Pulsed Flash Two-Phase Cooling for High Heat Flux Thermal Management of Wafer-Scale Systems

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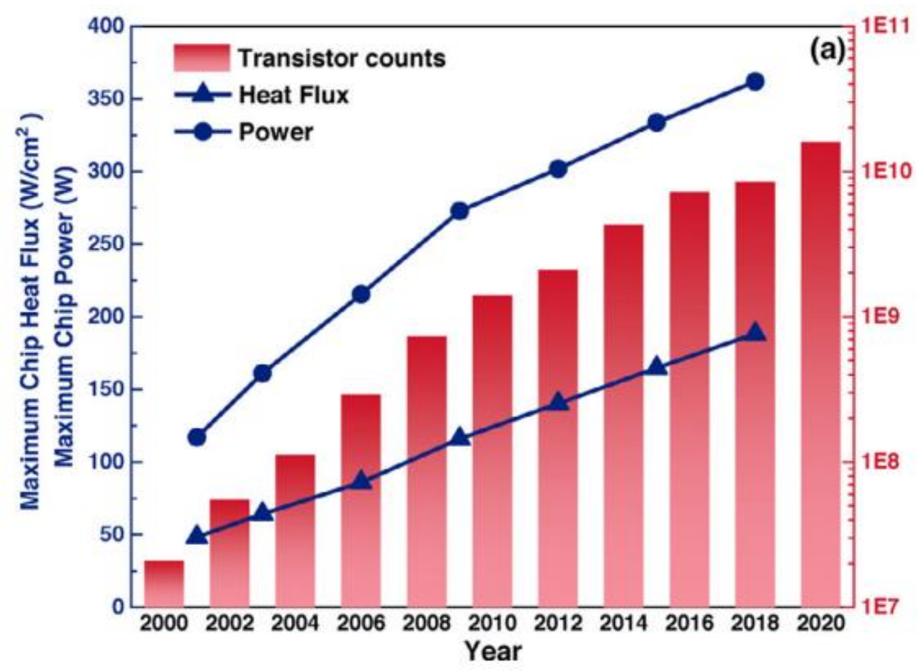
Introduction

- High-performance computing demands reliable cooling system for 1 W/mm² heat flux.
- Wafer-scale system demands total heat removal ability in kW.
- Provides little if any heat spreading area.



[1]

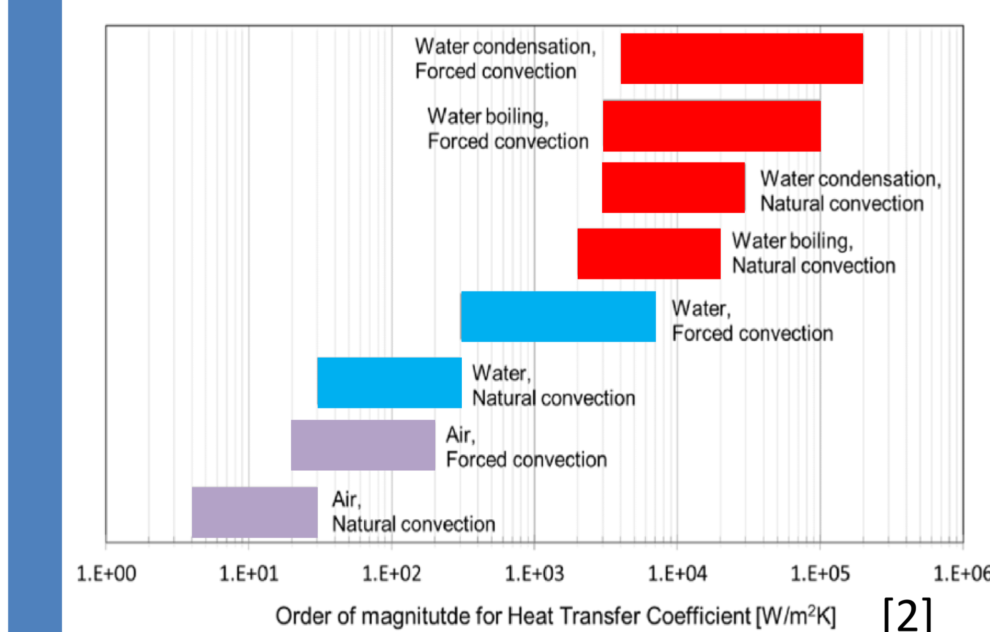
Wafer-Scale (300 mm Si-IF) System

Power Delivery	Thermal Dissipation
50 kW	Average Heat Flux 1W/mm²

Flash cooling

Why Flash cooling?

