The implementation of the Additive Manufacturing for metals technology for the DTT Plant: NBI, ION SOURCE and ECRH components

Adriano Pepato
on behalf of the DIAM Lab

INFN – Padova Division

ISFNT-15 – International Symposium on Fusion Nuclear Technology

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DIAM – Development and Innovation on Additive Manufacturing

INFN – ***National Institute for Nuclear Physics***

***DIAM** lab – Internal Facility of Padua Division*

INFN PADOVA DIAM

Development & Innovation on Additive Manufacturing

Group components

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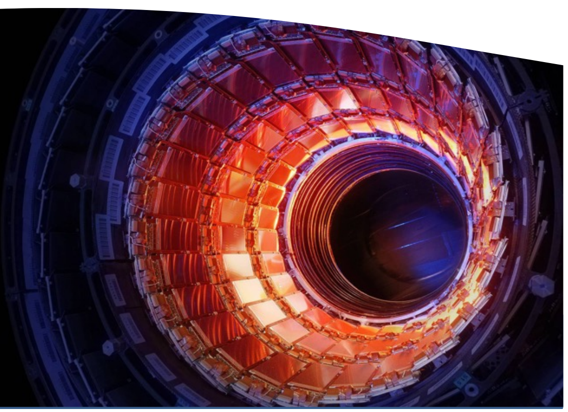
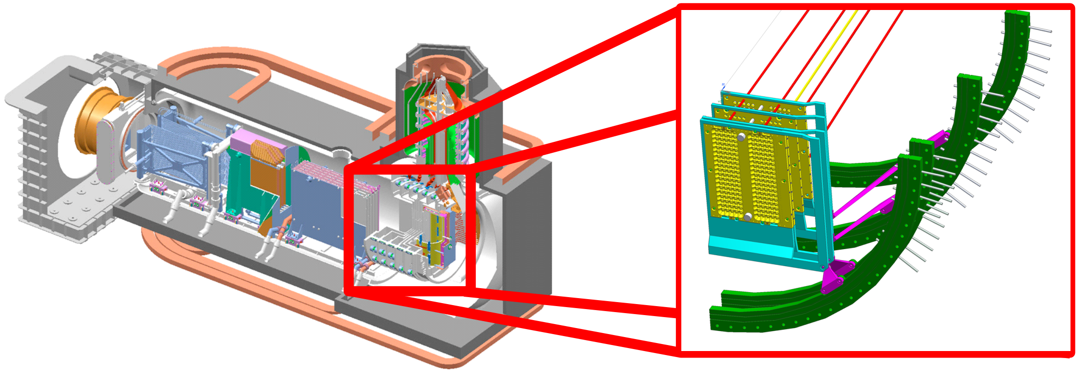
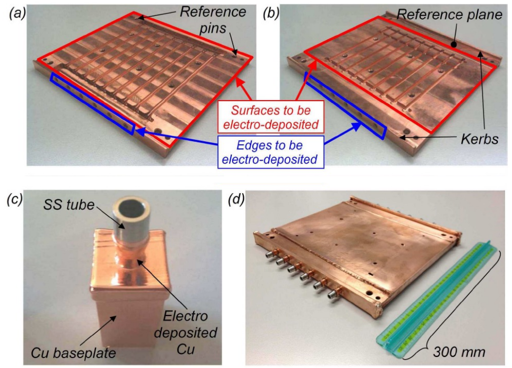
[c] Centro Ricerche Fusione (CRF), Università degli Studi di Padova, Italy



1 – Introduction (DIAM Group Origins)

Acceleration Grids





Current Manufacturing

Milled copper base (subtractive)

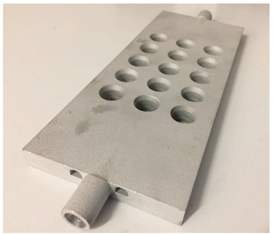
+

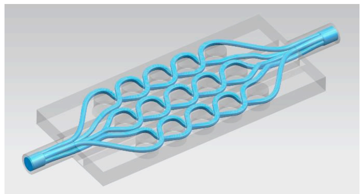
Copper electrodeposition

P. Agostinetti, G. Chitarin, N. Marconato, D. Marcuzzi and A. Rizzolo, "Manufacturing and Testing of Grid Prototypes for the ITER Neutral Beam Injectors," in *IEEE Transactions on Plasma Science*, vol. 42, no. 3, pp. 628-632, March 2014.

Alternative Additive Manufacturing

Singer, F.,et all. (2017). Additively manufactured copper components and composite structures for thermal management applications.





DIAM 1.0: POR-FSE 2016

sisma

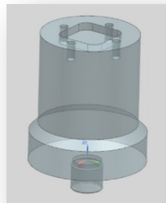
ENGIN SOFT

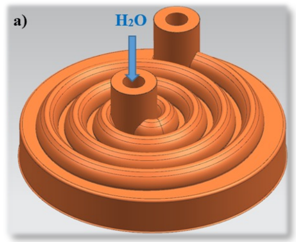
OFFICINA DEI MATERIALI

Università degli Studi di Padova

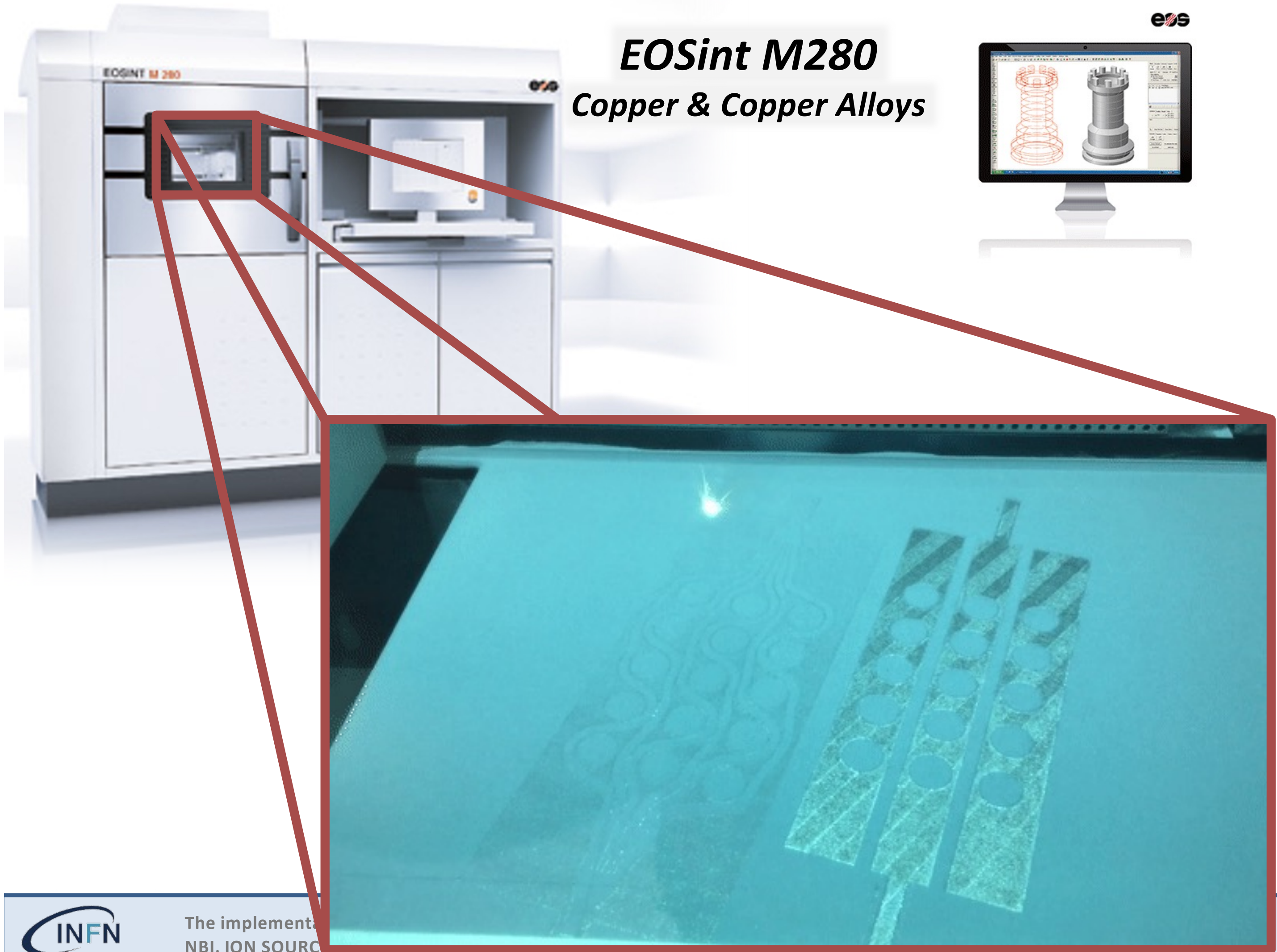
POLIDORO for excellence in combustion

OFFICINA DEI MATERIALI





Laser Powder Bed Fusion Process

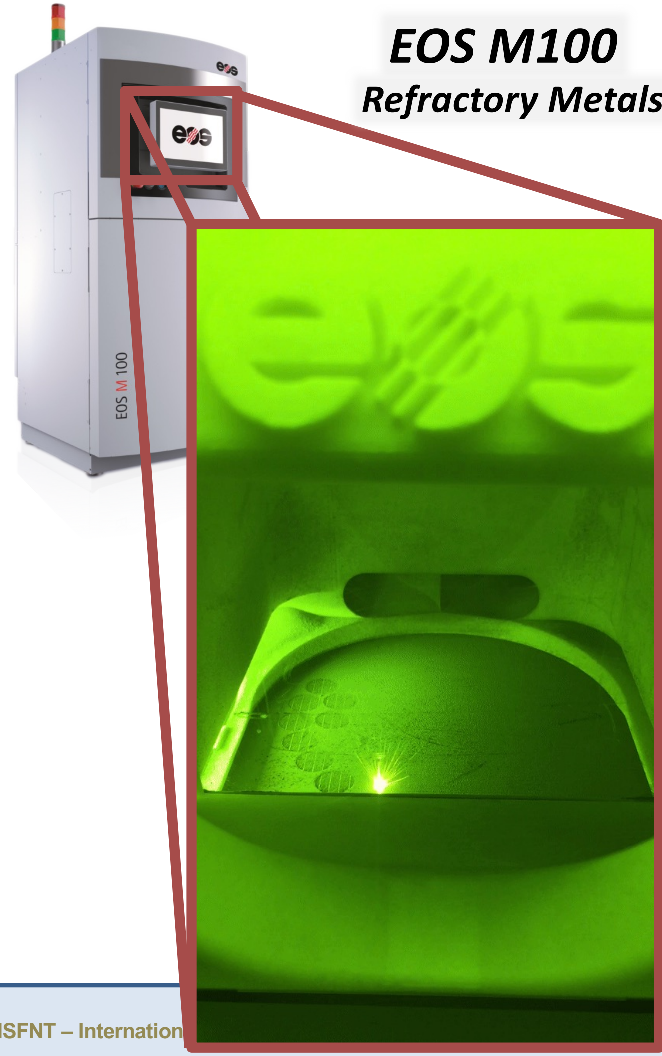


EOSint M280

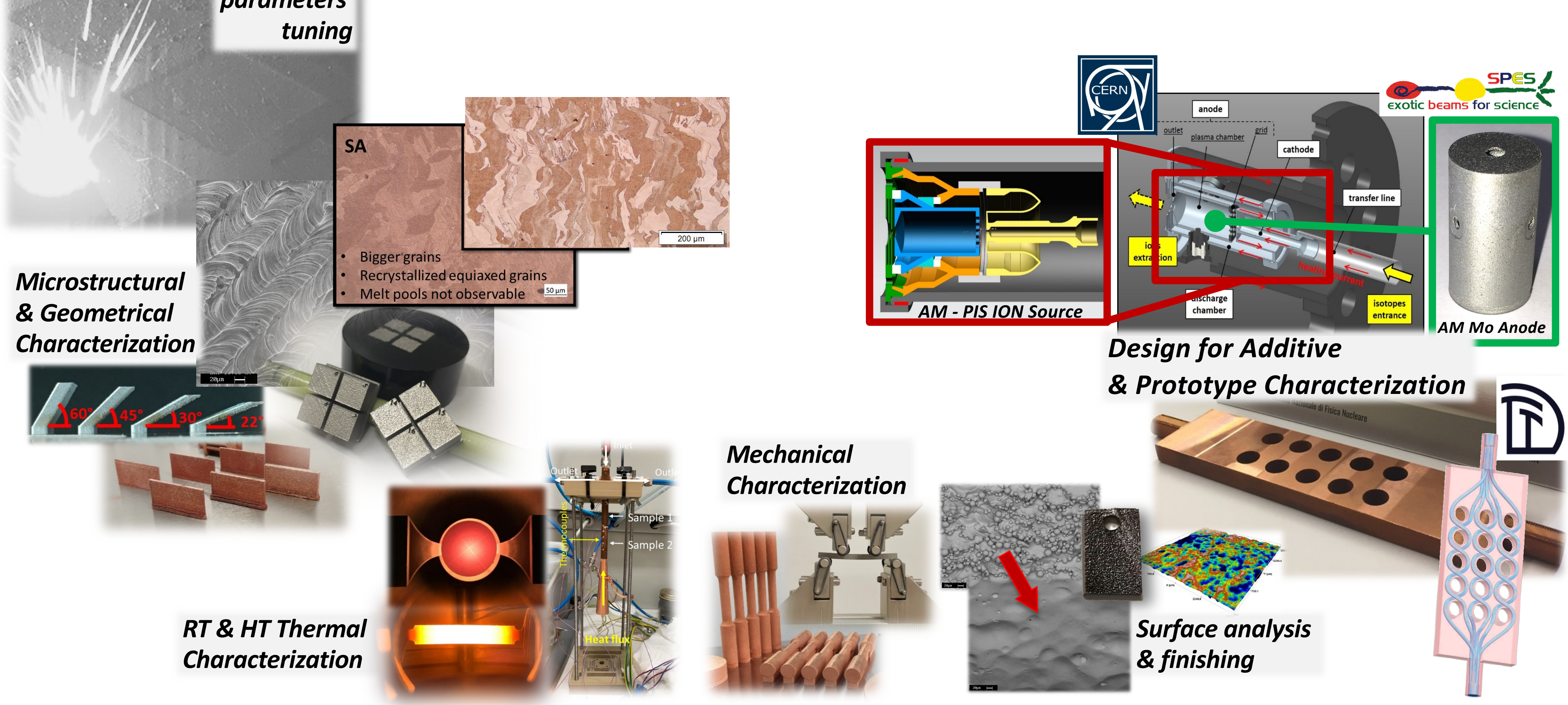
Copper & Copper Alloys

EOS M100

Refractory Metals



from MATERIAL to PRODUCT characterization



COP

@ DIAM lab:

