Advanced cooling: air cooling

L. Andricek (MPG Halbleiterlabor Munich) et al

02 November 2015

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package 9: New support structures and micro-channel cooling.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site <http://aida2020.web.cern.ch> or on the CERN Document Server at the following URL: <http://cds.cern.ch/search?p=AIDA-2020-SLIDE-2016-013>

Copyright © CERN for the benefit of the AIDA-2020 Consortium
Advanced cooling: air cooling and micro-channel cooling

L. Andricek\textsuperscript{1}, M. Boronat\textsuperscript{3}, J. Dingfelder\textsuperscript{2}, J. Fuster\textsuperscript{3}, I. Garcia\textsuperscript{3}, P. Gomis\textsuperscript{3}, C. Lacasta\textsuperscript{3}, G. Liemann\textsuperscript{1}, C. Marinas\textsuperscript{2}, D. Markus\textsuperscript{2}, J. Ninkovic\textsuperscript{1}, M. Perelló\textsuperscript{3}, E. Scheugenpflug\textsuperscript{1}, M.A. Villarejo\textsuperscript{3}, M. Vos\textsuperscript{3}

\textsuperscript{1}MPG Halbleiterlabor Munich, \textsuperscript{2}Bonn University, \textsuperscript{3}IFIC Valencia

Thanks to AIDA H2020, CERN LCD
Ultra-thin and ultra-precise

Increasing precision and reducing material budget. Challenge for supports, cooling and services.

Belle II Module 0. See also: DEPFET overview in this track
First generation mock-up

IFIC copy of the AIDA pulsing power supply
First generation mock-up

Mechanical samples for 50 μm petals based on the DEPFET all-silicon concept (HLL)

Frame, end-of-petal, balcony: ~450 μm

Ultra-thin sensitive area: down to 50 μm
Air flow & deformation

Vibrations induced by air are at 200 Hz. Finite-element simulation of just the petal predict 300 Hz.

Work on petal design and CF support to raise the lowest eigenfrequency.

Fast Fourier transform of the time series, subtracting the “0 air flow” case.
Air flow & deformation

IFIC measurements

<table>
<thead>
<tr>
<th>( \chi^2 / \text{ndf} )</th>
<th>5.993 / 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prob</td>
<td>0.3089</td>
</tr>
<tr>
<td>p0</td>
<td>1.22 ± 0.5412</td>
</tr>
<tr>
<td>p1</td>
<td>0.3218 ± 0.778</td>
</tr>
<tr>
<td>p2</td>
<td>0.3647 ± 0.1975</td>
</tr>
</tbody>
</table>

Air flow does introduce slight vibrations. For large air speed these become sizeable wrt the intrinsic resolution.

CERN LCD “wind tunnel”
LC thermo-mechanics of thin sensors

Thermo-mechanical performance of silicon sensors studied with thinned mechanical samples

Study of power pulsing & air cooling very encouraging:
- Power pulsing has no impact on mechanical stability (but still without B-field!)
- A laminar air flow in front of the disk, with a moderate speed of 1m/s, is sufficient to remove the nominal DEPFET heat load (assuming 1/25 duty cycle for power pulsing, IEEE TNS 60-2-2, arXiv:1212.2160
- Air flow of greater than “a few m/s” must be avoided

The challenge is to bring in the air and establish a gentle, laminar air flow
Micro-channel cooling, our take...

- Liquid cooling provides excellent temperature control, but is too bulky
- Industry is exploring micro-channel cooling (and, to some extent, high energy physics; LHCb, NA62, ALICE)
- DEPFET, with localized power dissipation and SOI process, provides an interesting application → integrate cooling in all-silicon ladder
- Compared to existing effort, aim at relatively high temperature, low pressure
- Keep it simple: mono-phase

- Small team at University of Bonn
  MPG-HLL Munich and IFIC Valencia
- Embedded in larger effort AIDA2020 (P. Petagna CERN)
All-silicon ladder with integrated cooling

-thinned all-silicon module with integrated cooling channels

- integrate channels into handle wafer beneath the ASICs
- channels etched before wafer bonding → cavity SOI (C-SOI)
- full processing on C-SOI, thinning of sensitive area
- micro-channels accessible only after cutting (laser)
MCC prototypes

Micro-channel pattern in handle wafer

6 ladders with integrated MCC manifolds on a wafer
All-silicon ladder with integrated cooling

Resistor circuits to mimic DEPFET power dissipation

Thermo-mechanical half-ladder for the LC inner vertex detector

Inlet and outlet visible after wafer cutting
The interconnect challenge

- Laboratory connector = interface to high-pressure Swagelok
- 3D-printed (stereo-lithography) 15 µm precision → self-aligning
- Sealed with glue (Araldite)
Pressure test