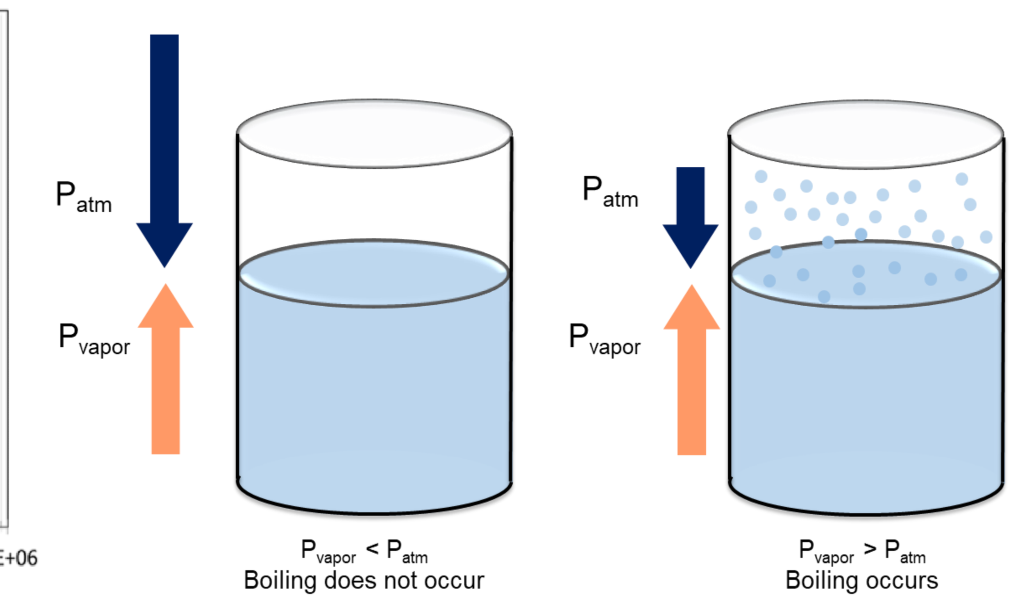
- Traditional chip-scale solutions are ineffective due to high pressure drop, scalability, cost, and requires heat spreading.



[2]

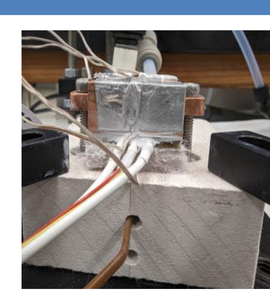
Working principle

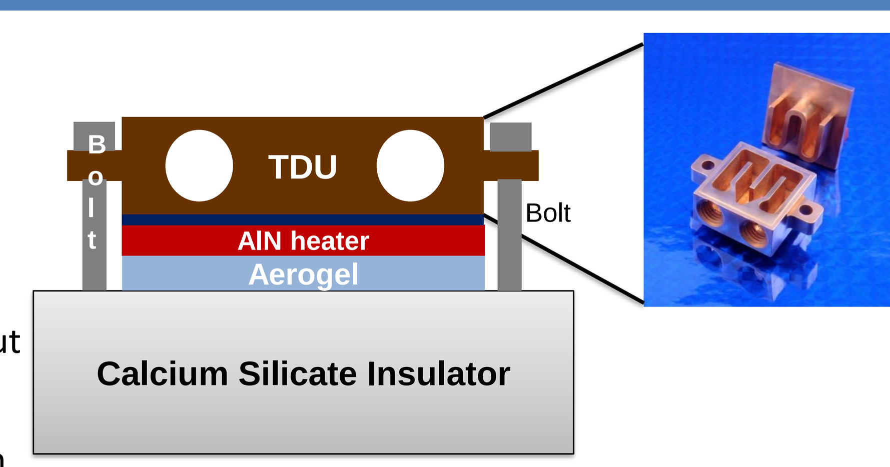
- Sudden exposure of liquid to a depressurized environment will boil the liquid facilitating both homogenous and heterogenous nucleation.

