TestConX 한국 Korea

November 18, 2025
Suwon, South Korea

Integrated Modeling and Experimental Optimization of a Thermal Management System for NkW Heat dissipation

Joseph Moon
SEMICS

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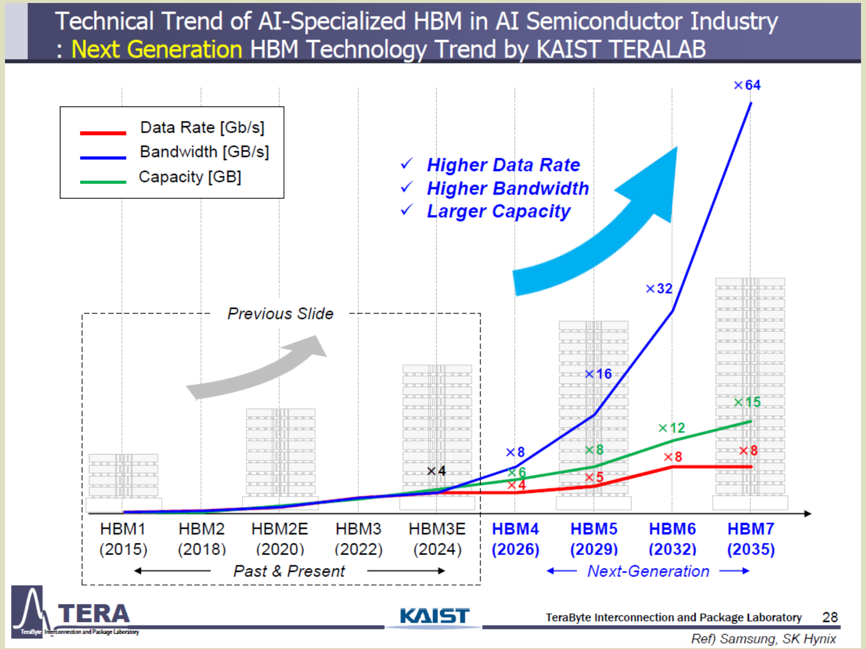
Thermal Requirements



Next-Generation HBM Roadmap by KAIST TERALAB

HBM Spec. / Packaging/Cooling / Architecture / AI Design Agent

Ver 1.2 / updated.250521

	HBM4 (2026)	HBM5 (2029)	HBM6 (2032)	HBM7 (2035)	HBM8 (2038)
Data Rate	8 Gbps	8 Gbps	16 Gbps	24 Gbps	32 Gbps
# of I/O	2,048	4,096	4,096	8,192	16,384
Bandwidth	2.0 TB/s	4 TB/s	8 TB/s	24 TB/s	64 TB/s
Capacity/die	24 Gb	40 Gb	48 Gb	64 Gb	80 Gb
# of die stack	12/16-Hi	16-Hi	16/20-Hi	20/24-Hi	20/24-Hi
Capacity /HBM	36/48 GB	80 GB	96/120 GB	160/192 GB	200/240 GB
Power/HBM	75 W	100 W	120 W	160 W	180 W
Die stacking	Microbump (MR-MUF)		Bump-less Cu-Cu Direct bonding		
Cooling Method	Direct-to-Chip (D2C) Liquid Cooling	Immersion Cooling		Embedded Cooling	
HBM Architecture	Custom HBM Base Die HBM-LPDDR	3D NMC-HBM & stacked cache / decap	Multi-tower HBM Active / Hybrid Interposer	Hybrid HBM Architecture HBM-HBF HBM-3D LPDDR	Full-3D / HBM Centric Computing Architecture
Additional Features (Patent)	NMC processor + LPDDR Ctrl	+ Cache + CXL + on-die/stacked decap + HBM shielding	+ Network switch + Bridge die + Asymmetric TSV	+ HBF/LPDDR Ctrl + Storage network	+ HBM Centric Interposer + Double side Cooling + Edge-expand Stack
AI Design Agent	ubump & TSV-array Decap placement Optimization	I/O Interface Optimization considering PSIJ	Hybrid Equalizer + Generative AI based SI/PI Metric Estimation	LLM based Human Interactive AI Design Agent	

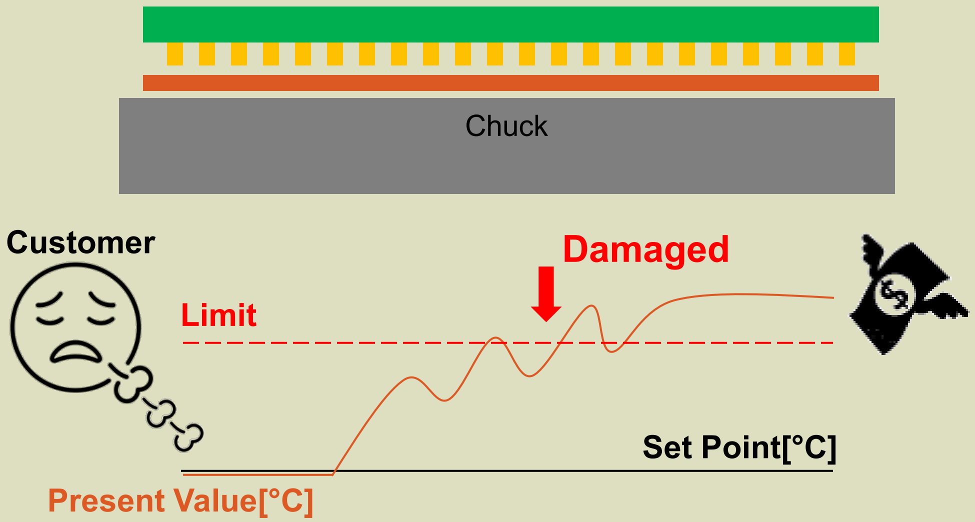
Source : HBM Roadmap Ver1.7 Workshop by KAIST TERALAB (2025)

