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HEIDELBERG

Cooling of chips and the principle of Heat Pipes

Seminar WS2012/13

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Outline

- Motivation
- Theoretical Principle of Heat Pipes
- Performance/Experiment
- Conclusion

Motivation

Why new cooling techniques are necessary?

Motivation

- Atoms are a fundamental lower bound for increasing CPU performance.
  => parallelism
- One of the main cost and performance drivers for HPC is the node-to-node interconnect.
  => denser systems
  => cooling?

Top500 List - November 2012

R_{max} and R_{peak} values are in TFlops. For more details about other fields, check the TOP500 description.

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	DOE/SC/Oak Ridge National Laboratory United States	**Titan** - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x Cray Inc.	560640	17590.0	27112.5	8209
2	DOE/NNSA/LLNL United States	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom IBM	1572864	16324.8	20132.7	7890
3	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu	705024	10510.0	11280.4	12660
4	DOE/SC/Argonne National Laboratory United States	**Mira** - BlueGene/Q, Power BQC 16C 1.60GHz, Custom IBM	786432	8162.4	10066.3	3945
5	Forschungszentrum Juelich (FZJ) Germany	**JUQUEEN** - BlueGene/Q, Power BQC 16C 1.600GHz, Custom Interconnect IBM	393216	4141.2	5033.2	1970
6	Leibniz Rechenzentrum Germany	**SuperMUC** - iDataPlex DX360M4, Xeon E5-2680 8C 2.70GHz, Infiniband FDR IBM	147456	2897.0	3185.1	3423

560640

8209

Motivation

„Intel believes that high-density data centers are the most efficient and that the major cost of any cooling system is the central plant – for both capital and expense costs.“

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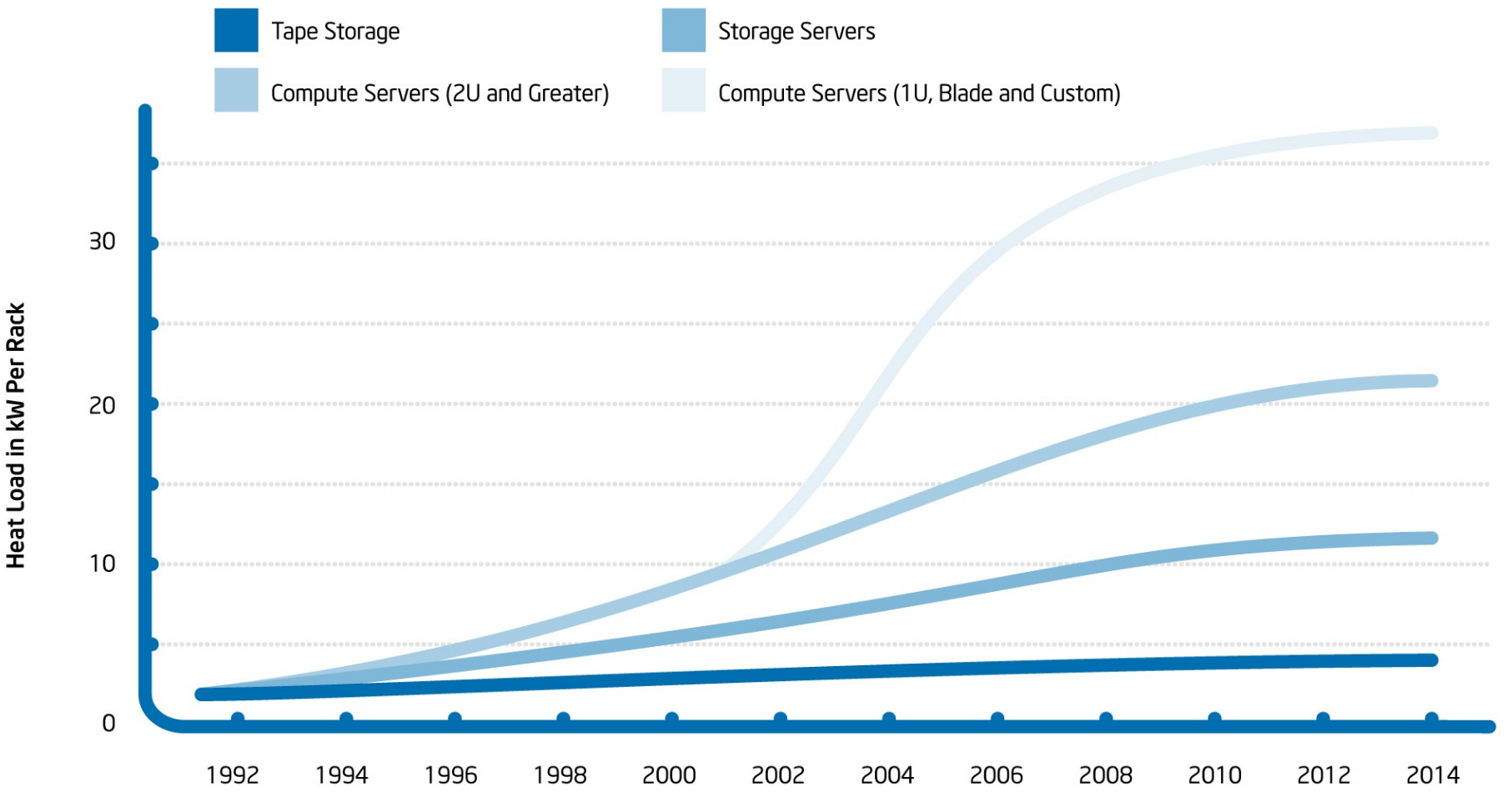
NMSC, hosted by Intel in Rio Rancho, NM

