Relevance of Atomic Diffusion Additive Manufacturing (ADAM) in cryogenics and vacuum applications

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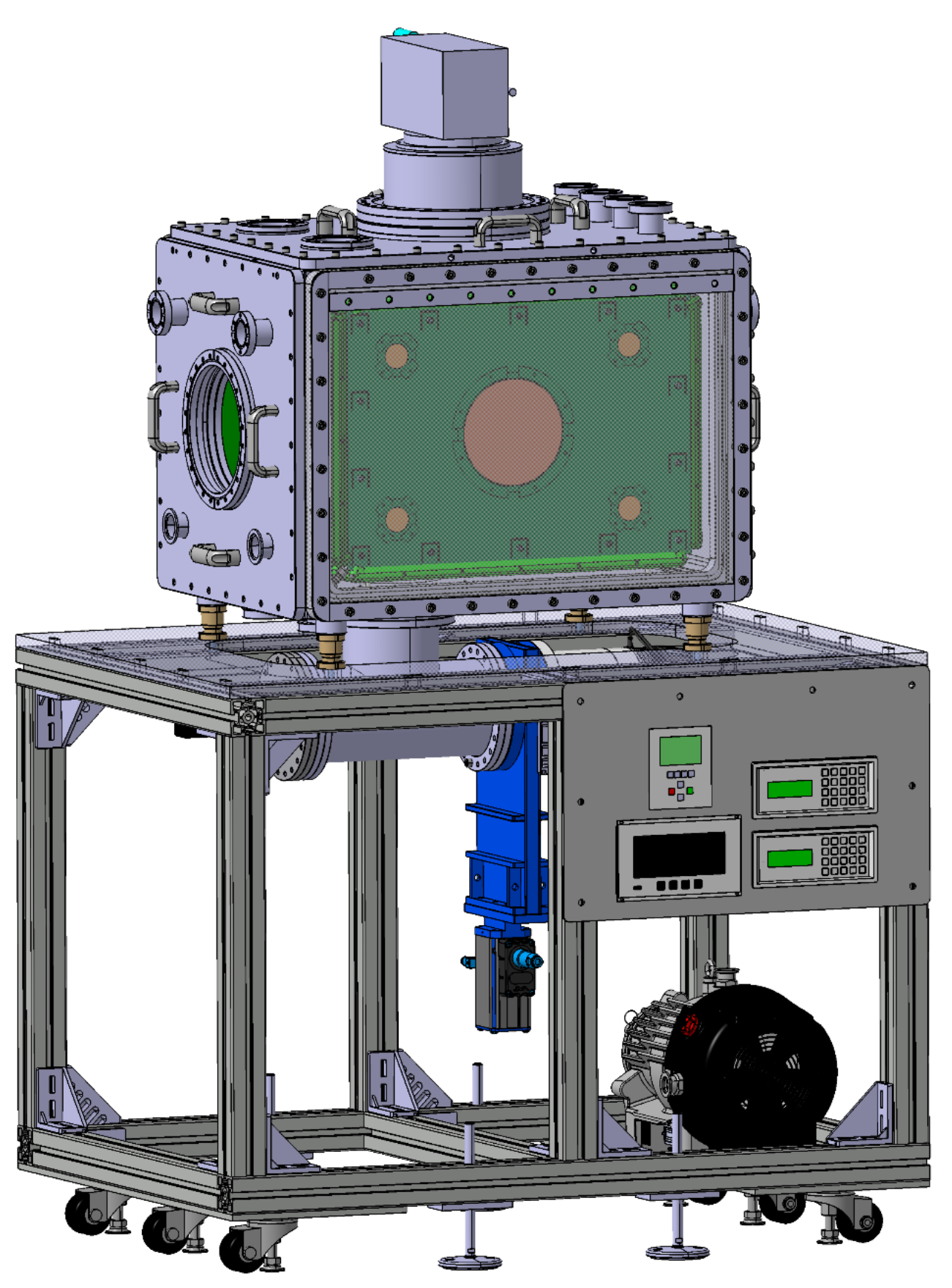
Abstract

Atomic Diffusion Additive Manufacturing (ADAM) represents cutting-edge technology in the field of cost-effective additive manufacturing. However, concerns arise regarding the suitability of ADAM-produced parts for these extreme cryogenic temperatures and vacuum tightness due to the possible imperfection of the powder bonding after the thermal sintering and binder removal. To address this, an experimental evaluation was conducted on a new experimental device (CryPT-ON), focusing on different heat transfer performances of ADAM-produced parts under cryogenic conditions, like thermal conductivity and diffusivity which one was measured by thermal wave propagation.