- ✓ Pure Copper
- ✓ CuCrZr

***Physical and Chemical properties*:**

- Excellent thermal conductivity;
- Excellent electrical properties;
- Good mechanical properties (alloy);
- Good corrosion resistance;
- Anti-bacterial performances.

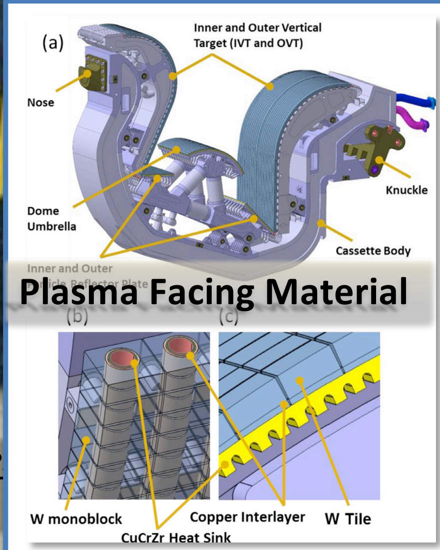
@ DIAM lab:

- ✓ Tungsten
- ✓ Molybdenum
- ✓ Tantalum
- ✓ Niobium

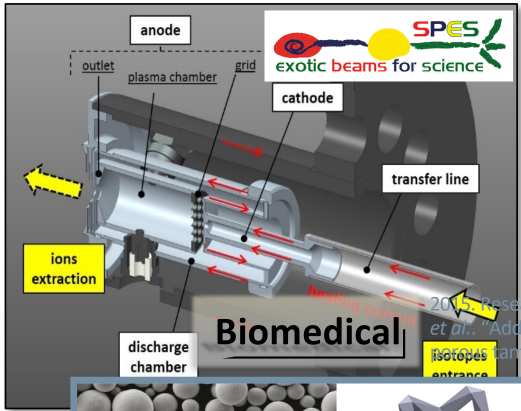
Physical and Chemical propertie

- Ultra-high melting point
- High density;
- Excellent corrosion resistance;
- Good thermal conductivity;
- Low thermal expansion;
- High strength and hardness.

Nuclear Fusion

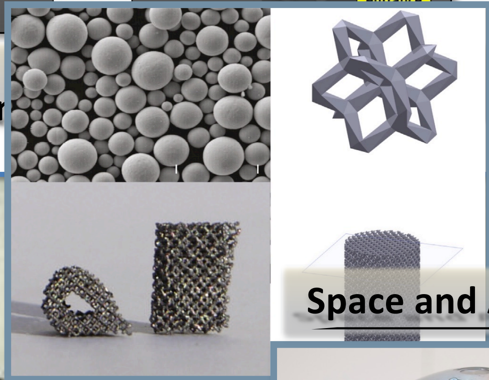


Plasma Facing Material



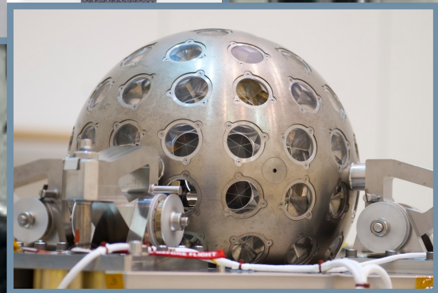
Biomedical

2015. Research paper. R. Wauthle et al.: "Additively manufactured porous tantalum implants."



Extrem

Space and Aerospace



Lares Satellite. Courtesy of LARES Team.
Produced in Tungsten

LPBF of Copper and CuCrZr

- The LPBF of pure copper is challenging mainly due to the material's high **reflectivity** and **thermal conductivity;**
- Using low power (<500W) infrared laser leads to parts with high porosity;
- The solution to this problem is to use high power (1000W) infrared laser or green laser.

Hold Points to be satisfied

Parameter type	Status in DTT NBI	Values in DTT NBI	Values in MITICA
Geometrical	1	∅ ~3 m, length ~1.3 m, weight ~5 t	length~1.8 m, height~2.8 m, width~2.8 m, weight ~13 t
Electrical	2	Total D^- accelerated current 40 A, grid voltages in kV: PG -510, EG -500, AG1 -333, AG2 -167 and GG 0	Total D^- accelerated current 40 A, grid voltages in kV: PG -1010, EG -1000, AG1 -800, AG2 -600, AG3 -400, AG4 -200 and GG 0
Mechanical	1	Grids in Cu, grid supports and flanges in AISI 316 L, insulating rings in FRP, nominal loads to be evaluated (thermal loads from electrons, ions and neutrals)	Grids in Cu, grid supports and flanges in AISI 316 L, insulators in Alumina, $P_{tot,PG}$ ~ 50 kW, $P_{tot,EG}$ ~1 MW, $P_{tot,AG1}$ ~2 MW, $P_{tot,AG2}$ ~2 MW, $P_{tot,AG3}$ ~2 MW, $P_{tot,AG4}$ ~2 MW, $P_{tot,GG}$ ~2 MW
Thermal	2	Temperature of ~150 °C for PG and BP, ~20 °C for AG1, AG2, GG, supporting frames, flanges and insulating rings at room temperature, pressure downstream of the GG < 0.05 Pa	Temperature of ~150 °C for PG and BP, ~35 °C for AG1, AG2, AG3, AG4, GG, supporting frames, flanges and insulating rings at room temperature, pressure downstream of the GG < 0.05 Pa
Hydraulic	2	Mass flow < 1 kg s^{-1} for PG/BP, < 11 kg s^{-1} for the EG and < 20 kg s^{-1} for AG1, AG2 and GG; pressure drop < 1 bar for PG/BP, < 3 bar for EG, < 4 bar for AG1, AG2 and GG, considering also the manifolds. Electrical conductivity < 0.2 μS cm^{-1} for PG, EG, AG1 and AG2, < 1 μS cm^{-1} for GG	Mass flow < 1 kg s^{-1} for PG/BP, < 11 kg s^{-1} for the EG and < 20 kg s^{-1} for AG1, AG2, AG3, AG4 and GG; pressure drop < 1 bar for PG/BP, < 7 bar for EG, < 10 bar for AG1, AG2, AG3, AG4 and GG, considering also the manifolds. Electrical conductivity < 0.2 μS cm^{-1} for PG, EG, AG1 and AG2, < 1 μS cm^{-1} for GG

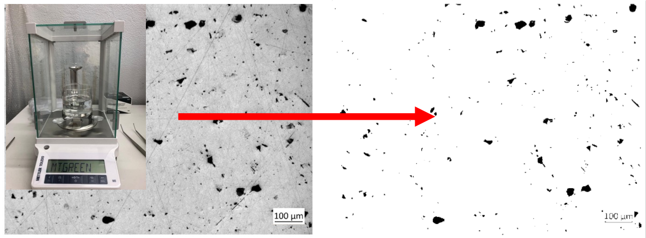
In order to satisfy requirement 2 and 4, the R&D results obtained so far indicate that the grid material must have a thermal conductance > 390 W m^{-1} K^{-1}, a yield strength > 200 MPa and a porosity < 0.1%. Moreover, the alignment between corresponding apertures in different grids must be better than 0.1 mm in cold conditions.

MATERIAL CHARACTERAZATION: density, thermo-mechanical and electrical.

ρ_{ref} = 8.89 g/cm^3 measured on an CuC2 (C10100) Pure Copper sample

Density measurements

- Archimedes method
- Optical density method

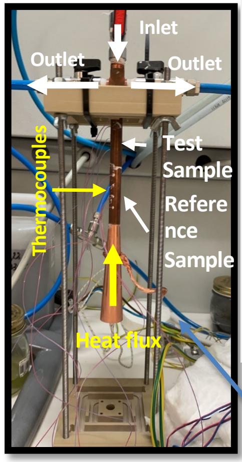


$$\rho_{bulk} = \frac{m_{dry} * \rho_{water}}{m_{dry} - m_{water}}$$

$$\rho_{rel}[\%] = \rho_{bulk} / \rho_{Ref}$$

Analysis of the cross section

Thermal conductivity measurements



- Measurements based on the physical principle of **Fourier law**
- Two samples are connected: one is a reference (Cu-OFE) and one is the sample
- The samples are heated from one side and cooled from the other
- Once in stationary condition, the gradients are measured, and the conductivity is measured
- The ASTM E1225-20 standard was followed
- Samples manufactured in both vertical and horizontal direction of printing

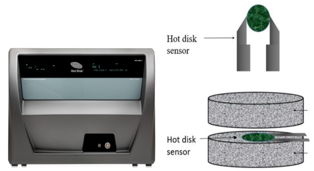
Direct Thermal Conductivity measurements

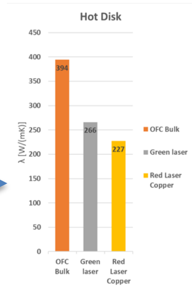
$$|\bar{q}| = k \cdot \frac{dT}{dx}$$

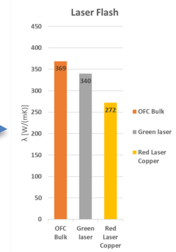
$$k_{TOP} = \frac{k_{ref} \cdot \left(\frac{dT}{dx}\right)_{ref}}{\left(\frac{dT}{dx}\right)_{TOP}}$$

k_{ref} = 396 w/mK

Measured with Hot Disk Method



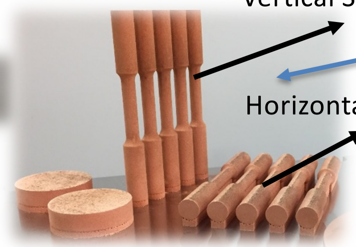




Tensile tests

Tensile test performed on samples manufactured in both horizontal and vertical direction of printing Standard ASTM E8 was followed

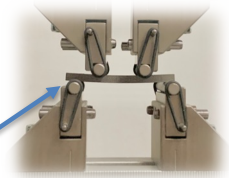
Vertical Samples



Horizontal Samples

Tensile test

Flexural test



Characterization of Additive Manufacturing (AM) copper parts

	EOS M290 1kW		TRUMPF TruPrint 5000		EOS M 400
	1 kW Infrared Laser Building Chamber: 250x250x325 mm Pure copper		1 kW Green Laser Building Chamber: Ø 300 x H 400 mm Pure copper		1 kW Infrared Laser Building Chamber: 250x250x325 mm CuCrZr
	FIRST BATCH	**SECOND BATCH**	**FIRST BATCH**	**SECOND BATCH**	
Porosity Archimede	0.64 %	0.38 %	1.04 %	1.02 %	0.63 %
Porosity Optical	0.16 %	0.18 %	0.13%	0.29%	0.29 %
Thermal conductivity [W/mK]	H 374 ± 19 V 389 ± 19	H 375 ± 19 V 376 ± 19	H 381 ± 19 V 380 ± 19	H 370 ± 19 V 374 ± 19	H 300 ± 15 V 323 ± 16
Yield Strength [MPa]	H 160.0 ±2.8 V 165.3 ± 4.6	H 159.3 ± 0.6 V 161.7 ± 1.2	H 139.7 ± 0.6 V 137.3 ± 2.1	H 140.3 ± 1.5 V 142.3 ± 3.8	H 199.3 ± 4.7 V 169.3 ± 27.0
Ultimate Tensile Strength [MPA]	H 224.9 ± 1.8 V 223.7 ± 0.5	H 225.9 ± 0.1 V 224.9 ± 0.6	H 221.2 ± 1.4 V 200.4 ± 0.1	H 211.6 ± 4.1 V 192.7 ± 4.8	H 340.9 ± 3.0 V 283.3 ± 20.5
Young Module [GPa]	H 125 ±4 V 124 ± 3	H 117 ± 7 V 127 ± 4	H 136 ± 3 V 124 ± 5	H 113 ± 5 V 112 ± 6	H 128 ± 1 V 106 ± 4
Elongation at Break	H 53 ± 1% V Over 50%	H 51 ± 1% V Over 50%	H Over 50% V Over 50%	H 49 ± 1% V 31 ± 2%	H 35 ± 1% H 36 ± 1%

