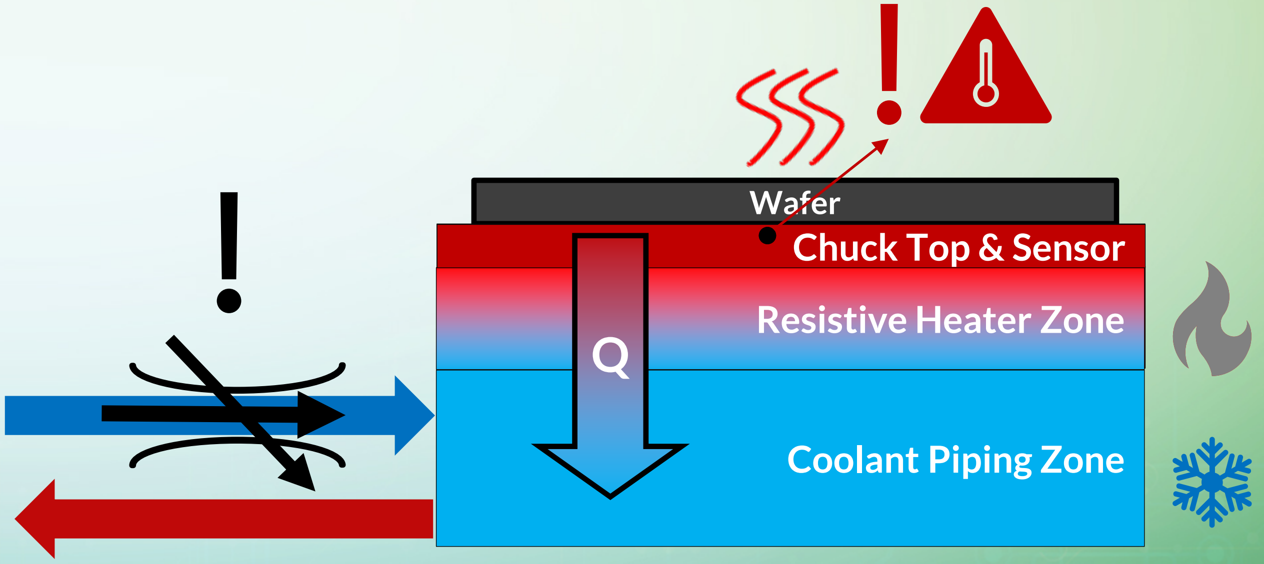
Variable coolant flow

- Heater & cooling element balancing
- High fluid temperature differential



$Q_{CPZ} = Q_{RHZ} \longrightarrow Q_{CPZ} = \downarrow Q_{RH} + Q_W$

$Q_{Static} = Q_{Test}$



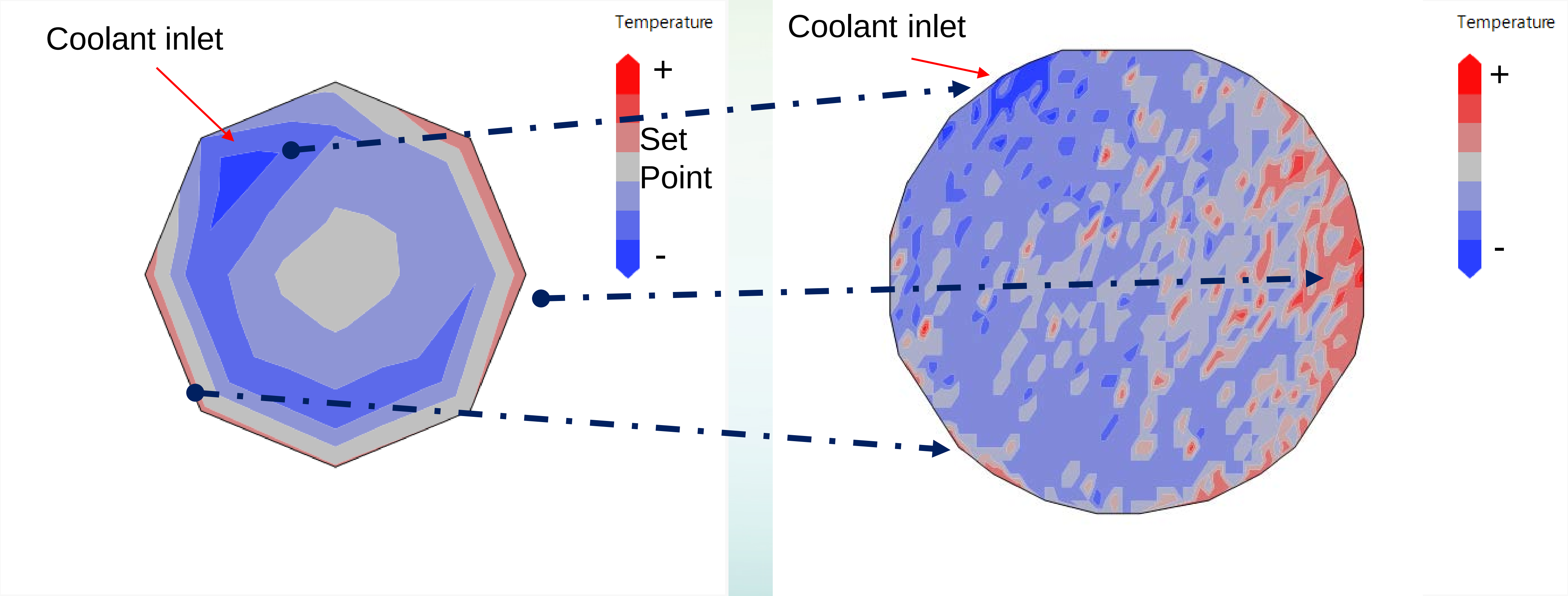
$Q_{CPZ} = Q_{RHZ} \longrightarrow \uparrow Q_{CPZ} = \downarrow Q_{RH} + Q_W$

