DEVELOPMENT AND EXPERIMENTAL CHARACTERIZATION OF PROTOTYPES FOR LOW MATERIAL BUDGET SUPPORT STRUCTURE AND COOLING OF SILICON PIXEL DETECTORS, BASED ON MICROCHANNEL TECHNOLOGY

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11th Pisa Meeting on Advanced Detectors

Introduction

Pixel detectors at future colliders will need to match very stringent requirements on position resolution. The support structure and cooling add important contributions to the total material in the active area.

Advantages of the MICROCHANNELS technology:

- due to the high surface/volume ratio, heat exchange through forced convection of a liquid coolant is taking place efficiently, obtaining high thermal conductivities without affecting the stiffness of the structure
- the contiguity between the fluid and the circuit dissipating power reduces thermal resistances
- uniform distribution of the passive material and uniform temperature of the surface covered by the sensors can be obtained.

Several prototypes with different geometries of micro-machined channels have been realized in ceramics (AlN) and composite materials (CFRP). FEA simulations have been validated by the experimental tests performed in the thermofluidodynamics test-bench, recently assembled at the INFN-Pisa laboratory.

The key concept

In a thermal convective exchange the film coefficient is:

$$h = \frac{Nu \cdot k}{D_h}$$

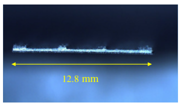
Nu = Nusselt number
K = Conductive heat transfer coefficient of the liquid
D_h = Hydraulic Diameter of the cooling channel

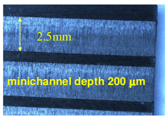
To maximize the h value it is important to minimize the hydraulic diameter:
this remark points us to the microchannel technology.

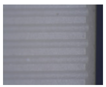
Minimize D_h → high pressure drop (needed a compromise between pressure drops and film coefficient value).

Prototype production

CFRP Subtractive Method and AlN Micromachining

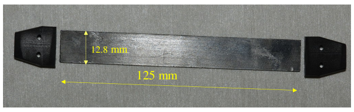


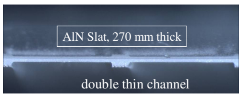


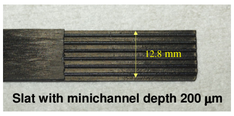


Minichannel top view(pitch 400 µm)

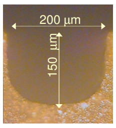
Slat Dicing

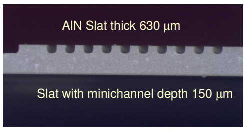






Slat with minichannel depth 200 µm



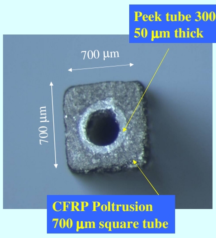


Slat with minichannel depth 150 µm

The specifications for the pixel support (layer0 SuperB)

- evacuate the heat dissipated by the electronics (specific power ~2 W/cm²) , keeping the temperature of the sensors below 50 °C
- material budget: the pixel support structure (w/o cables and sensors) has to remain below 0.30% X_0.

Microchannel CFRP single unit

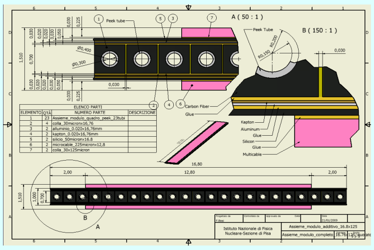


Peek tube 300 µm inter. diam, 50 µm thick

CFRP Poltrusion 700 µm square tube

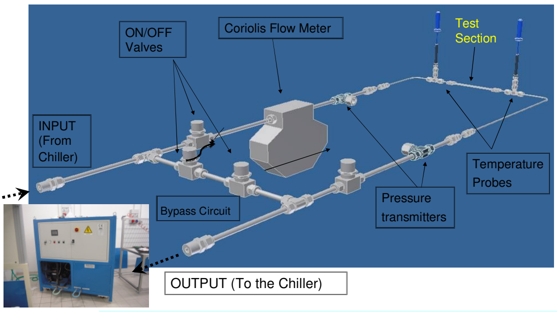
CFRP microchannel in the hydraulic interface