Thanks to AIDA2020, Jerome Noël, Alessandro Mapelli, CERN

Connector and glue sealing stand 180 bars
Experimental setup

Commercial components: 3D printed interface is the only custom piece
Experimental setup

For operation above 0°C mono-phase liquid cooling with $(\text{H}_2\text{O})$
Thermal measurements: Maximum Power vs Volumetric flow

Maximum power supported for a ΔT of 10 °C as a function of the volumetric flow

- **Temperature stable** even with power density of 25 W/cm²
- **Power vs vol. flow** at max. pump power (~ 3 l/h)
- **Low pressure** needed: 0.2 - 1.5 bar

**Extremely powerful**: MCC removes many times the instantaneous with very small temperature gradient
Thermal measurements: MCC

Good agreement with the FE simulation within 10%

Measurement data errors
- P ±1% W
- T ± 1 °C
- ΔT/Power density ± 0,14 °C/W
- flow ± 0,03 l/h
Thermal simulations: MCC

Realistic design
300 μm Si ASICS + 100 μm Bump-boundings thermal resistivity of 6 W/m·K
C.Mariñas PhD thesis [link]
Thermal measurements: MCC + air

- Big difference between MCC and MCC+air at the sensor area hottest point
- Nearest regions to air input are efficiently cooled even with low air flow
- MCC has less impact in away points as expected and great cooling locally

Cooling strategy: micro-channels running under the front end and gentle air flow on the sensor part
Thermal simulations: MCC Layouts

Standard MCC layout
\[ \Delta T = 73 \, K \]

Standard MCC layout + channel below switchers
\[ \Delta T = 15 \, K \]

Standard MCC layout + channel below switchers + channel in the balcony
\[ \Delta T = 5 \, K \]
Vibrations and deformations

One extreme of the dummy is clamped to the 3D adaptor → amplifies vibrations
Vibrations and deformations

No fluid circulation and no air flowing

Peak to peak of the signal $\sim 0.7 \, \mu m$

RMS $\sim 0.3 \, \mu m$

Fluid circulation 1.47 l/h

Peak to peak of the signal $\sim 0.1 \, \mu m$

RMS $\sim 0.4 \, \mu m$

Air flowing 3 m/s

Peak to peak of the signal $\sim 130 \, \mu m$

RMS $\sim 57 \, \mu m$

MCC has no significant impact on mechanical stability
Towards a low mass interconnection

Material budget is reduced a factor ~4
1.5% X0 Still largely driven by connector
Conclusions

Measurements on mock-up and mechanical samples confirm that the combination power pulsing + air cooling can be made to work if care is taken to limit the air flow to several m/s

To be done: impact of the B-field, long term stability, viable way to set up air flow

For localized power dissipation, up to many W/cm\(^2\) with, a minimalistic micro-channel cooling (mono-phase, low pressure) can provide excellent control and a modest temperature increase (10\(^\circ\)C)

To be done: miniature connector
Thank you for your attention
Thermal measurements: cold water

\[ T_{\text{in}} \approx 5^\circ\text{C} \]

\[ T_{\text{out}} \approx 10^\circ\text{C} \]
Thermal measurements: cold water

$T_{in} \sim 5^\circ C$

$T_{out} \sim 10^\circ C$

Condensation problems

High humidity in the room ~ 70 %
impossible to power on the aluminum resistances (possible short-circuit due to the water on the soldering)
Thermal measurements: cold water

- $T_{\text{out}} \sim 10^\circ C$
- $T_{\text{in}} \sim 5^\circ C$

MCC region is cooled 18$^\circ$C below $T_{\text{Room}}$

In this region the effect of the MCC is quite less pronounced 5-10 $^\circ$C below
Amplitude vs $v_{\text{air}}$

- **Peak-to-peak amplitude** is the change between peak (highest amplitude value) and *trough* (lowest amplitude value)

- RMS $\approx \frac{\text{PeaktoPeak}}{2} \times 0.707$ (approximation)

- For $v= 2.5 \text{ m/s}$ the amplitude of vibration is:
  - $\approx 19 \mu\text{m}$ for clamped-free configuration
  - $\approx 2.8 \mu\text{m}$ for clamped-clamped configuration
Optimized MCC geometry

- More homogenous flow
- Reduce pressure gradients
- Minimize and confine the heat spread

Recent geometry

Optimized geometry
Micro-channel Cooling

Tests made: 5W and water cooling

As shown first measurements, MCC with a flow of 0.1 l/h offers promising results

Cooling strategies

Massive structures outside the acceptance to cool down the readout chips

Stainless steel Fast sintering Coolant: CO$_2$

PXD Cooling and support structure

Belle II