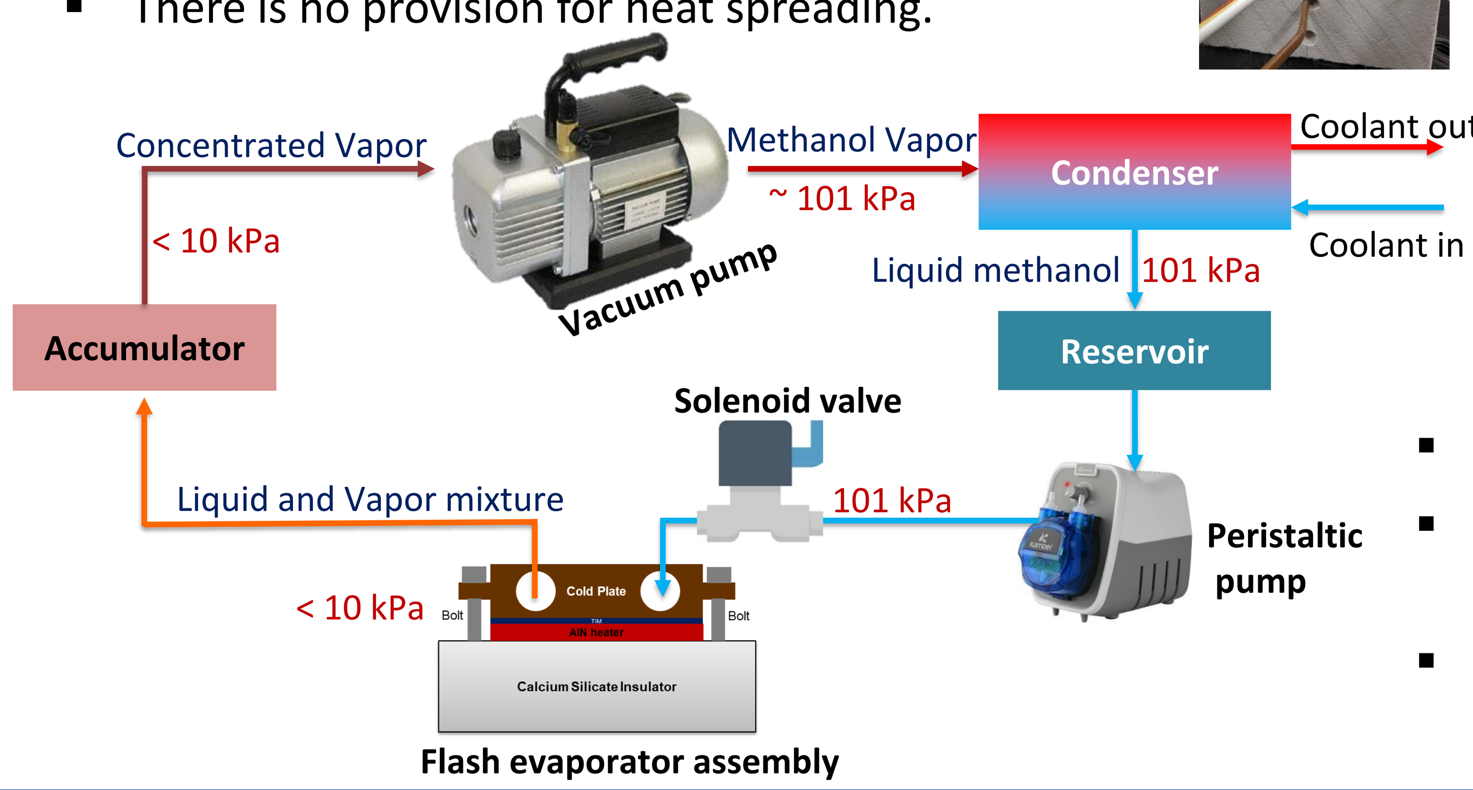


Experimental Setup and Design of Experiments

- A Closed Loop Flash Cooling System is developed.
- Methanol is employed as an operating fluid.
- There is no provision for heat spreading.