- The rapid expansion of the AI market is pushing HBM requirements to new levels
- Bandwidth nearly doubles every 2~3 years

→ Driving a sharp rise in NkW(per shot) Heat dissipation requirements in the Prober Market

Customer's Requirements

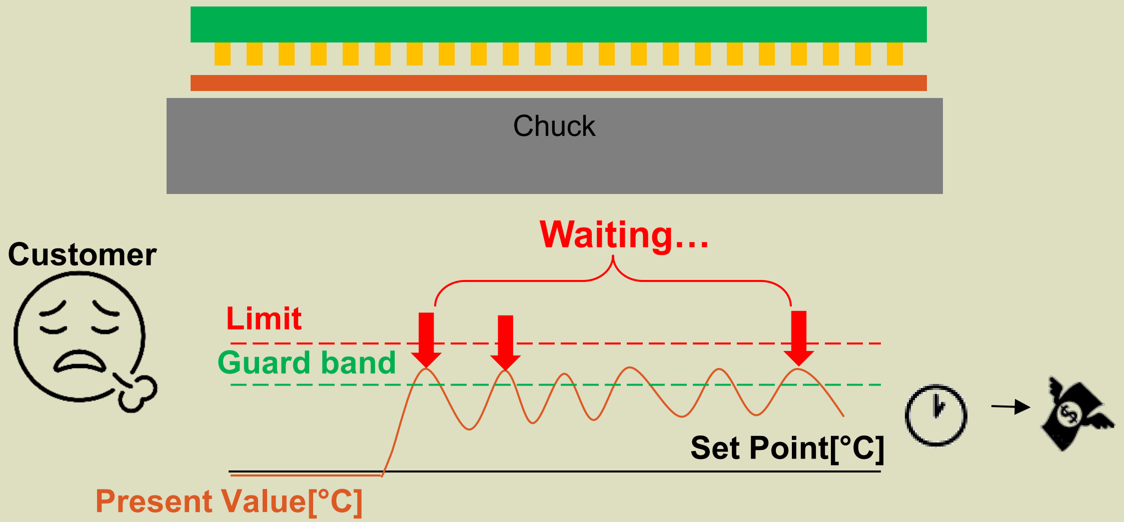
Thermal interlock X



Probe card damaged → Wafer damaged

→ X ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑

Thermal interlock O

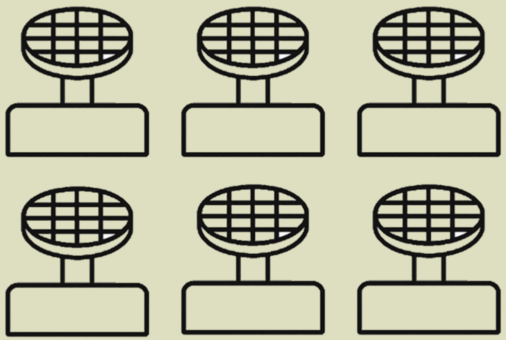


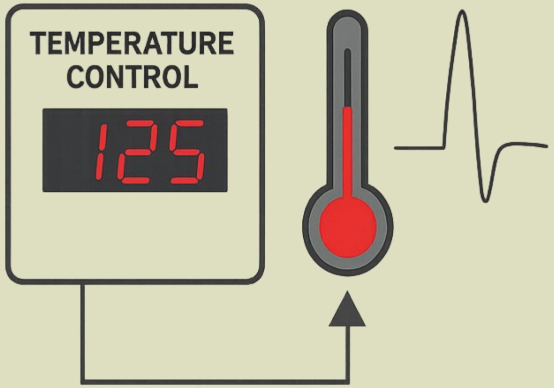
Waiting for PV within Guard band

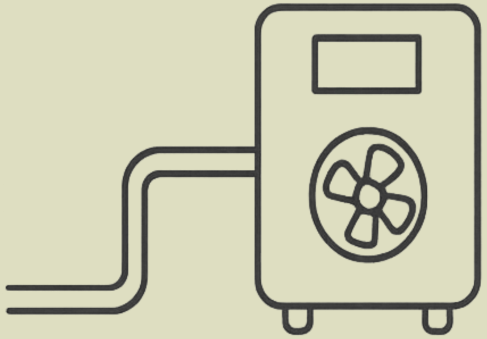
→ X ↑ ↑ ↑

No more Waste!!!

