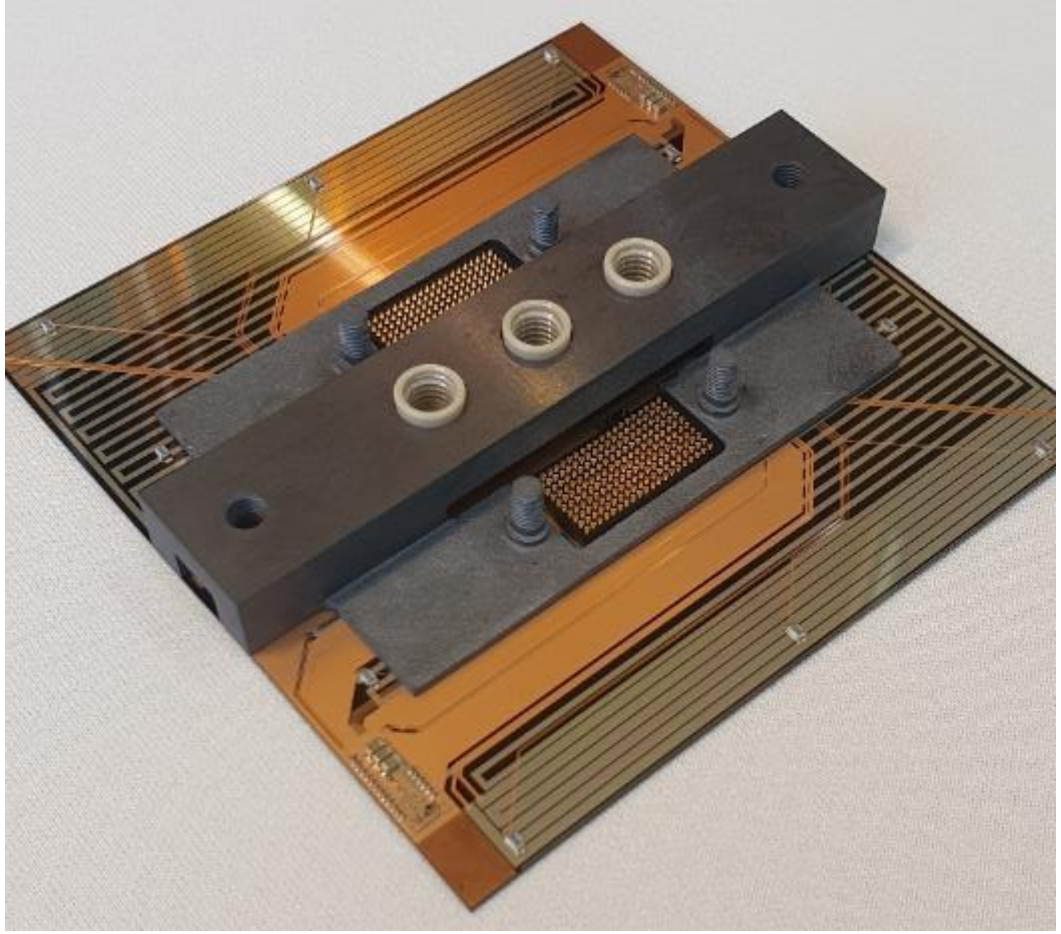
Proof of Concept:
Single-Phase SOI-Based Microchannel Coolers (MCC) for large Semiconductor Detector Cooling

A Compact, Efficient Alternative.

Speaker: Sebastian Stadler

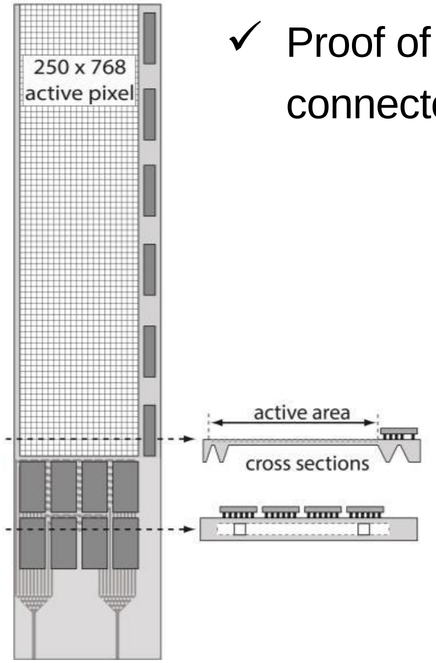
MAX PLANCK
SEMICONDUCTOR
LABORATORY

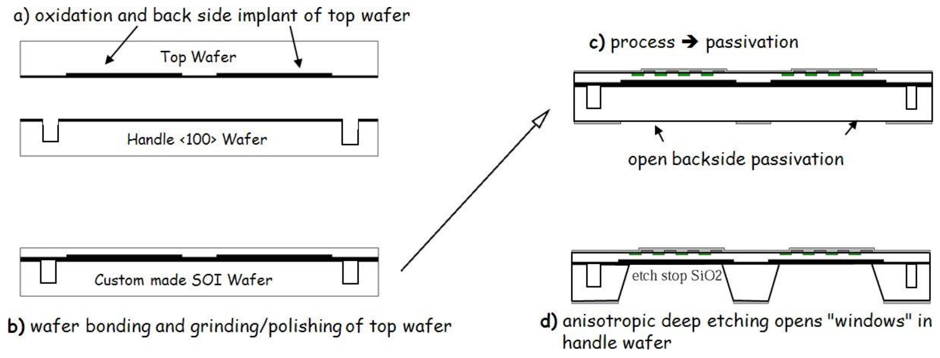


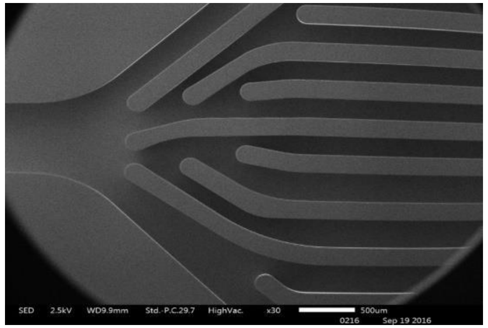
INTRODUCTION

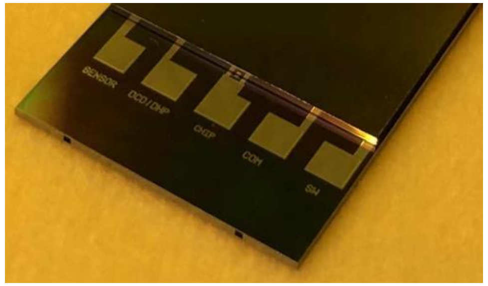
Starting point

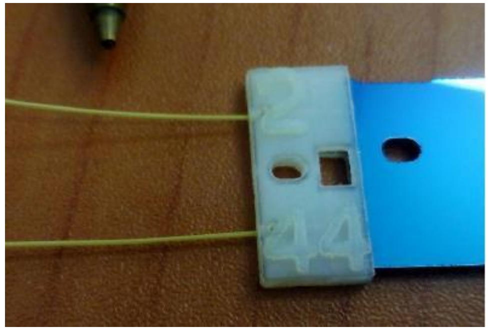
- **A spin-off from Belle II: thinned all-silicon module with integrated cooling**
  - full processing on C-SOI, thinning of sensitive area
  - micro-channels accessible only after cutting
  - AIDA2020: Small team within Belle II DEPFET PXD: Bonn, HLL, IFIC
    - ✓ Proof of principle with thermal samples, incl. flip chip and hydraulic connectors

