Centro Nacional de Microelectrónica CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

# Micro-channel cooling for experimental Particle Physics at CNM

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# Scope

- Framework
- Technology and prototypes
- Design
- Simulation
- Tests
- Summary

# Framework

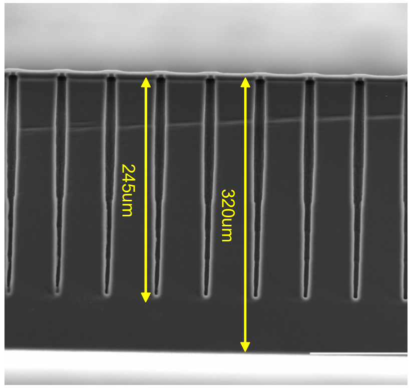
- In current HEP experiment there is a need to keep detectors at low temperature
  - ➢ Leakage current increase with temperature and irradiation
    - ⇒ Power needs → partial depletion → inefficiency
    - ⇒ Thermal runaway
  - ➢ -10 ºC to -30 ºC
- Different solutions
  - ➢ Air cooling
  - ➢ Liquid cooling
  - ➢ Bi-phase cooling
- Complex setups at module level
  - ➢ Technology limits for pipe reduction and coverage
  - ➢ Thermal connection with sensors and electronics
  - ➢ Complex assembly

# Micro-channel cooling

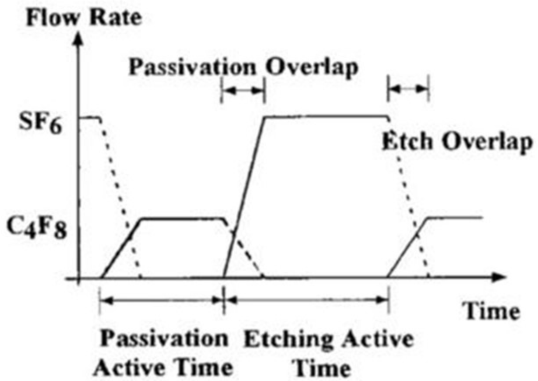
- In Electronics:
  - Scaling
  - High power (heat) densities
  - Thermal efficiency
- In HEP
  - Save material (radiation length)
  - Many thermal cicles + position resolution → small (no) CTE mismatch
  - Large areas to refrigerate (low heat density)
  - Thermal Uniformity → Non-uniform heat removal – “capilars”
  - Assembly
- At CNM
  - Microchannels basic technology development and prototyping
  - DRIE and wafer bonding capabilities
  - In collaboration with DESY (Hamburg) for tests

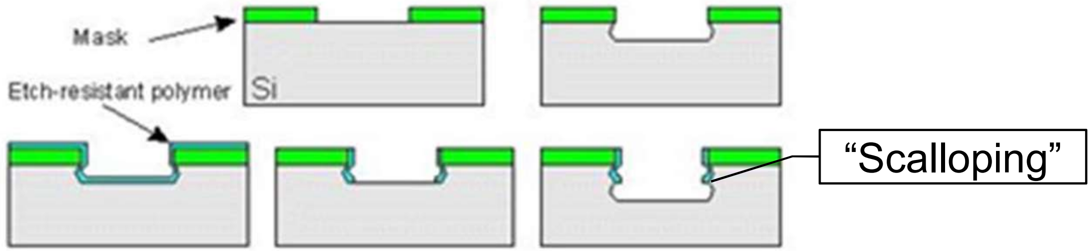
# Technology: micro-channels

## Creation of micro-channels



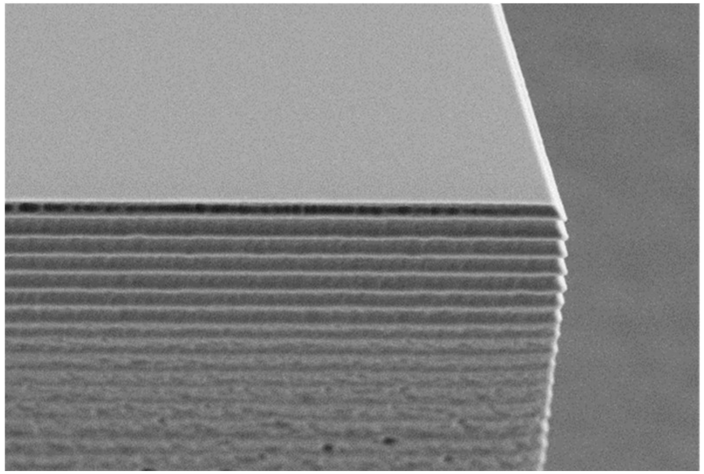

- Deep Reactive-Ion Etching (DRIE)
  - Chemical-Physical etch of silicon
  - Very anisotropic → high aspect ratio (deep and vertical holes)