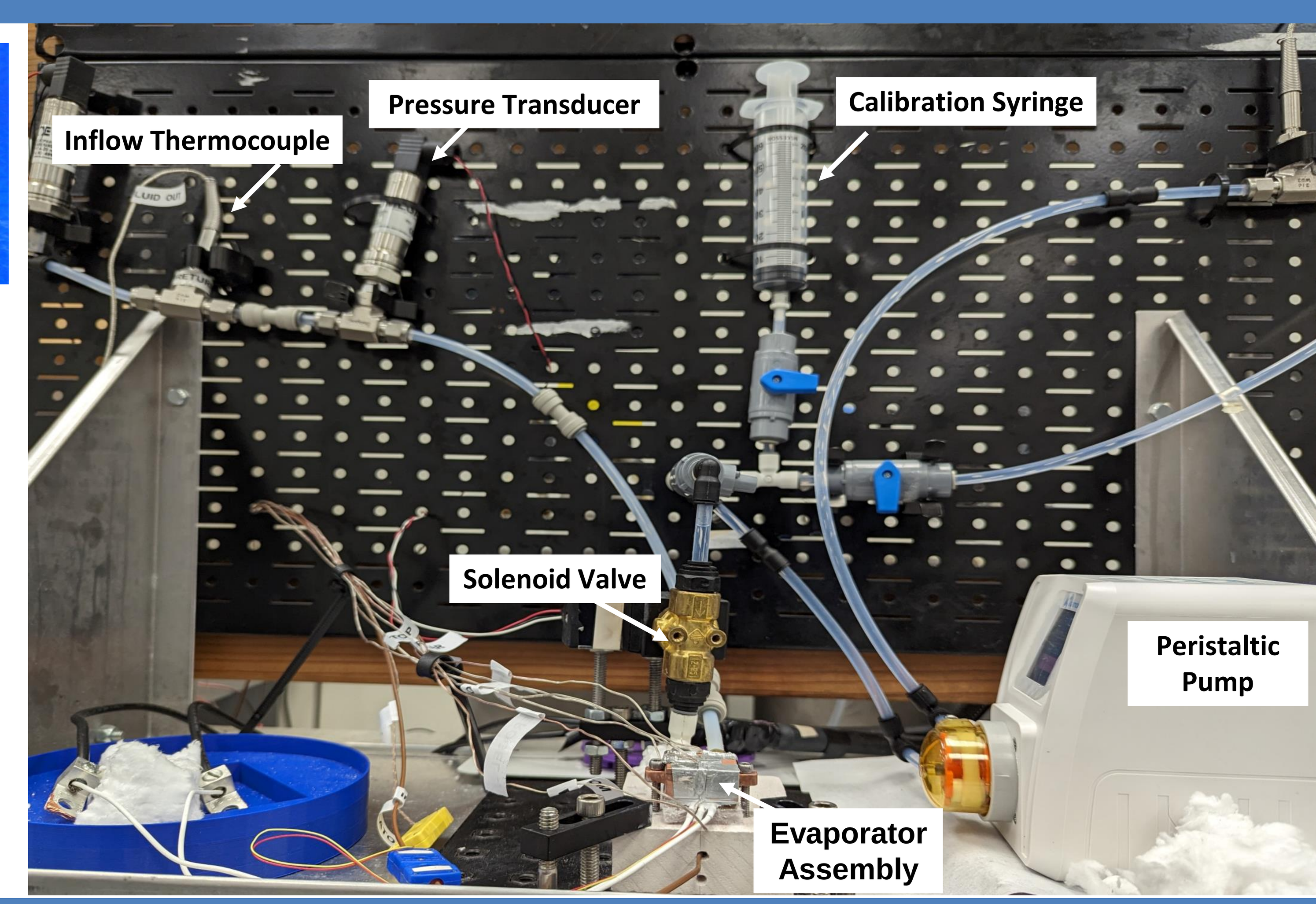






Design of Experiments

- Heat flux is varied from **0.2 to 1 W/mm²**.
- Flow rate is controlled using peristaltic pump.
- 8 thermocouples and 3 pressure transducers are used for data collection.