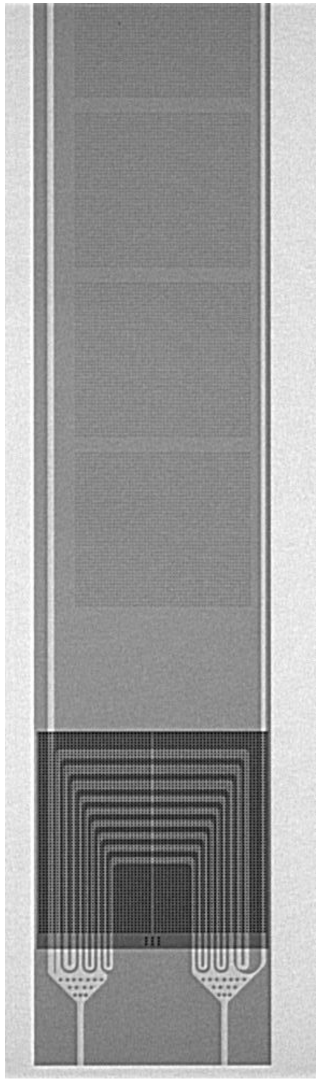












INTRODUCTION

Challenges, Motivation, Goals

- **General Development Direction**

  ↓ Cooling cycles and mass
  - better CTE, (less big copper blocks)

  ↑ Big field of view
  - True tile -> modular system
    -> and Big FOV possible

  ↑ el. Integration
  - ASICs and SMDs on the back

  ↓ Overall size (with peripheral components:
  cooling, SBC ..)

  ↑ Cooling homogeneity
  - Flexible target cooling depending on application and power dissipation

  ↓ Complexity, ↑ Reliability, ↑ Applicability

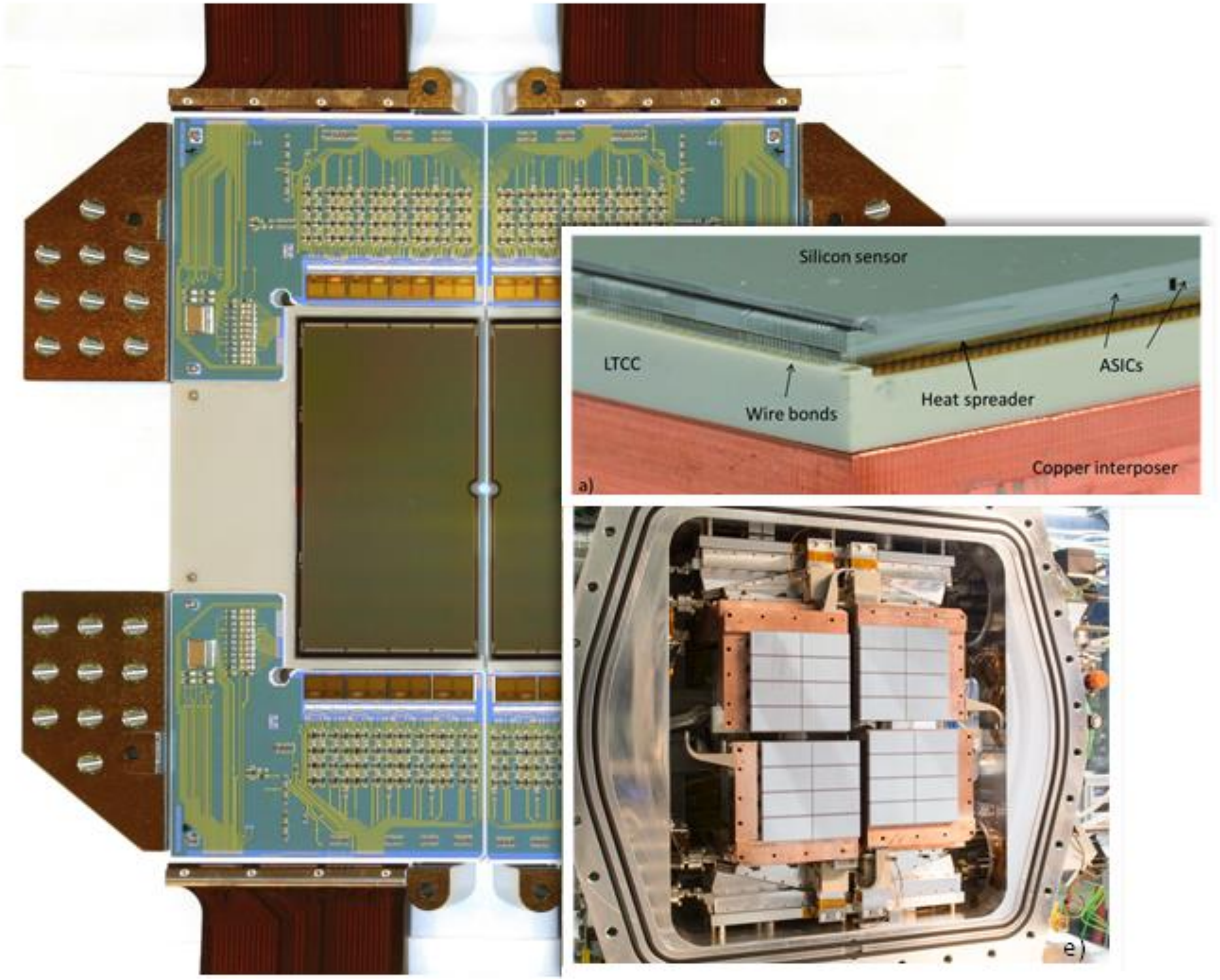
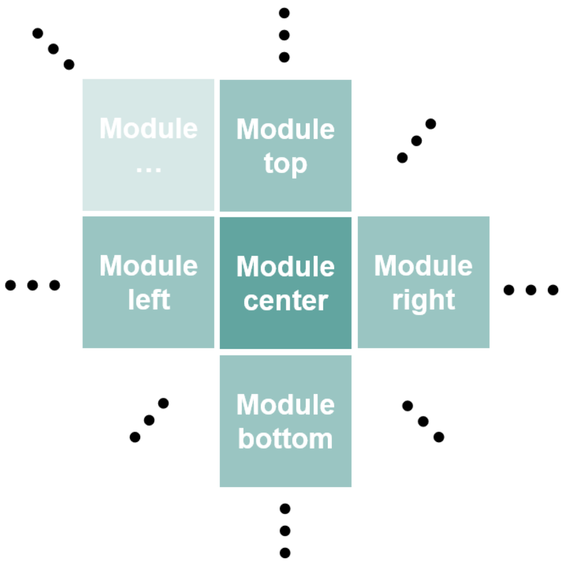