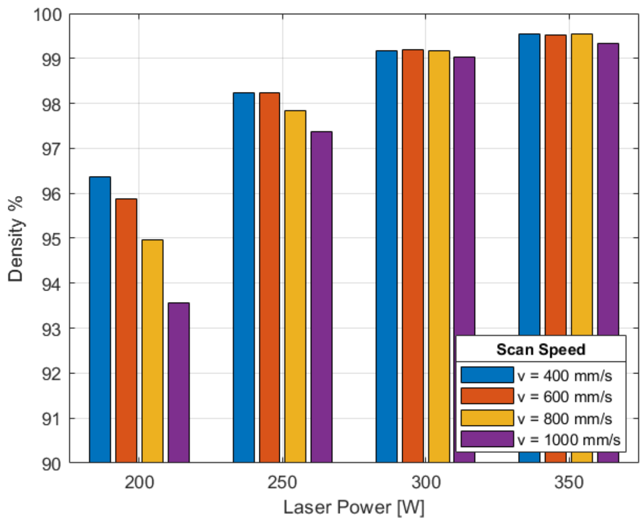
- EOS samples show constant results
- TRUMPF’s second Batch shows similar result, except for the optical porosity and the elongation at break.

Laser Powder Bed Fusion of Copper and Copper alloys

CuCrZr – Parameters optimization & Thermal conductivity & Resistivity

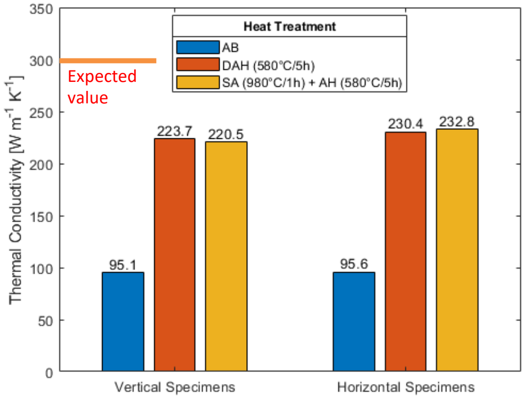
Parameters optimization

- Layer thickness: 20 µm
- Hatching Distance: 90 µm



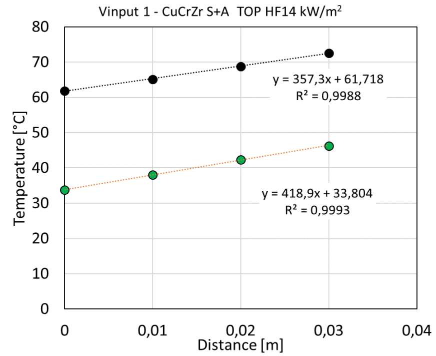
Thermal conductivity analyses

Transient Hot Disk TPS 2500 S



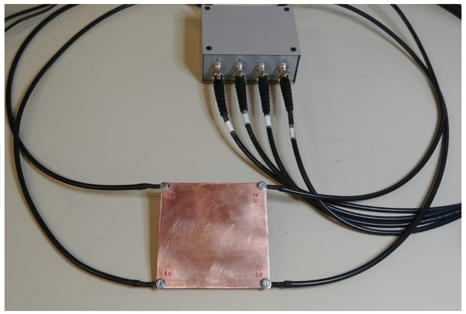
q	(dt/dx) Ref	(dT/dx) TOP	dev	k ref	k TOP
[W/m2]	[K/m]	[K/m]	[%]	[W m-1 K-1]	[W m-1 K-1]
14	357,3	418,9	-17,2	396	337,8

Direct Thermal Conductivity measurements

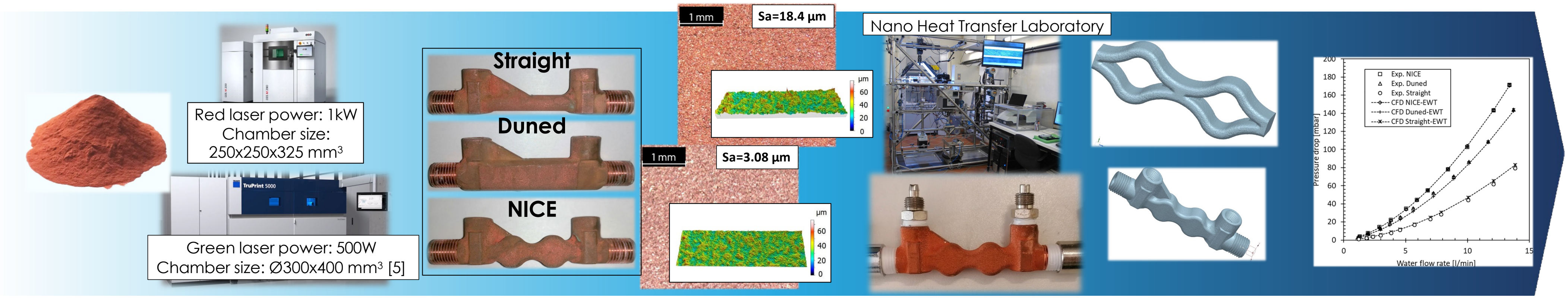


	AB	AB Polished	DAH	DAH Polished	S+A	S+A Polished
ρ [ohm*cm]	9,36E-06	8,62E-06	3,54E-06	2,13E-06	2,57E-06	2,03E-06
DEV [ohm*cm]	5E-08	4E-08	4E-08	4E-08	6,0E-08	4,0E-08
%IACS	18,42	20,00	69,61	80,79	67,01	85,02

4 Point Probe Method

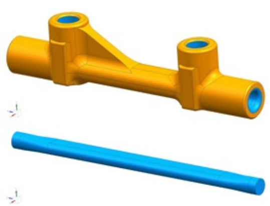


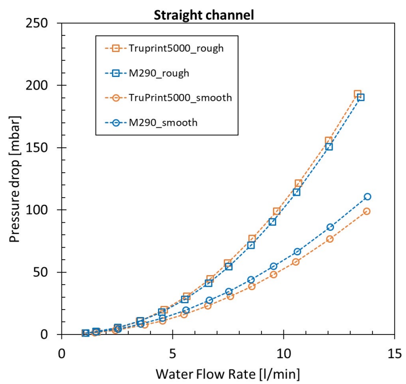
The integrated cooling system: performance optimization and pressure drop minimization.

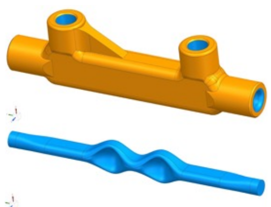


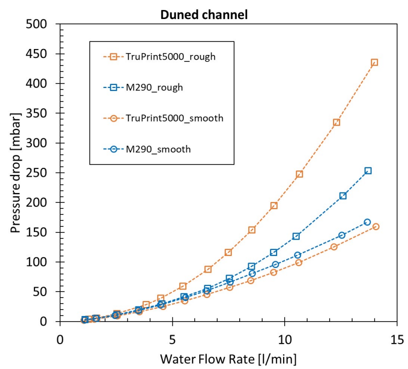
Pure Cu metal powder | **LPBF machines** | **6 channels samples** | **Chemical finishing treatment** | **Pressure drop tests before and after finishing** | **X-ray computed Tomography verification** | **CFD calibration-smooth channel**

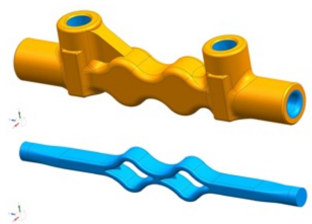
RESULTS

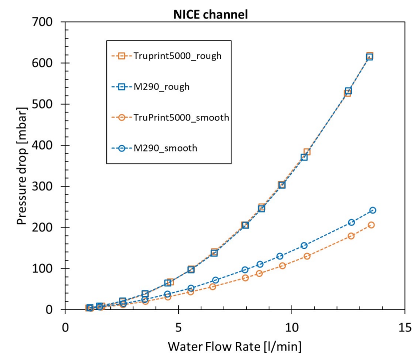












AM implementation to the Accelerator grids': design evolution.

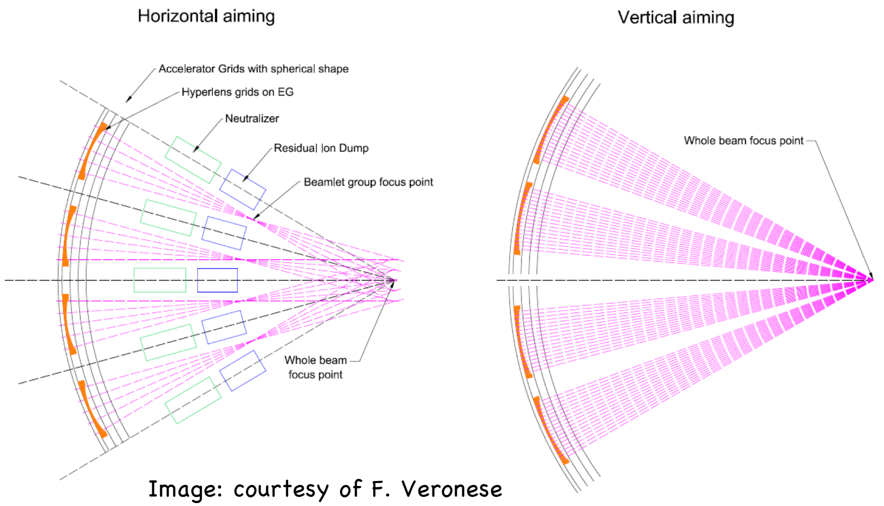
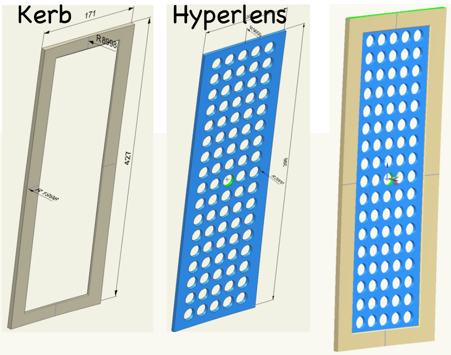
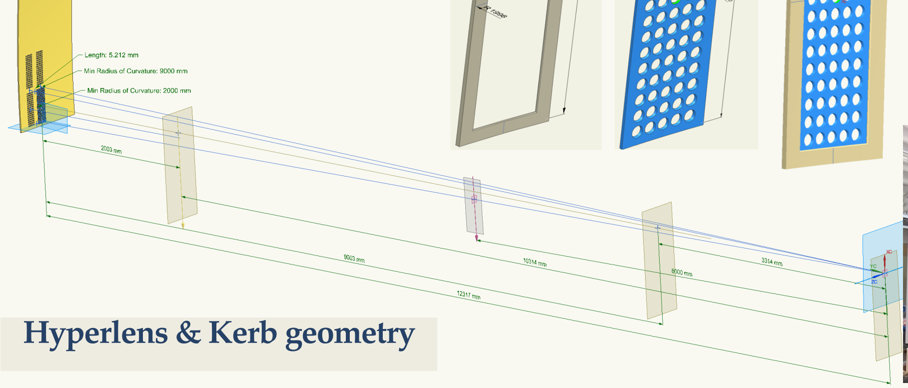


Image: courtesy of F. Veronese

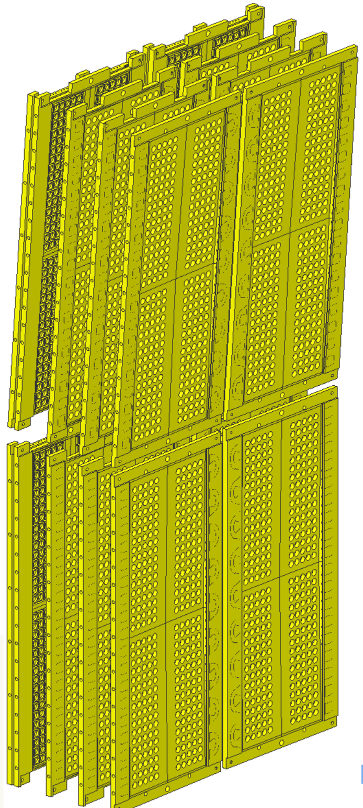
Both of them present double curvature radius on Beam OUT side (9000mm and 12000mm) and one on Beam IN side (12317mm)