Motivation



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Principles of Heat transfer

- Heat transfer is classified into various mechanisms:

1. Thermal radiation
2. Convective heat transfer
3. Thermal conduction

Air Cooling

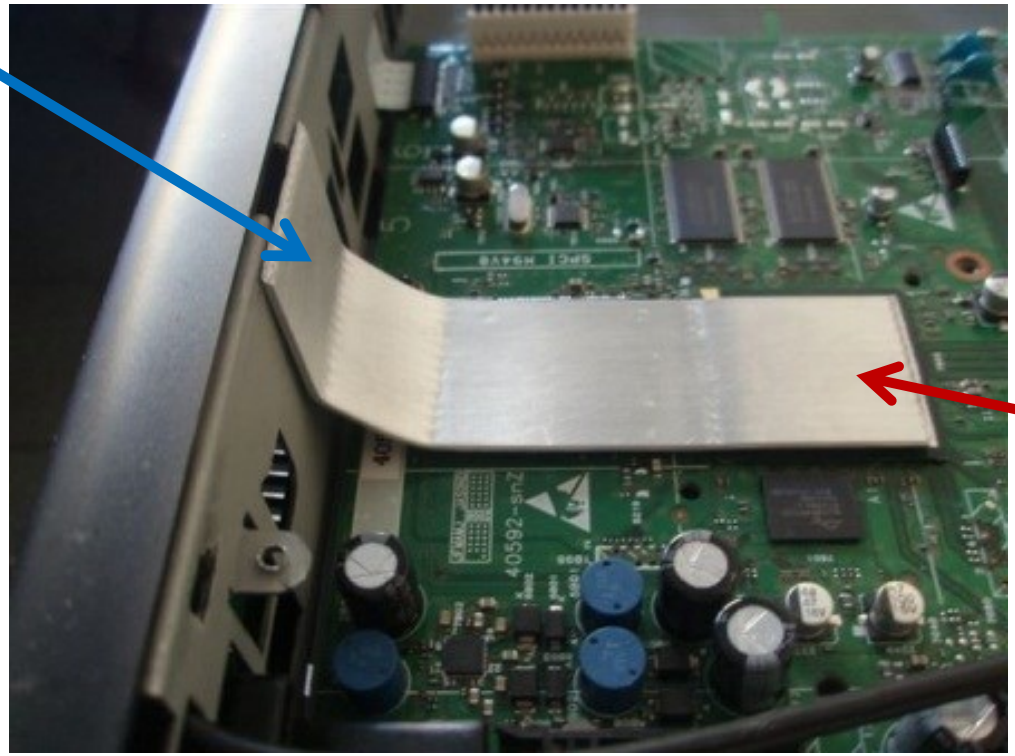
- Today: racks of 30 kW can be air-cooled
- Design of a data center set a practical upper bound on the air cooling
- Bad thermal attributes of air
  - High heat resistancy
  - Low heat capacity
- Additonal power supply for fans
  - More power
  - Mechanical elements

Liquid Cooling

- High heat capacity and lower heat resistance
- Lower noise levels
- Pumps necessary
- Elements difficult to change
- Leaked water can damage any electronic components

