



The Additive Manufactured RFQ prototype

Maurizio Vedani (Politecnico di Milano)
on behalf of the whole AM team of WP10

How the RFQ was born from activities of task 10.2

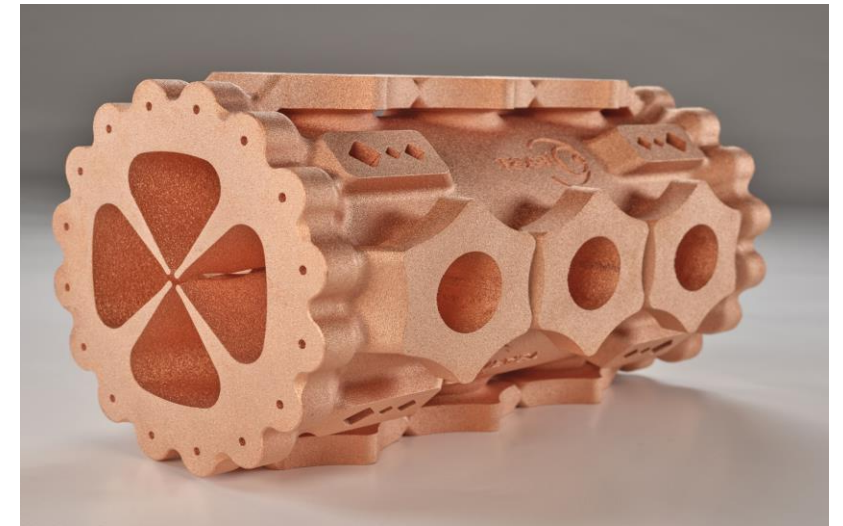
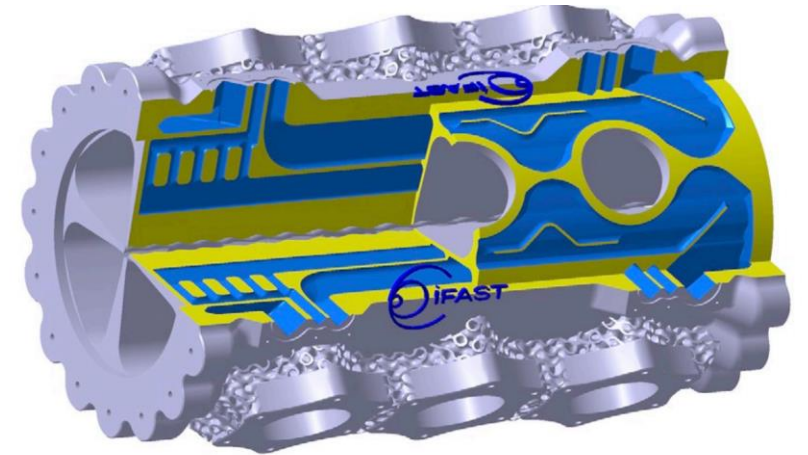
T10.2: Additive Manufacturing. Survey of applications and potential development (M1-M36)

- Survey of current AM applications in accelerators and identification of needs for future development and research actions
- Promote initiatives to identify how AM can address the needs of the accelerator community
- Define strategic directions for future AM technologies and foster their impact on accelerator applications (sterilisation, medicine, industry), **identifying technology barrier and challenges**

The design process of the RFQ prototype

We tried to exploit the opportunities offered by the most updated LPBF printing systems

- Complex shape in a single part, without joining issues
- Internal conformal channels for temperature control
- Integration of flanges and connections in the printed part
- Use of green laser for improved printability with pure copper



Some of the very first mistakes

Despite the accurate design stage, some «youthful mistakes» have been made (lessons learned)

- No need to have «precursors» of holes in the printed part, more complex to center the final ones
- Need to have and keep reference surfaces for clamping during post-print finishing and machining
- Keep in mind how much material to be removed / shrinkage to compensate for the final dimensional accuracy
- Put more effort on contour parameters to improve as built roughness, especially on functional surfaces (e.g. vane tips)