Hyperlens & Kerb geometry

Original multi plane grid design

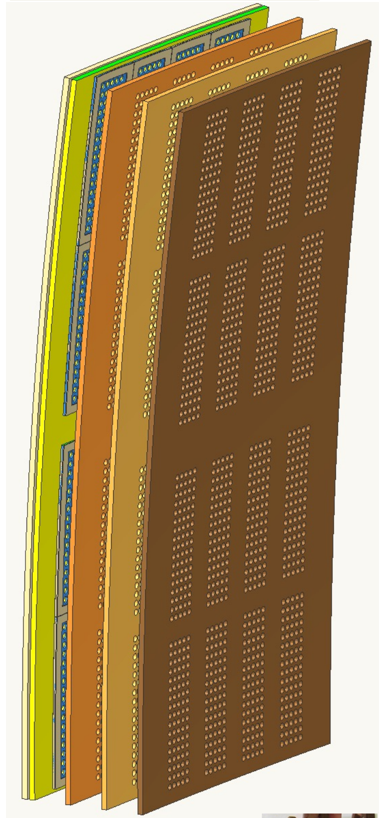


Acceleration Grids (5 layers)
Plasma Grid (PG)
Extraction Grid (EG)
Acceleration Grid 1 (AG 1)
Acceleration Grid 2 (AG 2)
Grounding Grid (GG)

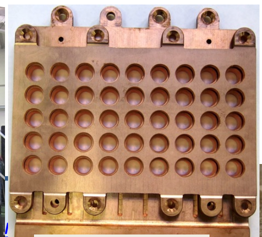
Main MODIFICATIONS:
1. **TECHNOLOGY: Additive Manufacturing**
2. SHAPE: **SPHERICAL**
3. grids' THICKNESS: **11mm -> 14mm**
4. cooling channels' GEOMETRY: **optimized**

Additive Manufacturing advantages:
- Manufacturing process: less time, less complicated -> better reliability
- Possibility of printing (raw production) of 5 quarter-grid in a single batch
- Flexibility of design (especially of the cooling channels)

New spherical grid design

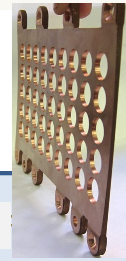


5Axis Milling centre OKUMA



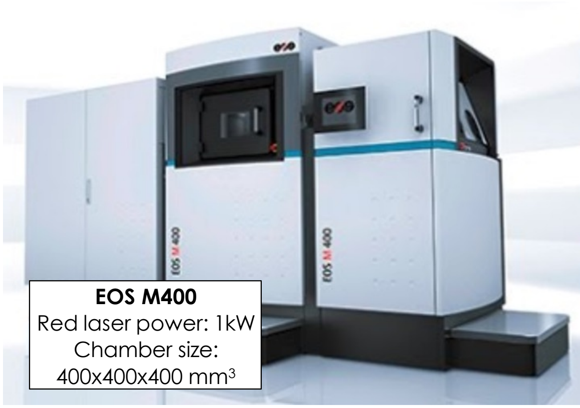
EG & Hyperlens

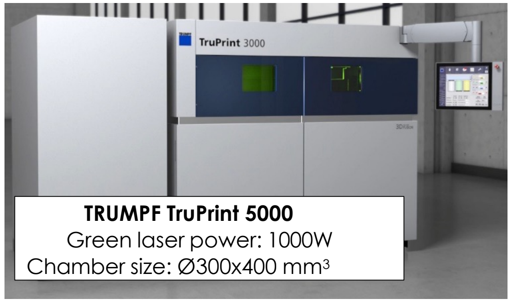
Kerb



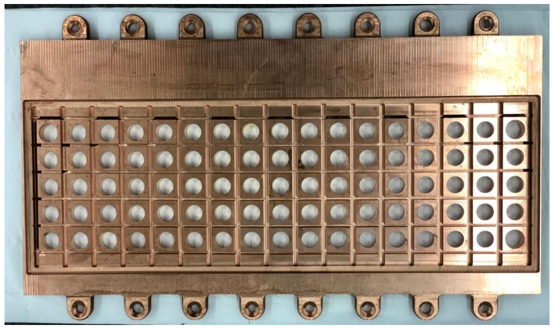
Hyperlens

Prototyping: material and laser technology selection





Pure copper



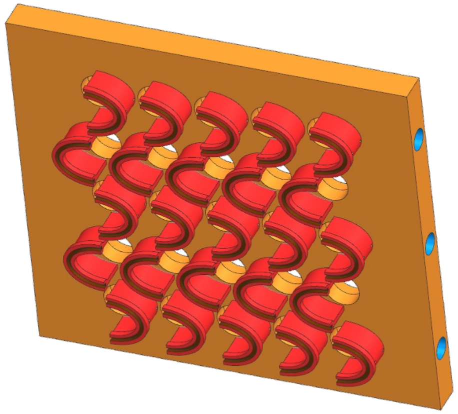
CuCrZr

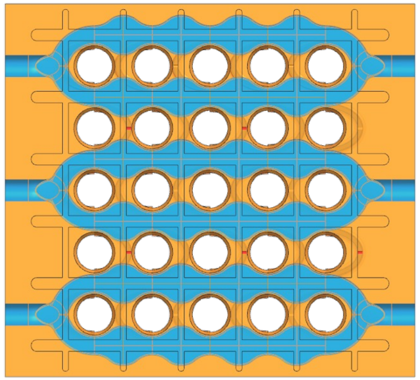
Pure copper

Two batches of pure copper have been tested

The cooling system performance: test setup and CFD optimization.

C-shaped ears to reproduce the control of the heat flux



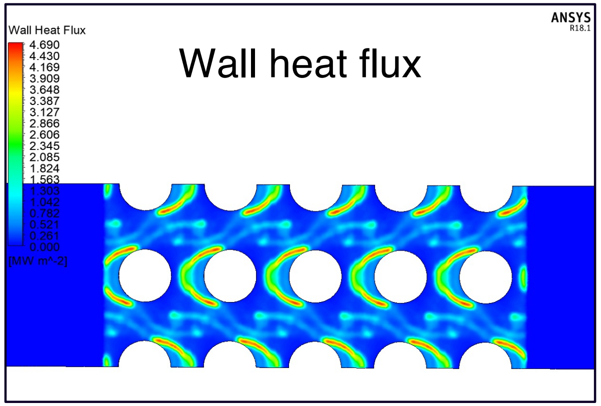


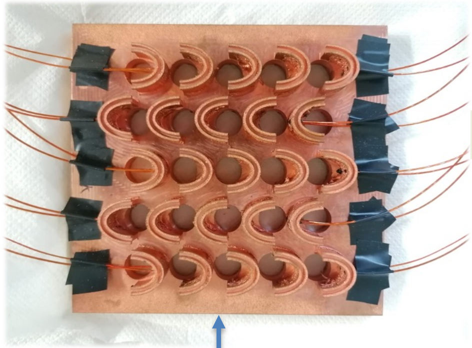
135

145

Duned cooling channels layout

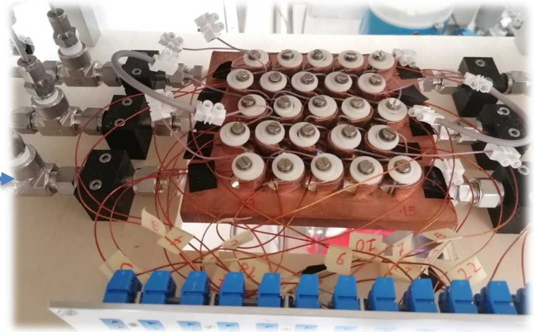
5x5 beamlets



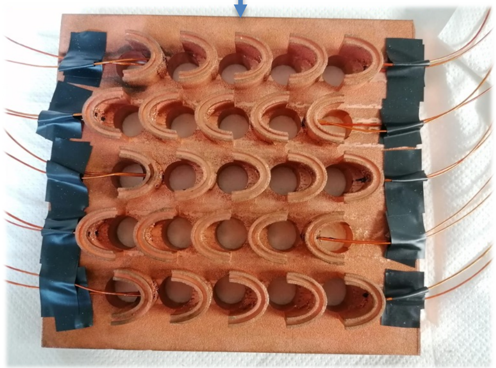


Cu pure, red laser 1 kW

Three prototypes manufacturing

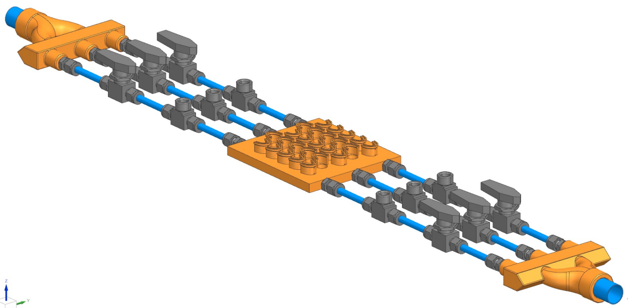


CuCrZr, red laser 1 kW

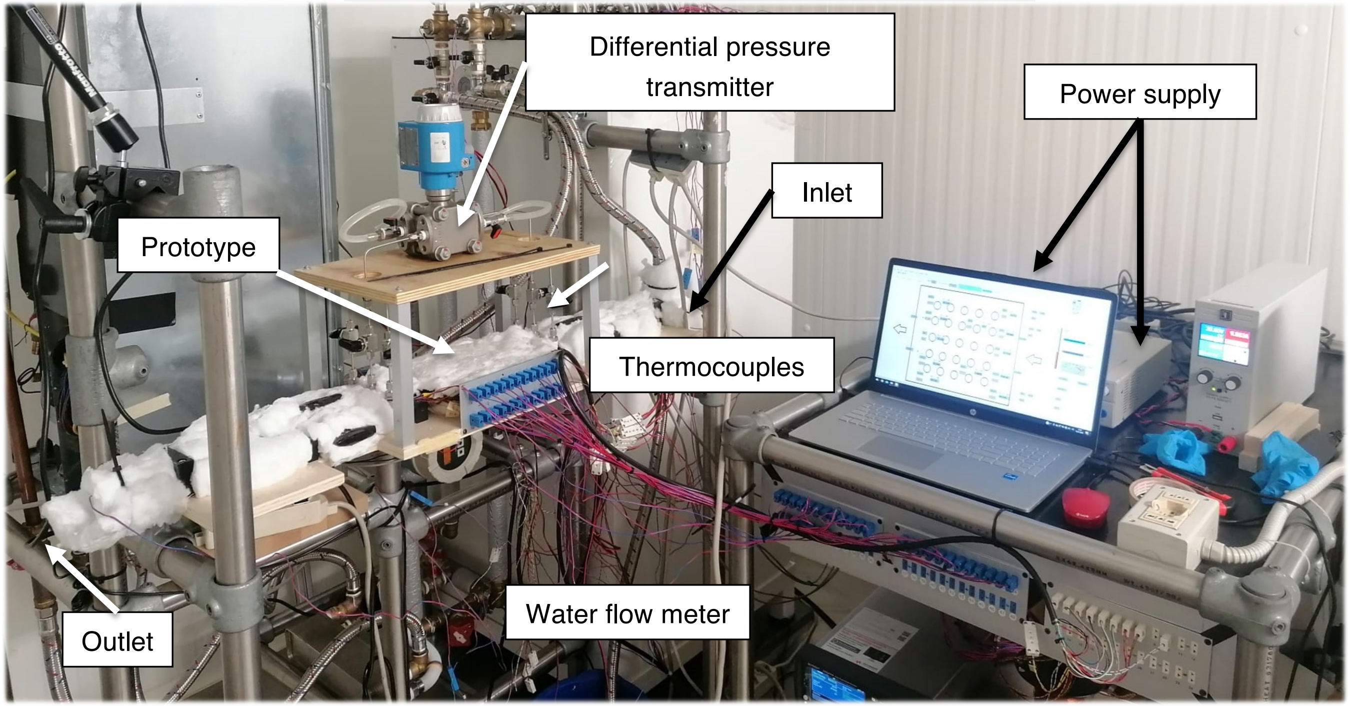


Cu pure, green laser 1 kW

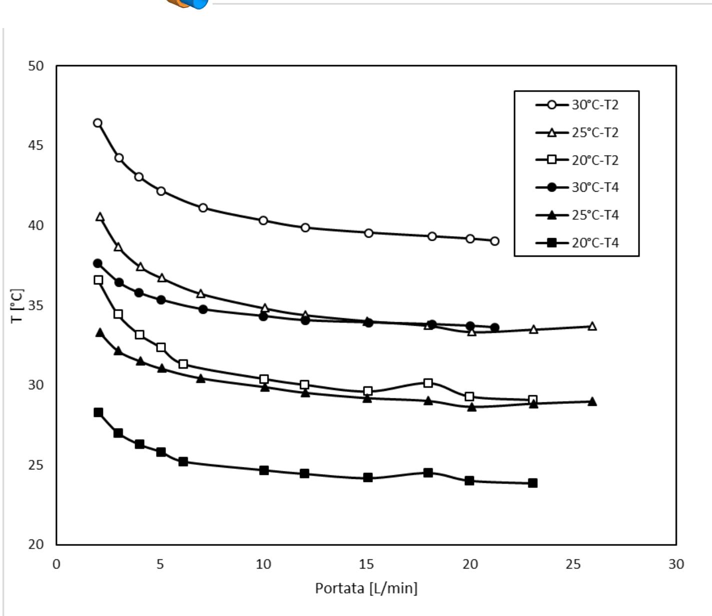
Experimental lab tests



Experimental setup



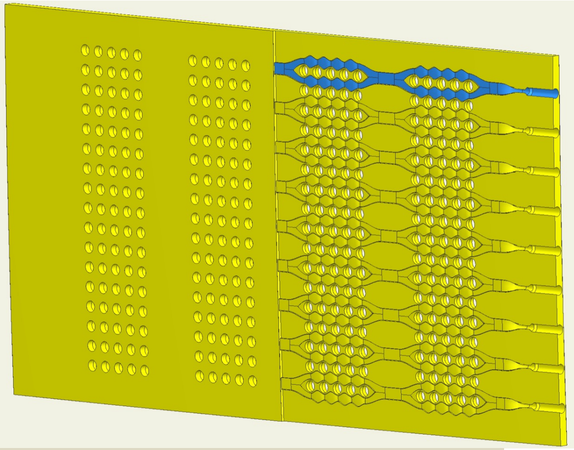
Temperature data



Conditions tests:

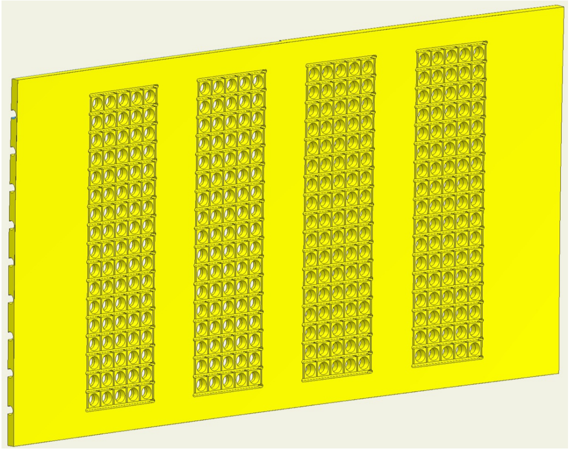
- Total heat flux 500 W
- Room temperature 20°C

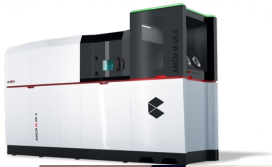
AM production of FULL-SCALE Accelerating Grids for the DTT NBI



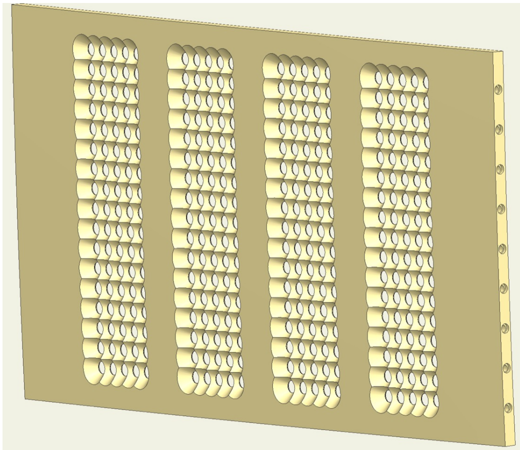
EG raw blank
Dim: 880x450x17 [mm]

The raw blanks are printed with a stock material of about 0.5 mm/side

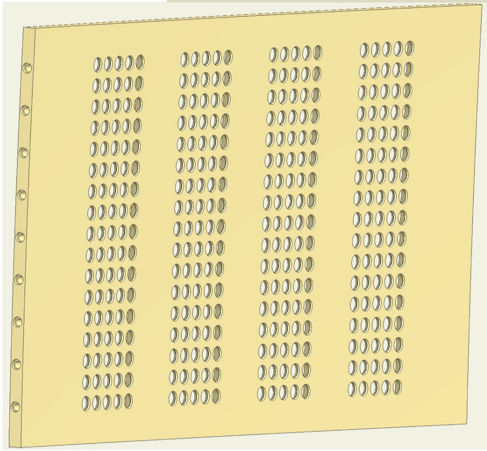




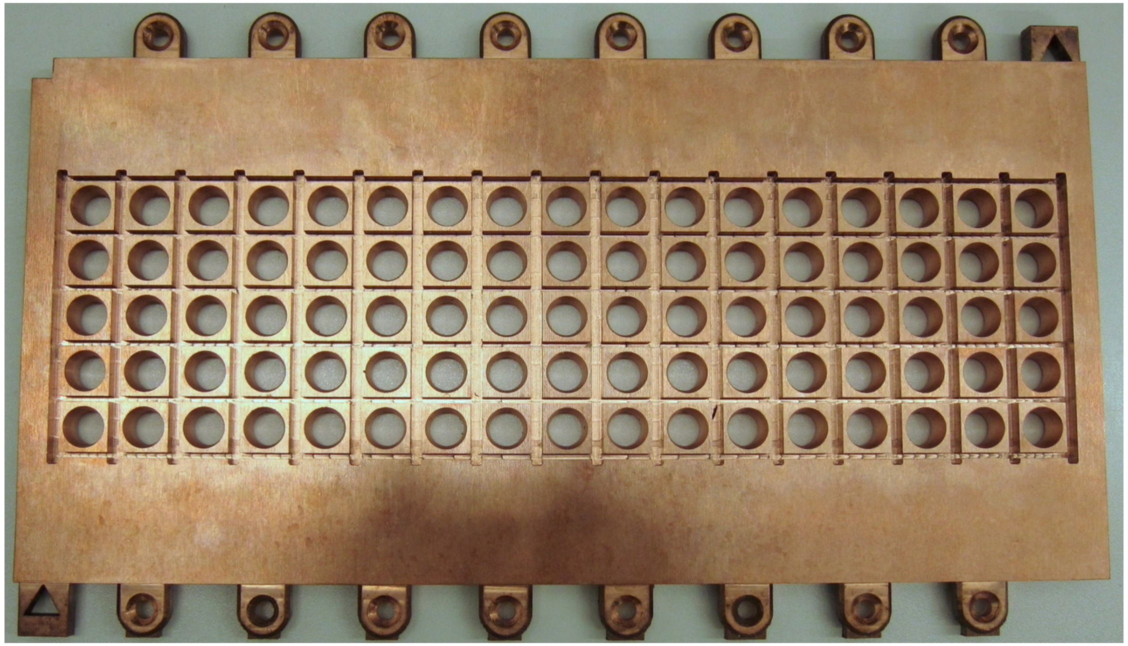
AMCM M4K:
- 4 laser 1 kW
- Dim: 450x450x1000 [mm]



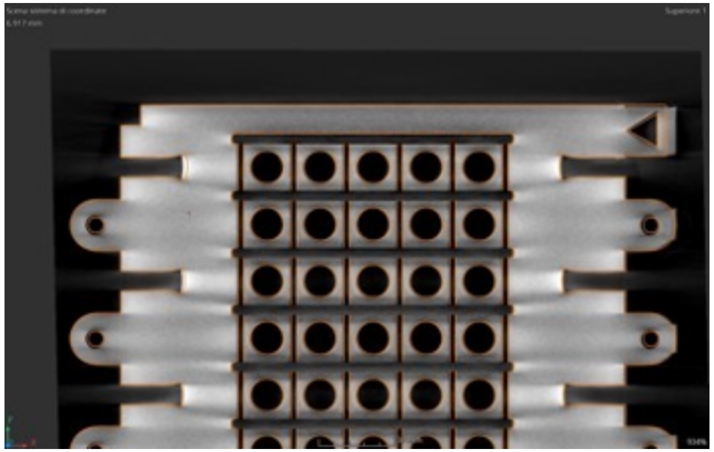
PG raw blank
Dim:880x450x17 [mm]

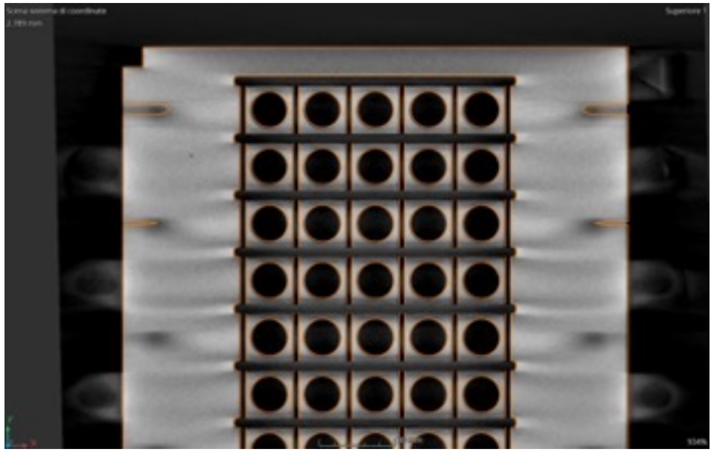


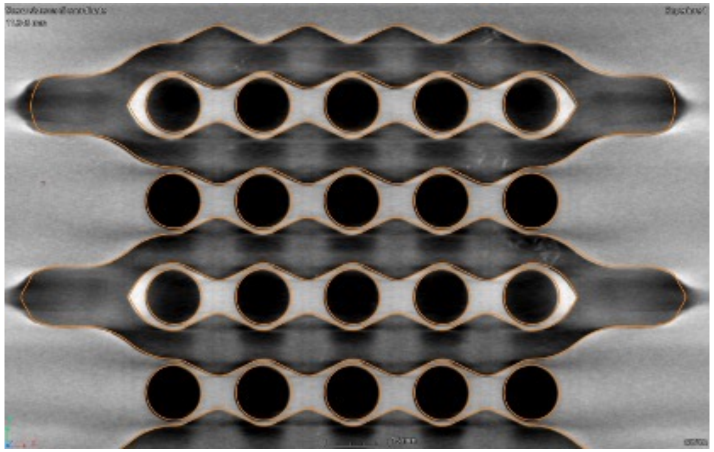
Quality assurance: tomographic scan.



- The surface material quality CuCrZr was excellent during the milling of the raw blank.
- The tomographic scan to recover the integrated cooling system geometry reveals an excellent correspondence with the design as well as the alignment of parts.