Heat Pipes

Cooling plate

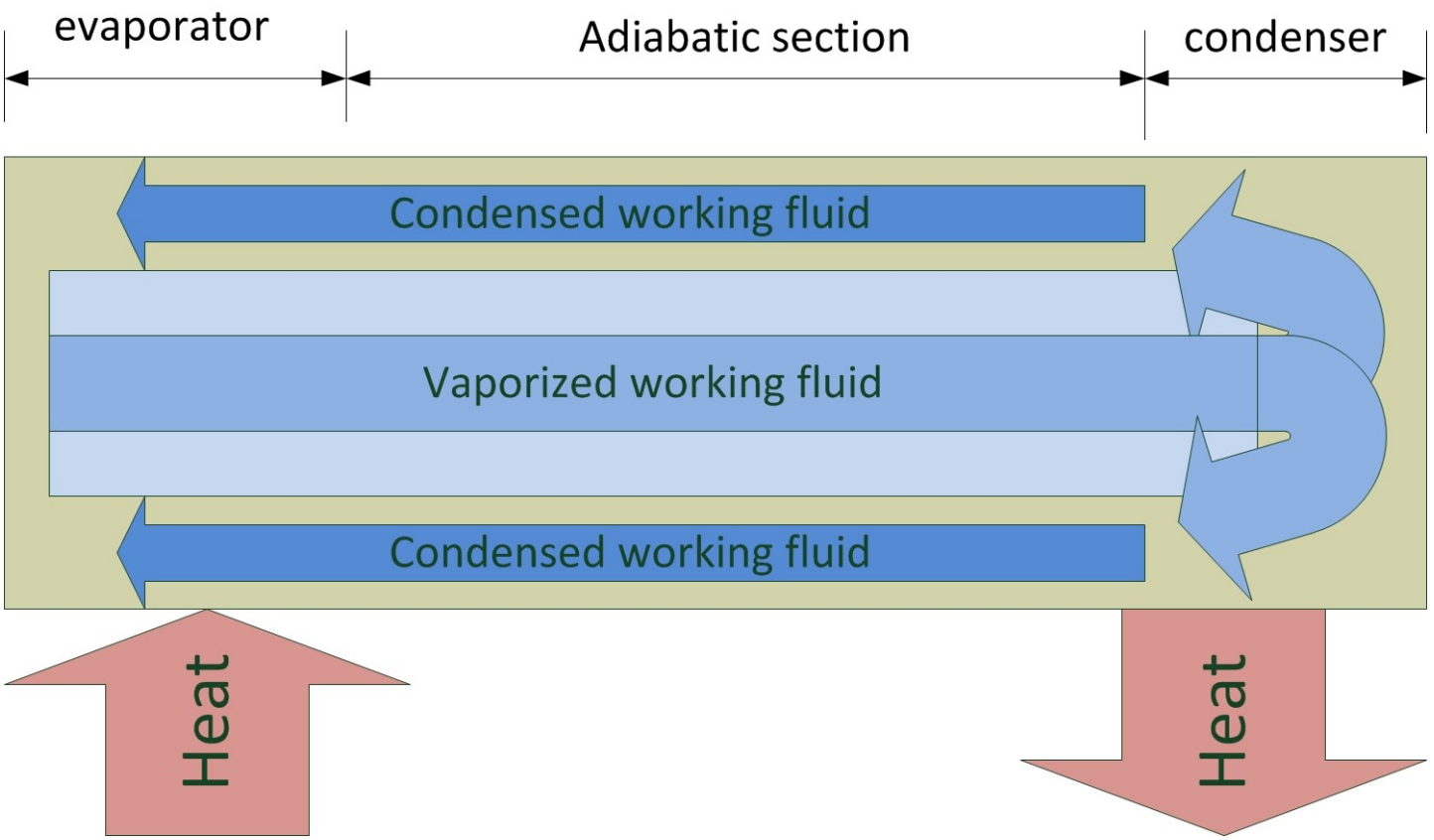


Heat source

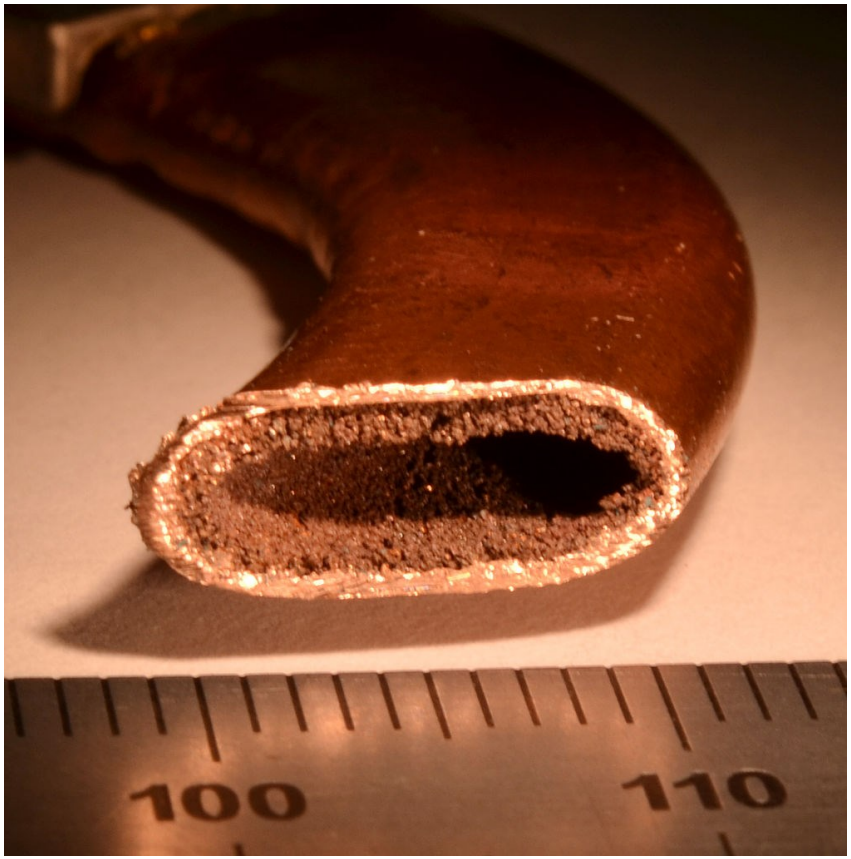
Theoretical Principle of Heat Pipes

How does a heat pipe work?