$Q_{Static} \neq Q_{Test}$

Continuous coolant flow uniformity

Chuck Temperature Calibration

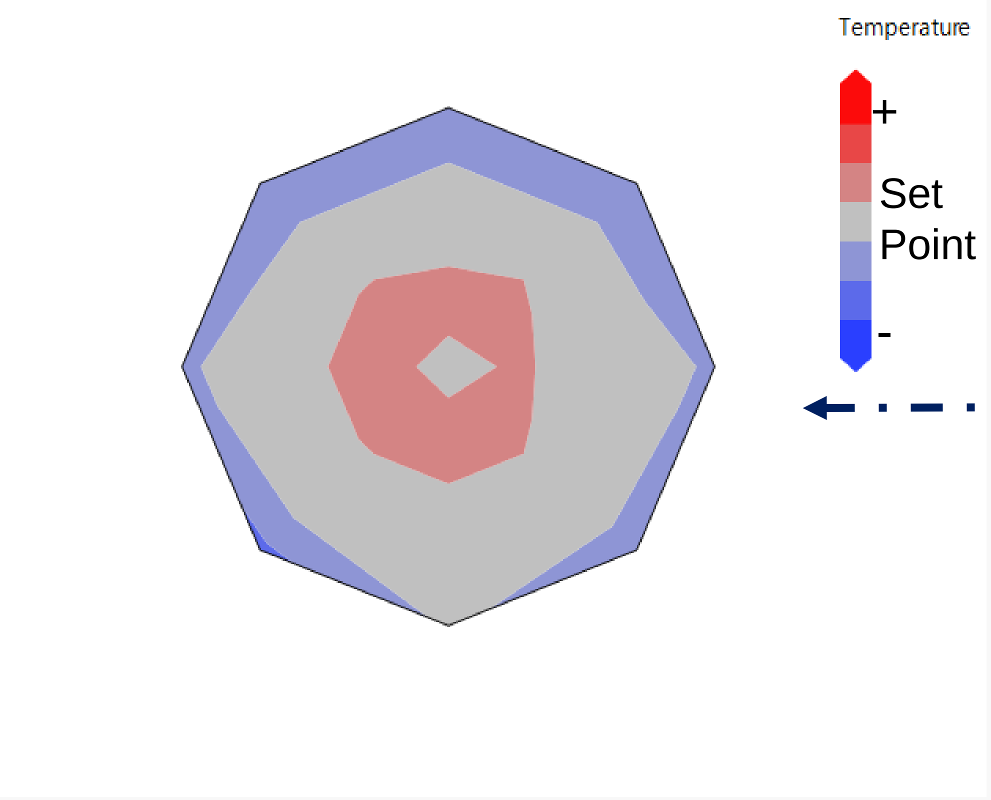
Die Level Temperature Measurement

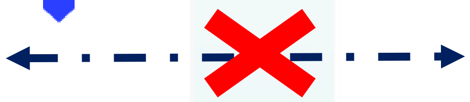


- Chuck uniformity is at the edge of our maximum specification.
- Similar temperature patterns between chuck calibration data and wafer level test.