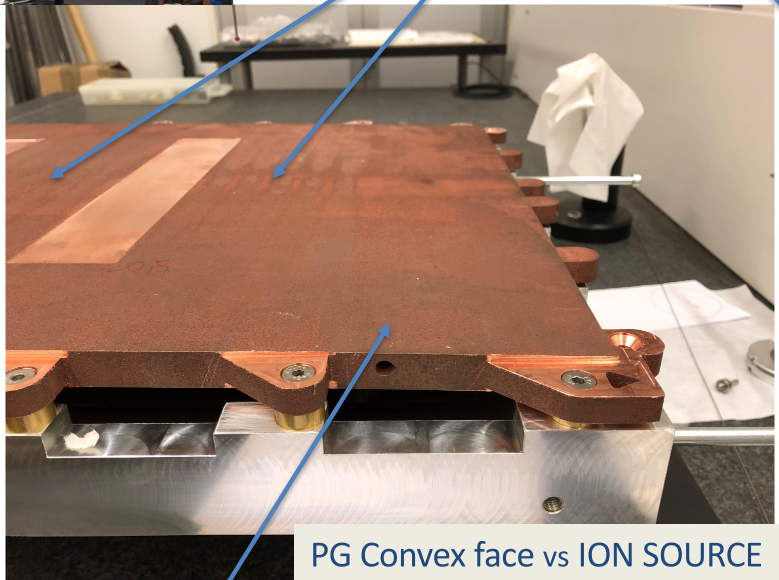


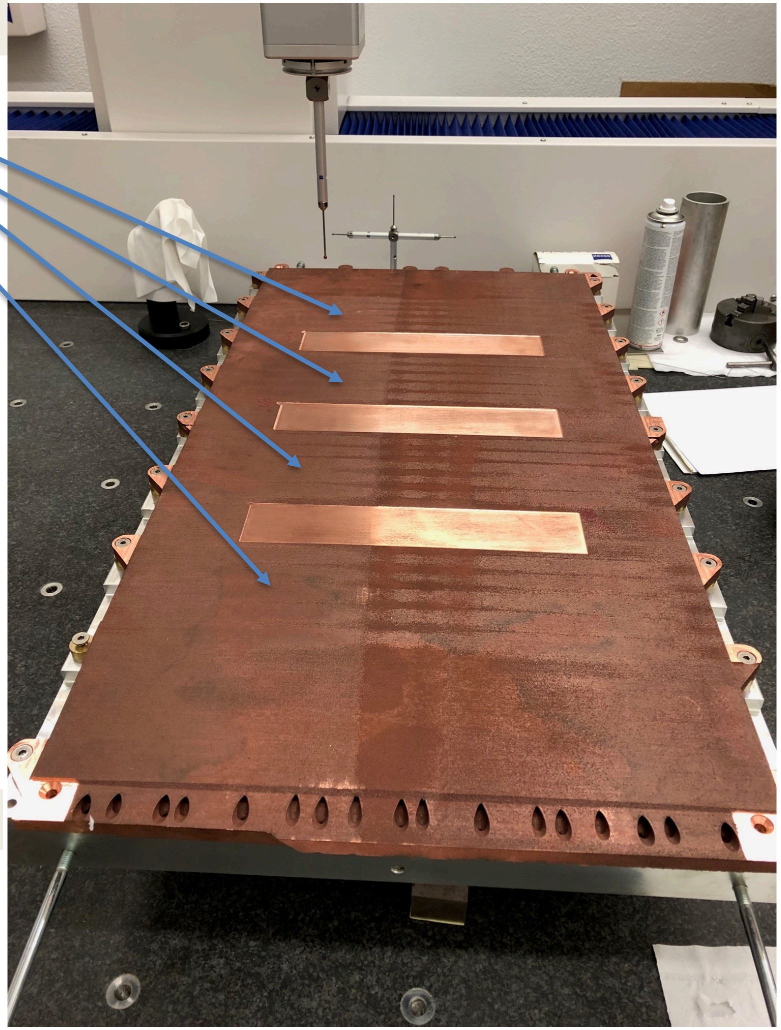


Quality assurance: metrology VS milling.
PG of the DTT NBI NAP – AM CuCrZr

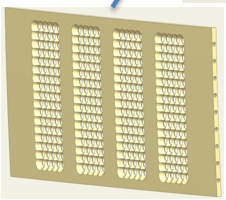
5Axis Milling centre OKUMA

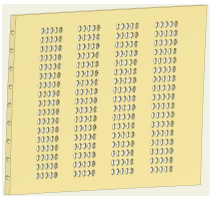
Beamlets: 4x17x5





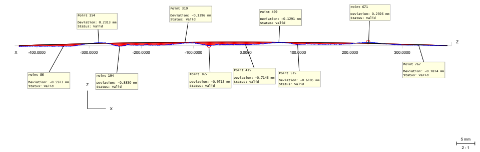
PG Convex face vs ION SOURCE





ZEISS Calypso 7.0.16	Carl Zeiss		Date September 8, 2023 Order
Part Number 1	CMM Type ACCURA_MASS	Drawing No.	Department: Operator Master
Meas. Plan Name	PG prototype 025 Phase 1		Signature:

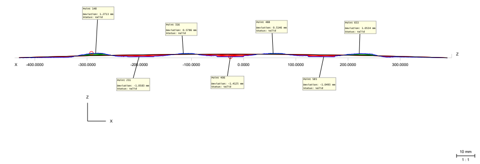
1: Curve Y-150



No	Identifier	Sigma [mm]	Form [mm]	Number of Points	Lower Tol. [mm]	Upper Tol. [mm]	MinInd	Min Dev. [mm]	MaxInd	Max Dev. [mm]	Best Fit	X [mm]	Y [mm]	Z [mm]		X	Y	Z
1	Curve Y-150	0.4698	1.3466	822	0.0000	0.0000	365	-0.9715	670	0.3751	Translation	0.0000	0.0000	0.0000	Rotation	0.0000	0.0000	0.0000

ZEISS Calypso 7.0.16	Carl Zeiss		Date September 8, 2023 Order
Part Number 1	CMM Type ACCURA_MASS	Drawing No.	Department: Operator Master
Meas. Plan Name	PG prototype 025 Phase 1		Signature:

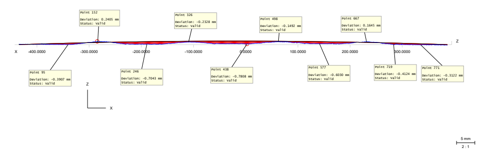
1: Curve Y0



No	Identifier	Sigma [mm]	Form [mm]	Number of Points	Lower Tol. [mm]	Upper Tol. [mm]	MinInd	Min Dev. [mm]	MaxInd	Max Dev. [mm]	Best Fit	X [mm]	Y [mm]	Z [mm]		X	Y	Z
1	Curve Y0	0.7178	2.7669	822	0.0000	0.0000	406	-1.4125	140	1.3545	Translation	0.0000	0.0000	0.0000	Rotation	0.0000	0.0000	0.0000

ZEISS Calypso 7.0.16	Carl Zeiss		Date September 8, 2023 Order
Part Number 1	CMM Type ACCURA_MASS	Drawing No.	Department: Operator Master
Meas. Plan Name	PG prototype 025 Phase 1		Signature:

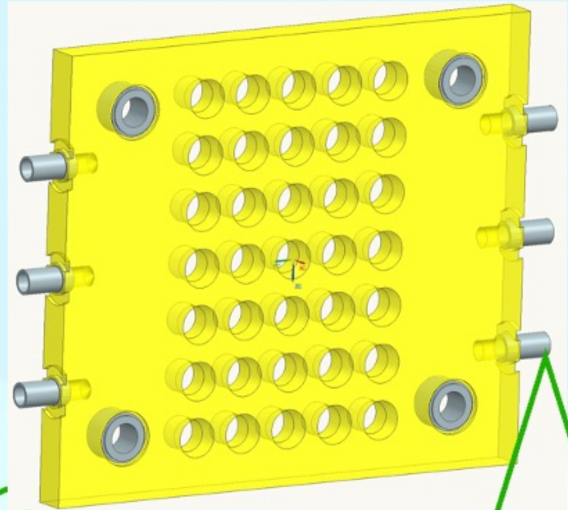
1: Curve Y150

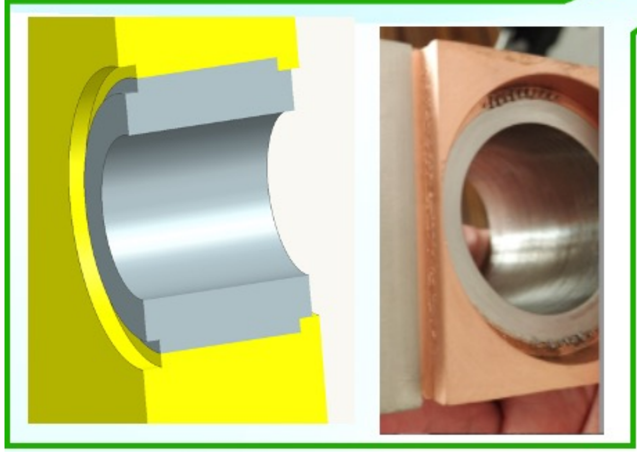


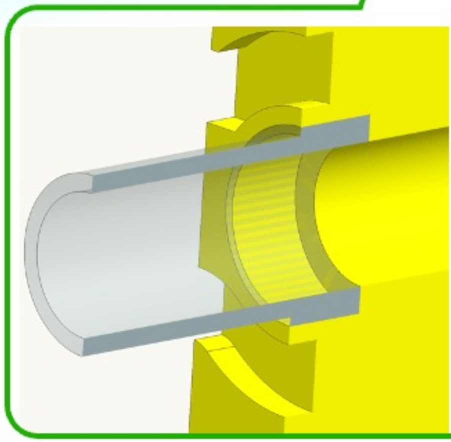
No	Identifier	Sigma [mm]	Form [mm]	Number of Points	Lower Tol. [mm]	Upper Tol. [mm]	MinInd	Min Dev. [mm]	MaxInd	Max Dev. [mm]	Best Fit	X [mm]	Y [mm]	Z [mm]		X	Y	Z
1	Curve Y150	0.4280	1.0757	822	0.0000	0.0000	438	-0.7808	151	0.2949	Translation	0.0000	0.0000	0.0000	Rotation	0.0000	0.0000	0.0000

Connectivity of Additive Manufacturing parts: Copper to AISI316LN

EBW connections
- Cooling ducts (AISI316LN)
- Connection inserts (AISI316LN)

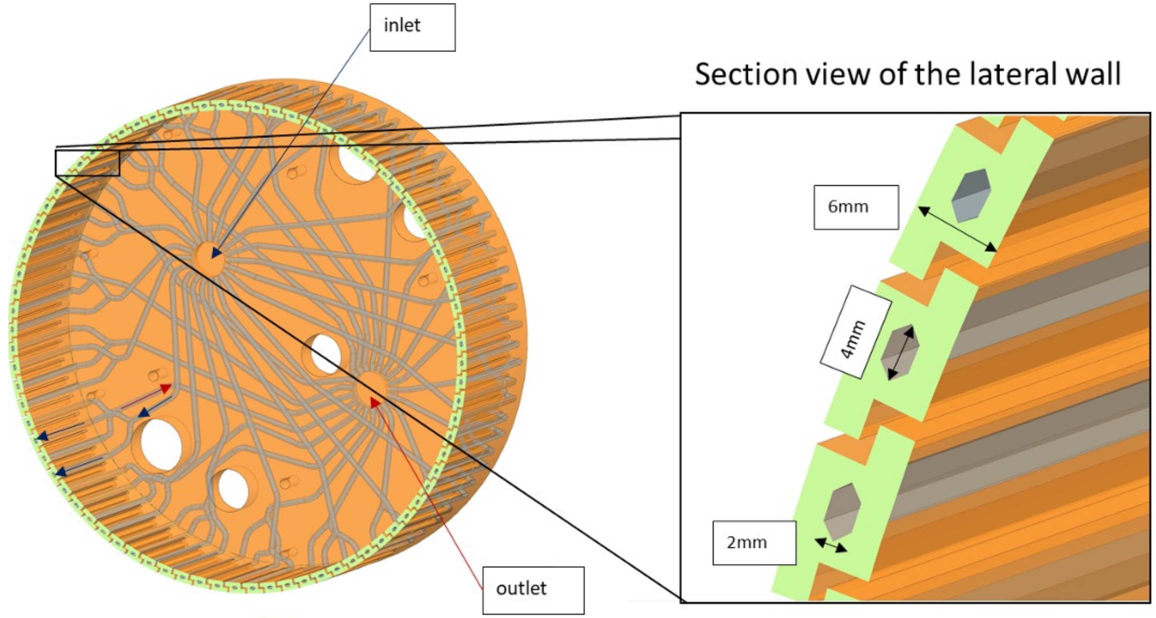




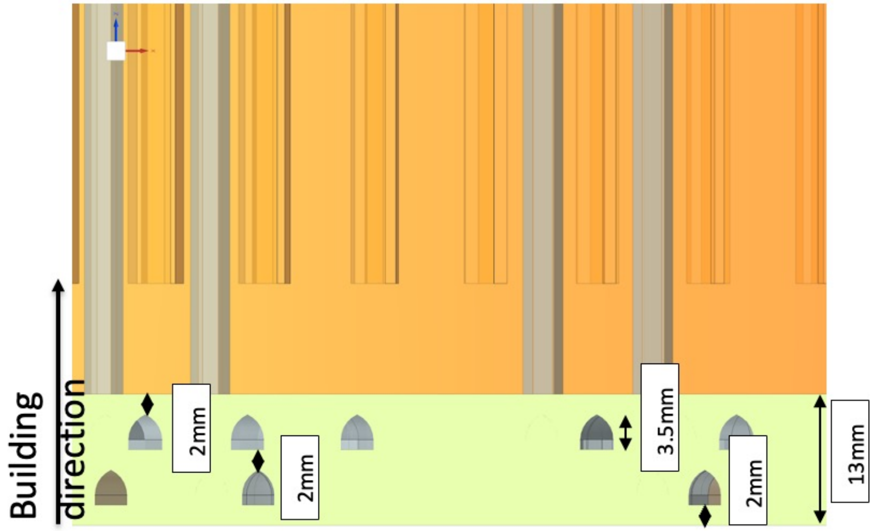


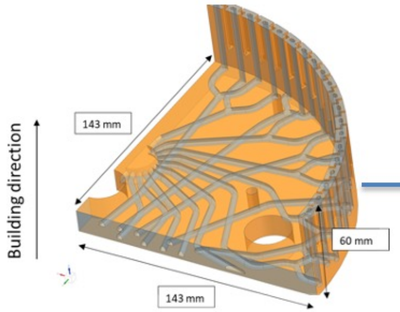
DTT AM applications for the ION SOURCE: Faraday Shielding

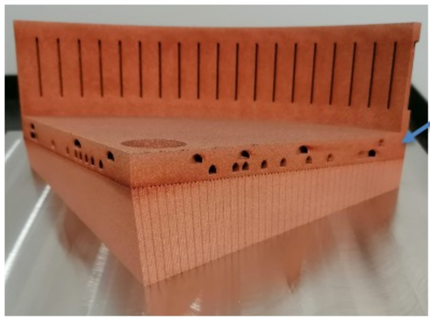
Section view of the lateral wall



Section view of the base wall







Faraday shielding – prototype manufacturing

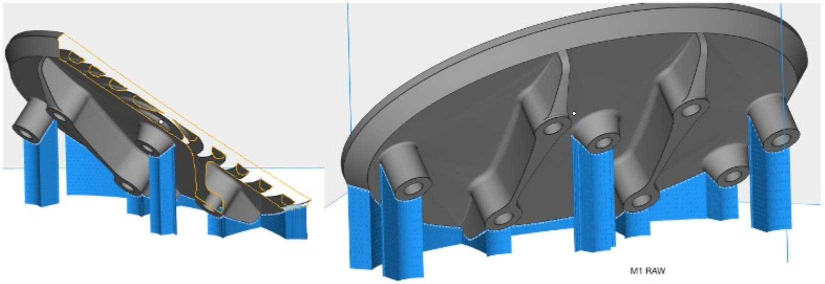
Self-supporting cooling channels after the AM process.