Theoretical Principle of Heat Pipes

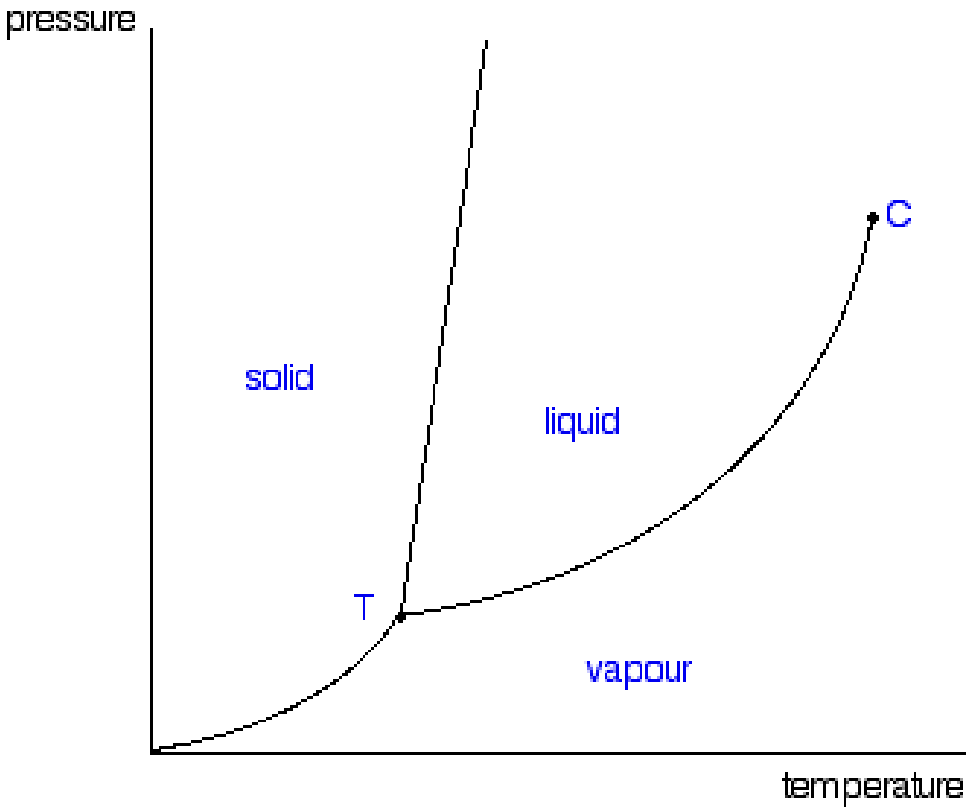


Theoretical Principle of Heat Pipes



Theoretical Principle of Heat Pipes

- phase transitions depend on pressure and temperture



Basics

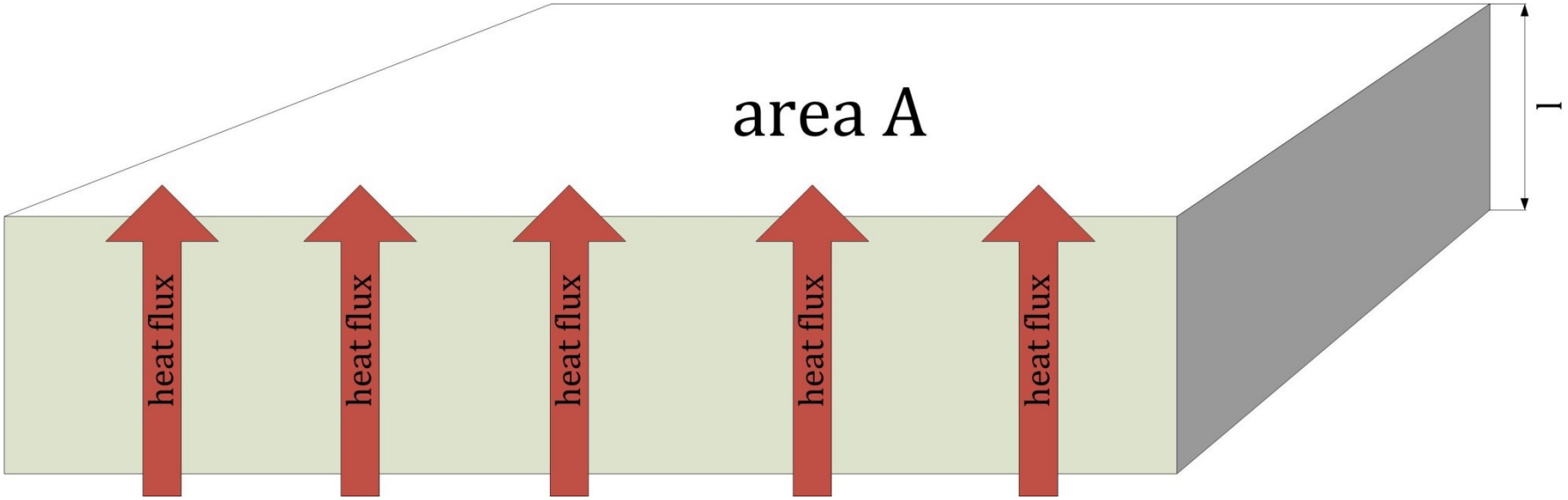
- Thermal conduction is similar to electric circuits:

Current I	Heat flux $\dot{Q}$
Voltage U	Temperature difference ΔT
Resistance R	Heat-resistance R

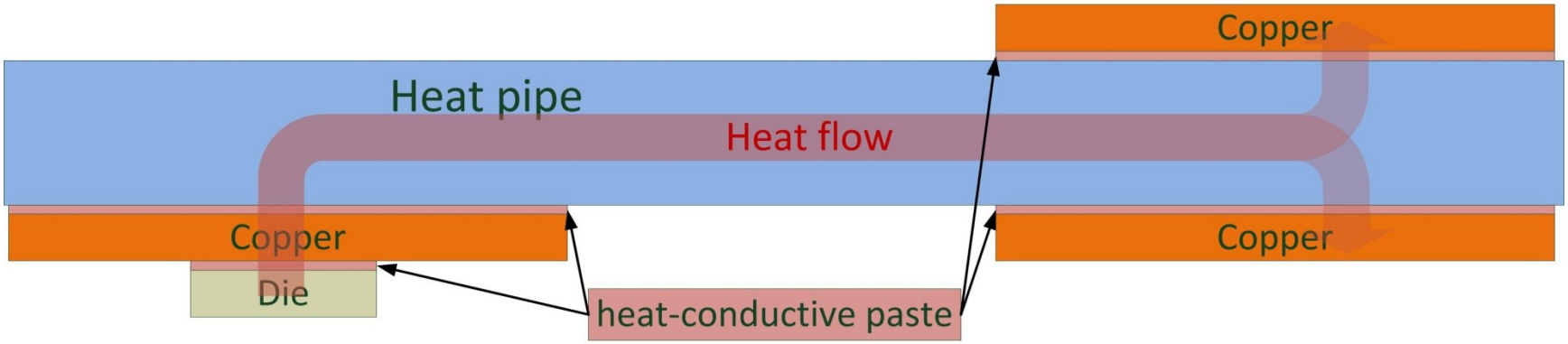
- Serial resistances: $R_{col} = R_1 + R_2 + \cdots$
- Parallel resistances: $\frac{1}{R_{col}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

