Grant Agreement No: 101004761

AIDAinnova

Advancement and Innovation for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDAINNOVA

MILESTONE REPORT

WORK PLAN INCLUSIVE OF THE DETAILED PROGRAMME ANNOUNCED IN MS10.1 (MS41)

MILESTONE: MS42

Document identifier:	AIDAinnova_MS42
Due date of milestone:	End of Month 12 (March 2022)
Report release date:	31/05/2022
Work package:	WP10: Advanced mechanics for tracking and vertex detectors
Lead beneficiary:	CNRS
Document status:	Final

Abstract:

The document describes the agreed plan of action for the Task 10.3 “Development of advanced engineered solutions for the hydraulic interconnection of multiple micro-structured silicon cold plates”. The planned R&D activities aim at different objectives:

- Review existing results in the use of PEEK for 3D printed connectors, obtained in the first year of AIDAinnova but also by other projects) and produce PEEK prototypes with improved printing techniques.
- Develop 3D printing on different materials and compare with the available results on PEEK.
- Improve the design of the prototype connectors to optimize it to the features of the used materials and in synergy with Task 10.2.

For more information on AIDAinnova, its partners and contributors please see http://aidainnova.web.cern.ch/

The Advancement and Innovation for Detectors at Accelerators (AIDAinnova) project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 101004761. AIDAinnova began in April 2021 and will run for 4 years.

Delivery Slip

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Executive summary

Task 10.3 in AIDAinnova is centred on the development of advanced engineered solutions for the hydraulic interconnection of multiple micro-structured silicon cold plates. In this document a detailed workplan is presented, with objectives and timelines for the development of improved prototyping techniques of connectors based on 3D printing with existing and new materials, and the optimization of the connector design for the different technologies and materials.

1. INTRODUCTION

One of the main lines of research and development of WP10 is centred on the use of micro-channels to obtain a more uniform and efficient cooling for readout electronics and complex detector structures. This is particularly relevant for cases in which the Thermal Figure of Merit (TFM) plays a critical role in performance and operation, such as the high-radiation environment of hadron collider experiments, or in environments where efficient and controlled cooling must be achieved with a minimal material budget[1]. Micro-channel cooling has already been used successfully in many installations in High Energy Physics, in particular in the NA62 GigaTracker[2] and the LHCb VELO upgrade[3], and is used extensively in other fields of research and industrial applications [4].

While the manufacturing of micro-channels in cold plates has been already achieved in various technologies, the interconnectivity between different devices still represents one of the most challenging aspects of micro-channel cooling, and a fundamental limiting factor whenever the extension of the serviced area exceeds the typical maximum size of a single cooling plate, usually of the order of 10-15 cm, limited by wafer size. Several "standard" solutions were explored in AIDA-2020[1], as well as custom 3D-printed plastic connectors. The latter offer a low-mass solution for cooling systems that operate in the acceptance of the experiment. As the additional manufacturing capabilities evolve and the variety of materials increases, new possibilities open up for mechanically solid, light-weight solutions.

One of the goals of AIDAinnova 10.3 Task is to study the integration in silicon devices of cooling plates with the help of 3D printing techniques for the interconnection and for the manufacturing of the plate itself. This could also allow designs featuring the integration of the connection in the cooling element. Based on previous studies, prototypes of hydraulic interconnection elements are being tested on samples produced in the AIDA-2020 project.

The main R&D lines of the Task will be:

- Review existing results in the use of PEEK for 3D printed connectors, obtained in the first year of AIDAinnova but also by other projects, and produce PEEK prototypes with improved printing techniques.
- Develop 3D printing on different materials and compare with the available results on PEEK.
- Improve the design of the prototype connectors to optimize it to the features of the used materials and in synergy with Task 10.2

2. MICRO-CHANNEL CONNECTION BASED ON 3D PRINTING TECHNIQUES

2.1 GENERAL OBJECTIVES

For the interconnection of channels etched in silicon substrates, 3D-printed plastic connectors were developed and designed at IFIC (UV/CSIC) in Valencia during AIDA-2020, in collaboration with the University of Bonn and the semiconductor laboratory of the Max Planck Society in Munich. A number of batches of prototype connectors were industrially produced using standard plastics. The connectors self-align with the silicon prototypes and the connections are sealed using a glue dispensing robot. The assemblies were pressure-tested at CERN and found to hold 80 bars, which is sufficient for mono-phase cooling, and submitted to Helium leak tests at IFIC with satisfactory results. These connectors are used routinely for the characterization of prototype micro-channel cooling devices at IFIC and elsewhere.

Beyond solutions for silicon cooling plates, a significant amount of work has been done during the first year of the project to extend the development to other cooling technologies such as microtubes in carbon fiber, which could represent a valid solution to circumvent the size limitation of the individual cold plates. New materials are also actively investigated. One of the materials which has been most investigated until now to produce 3D-printed interconnectors has been PEEK, given the low density, the mechanical properties and the good radiation hardness, well matching some of the applications for which these connectors are designed. A few interconnector prototypes have been produced with additive methods by a commercial company (Roboze, Italy [5]) in a collaboration between INFN Pisa and CNRS-LPNHE, and they have been replicated in the internal infrastructure of CNRS-LPNHE which is equipped for PEEK additive printing (see Fig. 1).