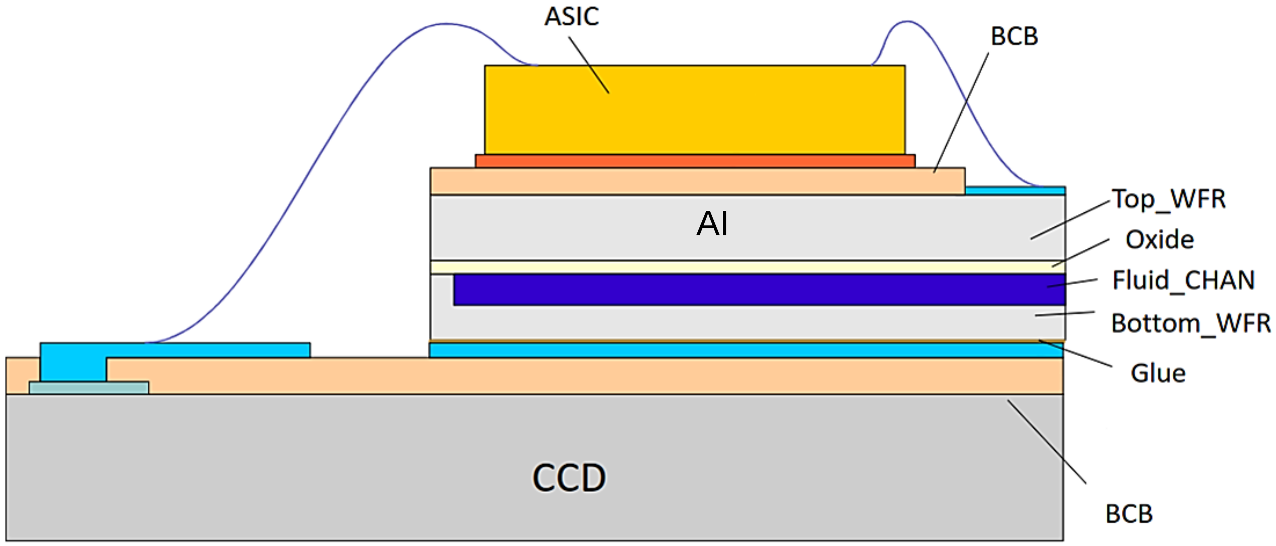
Figure: *Example of large detector (state-of-the-art synchrotron radiation detector (CAMP / LAMP) and X-FEL spectroscope from: https://www.mpg.de/forschung/roentgen-freie-elektronen-laser*

INTRODUCTION

Objectives

- **Active Interposer (AI):**
  - All silicon interposer based on SOI-Wafer:
    - Carrier for ASICs (readout) and passives
    - Carrier for peripheral connector
    - Substrate for power / signal trace system
    - Container for SOI based MCC
    - MCC connection perpendicular to surface
- **Benefits:**
  - Separated from sensor substrate
  - Interface to support mechanics
  - „PCB“ on the backside of CCD
  - Optimum CTE match to sensor (e.g. pnCCD)
  - Convectional single phase cooling

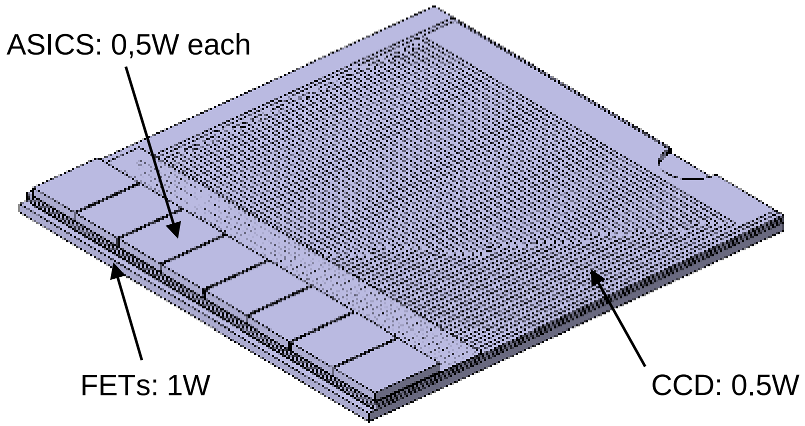




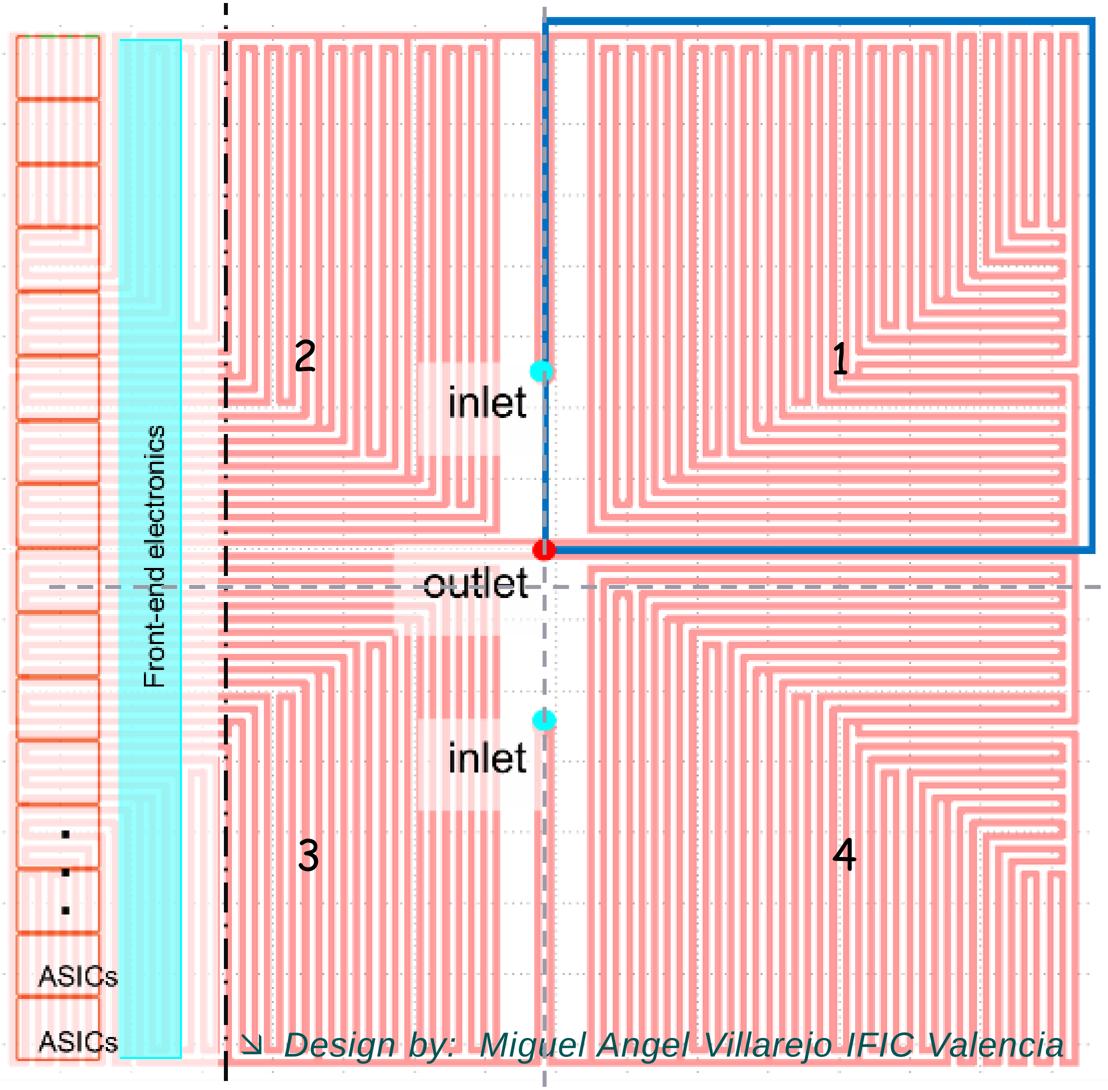
EXAMPLE ACTIVE INTERPOSER (AI) FOR LARGE CCD