Basics

- Heat flux: $\dot{Q} = \frac{R}{\Delta T}$
- Heat resistance $R = \frac{l}{\lambda \cdot A}$, λ: Thermal conductivity

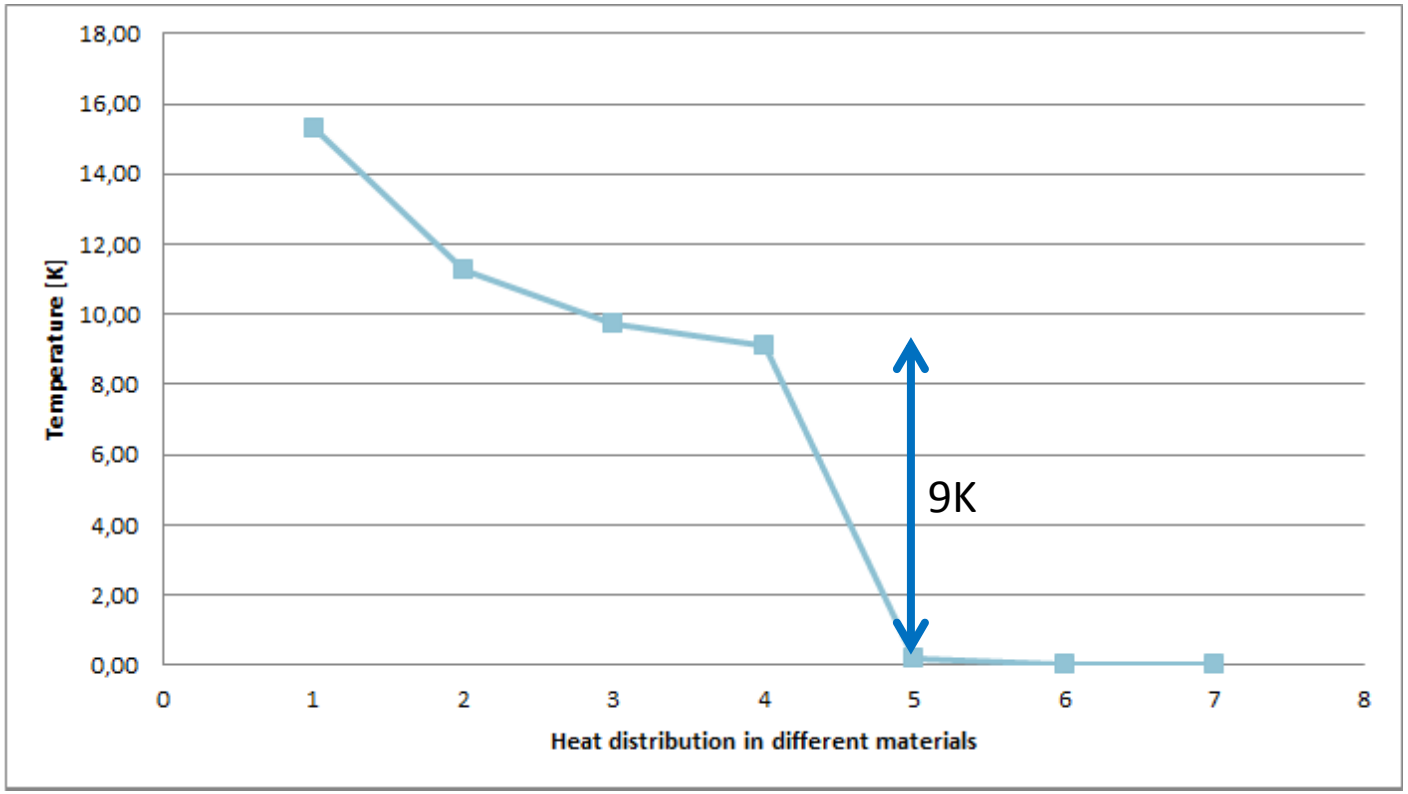


Theoretical setup



Basics

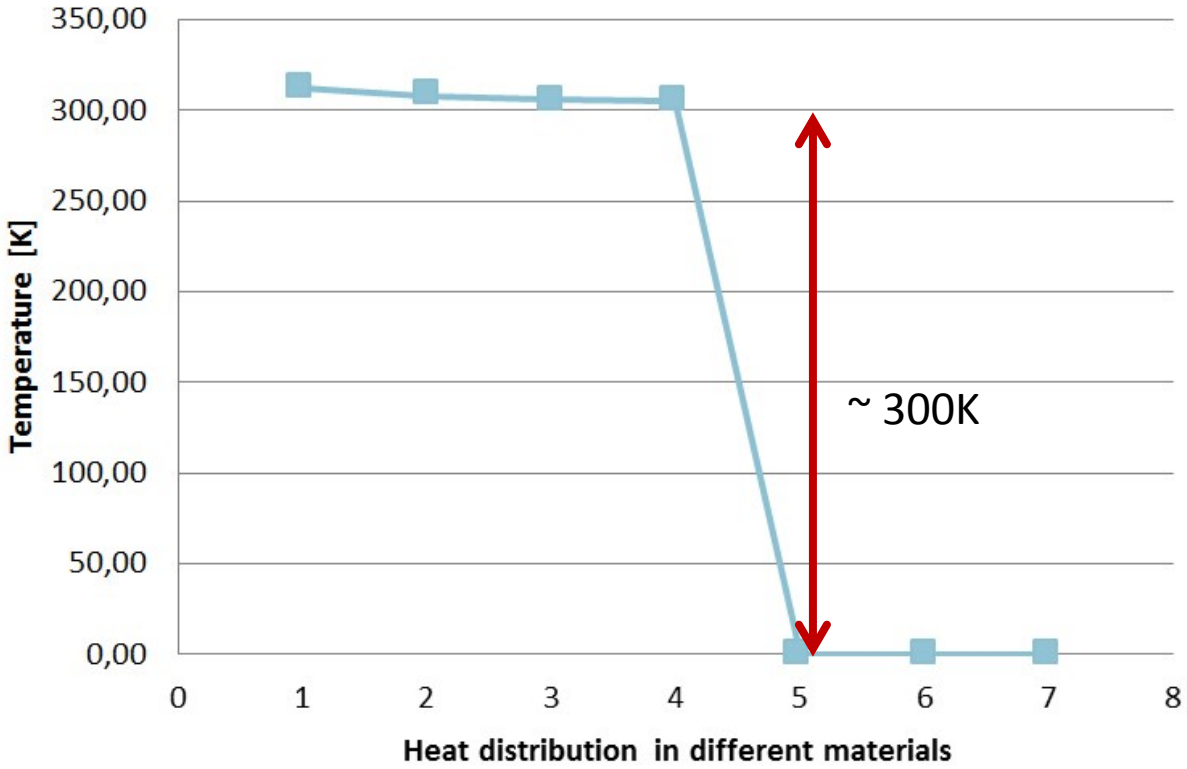
Heat reduction over all parts of the heat-transport-chain (heat pipe)