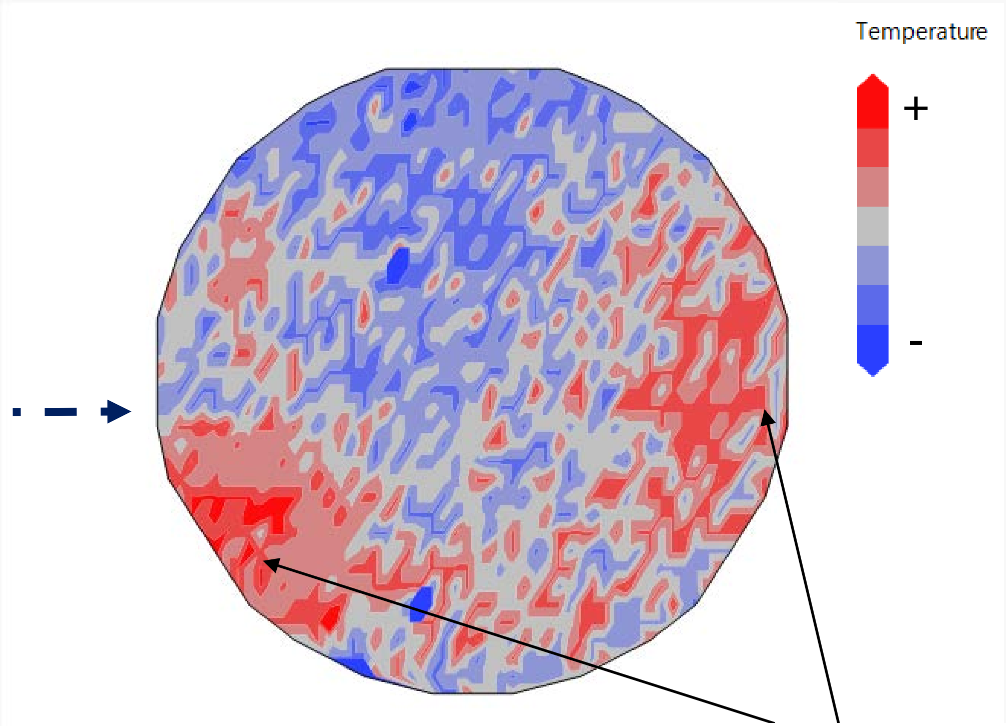
Variable coolant flow uniformity

Chuck Temperature Calibration





Die Level Temperature Measurement

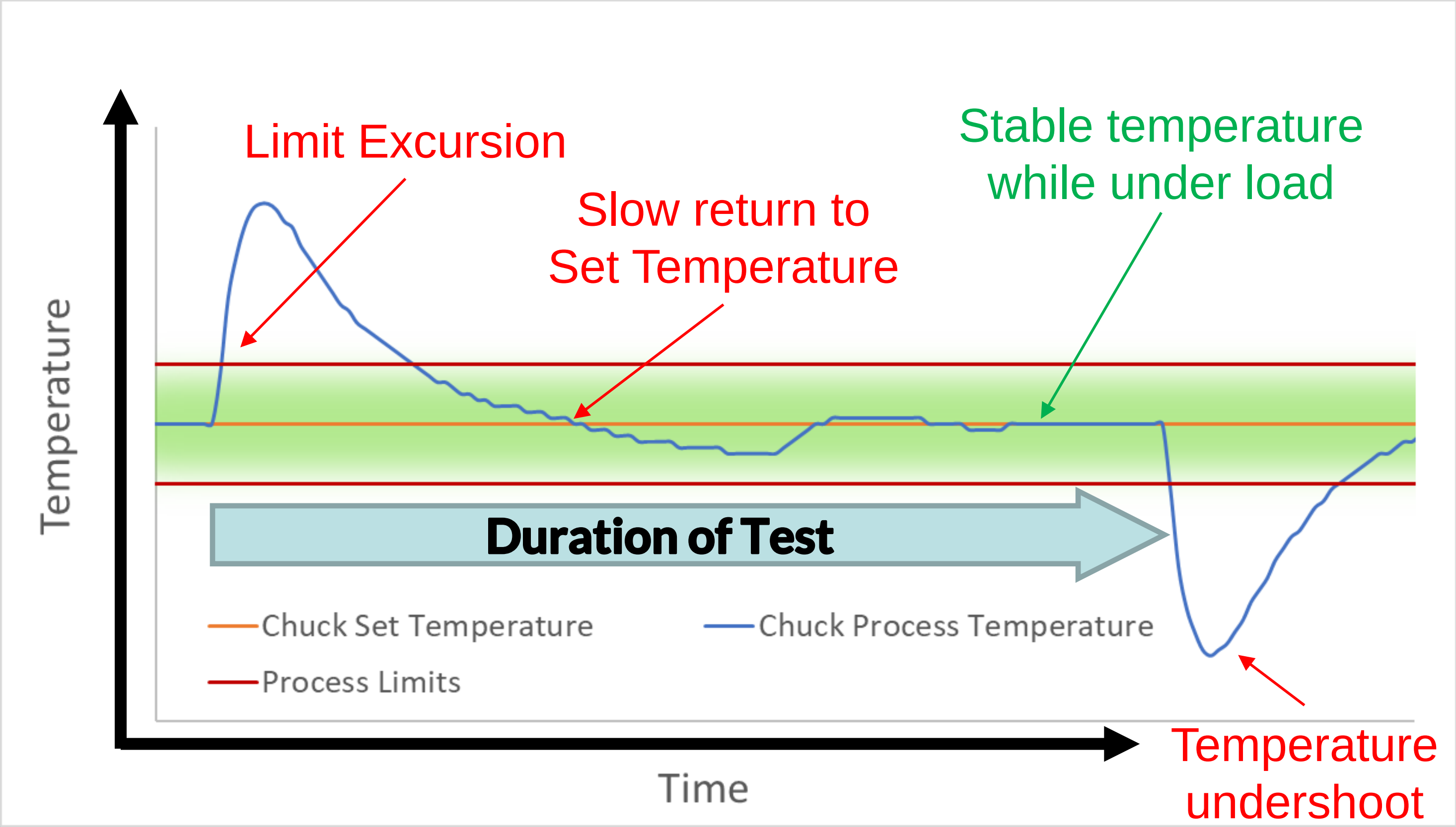


New “hot” zones

- Stable chuck temperature uniformity is well within specification.
- Wafer level temperature testing indicate little correlation with calibration data.