Concept and Design

- **MCC design:**
  - Large area (~ 8 x 8 cm2)
  - 4 quadrants, 2 inlets, 1 central outlet
  - Locations of elevated power dissipation are considered
    - and targeted by a thorough channel network design



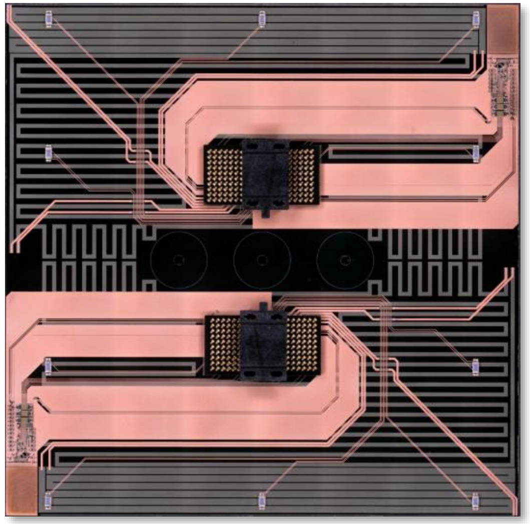
1 Quarter, Expected power dissipation = 5.5W



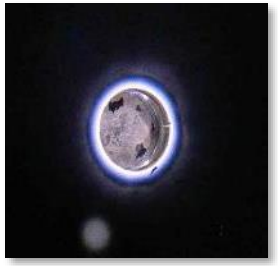
↘ *Design by: Miguel Angel Villarejo IFIC Valencia*

TEST-DEVICE (TEST-AI)