Experimental infrastructure



New experimental infrastructure has been built for nuclear fusion related cryogenic and vacuum experiments at HUN-REN CER. The infrastructure (called CryPT-ON) consist of a rectangular vacuum chamber with interchangeable lids and a SHI RDE-418D4 cryocooler. The chamber is capable to handle a self-made Continuous Flow Cryostat, design of the gas, LHe and LN handling system is underway.

Main objectives:

- Material testing at low temperatures
- Solid hydrogen production by desublimation (fusion device fueling)
- Parahydrogen production
- Model validation of desublimation codes
- Technology development for cryogenic pellet production

This poster will present the first results of a study of the thermal properties (conductivity, diffusivity) of 3D printed ADAM parts on the device.

Experimental results

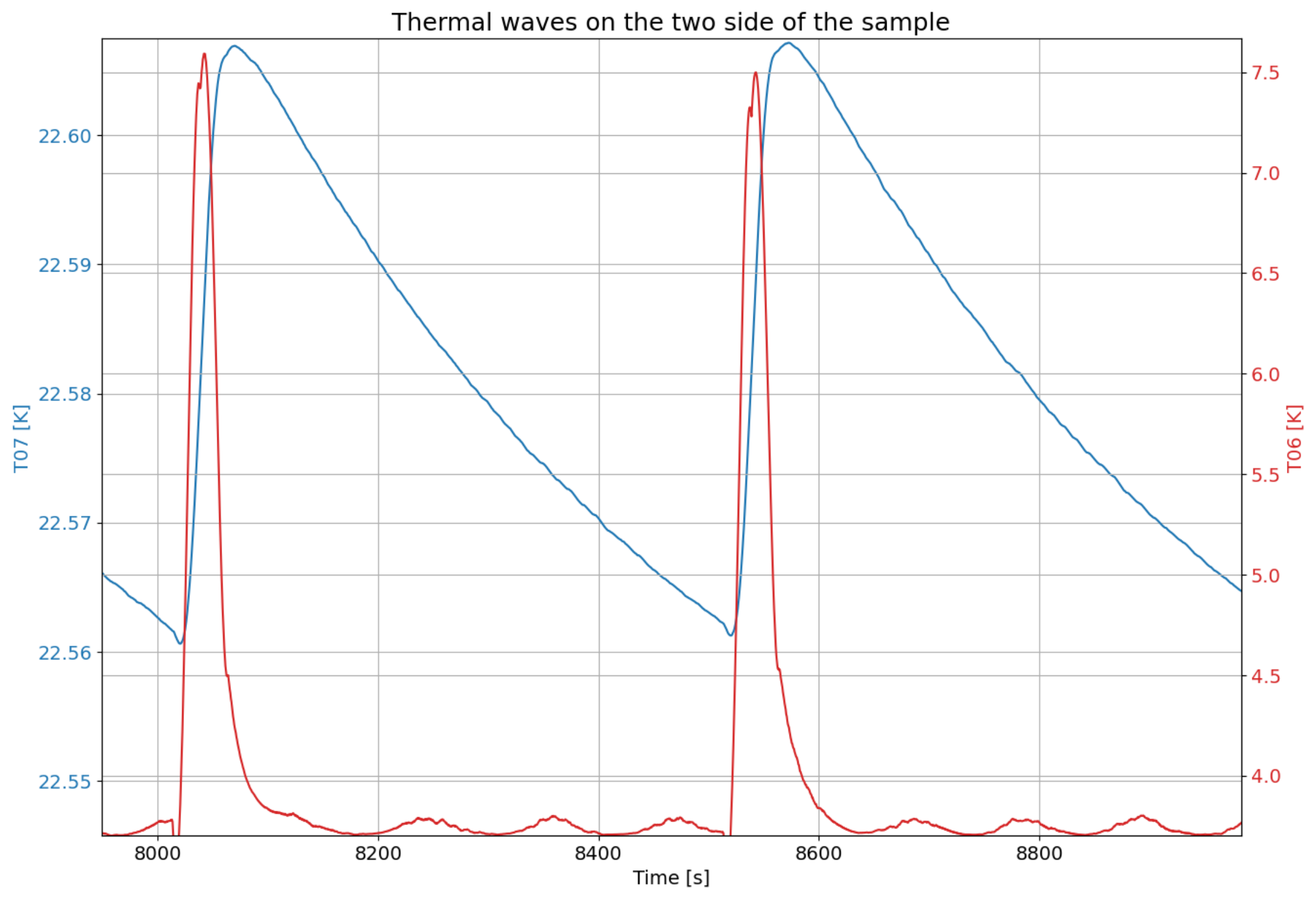
The fundamentals of the diffusivity measurement is that the thermal wave is strongly attenuated and phaseshifted along the specimen and can be calculated directly from the relationship below.