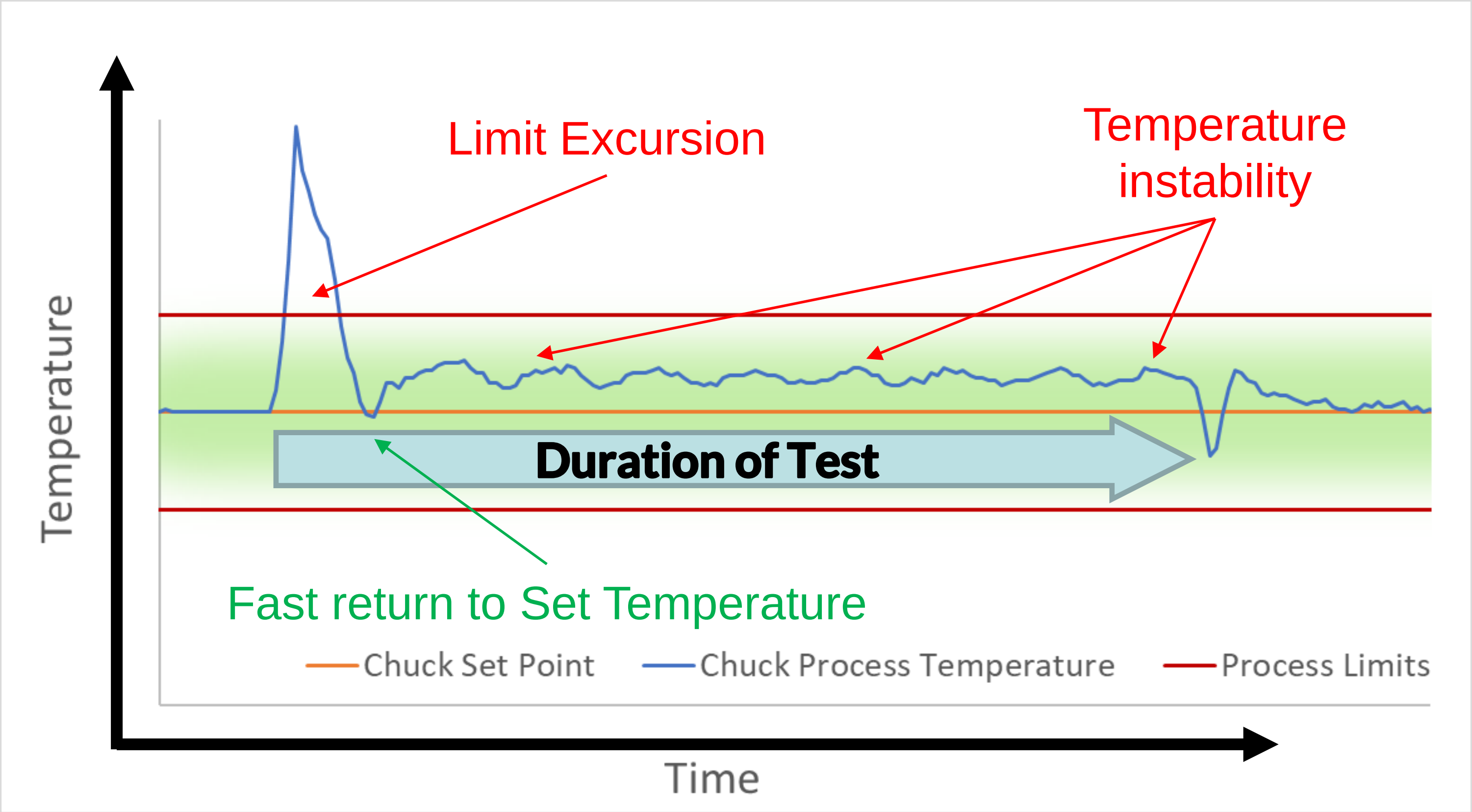
High-heat dissipation testing - Hot

- Continuous coolant flow
  - Slow response time to heat application
  - Stable after reaching set point