1) Chip; 2, 4, 6) Heat-conductive paste; 3, 7) Copper; 5) Heat pipe

Basics

Heat reduction over all parts of the heat-transport-chain (Copper)



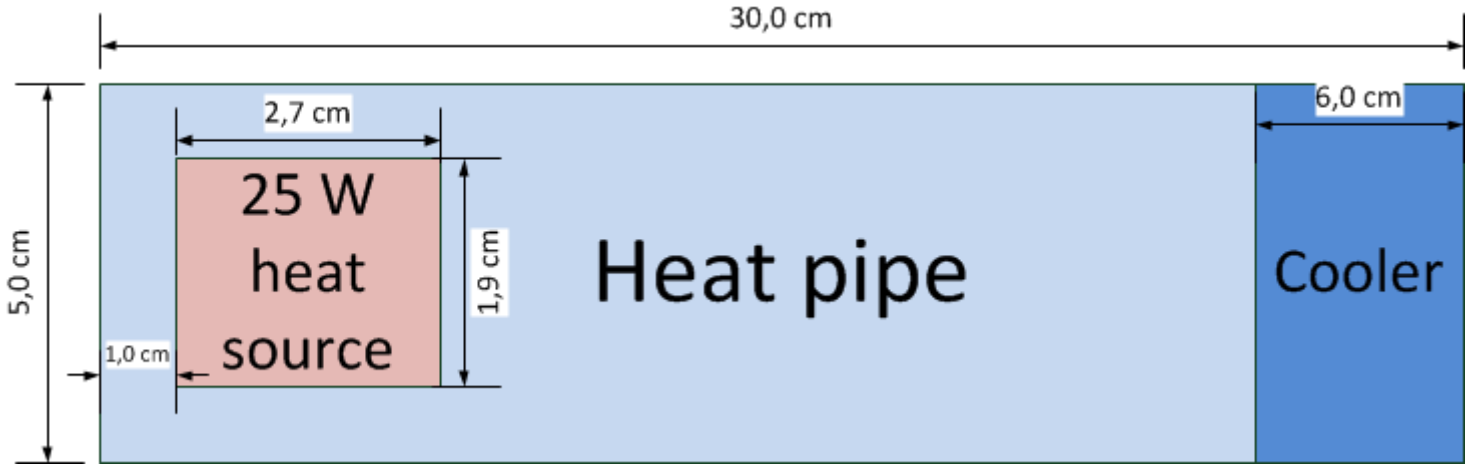
1) Chip; 2, 4, 6) Heat-conductive paste; 3, 5, 7) Copper

Performance

Do they keep what they promise?

Theoretical Performance

Experimental settings



Theoretical Performance

Material	Length [cm]	Heat resistance [K/W]
Heat-conductive paste 1	0.05	0.167
Heat pipe	29	0.2
Heat-conductive paste 2	0.05	0.033