DTT AM applications for the ECRH: M1 MIRROR FOR THE LAUCHER

LPBF of Mirror M1

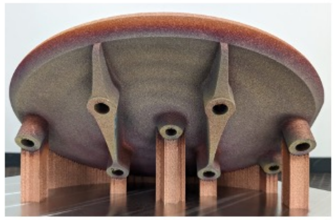
Print Orientation

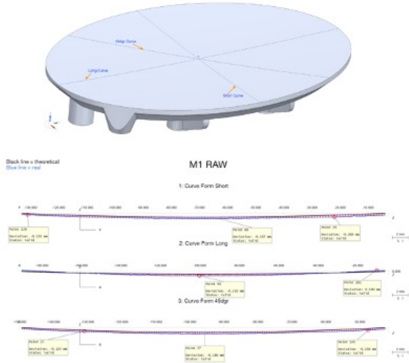
This positioning of the piece allows to avoid an excessive use of supports starting from the platform. Also, internal channels are not supported.



Succesfull print

Few defects on unsupported regions have been observed
Small deviation from CAD was measured





Post-process

- Heat treatments: Solubilisation and aging on Hot Isostatic Pressing oven
- Leak and Pressure Tests
- Mechanical and/or chemical polishing of reflecting surface (performed by INFN or externally)

I invite you to attend to these two posters on the Thursday Session at h=16.15 (14.09.2023):

- *PS3- TOPIC F. Nuclear System Design – PS3-91b: A. Salvitti*
- *PS3 – TOPIC E. Vacuum Vessel and Ex-vessel Systems – PS3-67: A. Moro*

Conclusions

- The R&D program on the AM for Metals implementation performed at DIAM INFN PD, demonstrates that this technology offers extremely challenging opportunities with consistent reduction on costs, production time and morphological improvements for complex geometries.
- We are finalizing the design of the **supporting structures of the accelerating grids** with a sandwich like structure that integrates the cooling ducts offering much higher stiffness while giving large openings for the vacuum requirements (base material: INCONEL 718).
- We are defining the design of the **Strap Antennas of the ICRH** (INCONEL 718 or CuCrZr).
- The R&D study for the W or W alloy for the controlled porosity structures of the Divertor is well developed (EOS Turku Finland: see the backup slide of the R&D programme of Eng. Silvia Candela).
- The **post processing of the AM PG and EG** is ongoing. We'll produce a full-scale prototype for each of the remaining grids as well as for their corresponding supporting structures.
- The integration and assembly test of a quarter of the NBI Accelerating system will be done within few years.

PhD Programmes

To support the advancement of knowledge in this field, **three PhD scholarships** and **a research grant** have been secured, with their activities scheduled to begin between October and November 2023. The INFN will fund two of the PhD scholarships, and the DTT project will fund the third.

The PhD programmes are:

- Characterization of the **fatigue life** of additively manufactured pure copper and copper alloys (funded by DTT);
- Characterization of the **erosion and corrosion** of AM pure copper and copper alloys;
- Research and development of **new heat exchange systems** (e.g. gyroids) enables by the LPBF process.

The research grant from I.FAST will enable **multi-physical simulations** of components produced using metal additive printing. The primary goal of this project is to study superconductive cavities and components for ion beam acceleration lines.

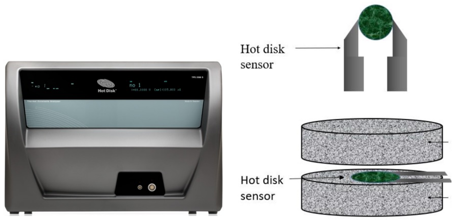
THANKS FOR YOUR ATTENTION

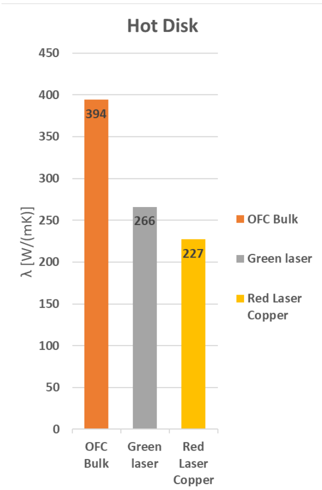
BACKUP SLIDES

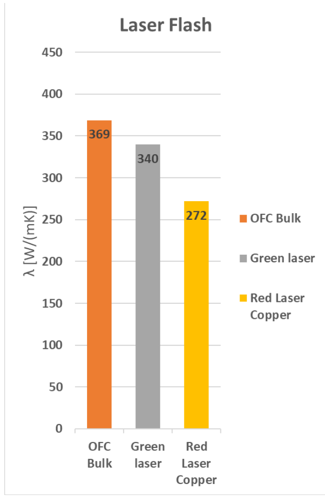
email: adriano.pepato@pd.infn.it

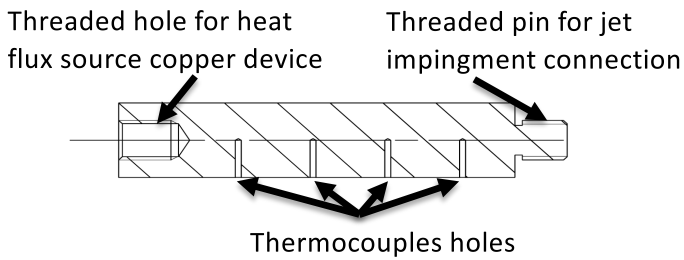
Laser Powder Bed Fusion of Copper and Copper alloys

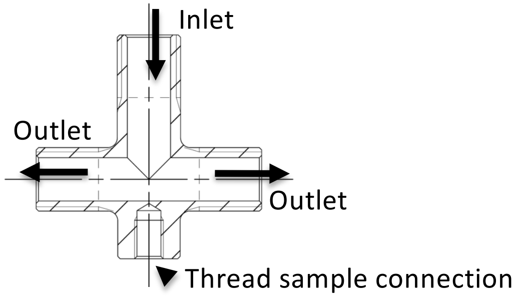
Thermal Conductivity Measurements Comparison

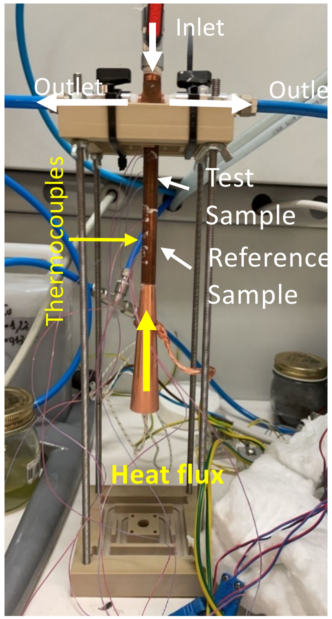


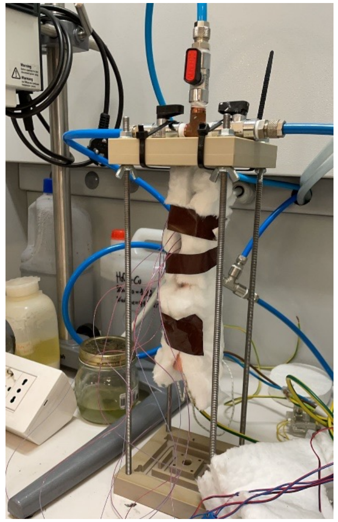












Direct Thermal Conductivity measurements

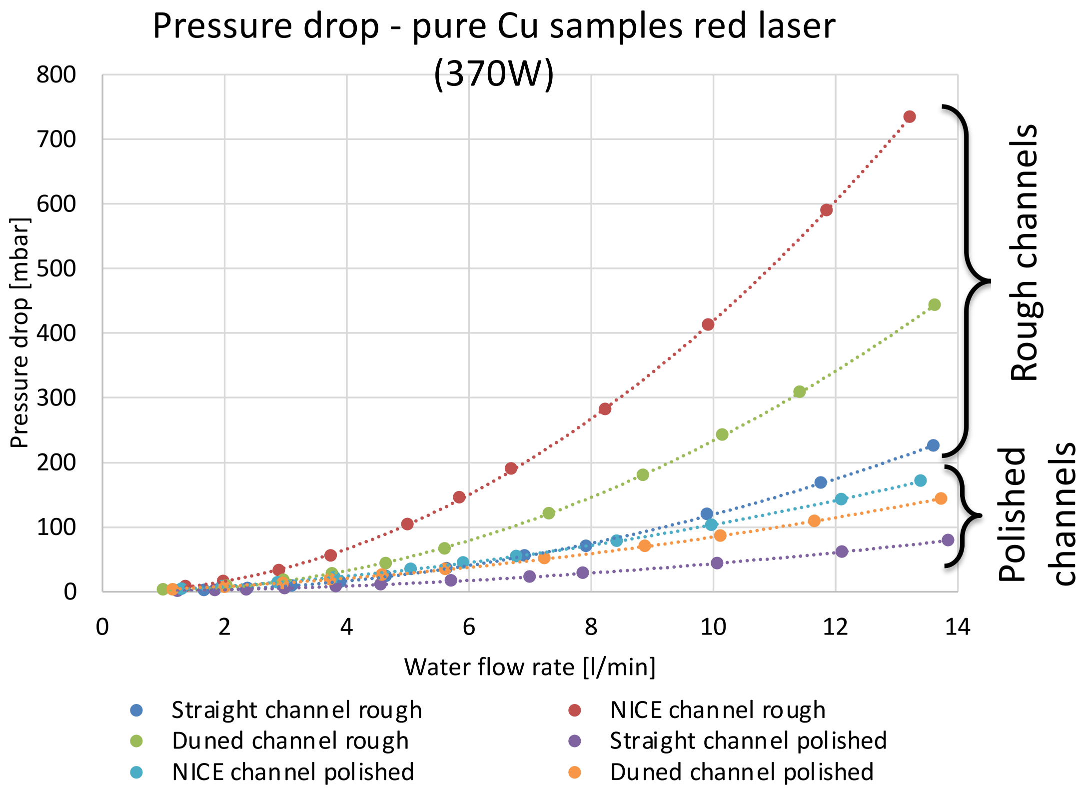
Laser Powder Bed Fusion of Copper and Copper alloys

Cu cooling channels samples – Pressure drop tests

Cu samples

AM samples M280
LPBF machine

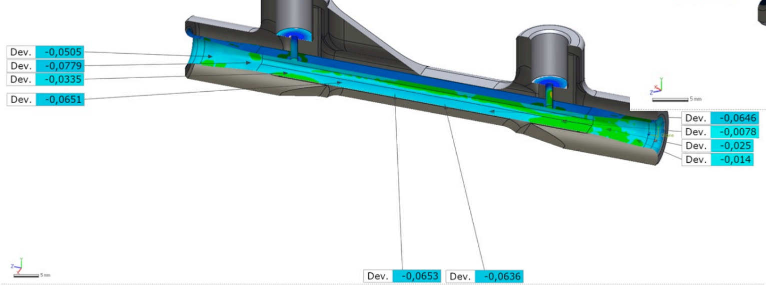
- Hydraulic tests in channels as built
- Hydraulic tests in polished channels

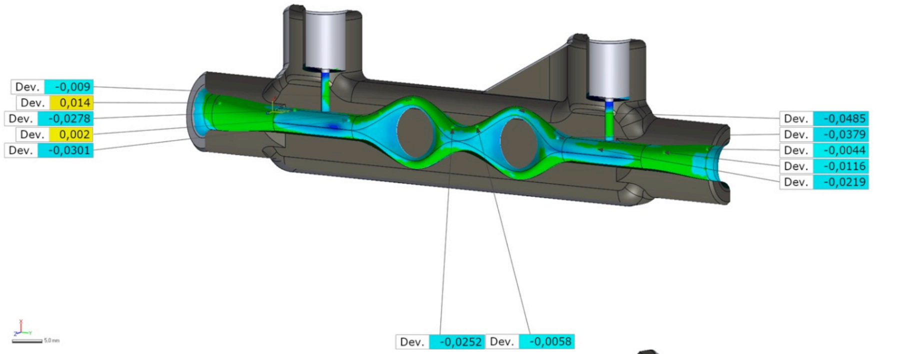


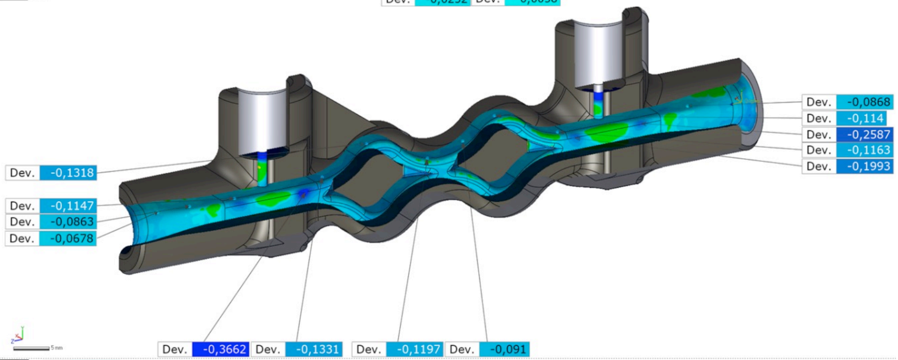
Laser Powder Bed Fusion of Copper and Copper alloys