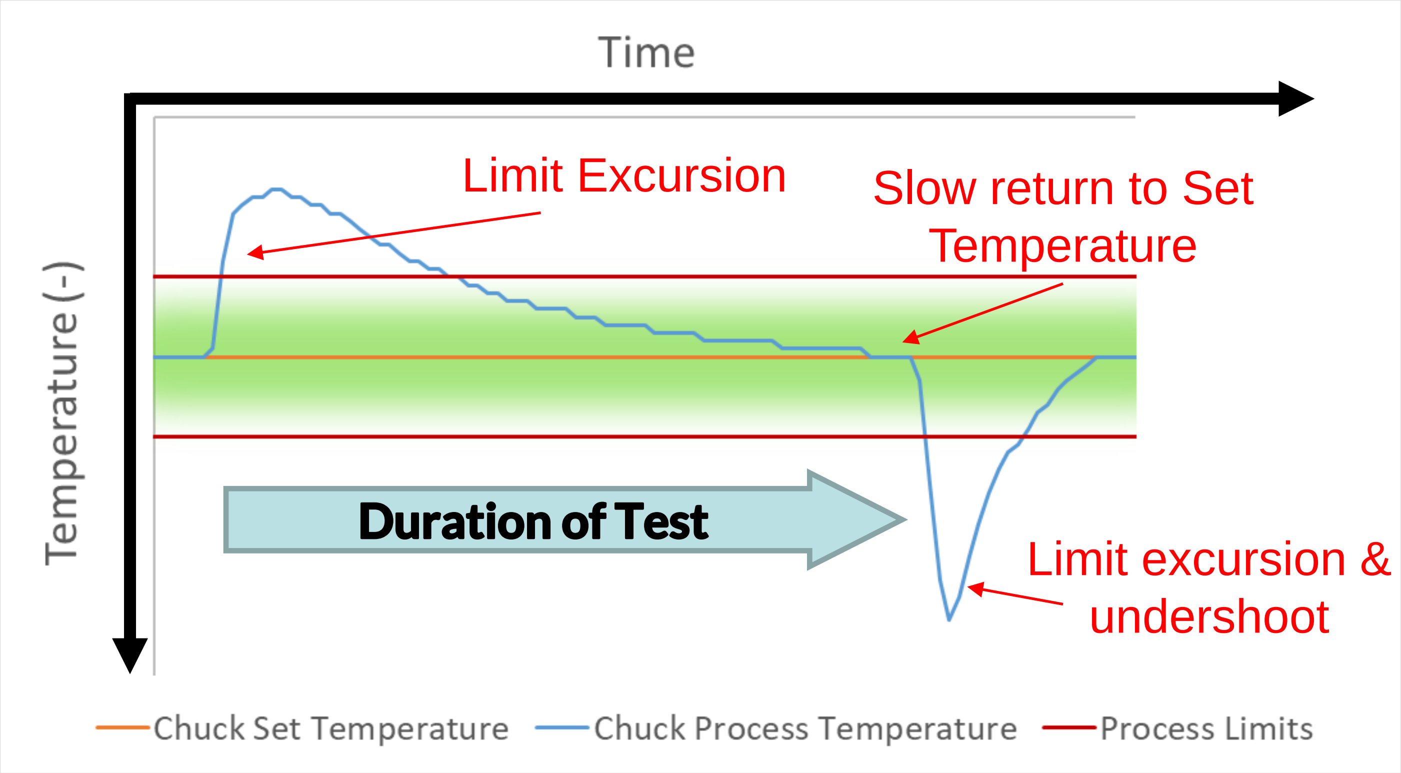
High-heat dissipation testing - Hot

- Variable coolant flow
  - Fast reaction time to high-power loading
  - Thermal instability after initial reaction