Results and Discussion

- Flow rate can be dynamically controlled to achieve rapid transient response to heat load.
- Operating boiling regime can be controlled and tuned by varying pulse cycle time.
- Heat flux, pulse cycle time and flow rate are the control parameters.

Calculation for Thermal Resistance of the TDU:

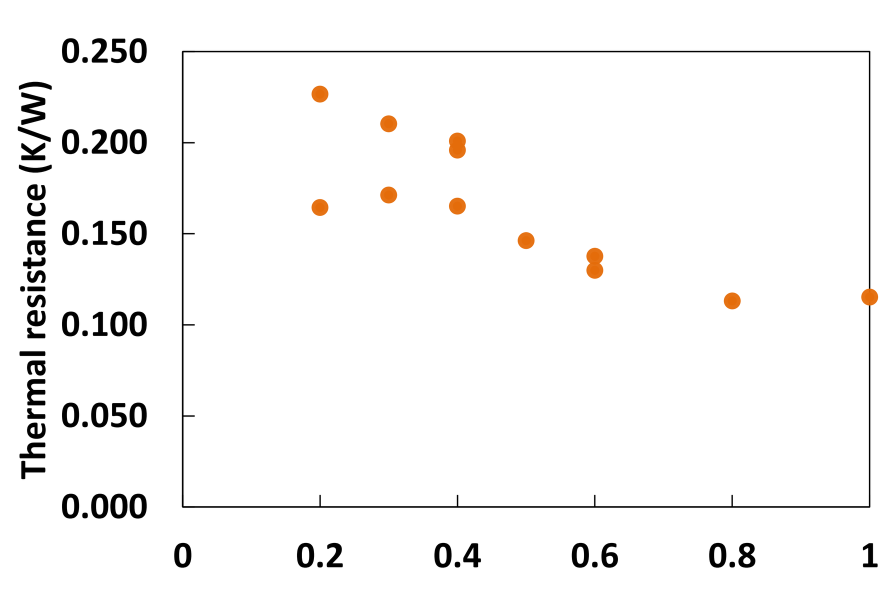
$$\Delta T = T_{TDU} - 0.5 * (T_{mi} + T_{mo})$$