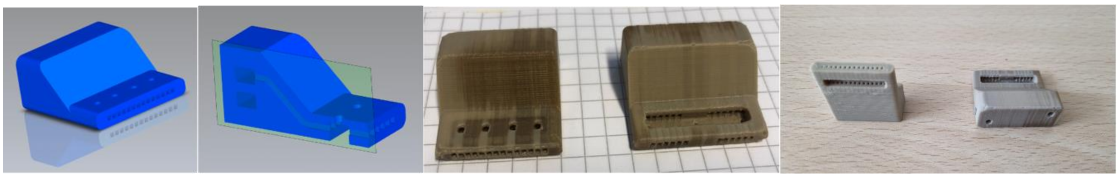

Fig. 1: Design (pictures 1 and 2) and prototypes of PEEK interconnection blocks produced with 3D printing techniques by Roboze (Italy) for INFN Pisa and CNRS-LPNHE (picture 3) and by CNRS-LPNHE (picture 4).

These blocks were designed to accommodate the pattern of carbon microtubes on one side, sealed to the blocks with a radiation-hard glue such as Araldite 2011 [6], and to host couples of standard connectors for inlet-outlet of refrigerant fluid, see Fig. 2.

Fig. 2: Photo of the assembled cooling structure with micro-pipes and interconnection blocks on the two sides.

After the first prototype has been tested under pressure of 2-3 bars, a leak of fluid has been detected through the bulk of the connector, probably intrinsic to the additive deposition technique, which is leaving micro-cavities between one deposition pass and the next. In the prototype realised by CNRS-LPNHE, the direction of deposition has been changed, attempting to avoid such an effect. This second prototype has also shown a similar structural weakness when tested under pressure, and a crack has been produced when the pressure was increased above 3 bars.

These tests have indeed been very useful to show some of the issues related to the additive method, at least when PEEK is used as material for the unit. One of the possible actions will now be to test a different post-processing method for the block, in order to obtain a better compactness of the material during the heat-up phase. One other feature which has been observed is the non-perfect shape definition in the print, which is visible in Figure 1. Tests on how to improve the PEEK printing will proceed in 2022 and will in part profit of the printing facility at CNRS-LPNHE that could allow to save costs and turn-around time. Also, a recently identified company that provides high-definition printing in PEEK will be characterised.

A parallel development will be pursued in the next 18 months on the study of different materials, in particular 3D printing on ceramic-like or epoxy. The first material is giving excellent radiation hardness, but also the second one presents a decent radiation resistance. Printing on ceramic-like can also be obtained with stereo-lithographic methods, which should provide an excellent shape definition. Also, direct 3D printing of polymers on silicon could be tested, to avoid the temperature issues related to metals or ceramic which make actually this deposition impossible with these materials.

In general, different materials used for the interconnection prototypes may need (or may allow) changes in the design, to optimise it to the constrains of the process. For instance, the cracks in the PEEK connectors when tested under pressure, may suggest not only to change the post-processing method to make the parts more resistant to pressure, but also to improve the internal fanout structure to reduce the inner exposed surface in the connector. Modified designs will be studied to find the optimal interface to the different printing solutions.

Finally, as already mentioned, the possibility to 3D-print directly on silicon may open very fruitful synergies with the Task 10.2, with the possibility to directly integrate the connectivity in the cold blocks and in the modules developed in that Task. Some prototypes which could be used to test interconnection solutions are already available from AIDA-2020 developments.

2.2 SUBTASK TIMELINE

The following table shows the planned timeline for the different activities described in Section 2.1

Activity		From	To
A1	**Improvement of 3D printing in PEEK**	**April 2021**	**March 2023**
	Prototyping of different deposition methods Study different post-processing methods to improve the compactness of the prototypes Testing high-definition commercial process with PEEK Verification of above methods under fluid pressure	24 months	
A2	**Testing of 3D printing with new materials**	**February 2022**	**April 2024**
	Evaluate ceramic-like material and stereo-lithography Evaluate printing with epoxy materials (Accura®) Verification of above methods on testbench	24 months	
A3	**Integration of interconnections and devices**	**April 2022**	**March 2025**

	Tests of 3D deposition on silicon Synergies with devices of Task 10.2 (channels etched in processed silicon devices, cold plates or readout electronics) Prototypes validation on testbench	36 months	

3. REFERENCES

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[4] AIDA-2020 Final Report, AIDA-2020-NOTE-2020-007
https://cds.cern.ch/record/2724324/files/AIDA-2020-NOTE-2020-007.pdf
[5] Roboze, Professional and Industrial 3D printing
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[6] Araldite 2011 ®, Huntsman Corporation
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ANNEX: GLOSSARY

Acronym	**Definition**
PEEK	Polyether Ether Ketone, $C_{19}H_{14}F_2O_3$
TFM	Thermal Figure of Merit