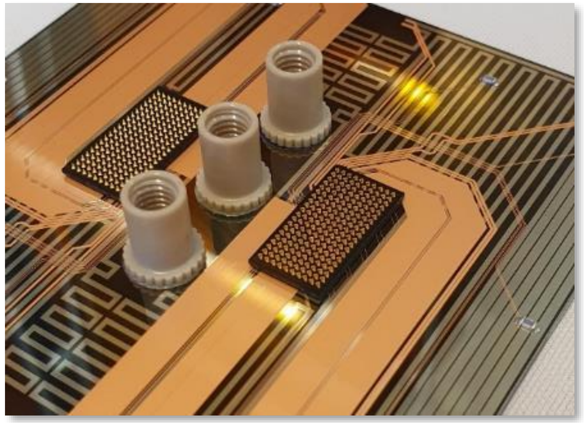
Assembly and components



Electrical
Assembly

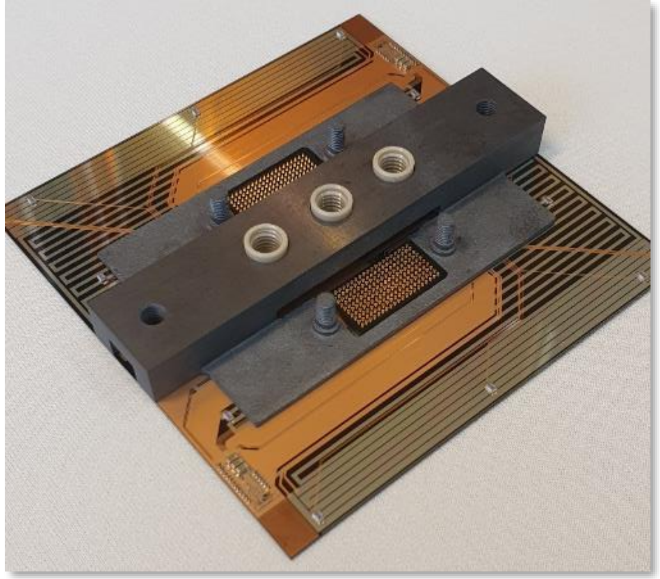


Inlets/outlet open
By Laser drilling

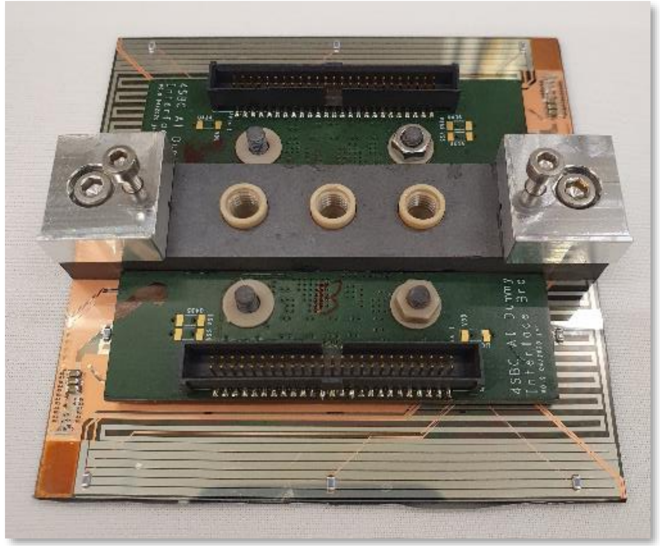


NanoPorts
glued on

Bracket
glued on



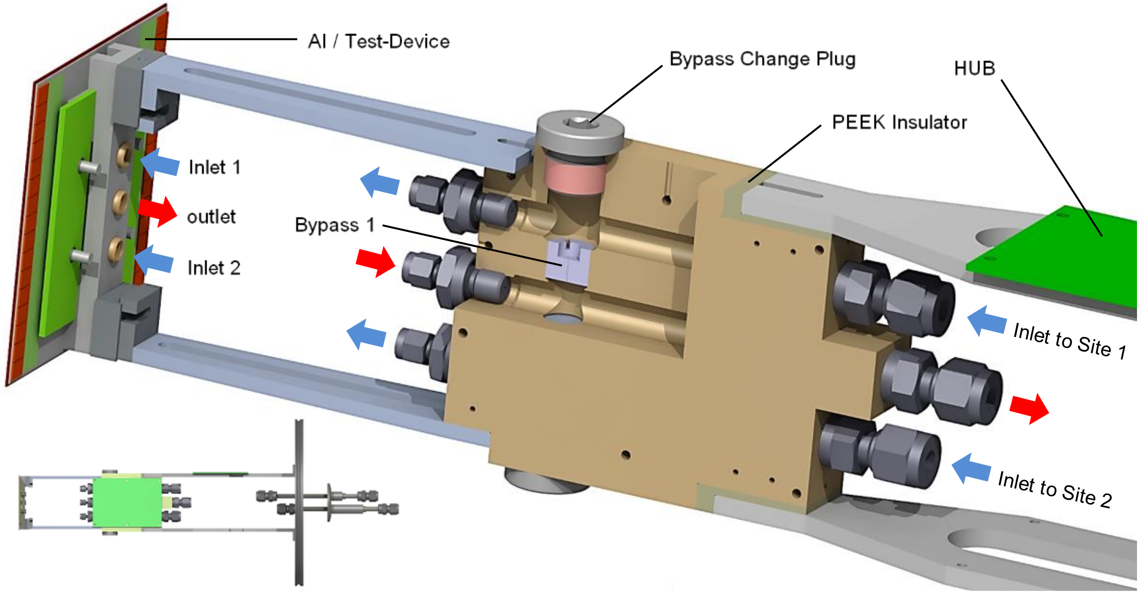
Interface PCB
and Bracket connectors
assembled

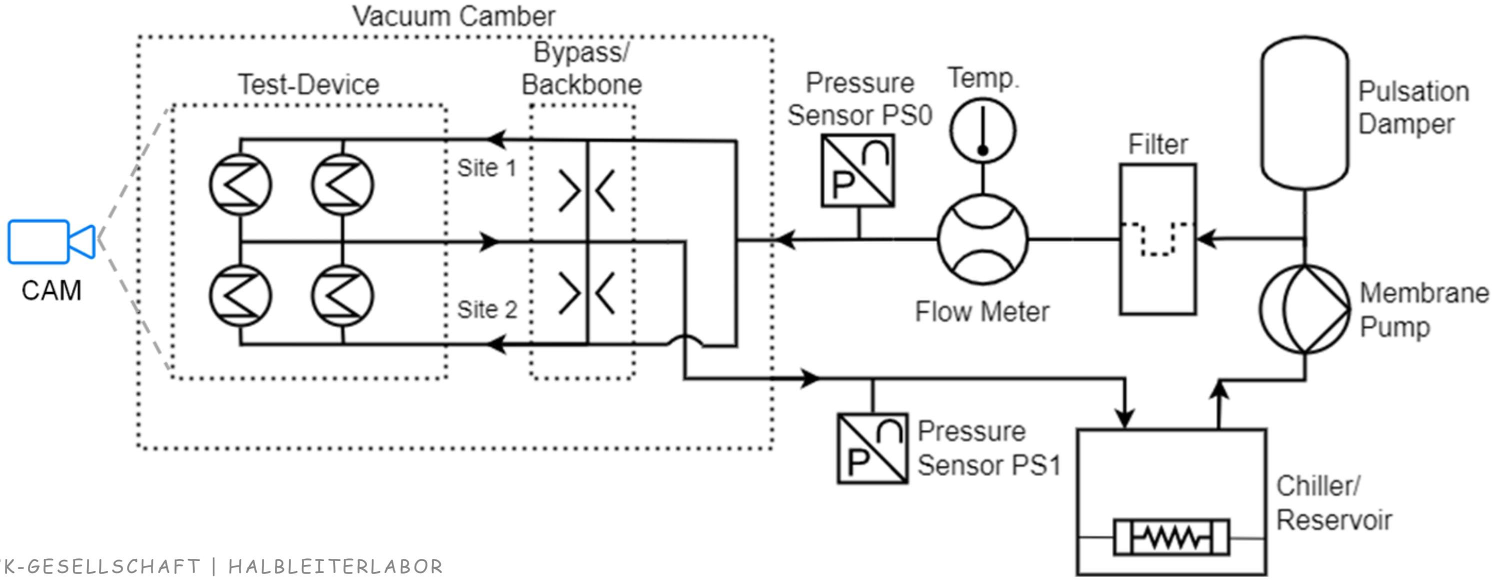


TEST BENCH

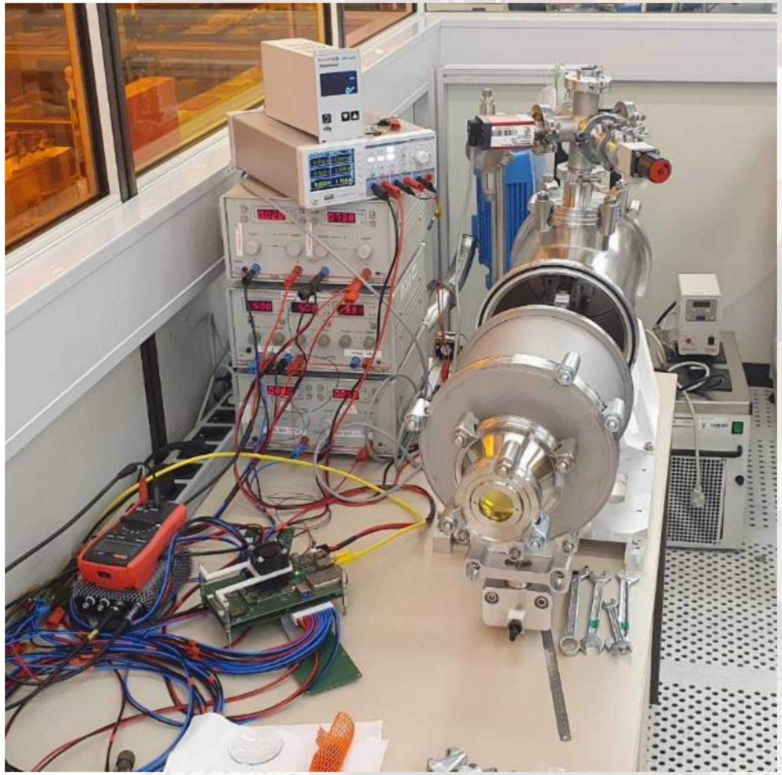
Cooling Circuit

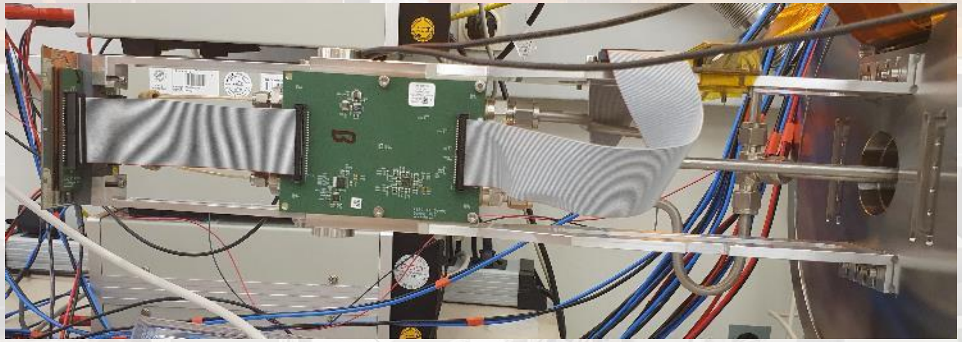
- Coolant: Galden H80 (PFPE)
- Max pressure: ~30bar
- Max pump flow: 1,7 l/min
- Lowest Temperature -50°C