$$\Delta\phi = x\sqrt{\frac{\omega}{2\alpha}} \quad [2]$$

where x is the distance of the measurement points, ω is the angular frequency, α is the diffusivity and $\Delta\Phi$ is the phase shift of the thermal waves.

Thermal waves were induced with H1 cartridge, and the phase shift is measured between T06 and T07 diodes.

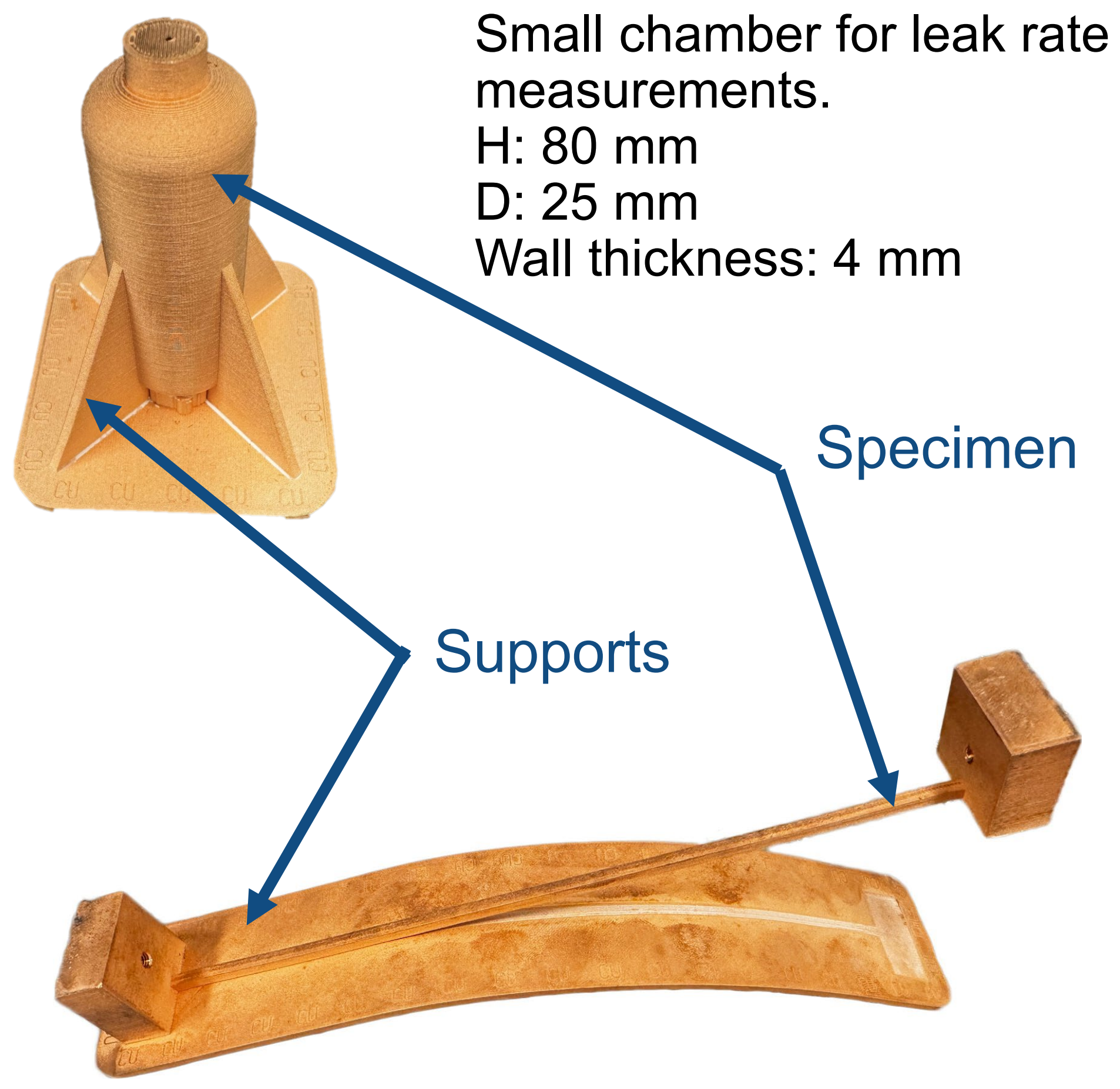
The estimated thermal diffusivity from first runs @15K: $5.6 \cdot 10^{-04}$ m²/s



Preliminary vacuum tests were conducted, where we found that the magnitude of the leak rate is around $1 \cdot 10^{-9}$ Pa·m³/s through the sample, which has a 4 mm wall thickness and a surface area of 3000 mm².