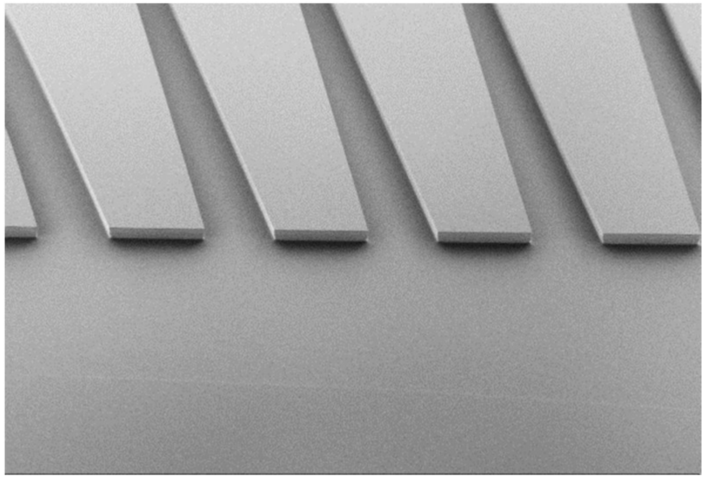


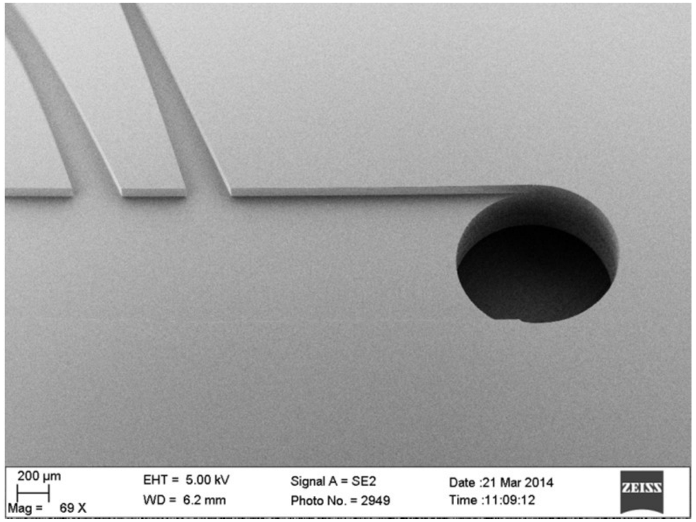



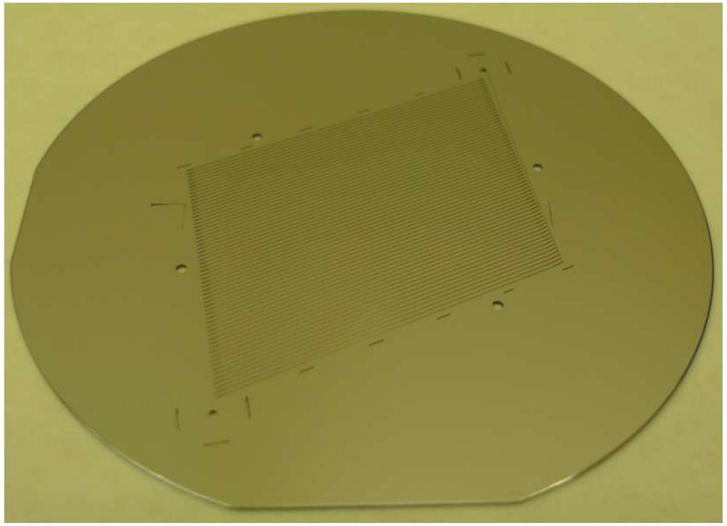

- 2 etching processes
  - 1st to create the channels (100 um deep)
  - 2nd to form the inlet and outlet:
    - ✓ Through hole
    - ✓ "double-side" alignment

Prototypes:





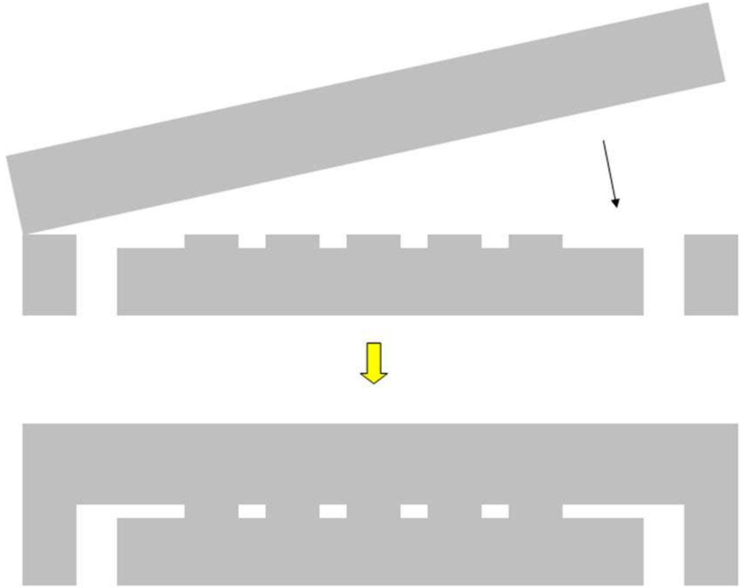

200 µm
Mag = 69 X
EHT = 5.00 kV
WD = 6.2 mm
Signal A = SE2
Photo No. = 2949
Date :21 Mar 2014
Time :11:09:12
ZEISS



# Technology: wafer bonding

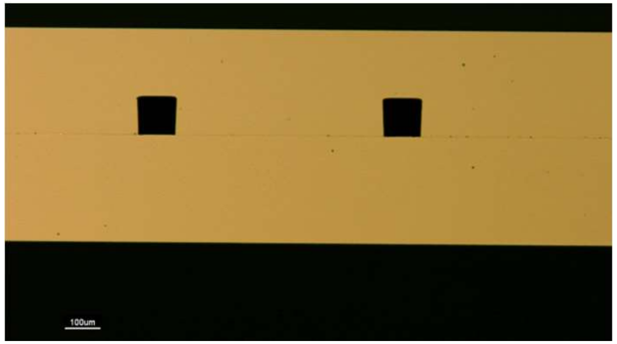
## Wafer bonding

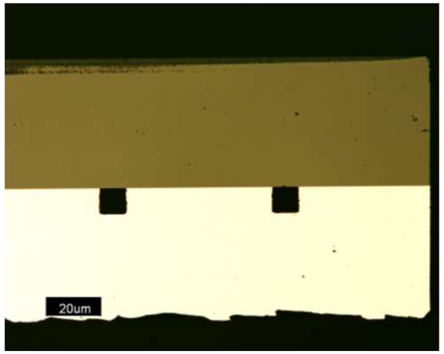
- Anodic: Pyrex - Si
  - High V (1000 V), Low T (~450 ºC),
  - ☞ Pyrex (not CMOS!)
- Fussion: Si-Si
  - High pressure (2-5 Bar), Low T (~400 ºC),
  - ☞ Surface preparation is critical
- Eutectic: Metal-Si
  - Low T (~400 ºC), Au
  - ☞ Al?

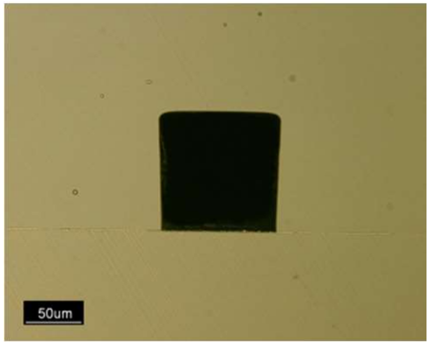


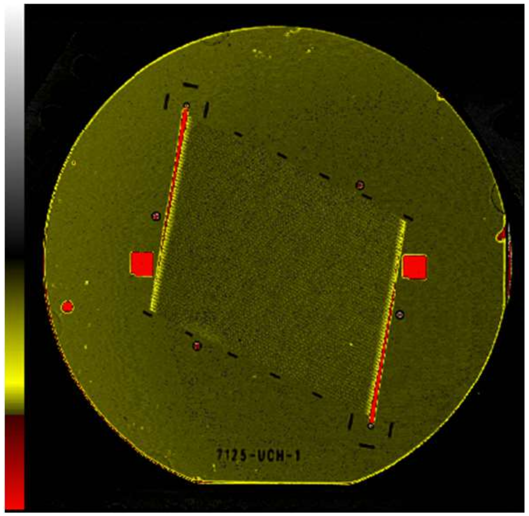
# Wafer bonding

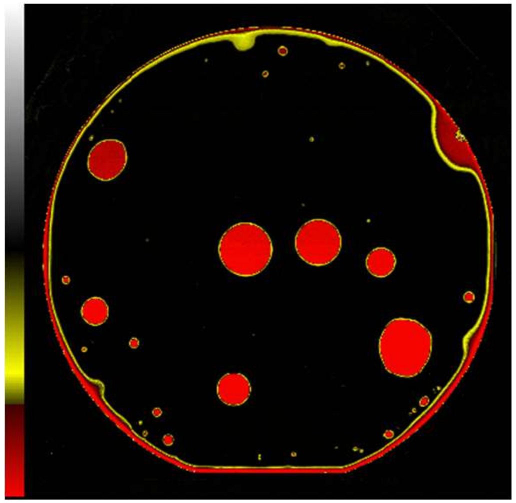
Prototypes:

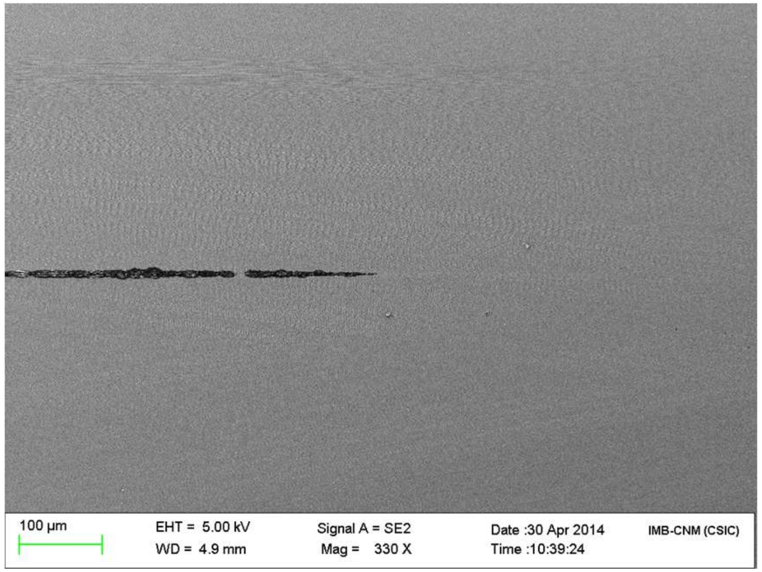


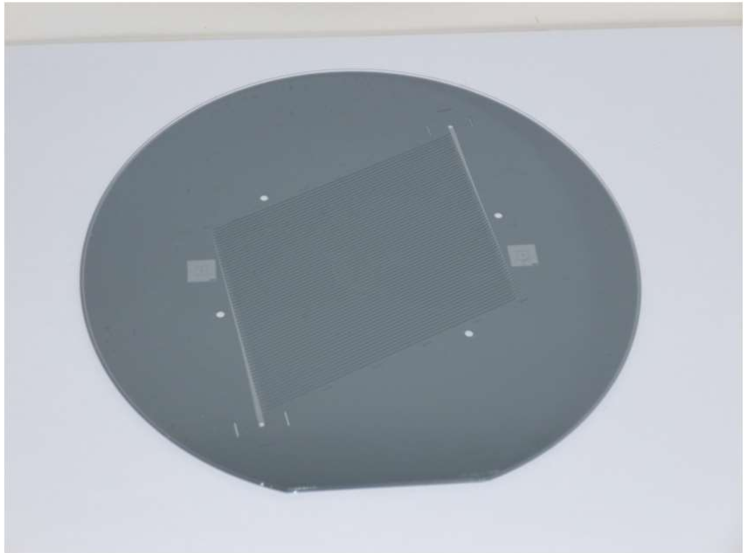





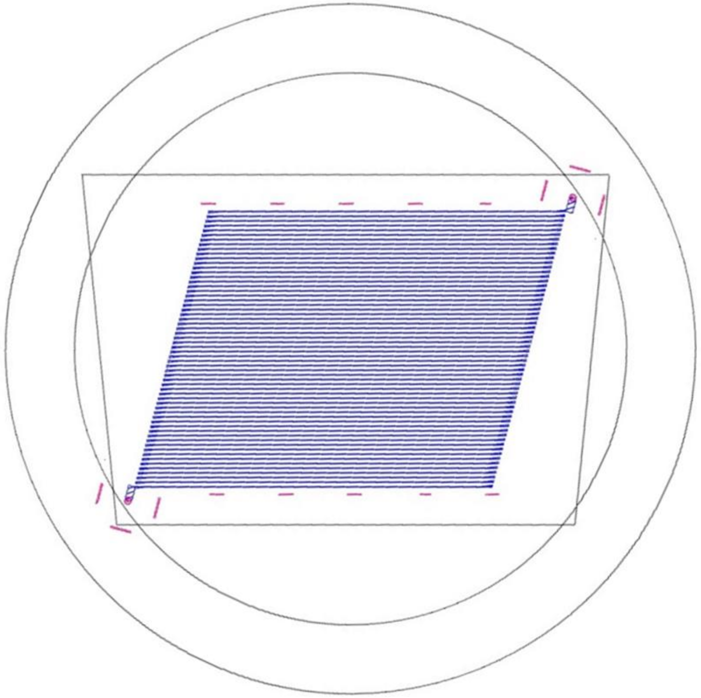
## Full Assembly

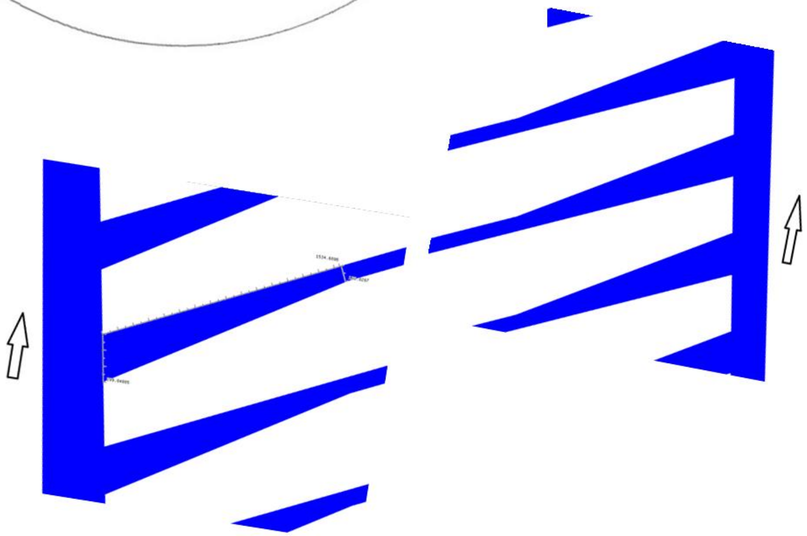
- More than 20 prototypes produced at CNM
  - Anodic ☺
  - Fussion 😐
  - Eutectic ☺
- Post-processing
  - Pre-processing not discarded
  - Active detector



## Design Features

- Full 4'' wafer ATLAS-like design (Petalet sensors)
- Parallel flux
- Uniform heat removal (*)
- 60 channels
- Width & depth 100 um,<br>pitch 675 um de centro a centro,<br>separation 575 um
- 15º inclination with respect to manifolds to facilitate flux
- Triangular channel inlet and outlet with 250 um width, and 2000 um length to facilitate flux