Development Challenge for Prober

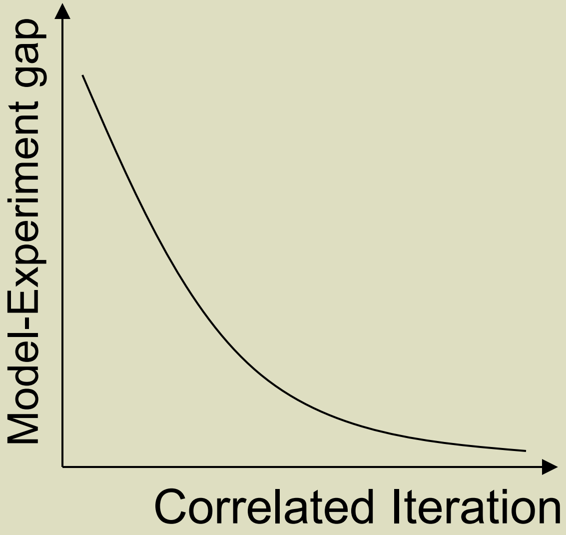


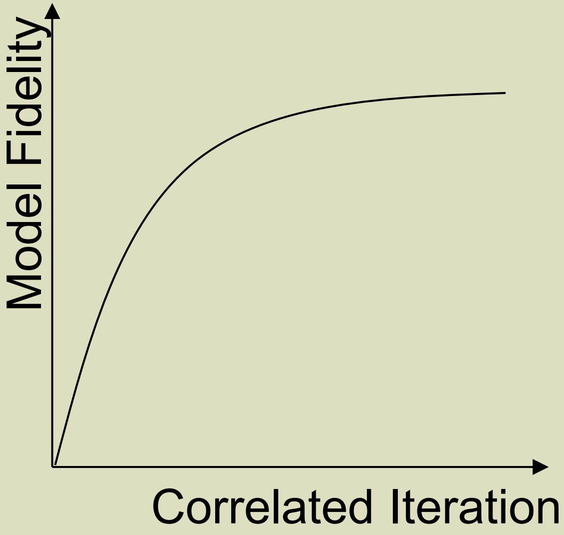


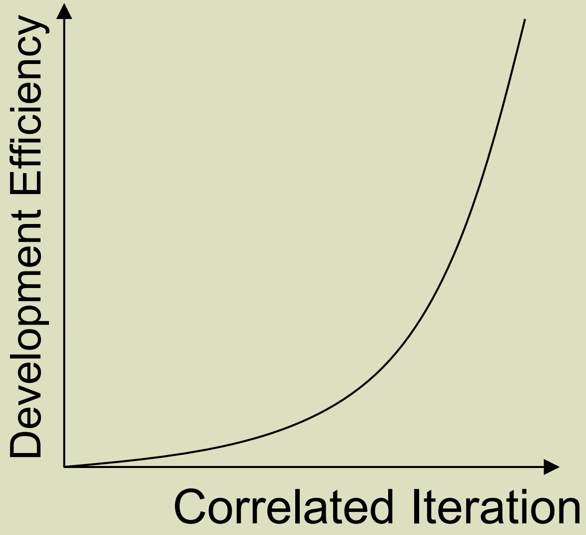


- **Chuck :** Rapid development of high-uniformity thermal chuck design, suitable for dissipation…
- **Chiller :** Optimizing Capacity, Multi-channel cooling, Rapid transient response…
- **Control system :** Capable of responding precisely and stably to various Thermal loads…
- **System Optimization & Stabilization**
  : Ensuring robustness and reliability under accelerated development cycles…

Strategy = Correlation



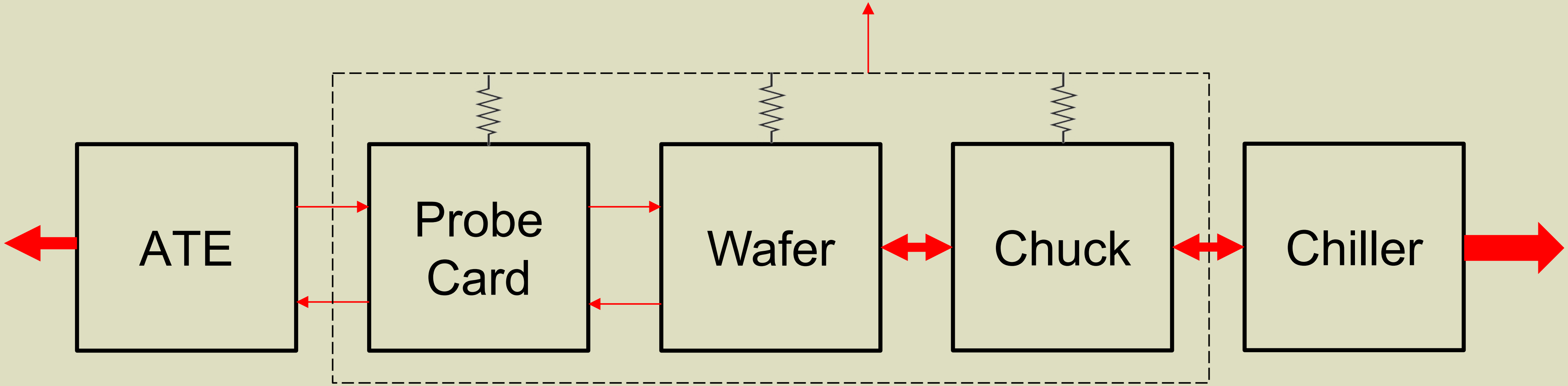




- "Correlation" : The Iterative Feedback loop between model and experiment
- The Correlation is the driver of accelerated development