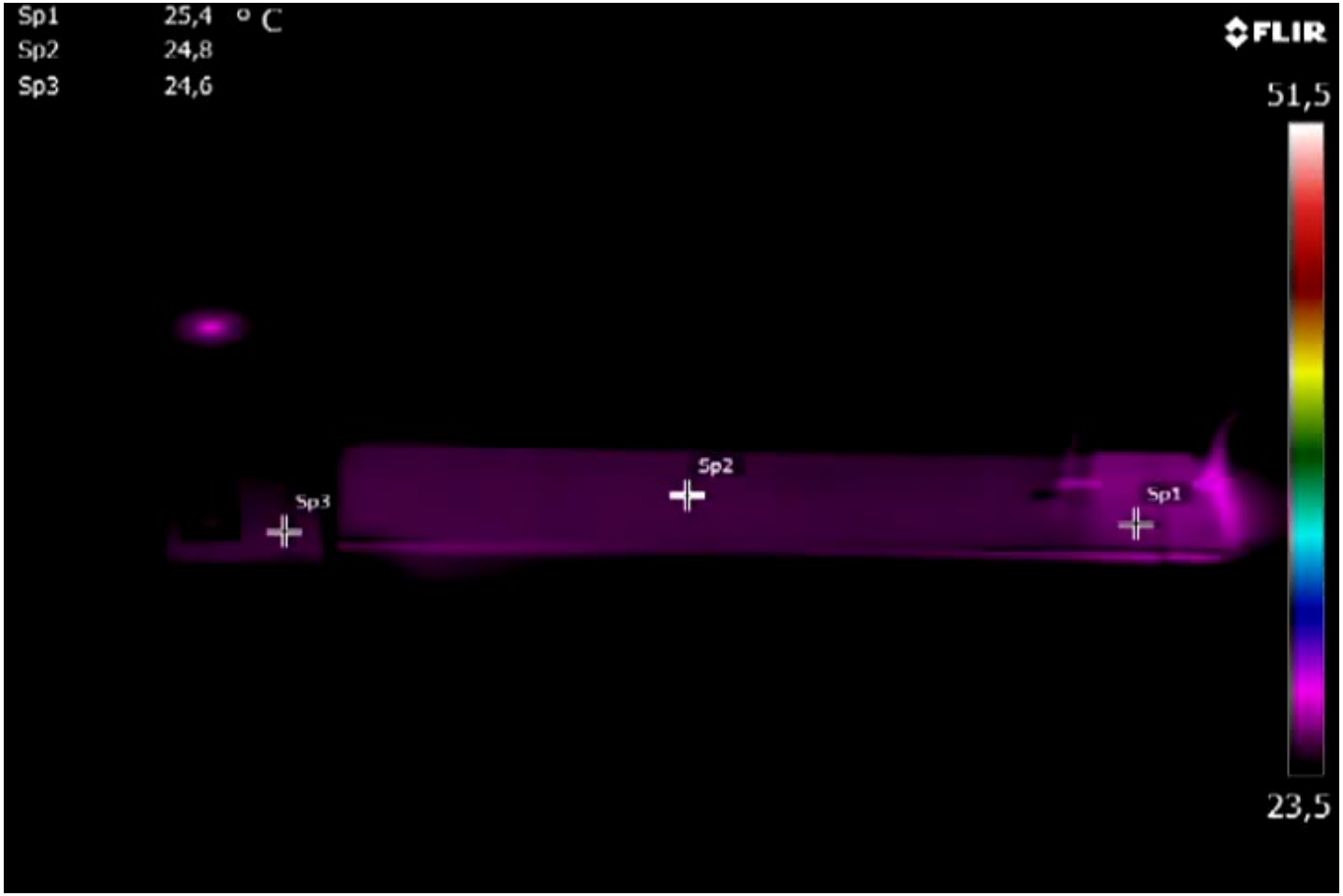
- Heat resistance: $R_{col} = \sum_i R_i = 0{,}4003 \ \frac{K}{W}$
- Relative temperature difference: $\Delta T = \ \dot{Q} \cdot R_{col} = 10{,}01 \ K$