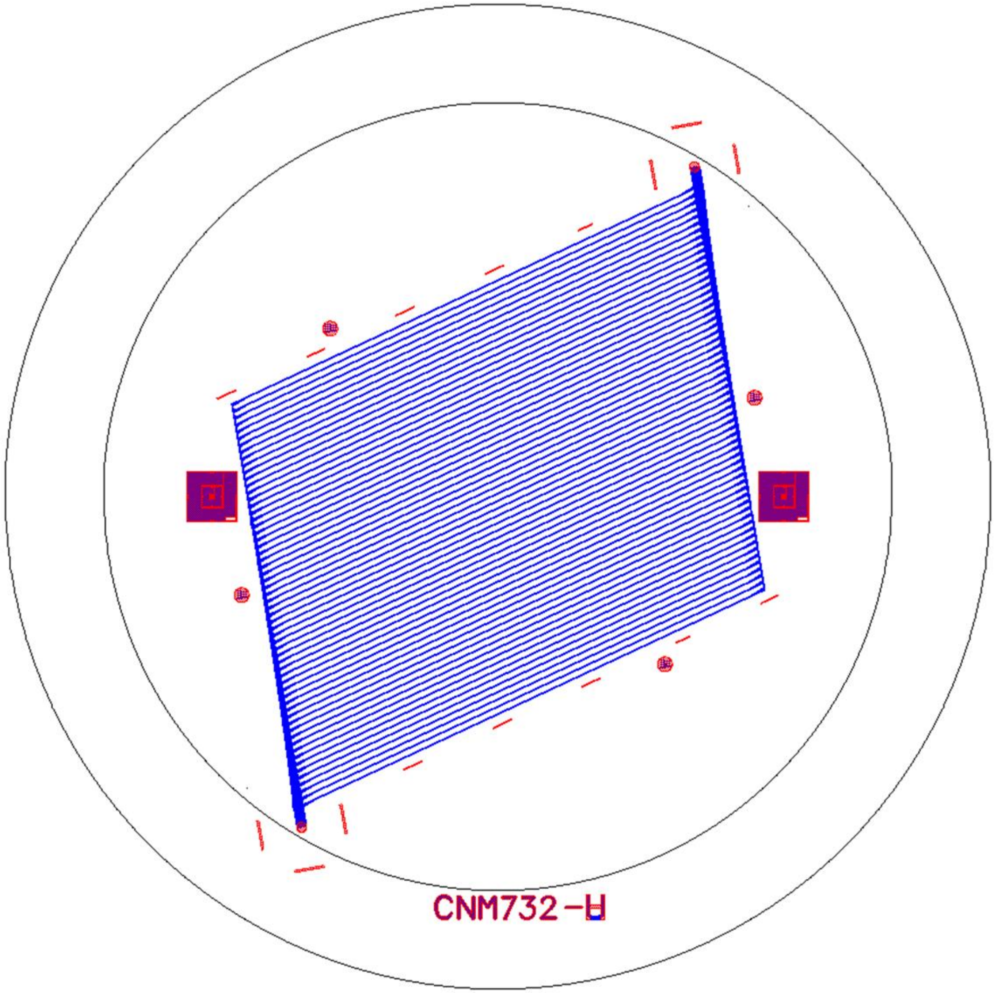




# Design

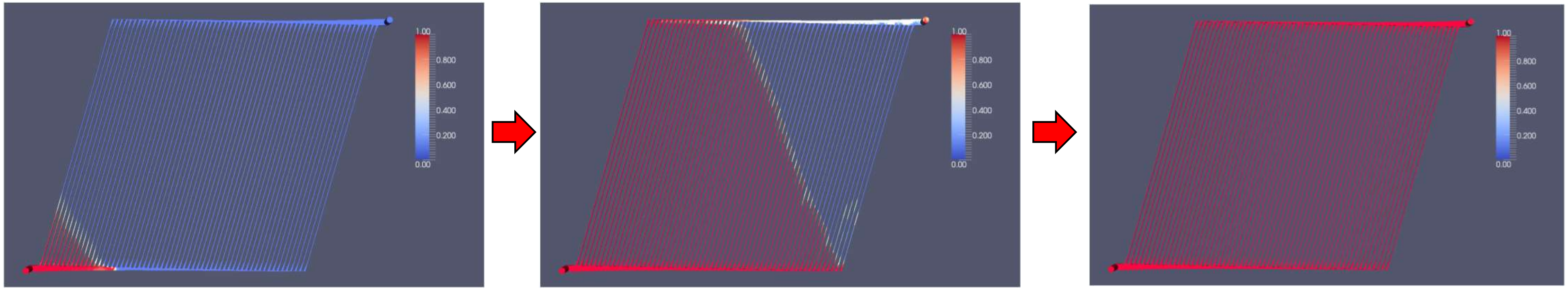
## Full Wafer Layout

- The whole design is rotated 10º to misalign from crystallographic planes

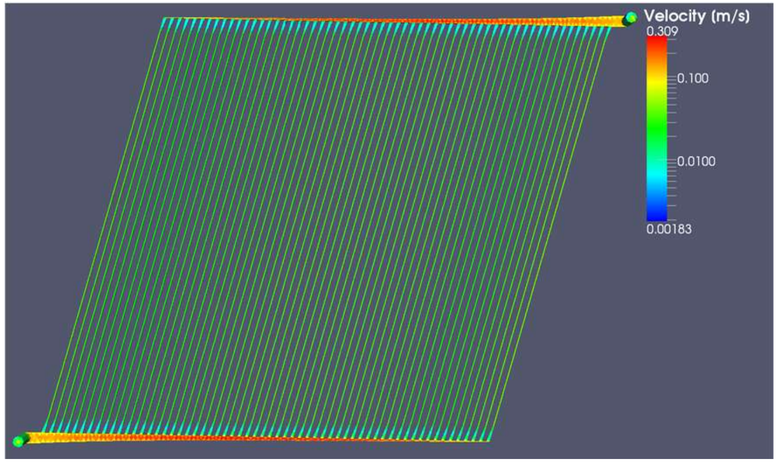