Heat dissipation schematics for NkW

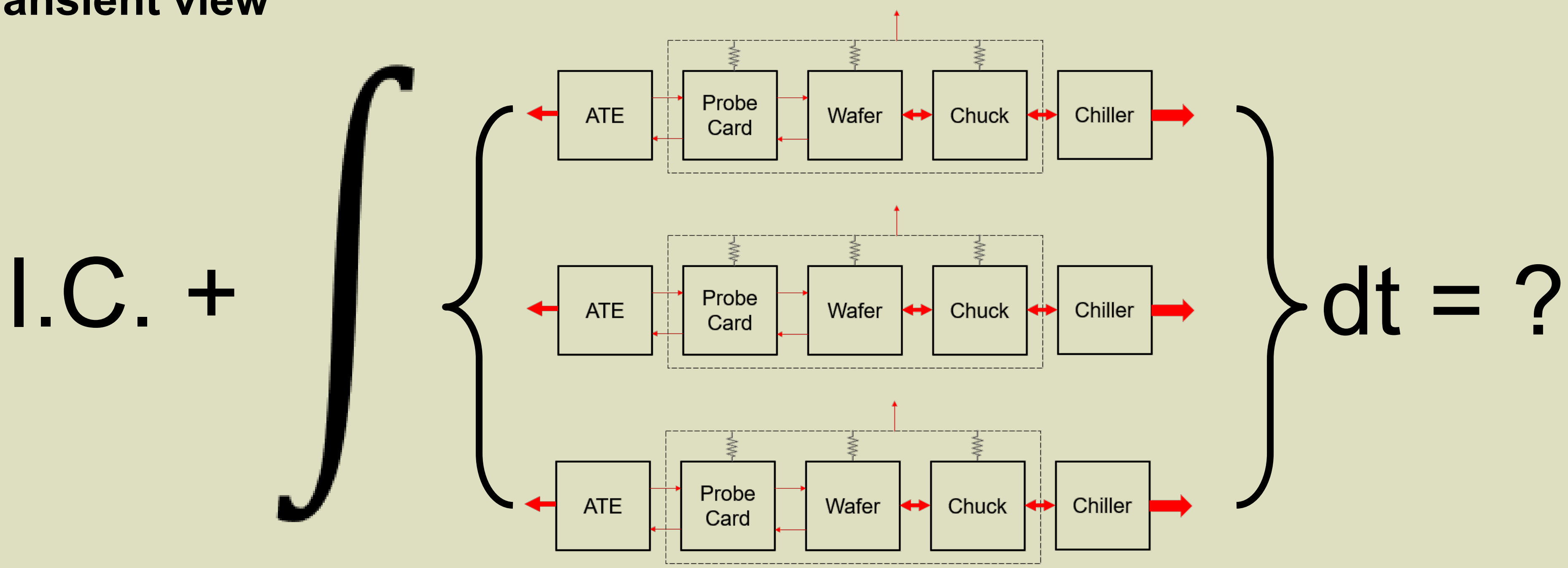
Steady-state view



- Steady-state energy flow perspective
  : Considering whether the system has reached thermal equilibrium (no change)

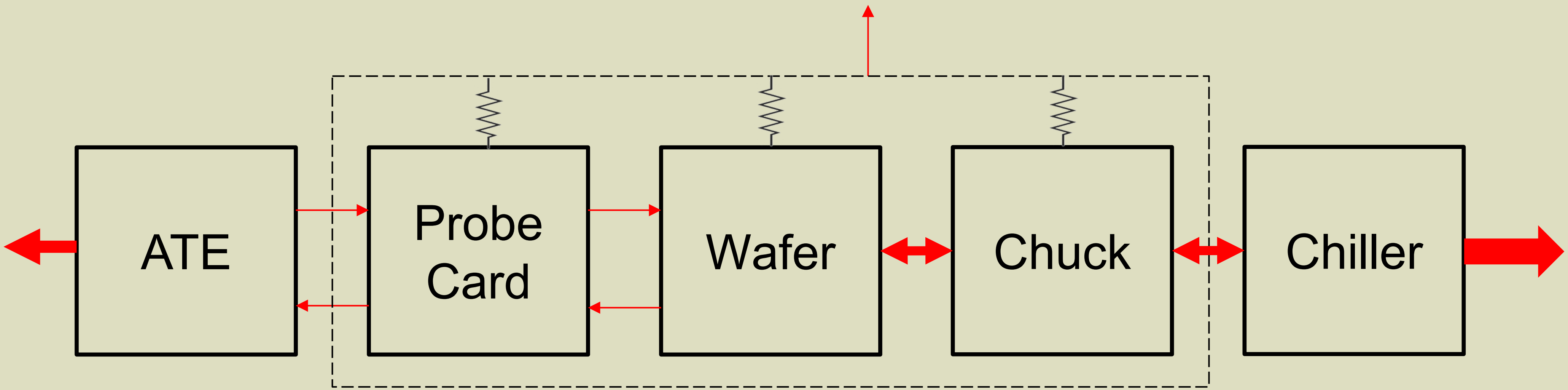
Heat dissipation schematics for NkW

Transient view



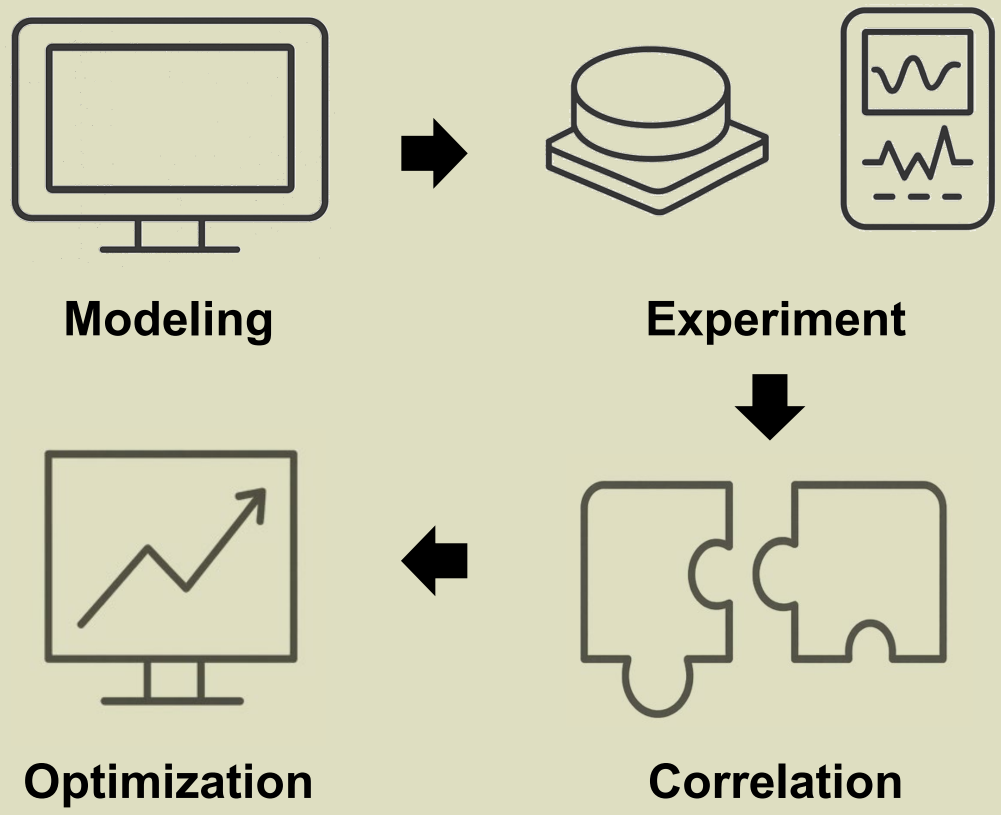
- Transient temperature control perspective
  : Considering how cumulative effects of energy flows over time result in the temperature response of each part