Properties of LPBF copper

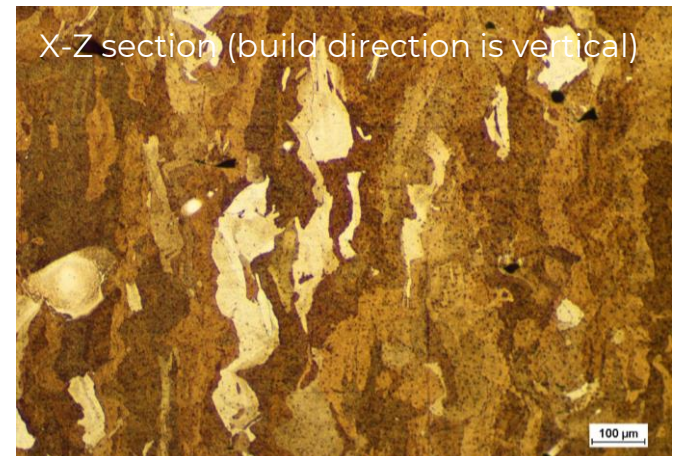
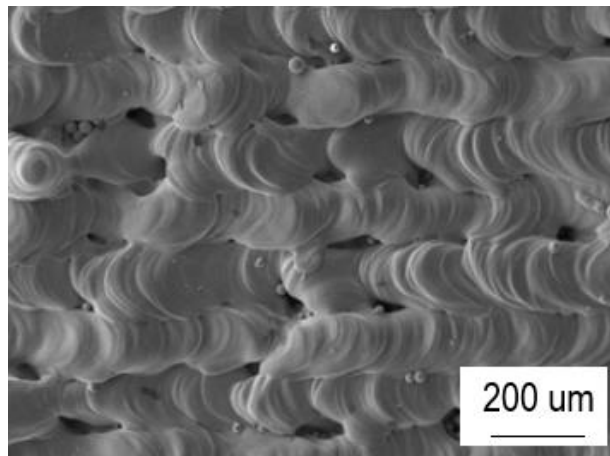
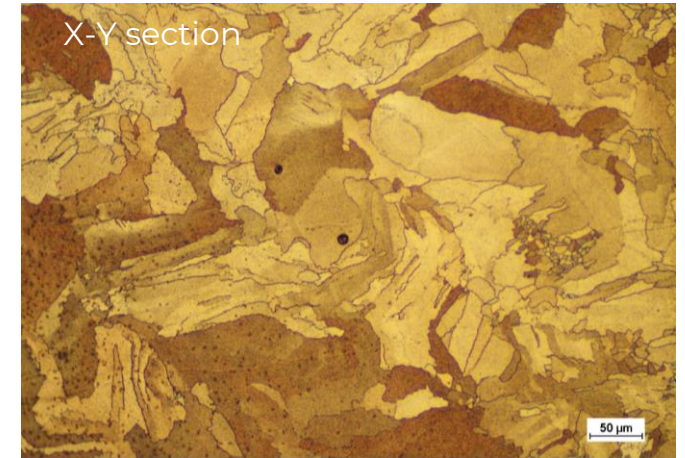
Copper has been printed by LPBF technology using both green and IR laser systems, both can provide the expected properties

Therm. diffusivity (cm ² /s @ 21°C)	reference Cu 99,99+%	IR laser BD	Green laser BD	Green laser TD
Average	1,174	1,166	1,172	1,165
%	-	99,32	99,82	99,23

Therm. conductivity (W/mK @ 21°C)	reference Cu 99,99+%	IR laser BD	Green laser BD	Green laser TD
Average	404,08	401,32	403,91	400,98

Electr. conductivity (MS/m @ 25°C)	IR laser BD	IR laser TD	Green laser BD	Green laser TD
Average	57,74	55,57	58,21	57,82
%	99,55	95,81	100,37	99,68