Performance

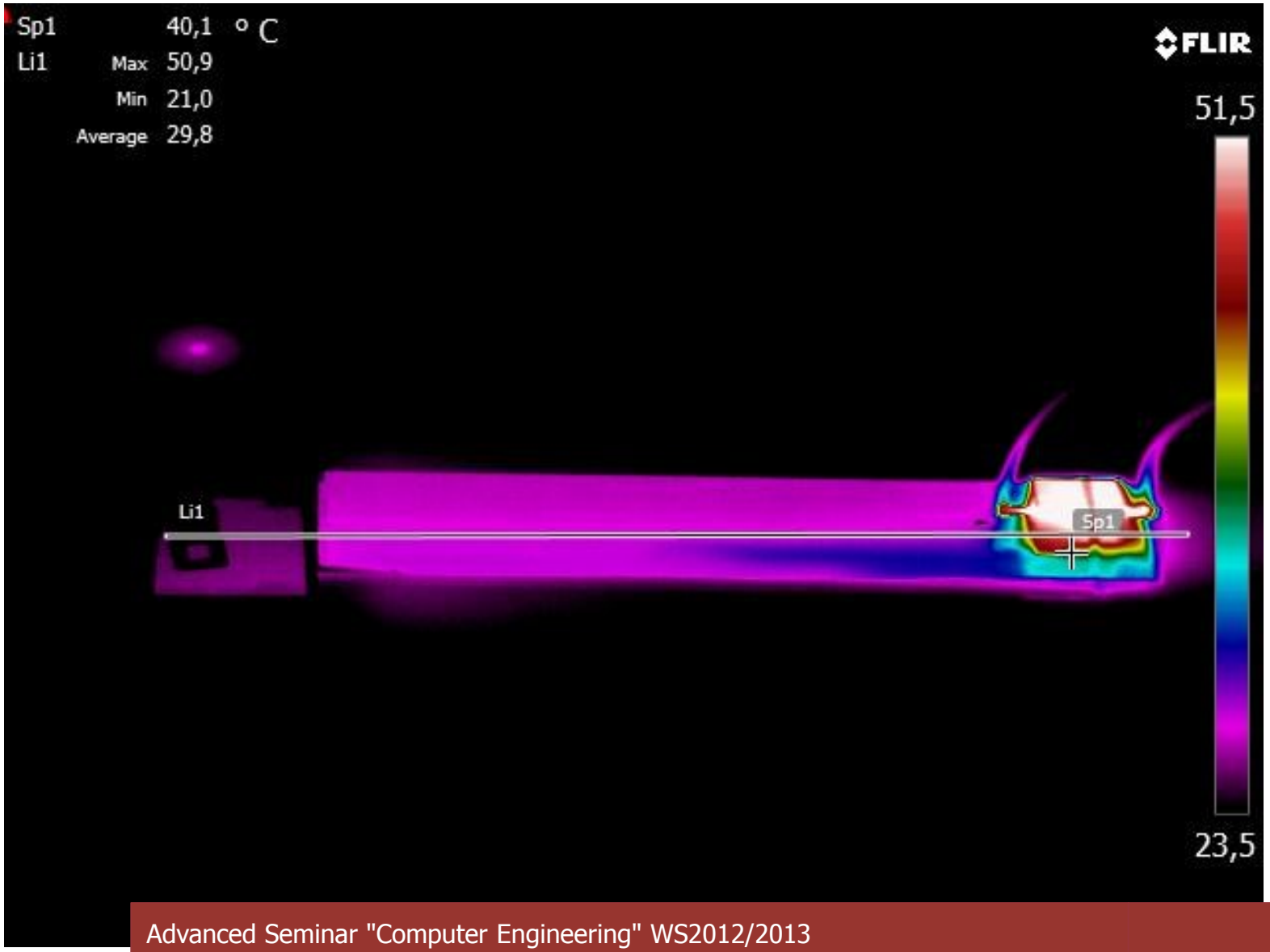
- Amec Thermasol‘s Flat Cool Pipe

Item		Description
Material of Container		Aluminium 1050
Working Fluid		Acetone
Q_{max}	Horizontal	75.0 W (at 50°C)
	Vertical	270.0 W (at 50°C)
Typical Thermal Resistance		<0.2°C / W (Average)
Operating Inclination, Ø		0 ~ 90°
Leak Temperature Criterion		-40~100°C

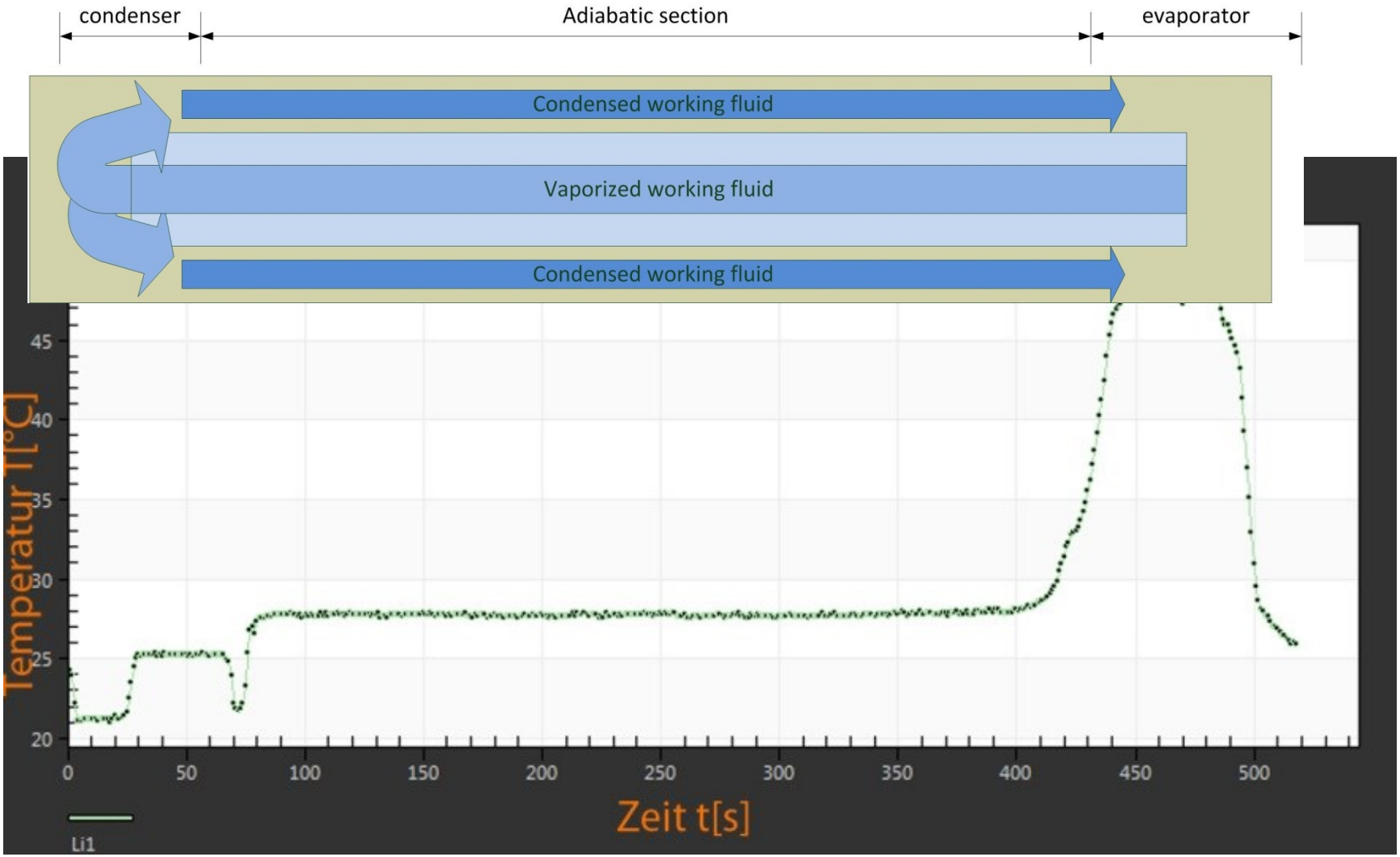
Performance



Performance



Performance



Performance

- Theoretical: $\Delta T = 10{,}01K$
- Experimental: $\Delta T \approx 15\ K$
- Causes of difference:
  - Thicker heat-conductive paste
  - Inappropriate geometry of heat source

Conclucions

Conclusions

- High-density supercomputer are reasonable due to high cost of node-to-node interconnects.
- Heat pipes are qualified for thermal conduction in supercomputer.
- ~1000x higher heat flux than an equal sized copper block.
- Heat flows through pins into the PCBs.
  =>additional cooling is necessary

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Thank you for your attention!