Heat dissipation schematics for NkW



- Wafer side heat load is irregular and unpredictable disturbance to Chuck temperature control system
- A good NkW class heat dissipation system has,
  - **High heat dissipation capacity**
  - **Rapid recovery to SP**
  - **Overshoot/Undershoot must be minimized**
  - **Robust control under various heat loads**

Development cycle



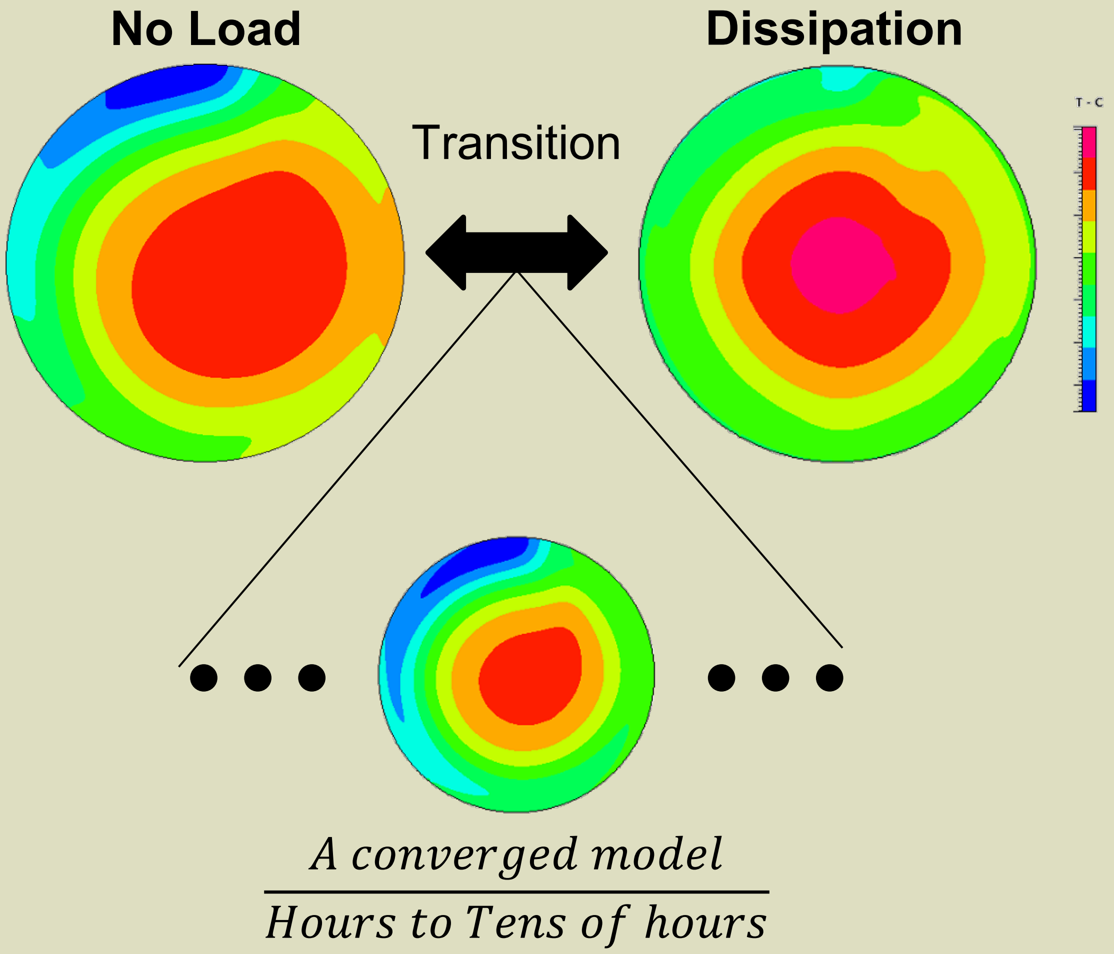
- **Modeling**
  - Modeling provides initial direction before experiments
  - Reduces trial and error in early stage
  - Establishes baseline expectations for performance

- **Experiment**
  - Verification of actual performance under real conditions
  - Ensures repeatability and reliability of results
  - Identifies unexpected factors in real operation

- **Correlation**
  - Validation of model to experiment correlation
  - Key factor for accelerating the development cycle