# Simulations (DESY)

- Initial filling of micro-channels
  - No “clogging” (air voids)




- Velocity distribution

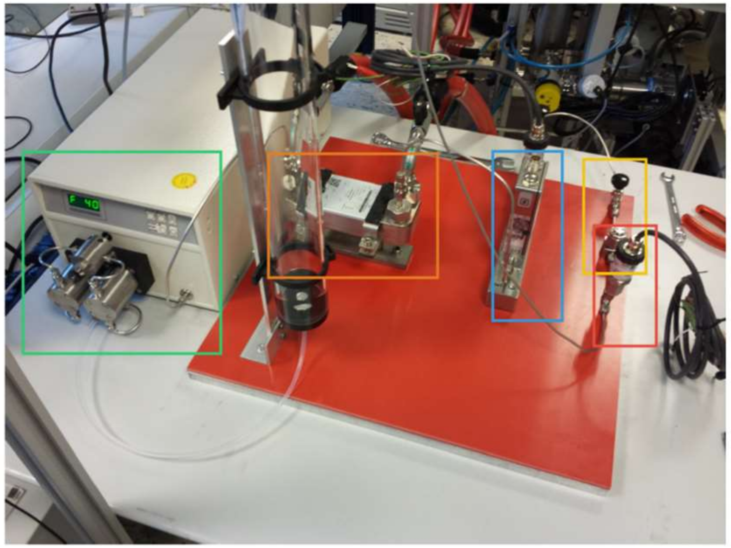



- Flow and thermal simulations (in comparison with tests)