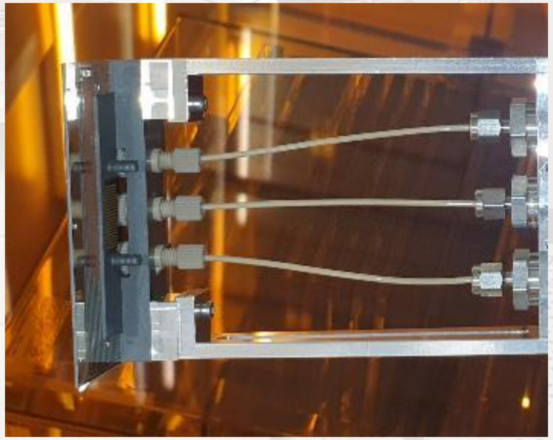


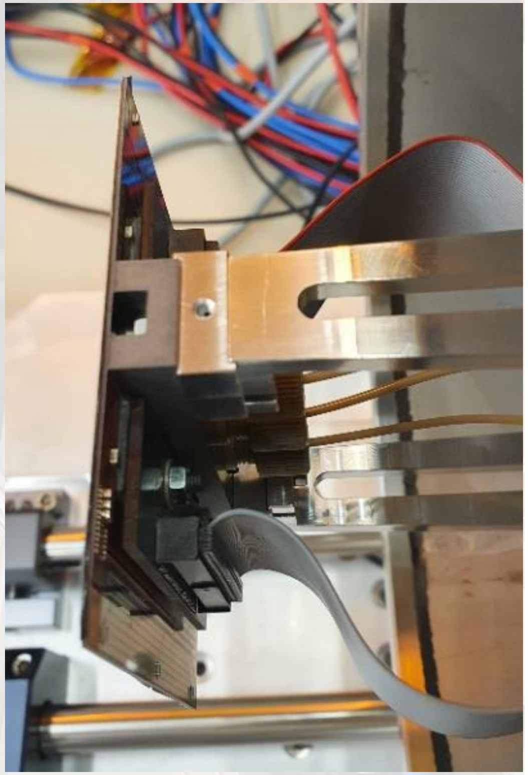


TEST BENCH







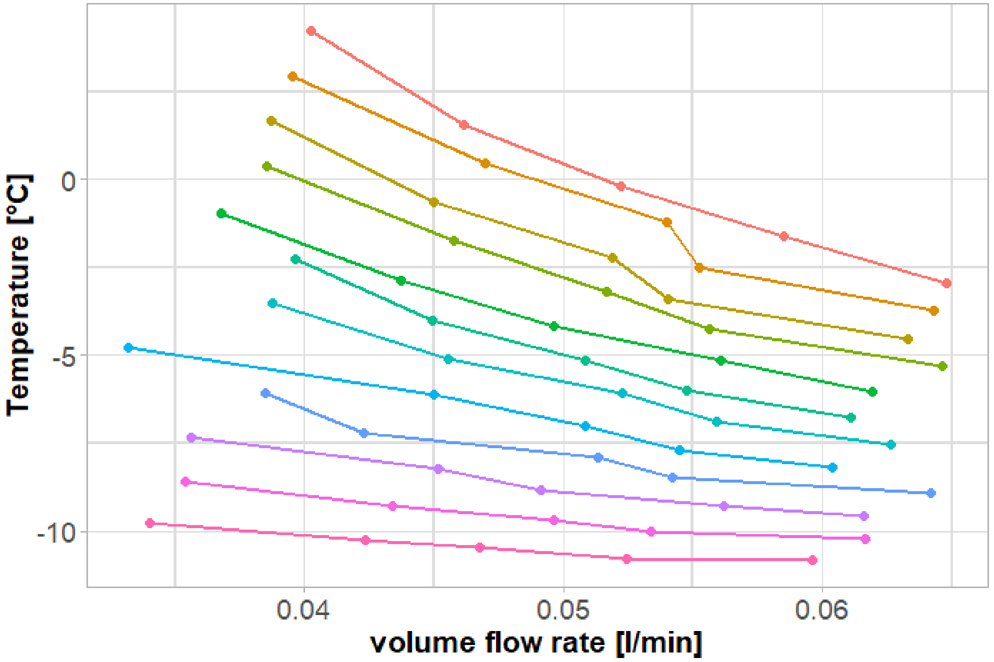


PRELIMINARY RESULTS

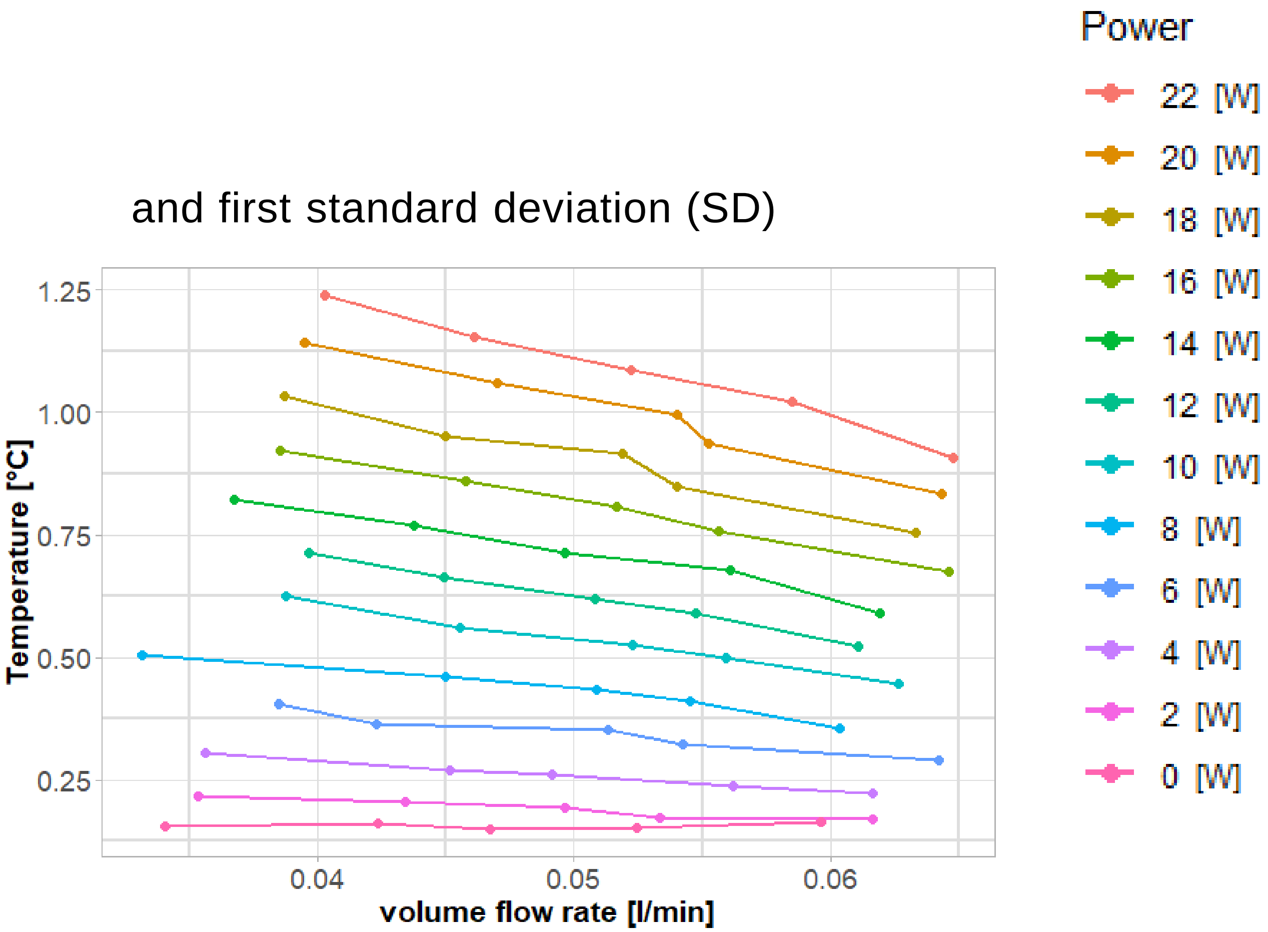
av. Temperature at Test-Device vs flow rate

- 12 different Power outputs per stroke
- And av. of 100 Measurements per point