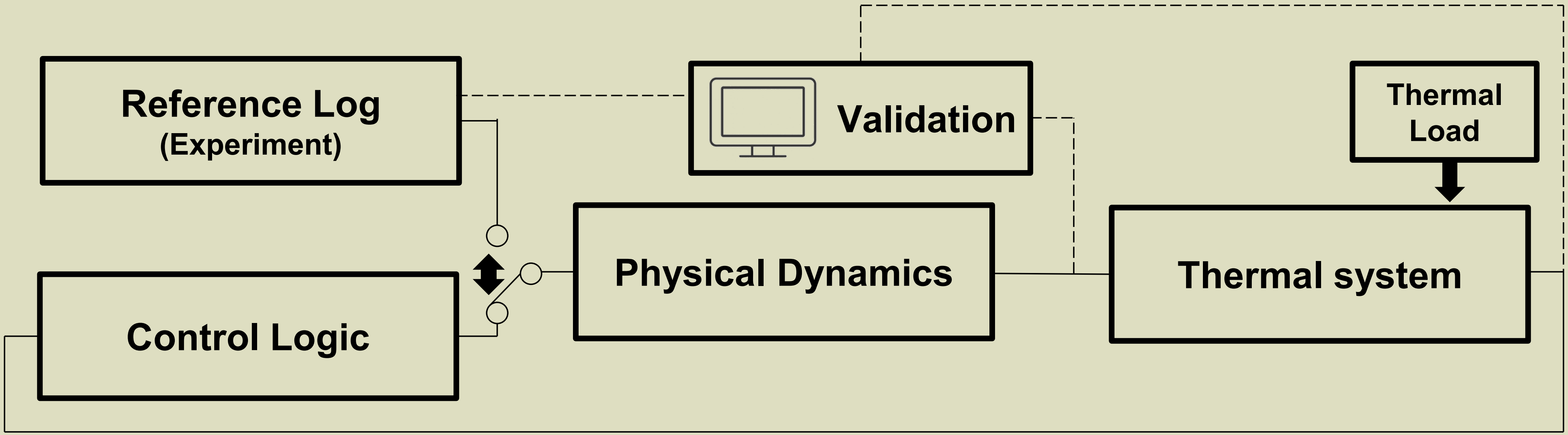
- **Optimization**
  - Performance improvement
  - System simplification

Computational Fluid Dynamics (CFD) Modeling



- **Steady-State Analysis**
  - High-level correlation with experiments can be achieved based on extensive past data
- **CFD Limits**
  - Transient CFD requires hours to tens of hours per each step (Full result -> Few months…)
- **Our Approach**
  - Use steady-state results for reliable baseline
  - Predict transient behavior from intermediate simulation outputs and validate through experiments
  - Control dynamics cannot be fully assessed by CFD alone
    → System level modeling is required

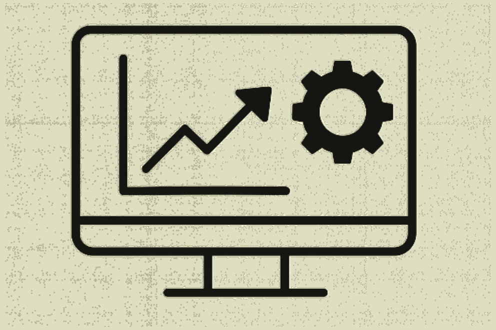
System level modeling



- CFD based steady-state analysis provides a high-fidelity baseline
- Transient dynamics are complemented through System-level modeling and experimental validation
- This integrated approach enables quantitative analysis, control tuning and optimization strategy development

Correlation

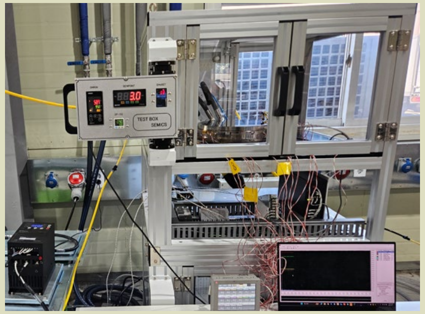
Model



Incorrect experimental setup
: Feedback to Experiment

Iteration

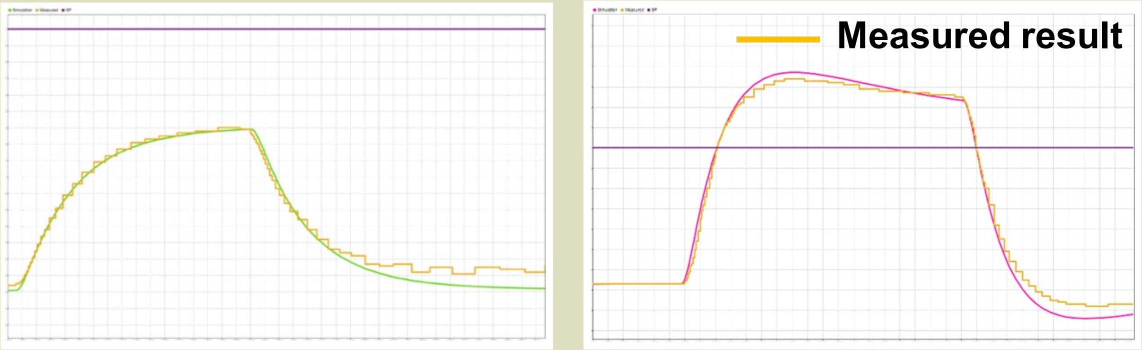
Experiment



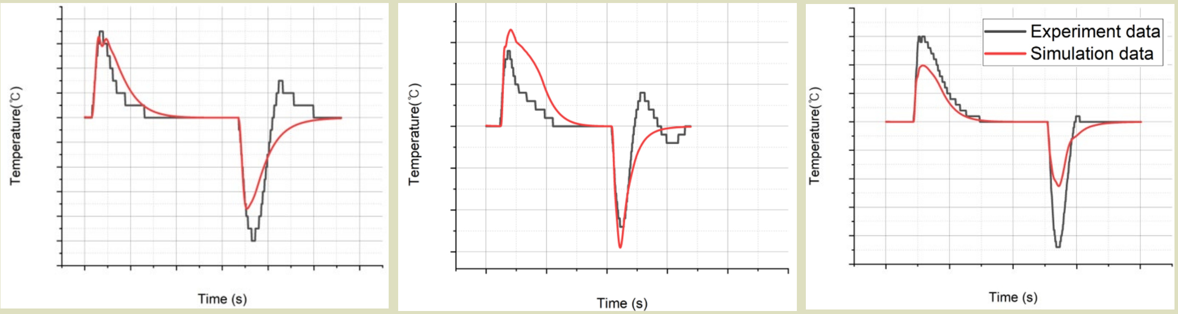
Incorrect boundary condition
: Feedback to Model