# Hydrodynamic tests

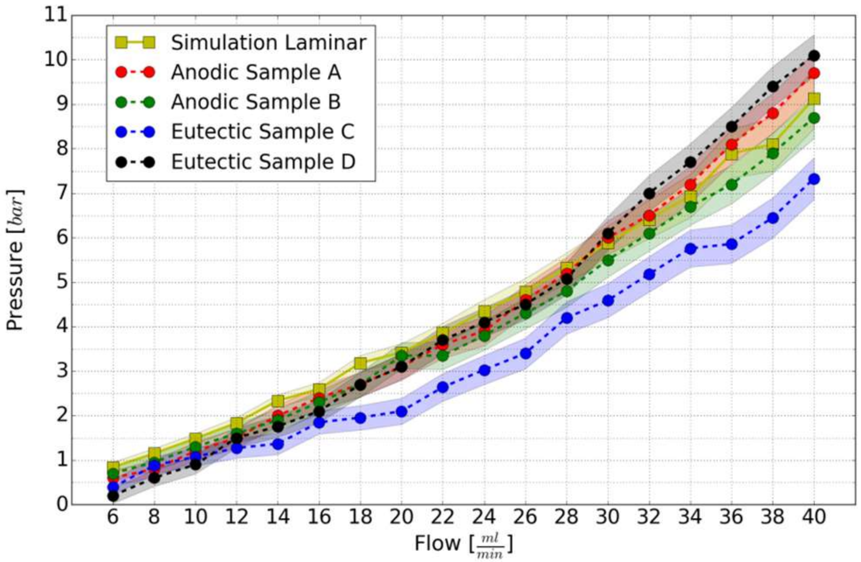
## Setup

- Green: Pump
- Orange: Heat Exchanger
- Blue: Flow Meter
- Yellow: Valve & Filter
- Red: Pressure Sensor
- Transparent column: Fluid Reservoir



## Pressure vs. Flow

- Simulation with laminar flow model
- Good simulation agreement with prototype A, B and D
- Most likely prototype C has some flow problems
- Critical pressure around 31 bar