- At a fixed inlet temperature of -16°C

Temperature over all PT1000



and first standard deviation (SD)

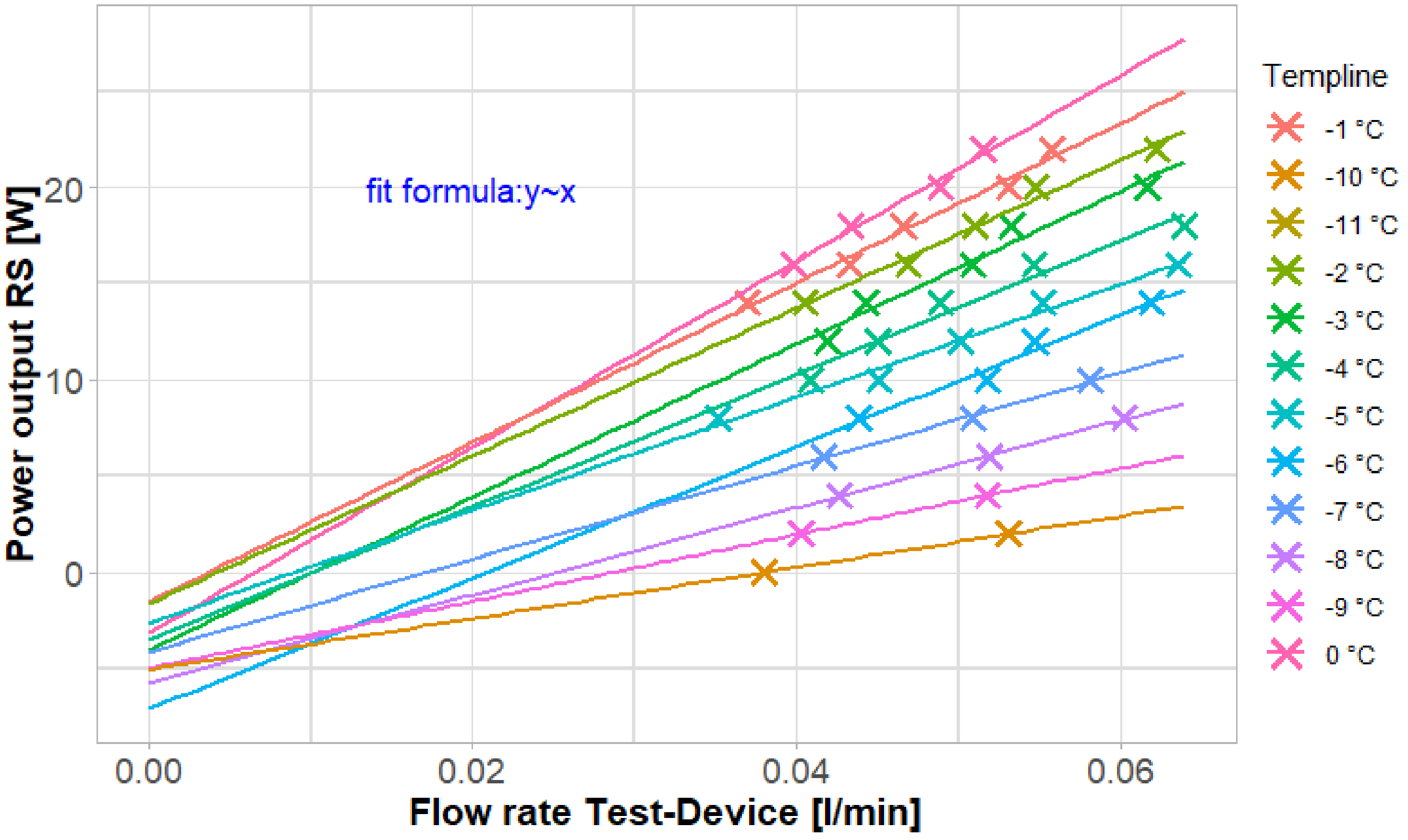


PRELIMINARY RESULTS

Heat removal at given flow rate and const. temperature

- 8 W/l/h heat removal at 0°C constant device temperature
- 2.5 W/l/h heat removal at -10°C constant device temperature