Correlation

Open Loop Validation



Closed Loop Validation



- **Validation Path**
  - Open-loop → Closed-loop validation
  - Verify the matching accuracy while gradually increasing the number of control points

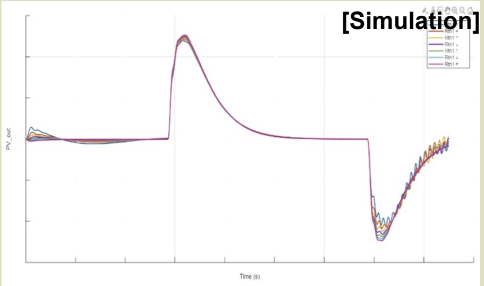
- **Key Challenges**
  - Coolant property variation depends on T
  - Lumped model
    → Heat exchange efficiency becomes critical
  - Dimension reduction → Fidelity limits

- **Fidelity vs. Speed**
  - Trade-off between fidelity and speed
  - Finding the optimum by complementing with experiments

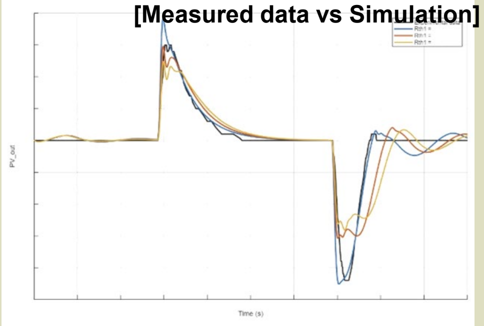
Correlation

Parameter sweep

A parameter

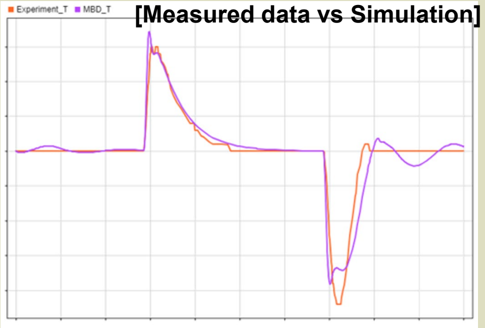


B parameter

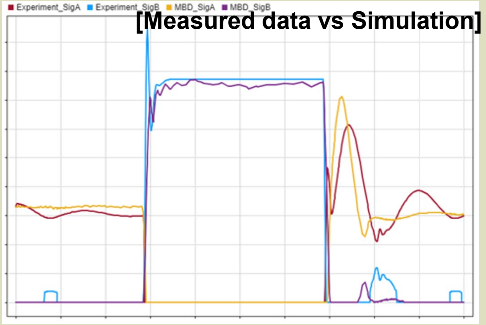


4kW Thermal Load

Temperature

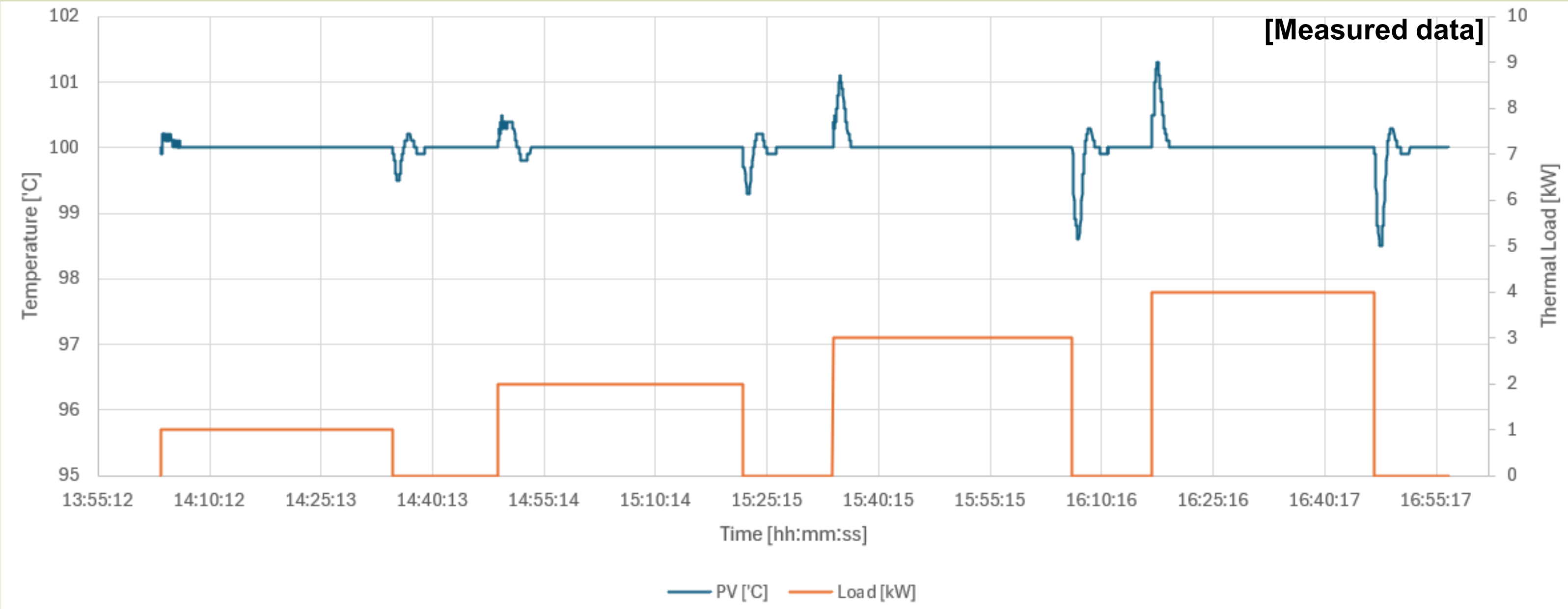


Control Output



- Parameter sweep quantifies the impact of key parameters on performance
- Automation of parameter sweep accelerates model refinement
- Enables modeling with high similarity to experimental results