Microchannel module assembly (additive method)



Test-bench hydraulic circuit

Liquid coolant: water + $C_2H_6O_2$ - 50 % @ 10 °C
Specific Power density: 2 W/cm² (using a kapton heater)



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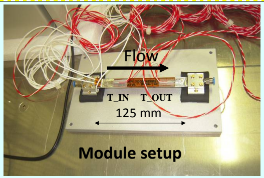


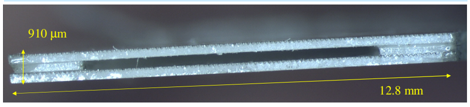
Module setup

DAQ system

Test results

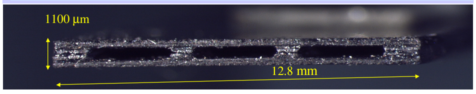
Single Channel AlN additive method: Thickness = 0.65% X_0

D_h=0.48 mm



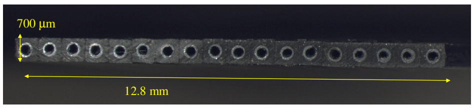
Triple channel CFRP subtractive method: Thickness = 0.40% X_0

D_h=0.84 mm



Microchannel CFRP additive method: Thickness = 0.28% X_0

D_h=0.3 mm

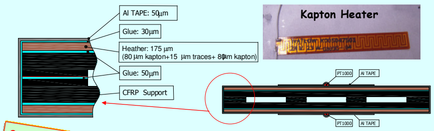


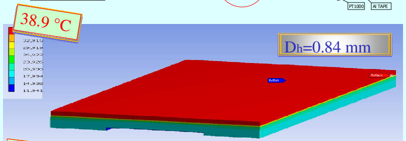
AlN single channel measurement	
T_{FLUID}	9.5 °C
Power Density δ_P	2 W/cm²
Flow Rate	0.45 Kg/min
T_IN_AVERAGE	32.4 °C
T_OUT_AVERAGE	42.8 °C
P_IN	1.9 bar

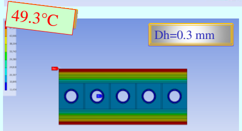
CFRP triple channel measurement	
T_{FLUID}	9.5 °C
δ_P	2 W/cm²
Flow Rate/ch	0.24 kg/min
T_IN_AVERAGE	41.1 °C
T_OUT_AVERAGE	43 °C
P_IN	2.6 bar

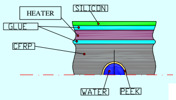
CFRP Microchannel measurement	
T_{FLUID}	9.5 °C
δ_P	2 W/cm²
Total Flow Rate	0.26 Kg/min
T_IN_AVERAGE	45.1 °C
T_OUT_AVERAGE	47.2°C
P_IN	3.6 bar

FEA studies









kapton heater between silicon and CFRP

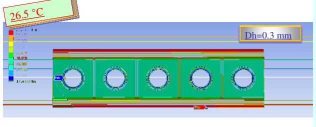
Triple Channel FEA Simulation

(1/6 of the total structure)

Thermal conductivities :
CFRP support:
Kx = Ky = 75 W/mK; Kz = 3 W/mK
Aluminum Tape: K = 180 W/mK
Glue: K = 0.15 W/mK
Heater: K = 0.15 W/mK
Boundary conditions:
Power density: 2 W/cm2
h = 15000 W/m²K, turbolent flow
(total flow rate = 1 kg/min,
Fluid H_2O + $C_2H_6O_2$ - 50 %)
Tfluid = 9.5 °C
Results: *Tmax = 38.9 °C*

Substantial agreement between the test results and FEA studies.

Electronics positioned on top (no kapton heater , similar to experimental layout)



Conclusions & perspectives

- **The microchannel CFRP prototype best matches the requirements on X_0 with efficient heat evacuation.**
- **Room for further optimization and reduction in material**
- **Future plan: evaporative cooling in microchannels to reach lower temperatures .**