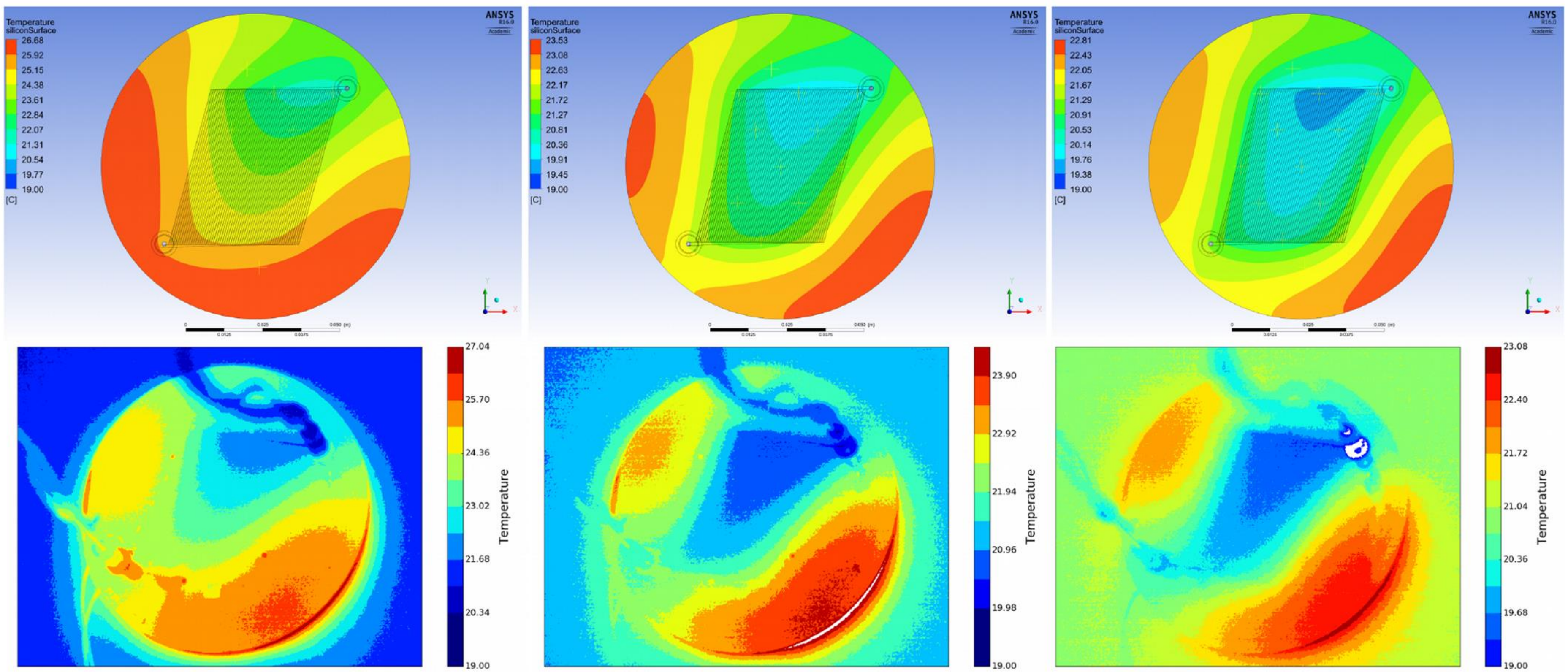


# Thermal tests

## Infrared camera tests

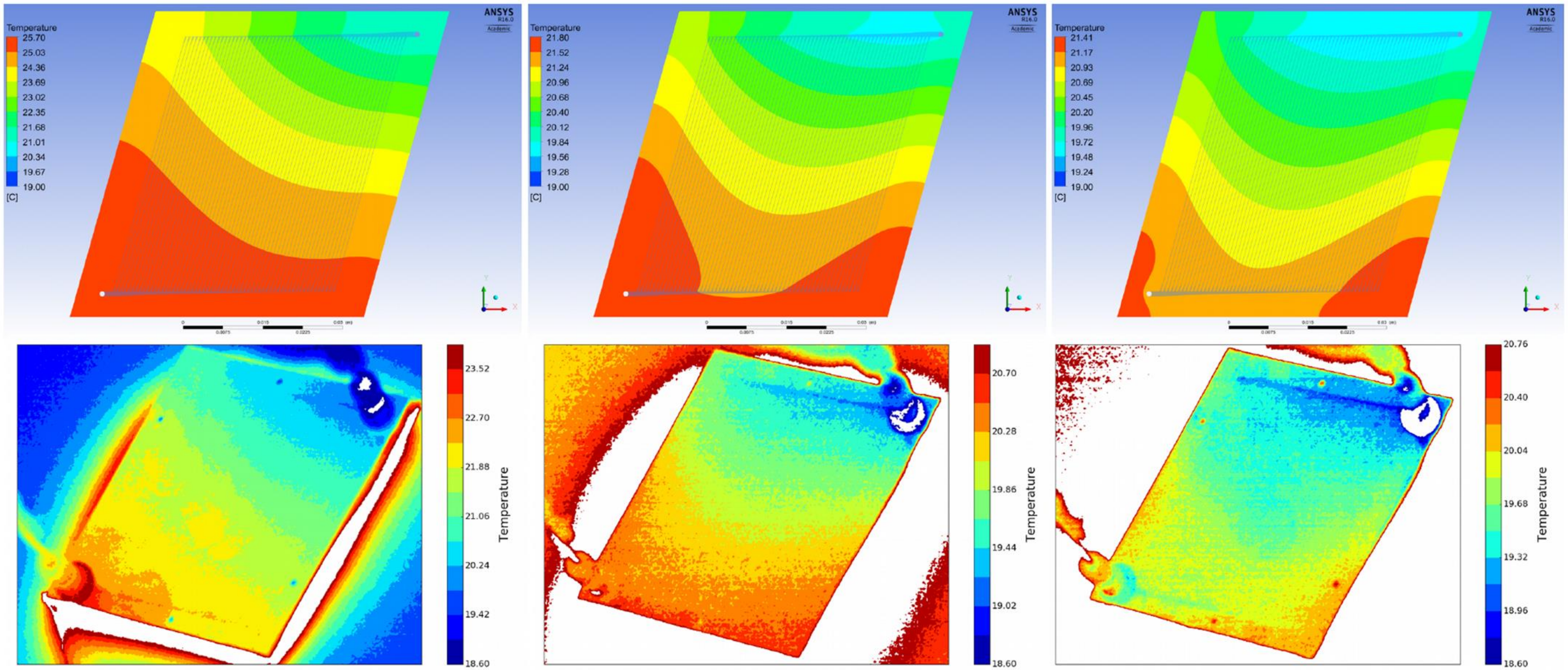
- Thermal homogeneity across the sample, < ±3 ºC (better for higher flow rate)
- Good agreement with simulation
- Wafer border effects

10 ml/min 30 ml/min 50 ml/min



- Cut sample
  - To avoid border effects
  - Thermal homogeneity across the sample, < ±1 ºC (for lowest flow rate)

10 ml/min | 30 ml/min | 50 ml/min



# Summary

- Technology for micro-channel fabrication demonstrated at CNM
- Optimization needed
- Good hydrodynamic and thermal behaviour
- Important technological development still needed for full active systems