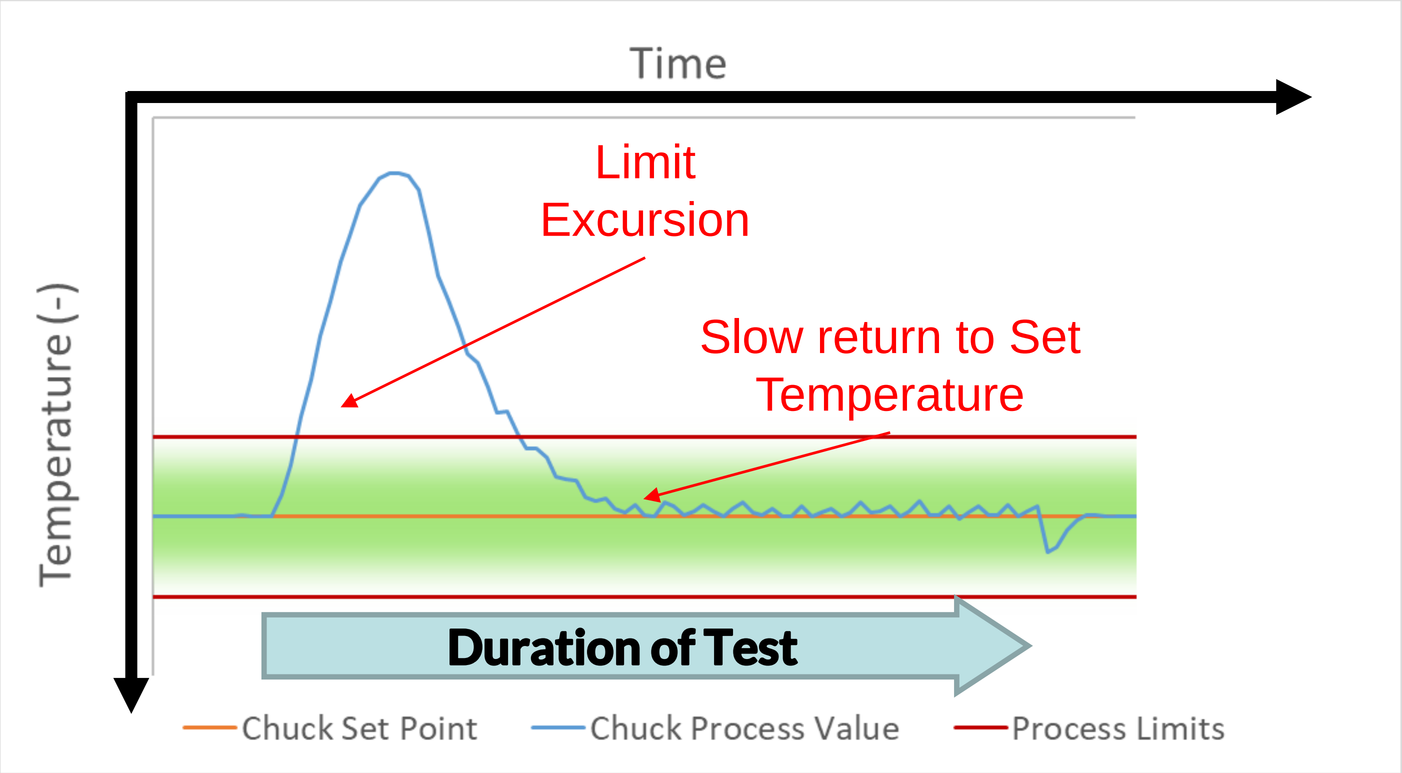
High-heat dissipation testing – Cold

- Continuous coolant flow
  - Slow response time to heat application
  - Large temperature undershoot



High-heat dissipation testing – Cold

- Variable coolant flow
  - High temperature spike during heat application
  - Slow response time to heat application



Industry performance results

Performance Specification	Continuous Coolant Flow	Variable Coolant Flow	Micron's Requirements
High-heat dissipation capability	✓	✓	🎯
No process limit excursions	✗	✗	🎯
Chuck uniformity during low-power testing	!	✓	🎯
Chuck uniformity during high-power testing	!	✗	🎯
Flexibility with HTF options	✗	✓	🎯
Fast reaction time to applied power loads	✗	✓	🎯
Temperature stability during test	✓	✗	🎯

- Current industry solutions do not meet all our needs.

Additional considerations

Heat transfer fluid (HTF) challenges

- **What is the HTF role in high-power testing?**

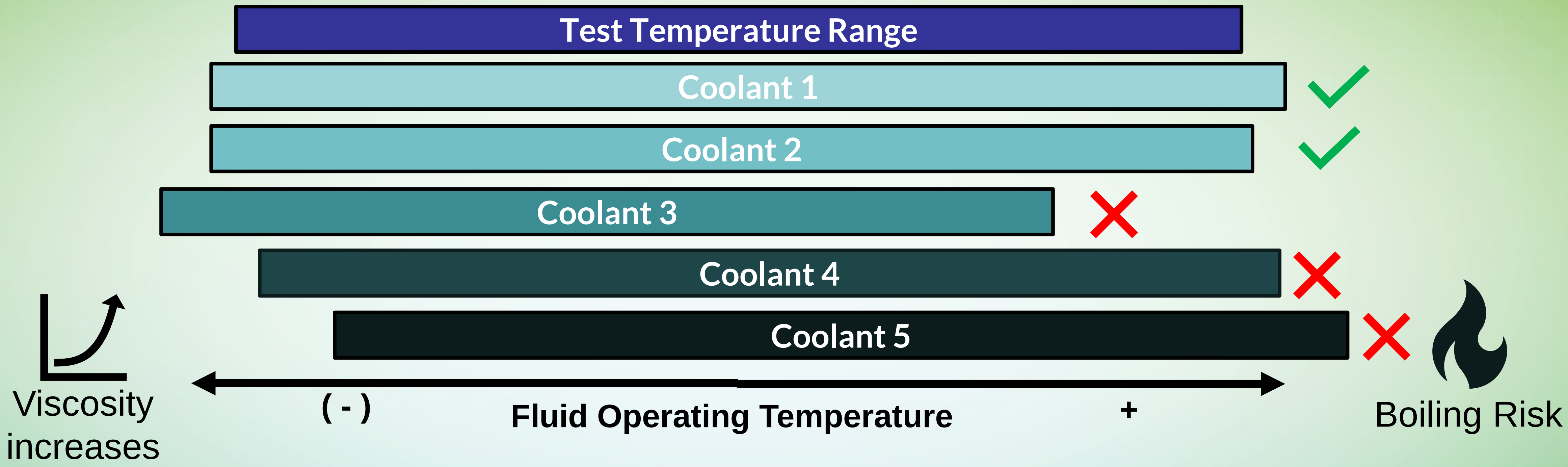
$$Q = \underline{\boldsymbol{H_C}}A\ \underline{(\boldsymbol{T_2} - \boldsymbol{T_1})}$$