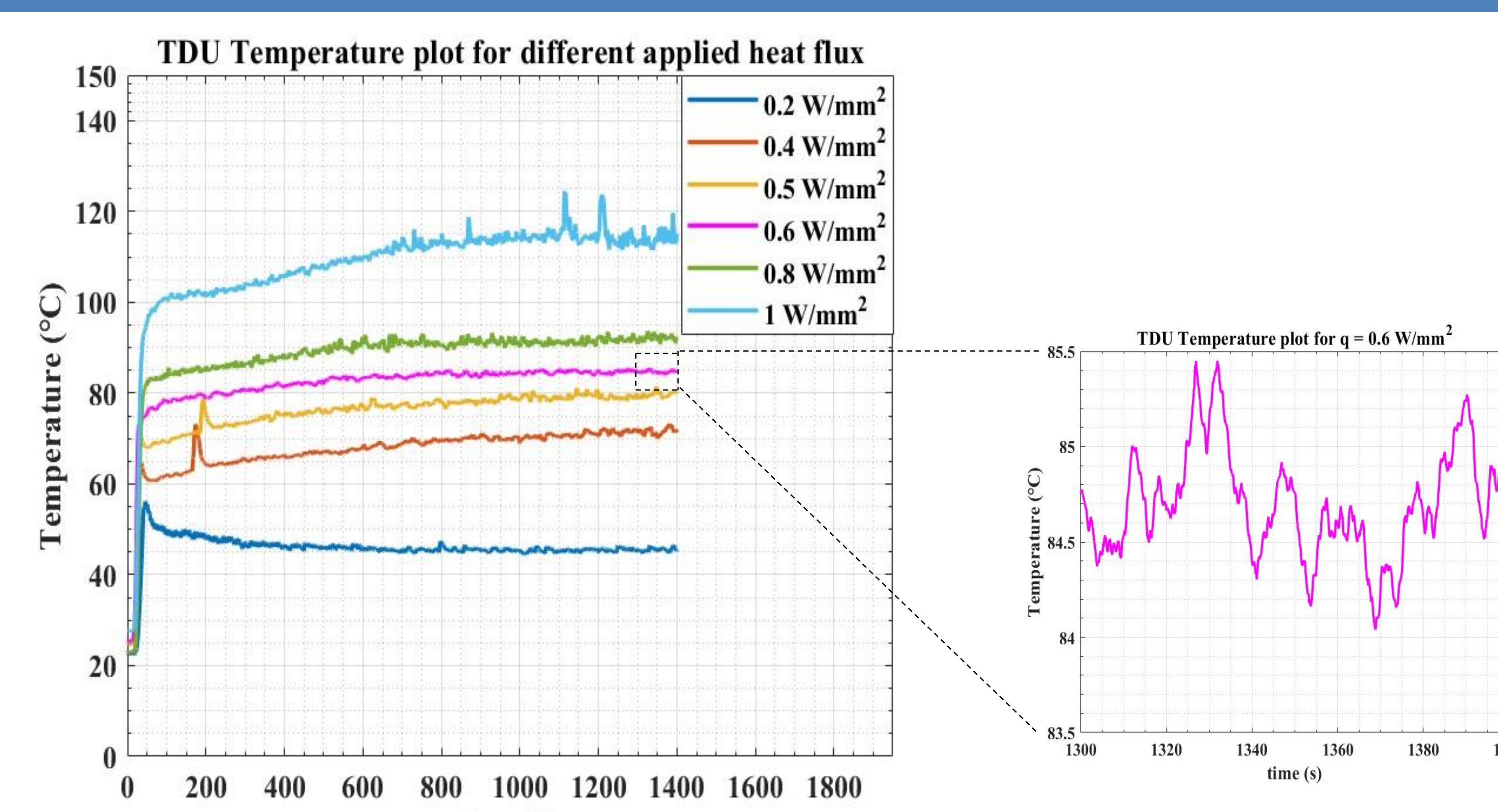
$$R_{th} = \frac{\Delta T}{q''}$$

T_{mi} Steady-periodic inlet temperature of methanol
T_{mo} Steady-periodic outlet temperature of methanol
T_{TDU} Steady-periodic average TDU Temperature [Plot]
q'' Applied Heat flux

Best case results for each heat flux

Heat flux	Pulse cycle time	Flow rate	TDU temperature	TDU Outlet Pressure
W/mm²	s	ml/s	°C	kPa
0.2	5.07	0.16	45.26	18.04
0.4	3.11	0.37	72.79	31.85
0.5	2.08	0.40	79.97	39.45
0.6	1.06	0.63	84.95	46.73
0.8	0.65	0.80	96.68	60.32
1	0.28	0.99	114.21	74.97





- The steady-periodic temperature of the TDU increases with heat flux, decreases with pulse cycle time and flow rate.
- Oscillations in temperature ranges from ± 1 °C to ± 3.5 °C.
- Oscillations are higher for larger pulse cycle time.
- Oscillations are higher for higher heat fluxes for same pulse cycle time.
- Oscillations are lower for higher flow rate for a given q" and cycle time (up to a limit).

Conclusions

- A two-phase closed-loop flash cooling technique for wafer-scale thermal management is engineered for up to 1 W/mm² heat flux.
- From the experiments conducted, a lowest thermal resistance of 0.115 K/W is achieved without heat spreading.
- Future work will be carried out for an optimal design of the evaporator to achieve a better thermal performance.

Acknowledgement and References

We acknowledge Dr. Ujash Shah, Haoxiang Ren, Nanoscale Transport Research Group and UCLA CHIPS consortium for their support and contributions.

References

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2. Pietrasanta, L., 2018. *Experimental analysis of two-phase flows in the context of Pulsating Heat Pipes for space applications* (Doctoral dissertation, University of Brighton).

2023 UCLA CHIPS Workshop Poster Session