- Additional heat input of -7W to -2W by radiation and conduction

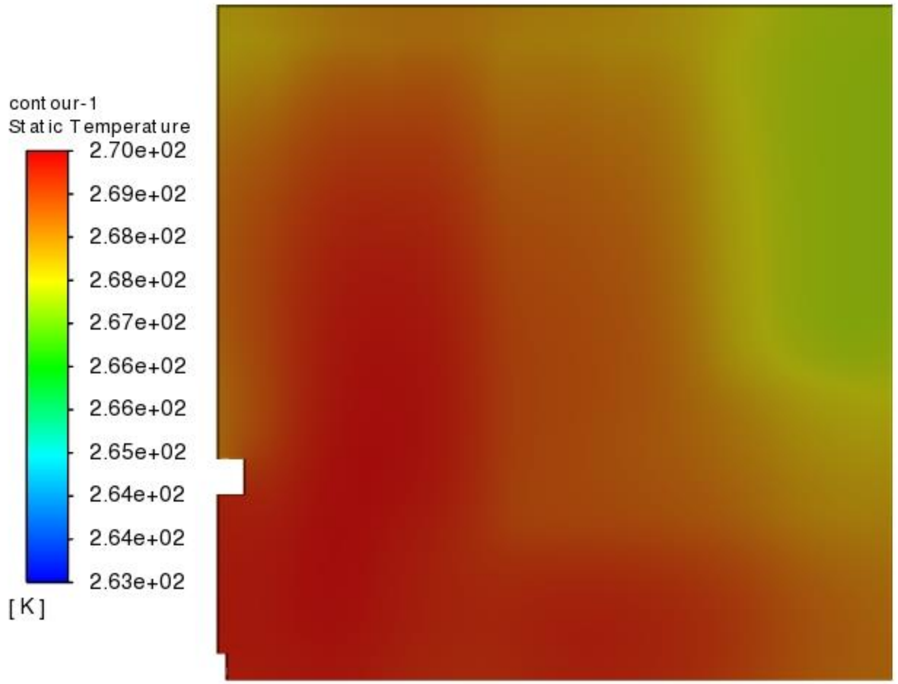


PRELIMINARY RESULTS

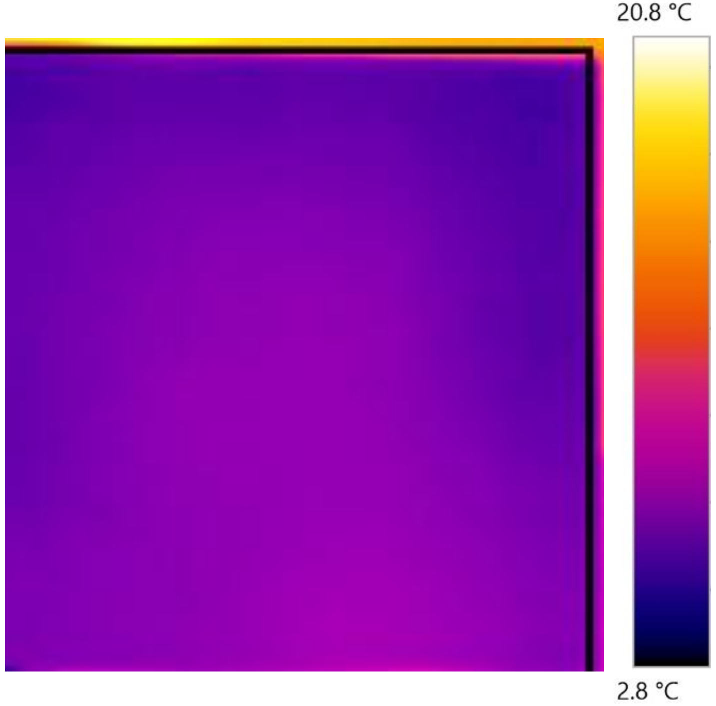
Comparison to Simulations

- **Results**
  - Lower pressure drop of 4.1 bar (vs 5.4 bar [measured])
  - Av Temp is -3.5°C (vs -2.5°C [measured])
  - Temperature field is comparable
  - Temperature range similar by ~2°C
  - ❖ *Only CCD heater lines were functional*

Simulation results



Measurement

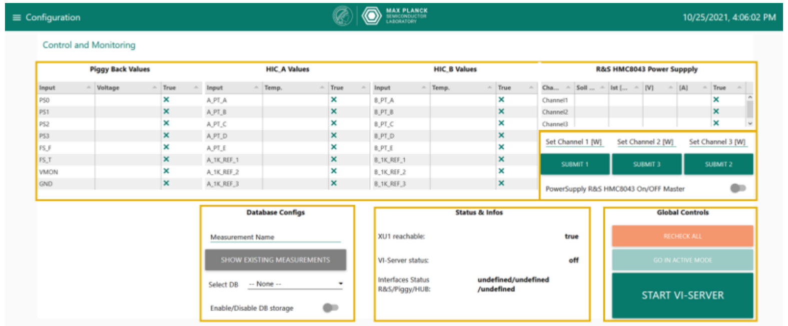


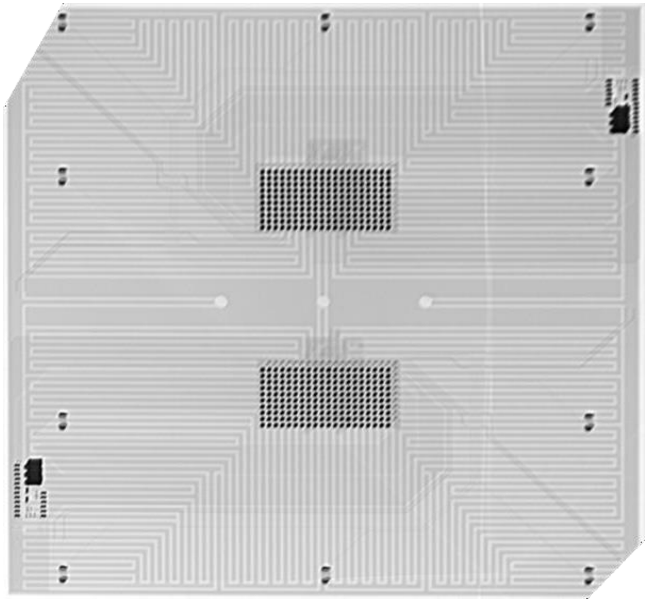
SUMMARY

Wrap it up

- **Experimental setup**
  - Test lasting 2 days without problems
  - Less than 5°C increase from chiller to inlet chamber
  - >0.2l/min for decent fluid circulation
  - Tools, script and web UI for in depth analysis and long term measurements are available

- **Test-Device**
  - No breakage and leakage at high pressure (~6.5 bar)
  - Good thermal homogeneity ~2°C
  - Issues Z-Ray interposer <-> PCB-interface





OUTLOOK

Stay tuned

- **Short term**
  - Long term test ink. Automated cooling cycles and more…
  - Experiments at low temperature approx. -50°C
  - Direct monitoring of flow rate at Test-Device
  - ➢ Experiments with fully functional device (inc. CCD/ASICs/electronics)
- **Long term**
  - Optimized MCC design -> reducing resistances e.g. of inlet/outlet
  - Optimization of the supply system by e.g. Peltier-Element
  - Supply system for up to 9 modules.

THANK YOU FOR YOUR INTEREST

Thesis to this work:

https://opus4.kobv.de/opus4-hm/frontdoor/index/index/docId/406