- **What main factors are considered for HTF selection?**

Fluid specifications

Sustainability & safety

Fluid specifications



Test Temperature Range

Coolant 1 ✓

Coolant 2 ✓

Coolant 3 ✗

Coolant 4 ✗

Coolant 5 ✗

Viscosity increases

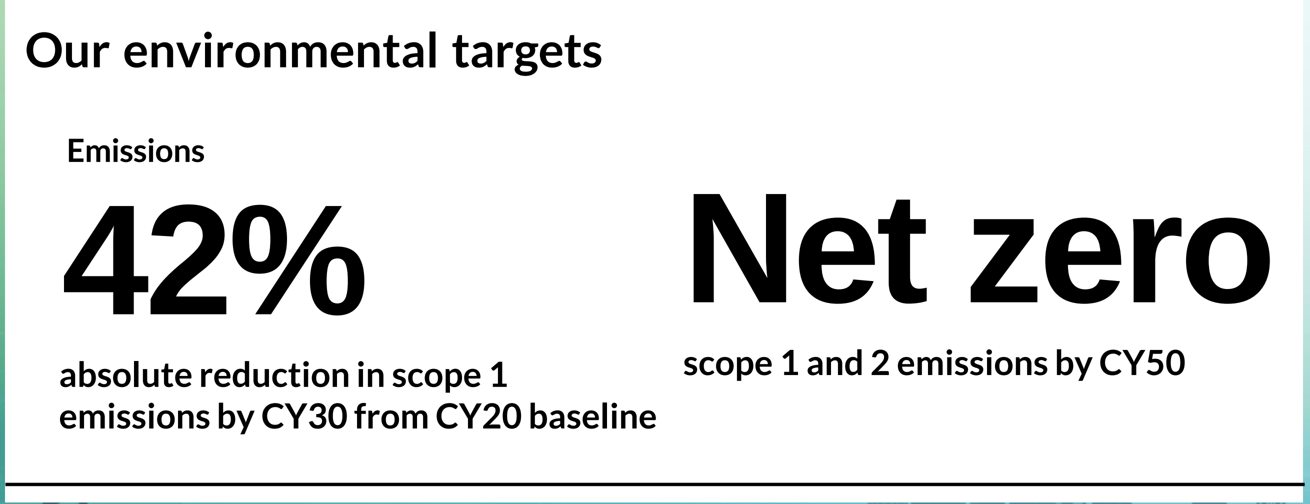
(-) Fluid Operating Temperature +

Boiling Risk

- **HTF solutions that match the required test range are limited.**

Environmental sustainability & safety

- Limiting global warming potential
- Per- and polyfluoroalkyl substances (PFAS) elimination
- Flash point & flammability risk