3D printed parts

Small chamber for leak rate measurements.
H: 80 mm
D: 25 mm
Wall thickness: 4 mm



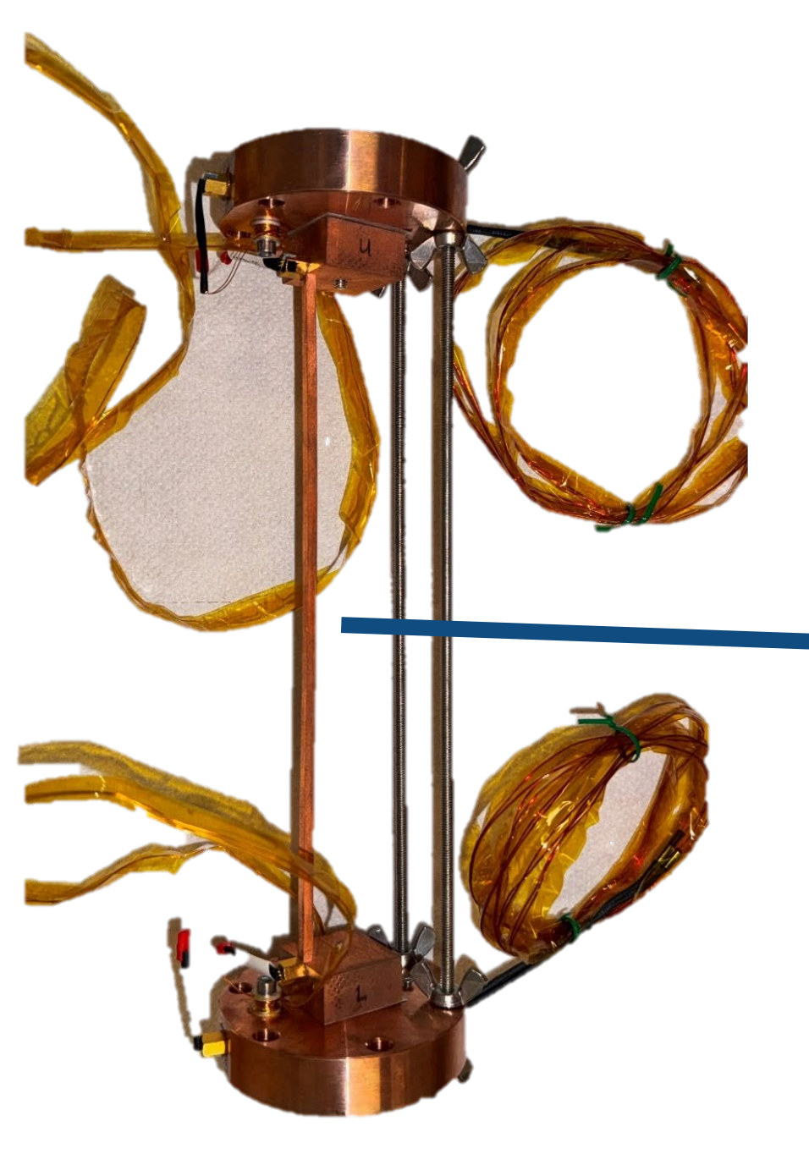
Sample for thermal conductivity and diffusivity measurements.
L: 180 mm
Cross section: 3x3 mm