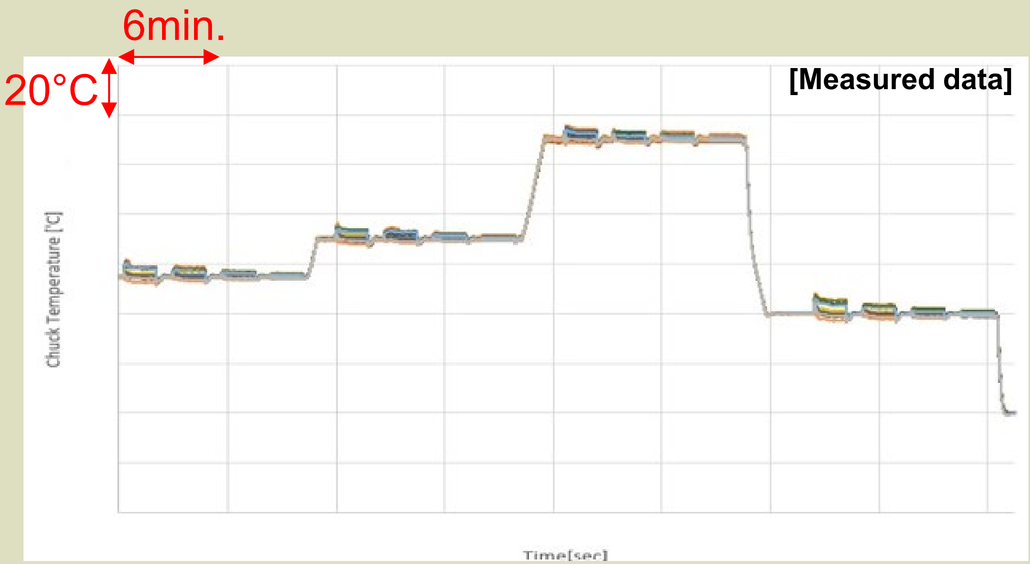
4kW Heat dissipation system



Chuck PV under 1~4kW from Wafer-side(12inch) load

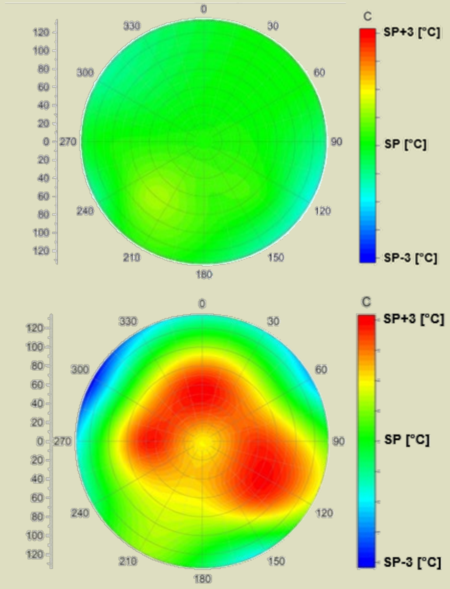
- At 4kW Sudden Load (80~125°C),
  - Overshoot / Undershoot <1.5°C
  - Recovery to SP < 3min.
  - Recovery within guard band(±1°C) < 1min.
- **The solution has already been successfully applied in the field**

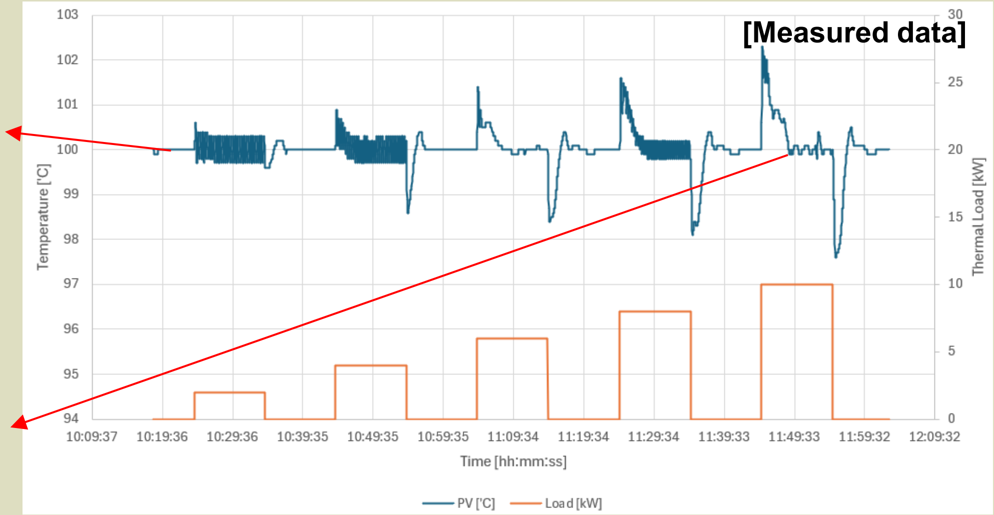
10kW Heat dissipation system



Chuck PV (21points)
under 8, 6, 4, 2kW from Wafer-side(12inch) load

[Measured map]





Chuck PV
under 2, 4, 6, 8, 10kW from Wafer-side(12inch) load

- At 10kW Sudden Load (80~150°C)
  - Overshoot / Undershoot < 2.5°C
  - Recovery to SP < 5min.
  - Recovery within guard band(±1°C) < 1.5min.
- **Ongoing control logic optimization to ensure stable control under various heat loads**

Closing

- Rapid scale-up achieved through Correlation from 4kW to 10kW
- We welcome the double-digit kW dissipation challenge

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