Cu cooling channels samples – CT dimensions

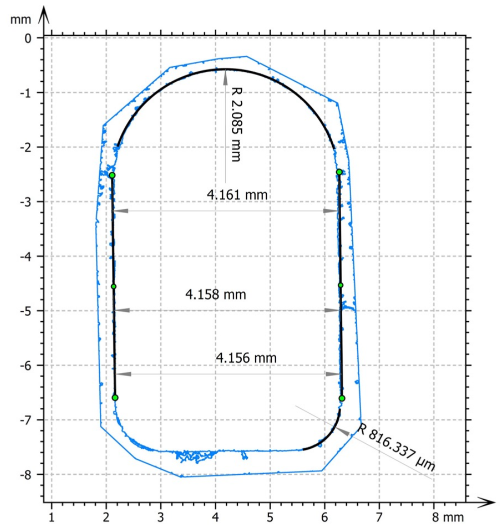
- Zeiss Metrotom 1500
- Voxel size: 55 µm
- Accuracy: ±25 µm
- Wall mean offset (CAD theoretical-samples after polishing): 50 µm







Verification with optical 2D scan match the Straight channel section computed with CT measurement.

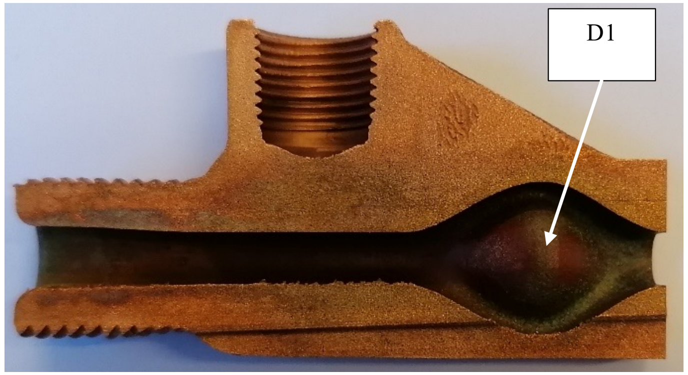


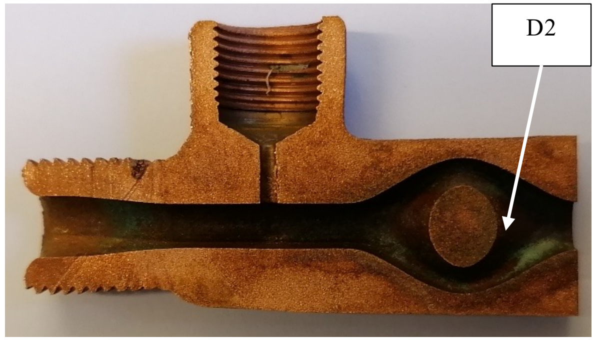
Laser Powder Bed Fusion of Copper and Copper alloys

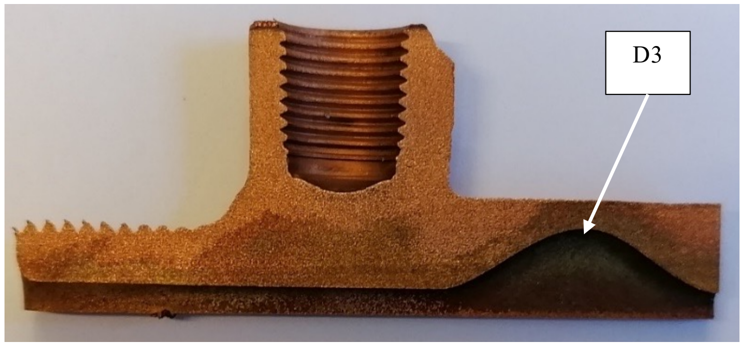
Cu cooling channels samples – Roughness analysis

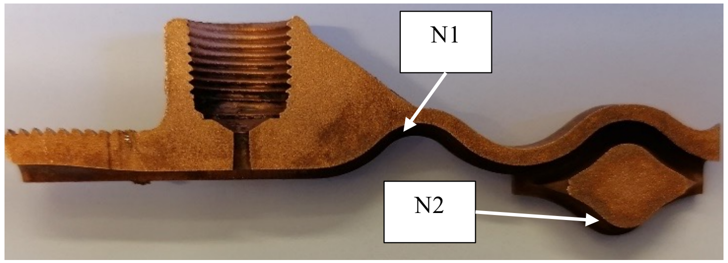
- 3D Non-Contact Profilometry
- Step size 2-5 µm

Samples cut with EDM





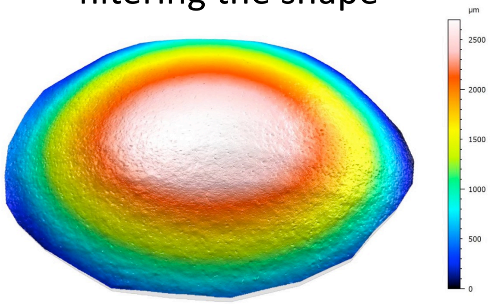




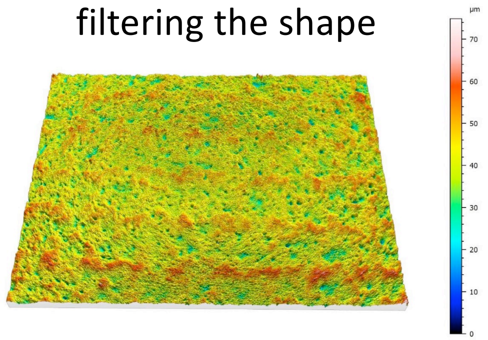
Laser Powder Bed Fusion of Copper and Copper alloys

Cu cooling channels samples – Roughness analysis

3D roughness profile before filtering the shape



3D roughness profile after filtering the shape



Rough samples

	S_p [µm]	S_v [µm]	S_z [µm]	S_a [µm]	S_q [µm]	S_{ku} [-]	S_{sk} [-]
Straight	131.7	134.8	266.5	18.4	23.7	3.88	0.109
D1	140.6	164.6	305.1	12.2	16.0	4.31	-0.060
D2	197.0	111.2	308.2	22.0	29.1	5.32	0.865
D3	219.5	167.5	387.0	19.9	26.1	4.81	0.723
N1	204.8	172.1	376.3	25.3	32.1	3.46	0.489
N2	348.8	109.9	458.7	17.0	22.5	6.94	0.552

Polished samples

	S_p [µm]	S_v [µm]	S_z [µm]	S_a [µm]	S_q [µm]	S_{ku} [-]	S_{sk} [-]
Straight	39.6	34.4	74.0	3.08	4.12	6.24	0.094
D1	32.8	41.5	74.4	4.37	5.66	4.07	-0.214
D2	214.9	42.3	257.2	5.06	6.91	38.5	1.77
D3	64.6	42.4	107.0	6.99	8.83	4.67	0.354
N1	181.1	52.8	233.9	5.93	7.57	9.78	0.472
N2	48.6	78.2	126.9	7.02	9.12	5.56	-1.10

DIAM

MASSIMILIANO BONESSO
Ruolo: *Research Fellow*
Progetto: *DTT*
PhD Thesis: *Characterization of Copper and Copper Alloys Produced by LPBF*
Supervisor: *Prof.ssa Irene Calliari*

PIETRO REBESAN
Ruolo: *Research Fellow*
Progetto: *DTT*
PhD Thesis: *Additively Manufactured Refractory Metals for Advanced Applications*
Supervisor: *Prof. Maurizio Vedani*

PhD

PhD students

GIACOMO FAVERO
Ruolo: *PhD Candidate – XXXVII Ciclo*
Area SSD: *Ingegneria Meccatronica e dell'Innovazione Meccanica del Prodotto*
SSD: *Fisica Tecnica Industriale (ING-IND 10)*
Università: *Università degli Studi di Padova (DTG)*

PhD Project: *Metal Additive Manufacturing for advanced heat transfer solutions: from material to thermal management application*
Supervisor: *Prof. Simone Mancin*

VALENTINA CANDELA
Ruolo: *PhD Candidate – XXXVII Ciclo - PON*
Area SSD: *Fusion Science and Engineering*
SSD: *Elettrotecnica (ING-IND 31)*
Università: *Università degli Studi di Padova (DII)*

PhD Project: *Additive Manufacturing of pure copper and copper alloys for High Energy Applications*
Supervisor: *Prof. Piergiorgio Sonato*

SILVIA CANDELA
Ruolo: *PhD Candidate – XXXVIII Ciclo*
Area SSD: *Fusion Science and Engineering*
SSD: *Elettrotecnica (ING-IND 31)*
Università: *Università degli Studi di Padova (DII)*

PhD Project: *Additive Manufacturing of refractory metals for nuclear fusion applications*
Supervisor: *Prof. Paolo Bettini*

Pubblications

Cu

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V. Candela, M. Pozzi, E. Chyhyrynets, *et al.* **Smoothening of the down-skin regions of copper components produced via Laser Powder Bed Fusion technology**, *Int J Adv Manuf Technol* (2022), DOI:10.1007/s00170-022-10408-8

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G. Favero, M. Bonesso, P. Rebesan, R. Dima, A. Pepato, S. Mancin, **Additive Manufacturing for Thermal Management applications: from experimental results to numerical modelling**, *International Journal of Thermofluids* (2021), DOI: 10.1016/j.ijft.2021.100091

G. Favero, G. Berti, M. Bonesso, D. Morrone, S. Oriolo, P. Rebesan, R. Dima, P. Gregori, A. Pepato, A. Scanavini, S. Mancin, **Experimental and numerical analyses of fluid flow inside additively manufactured and smoothed cooling channel**, International Communications in Heat and Mass Transfer (2022), DOI: 10.1016/j.icheatmasstransfer.2022.106128

Fusion

V. Candela, C. Cavallini, C. Gasparrini, L. Armelao, V. Candeloro, M. Dalla Palma, M. Fadone, D. Marcuzzi, M. Pavei, A. Pepato, *et al.* **Investigations on Caesium Dispersion and Molybdenum Coating on SPIDER Components**. Materials (2023), DOI: 10.3390/ma16010206

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1. A. Pepato, *et al.* **Implementation of the Additive Manufacturing for metals approach: the production of the acceleration grids for DTT NBI project**, 14th International Particle Accelerator Conference,Venezia (2023)
2. V. Candela, *et al.* **Additive Manufacturing of 6 GHz seamless SRF copper cavities: printing, surface treatments and performance investigations**, 14th International Particle Accelerator Conference,Venezia (2023)
3. M. Ballan, *et al.* **Additively manufactured tantalum cathode for FEBIAD type ion sources: production, geometric measurements, and high temperature test**, 14th International Particle Accelerator Conference,Venezia (2023)
4. M. Bonesso, *et al.* **Laser powder bed fusion of CuCrZr for nuclear fusion acceleration components**, 14th International Particle Accelerator Conference,Venezia (2023)
5. S. Candela, *et al.* **Laser powder bed fusion of pure niobium for particle accelerator applications**, 14th International Particle Accelerator Conference,Venezia (2023)
6. G. Favero, *et al.* **Predictive capabilities in CFD simulations of additively manufactured extraction grid cooling channels for the DTT NBI system**, 14th International Particle Accelerator Conference,Venezia (2023)

Process optimization of copper alloys

PhD stage at **EOS Electro Optical System Finland Oy**

Machine: M290 1kW red-laser
Materials: CuCrZr and pure copper

PhD student

Valentina Candela
Materials Engineer

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Activity:

- Printing parameters optimization
- Heat treatments
- Geometrical precision assessment
- Surface finishing optimization of as-built parts

Process optimization of tungsten-based alloys

PhD stage at EOS Electro Optical System Finland Oy

Machines: M100, M290
Materials: W-Ta, W-TiC, W-V

PhD student

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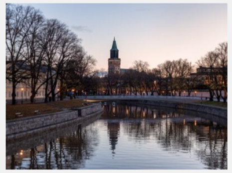
Activity:

- Printing parameters optimization
- Density improvement
- Cracks suppression
- Material properties assessments
- Evaluation of different compositions



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