Base material composition	
Copper	99.8% min
Oxygen	0.05% max
Iron	0.05% max

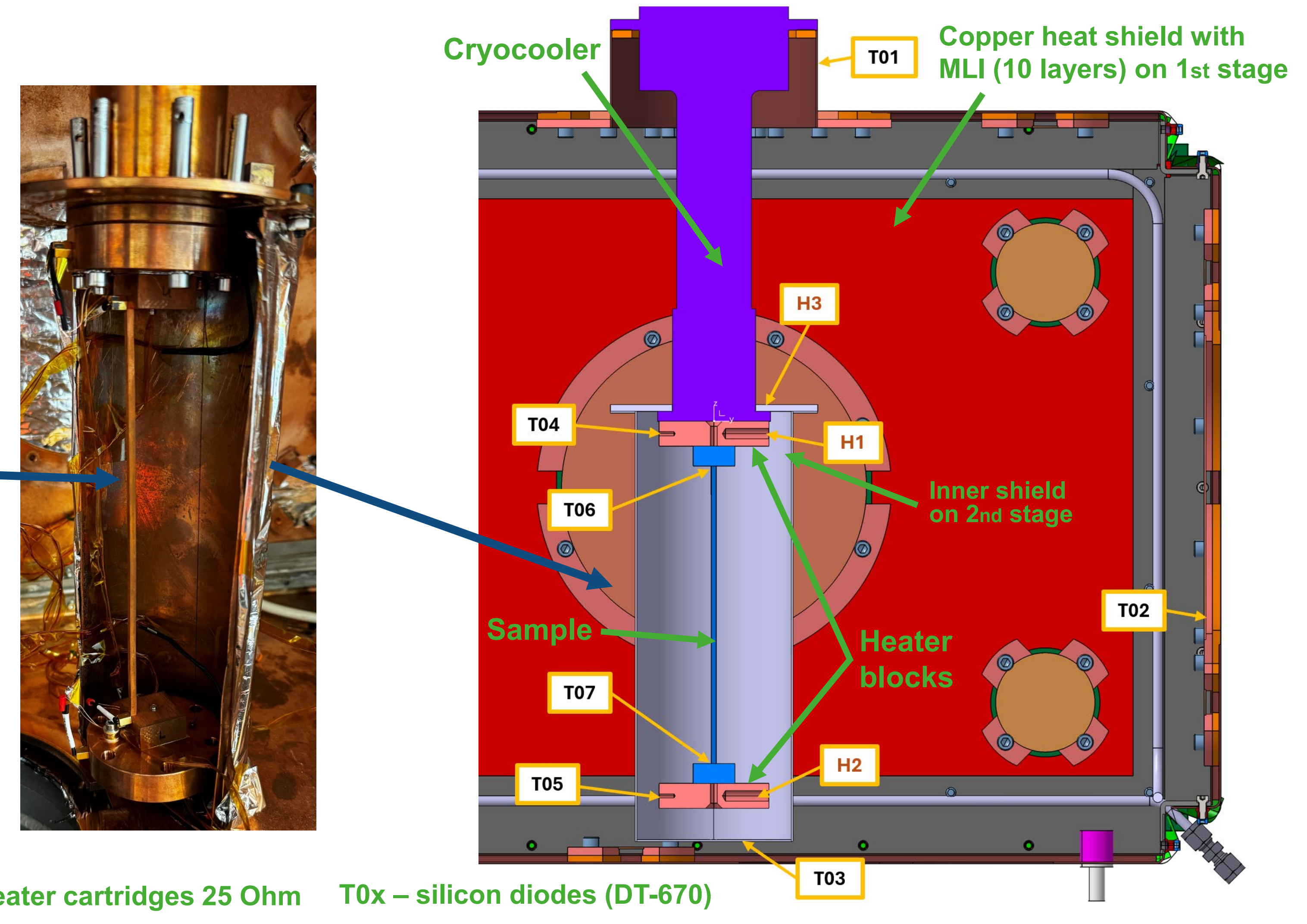
The thermal conductivity at room temperature is 350 W/m*K, measured by the manufacturer using the indirect method of ASTM E1461. [1]

Experimental setup

Two calibrated thermometers were placed on the sample piece. Heater blocks, each containing thermometers, were attached to both ends of the sample. The resulting assembly is connected to the second stage of the cryocooler along with the inner heat shield, which also has a thermometer at its bottom. Additionally, there are thermometer sensors located near the first stage and on the lower side of the outer heat shield. Apiezon grease was applied between the thermal connections, except between the sample piece and the heater blocks, which are compressed with Indium.