Our environmental targets

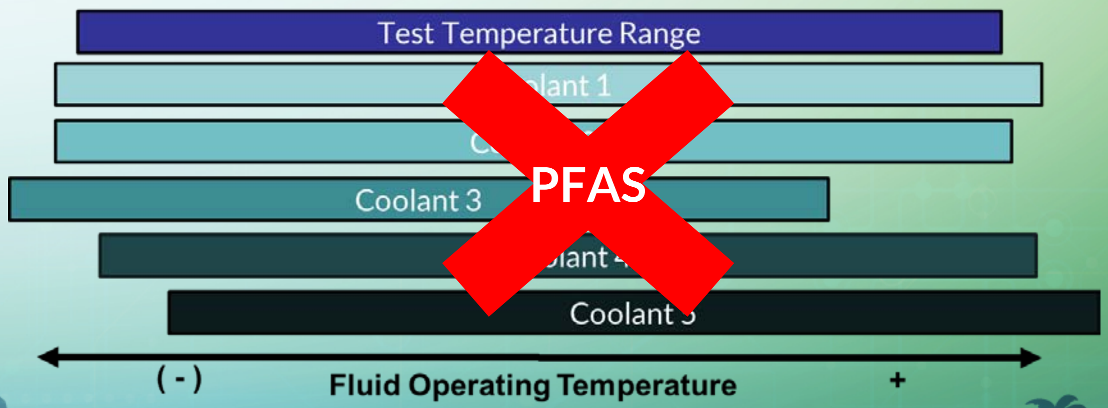
Emissions

42%

absolute reduction in scope 1 emissions by CY30 from CY20 baseline

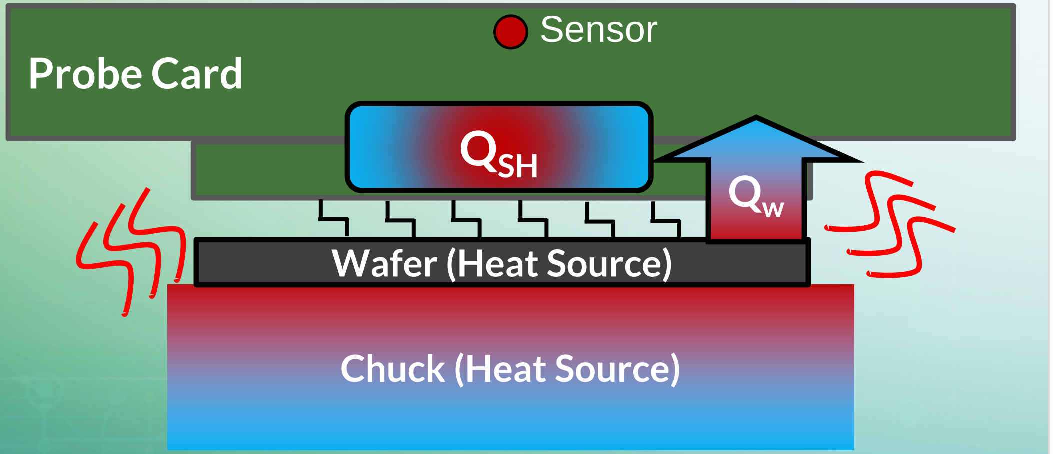
Net zero

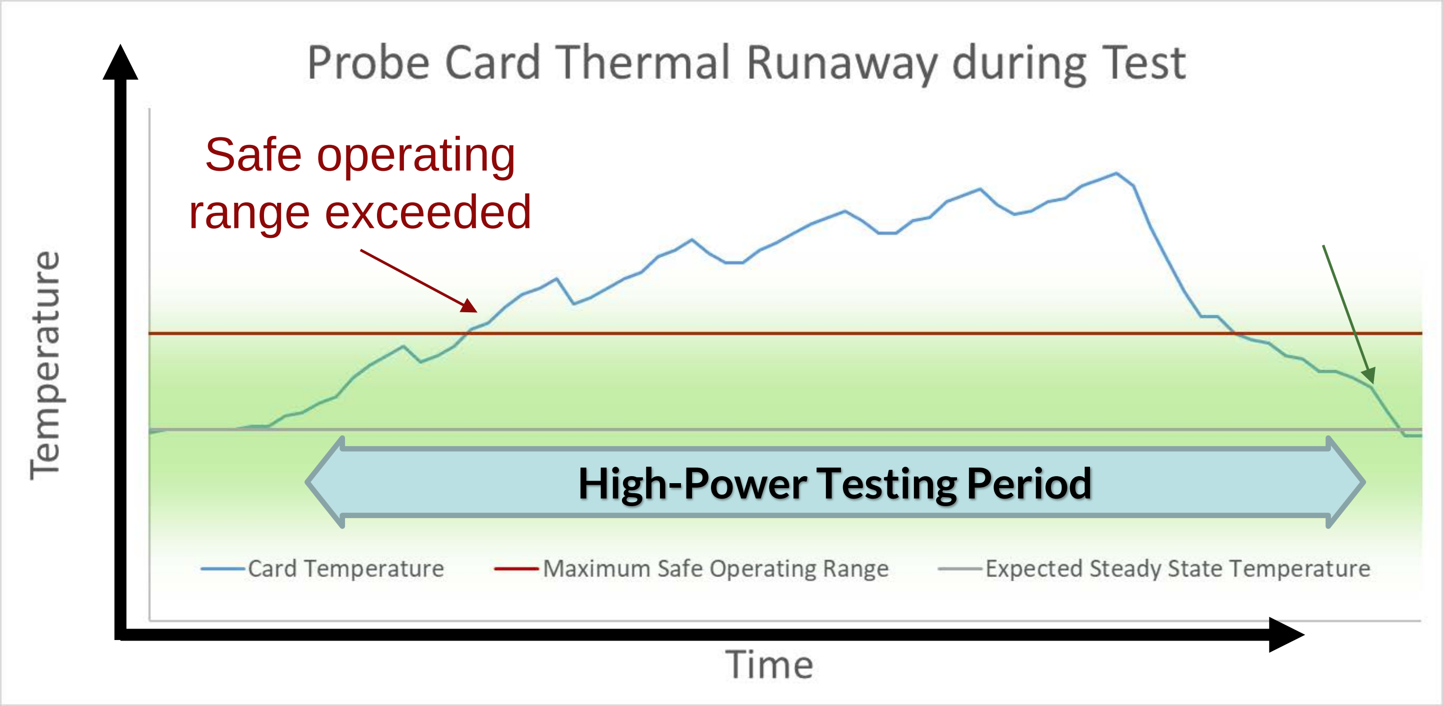
scope 1 and 2 emissions by CY50



High-power testing & probe cards?

- High-power testing is increasing card temperatures above their design specification.
- Primary cause of temperature gain and how to remove under consideration.





Conclusions

Summary

- Current industry thermal control methods display high-heat dissipation capability but do not meet all our requirements.
- Memory testing trends indicate that high-power testing has overtaken current industry high-heat dissipation capabilities.
- Probe card thermal management is a concern as testing power requirements will continually increase.

Thank you!

Acknowledgements:

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