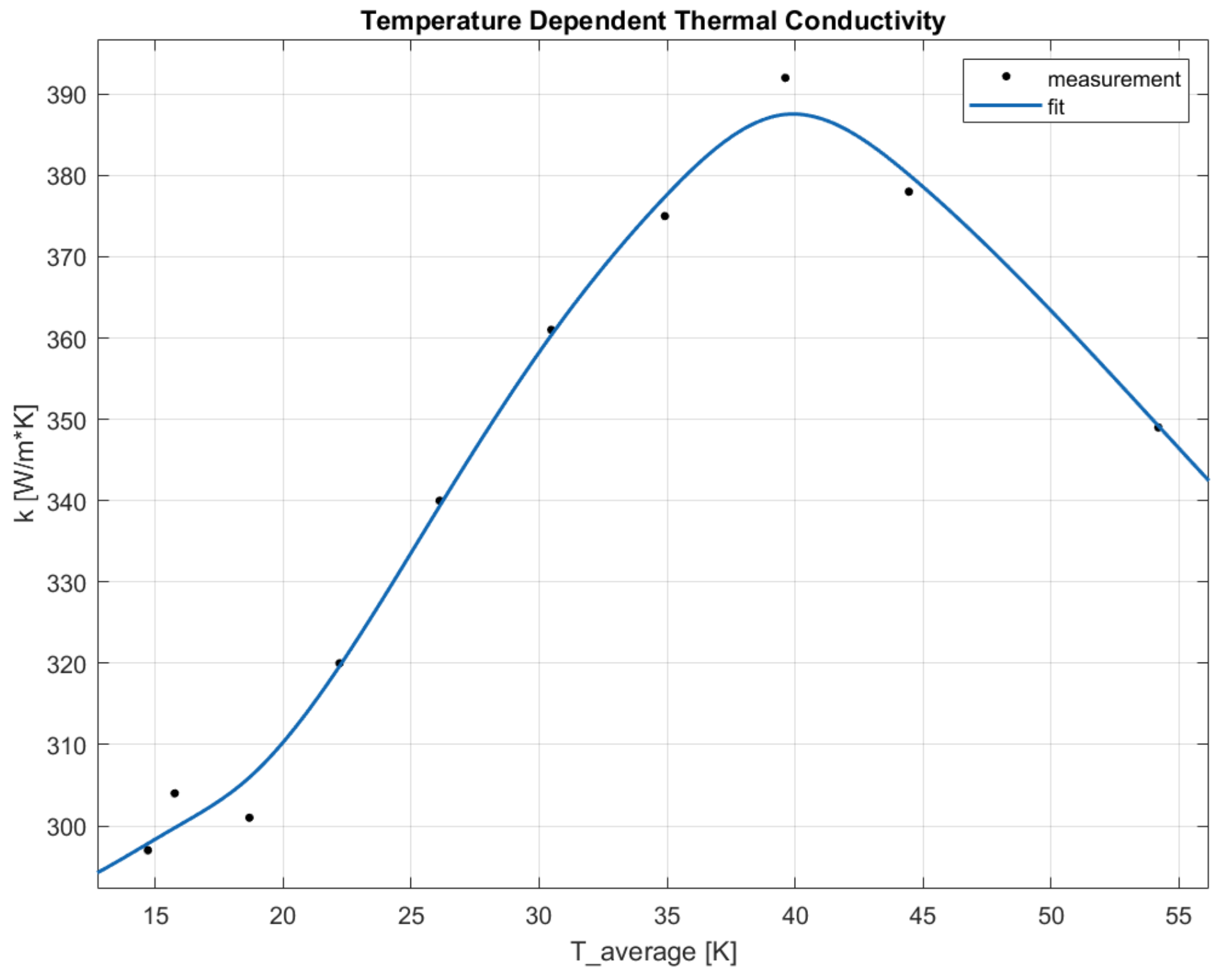
Specimen with heater blocks, thermometers and temporary support rods.



Hx – heater cartridges 25 Ohm   T0x – silicon diodes (DT-670)

Thermal conductivity is measured on different temperature levels of the specimen by applying a known DC power on H2 cartridge, while T04 was kept constant.

The thermal conductivity as a function of temperature follows the known profile of typical coppers; however, the magnitude is far below that of standard RRR=20 copper.



Conclusion

The initial experiments with the new CryPT-ON infrastructure were successfully completed, providing a broader understanding of the properties of materials produced with a new 3D printing technology. The thermal conductivity of copper components 3D-printed using ADAM technology at cryogenic temperatures falls short compared to standard coppers with RRR=20, likely due to the higher oxygen and steel content in the base material, as well as the imperfect bonding of grains during heat treatment. However, potential cryogenic applications are conceivable. In terms of vacuum tightness, the components are not vacuum-tight, but they can be made so by copper electroplating.

Special thanks to H-ION Ltd. for the 3D printed samples.

[1] Markforged, Copper material datasheet
[2] W. Czarnetzki, Thermal Wave Analysis for Measurements of Thermal Diffusivity, IEEE 1996

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