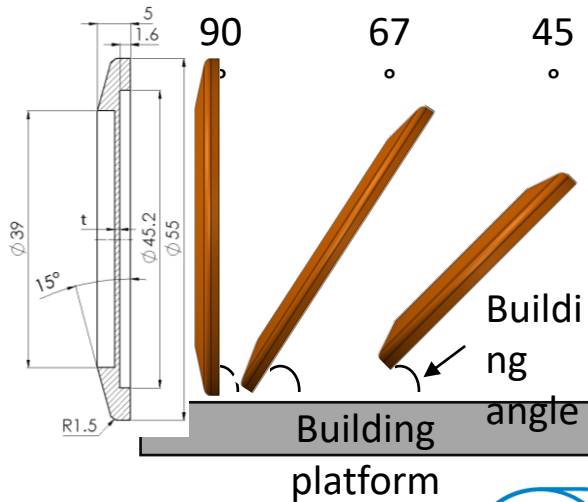
Vickers hardness (HV _{0.05})	IR laser	Green laser
	78.2 ± 1.9	75.5 ± 3.2



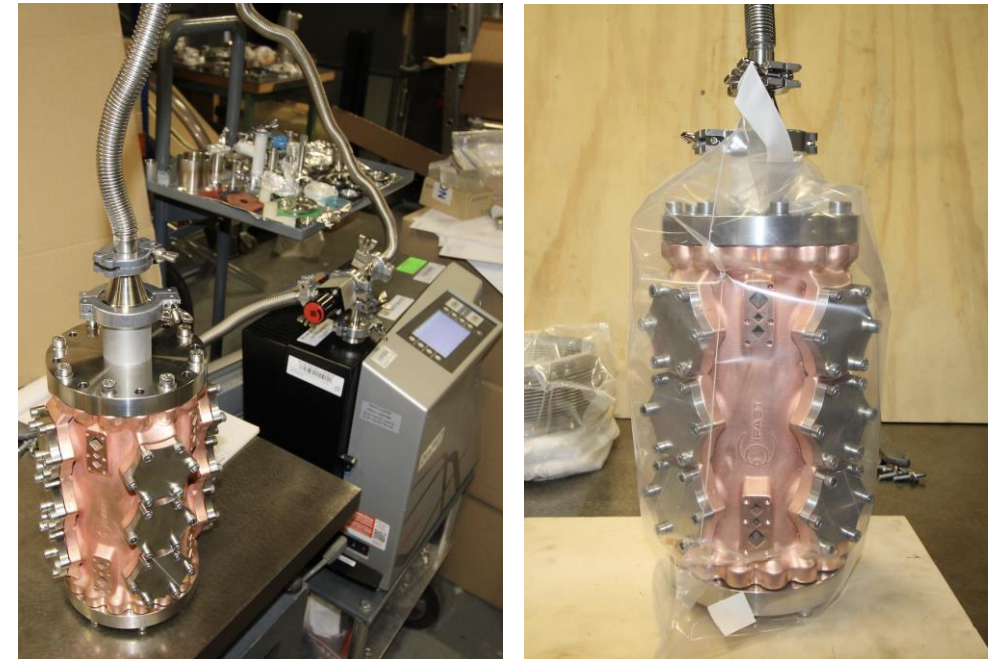
UHV tests on Cu printed membranes

Standard test membranes printed by a green laser with different thickness and print orientation

- Nominal thickness: 2,5, 5, 1,5, 1, 0,75, 0,5 mm and building orientation: 90°, 67°, 45°
- He leakage test on full RFQ

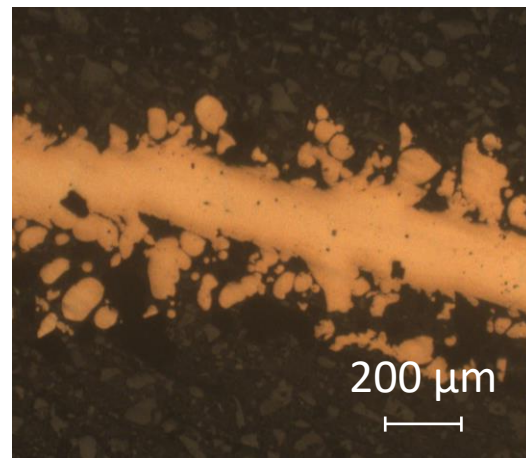
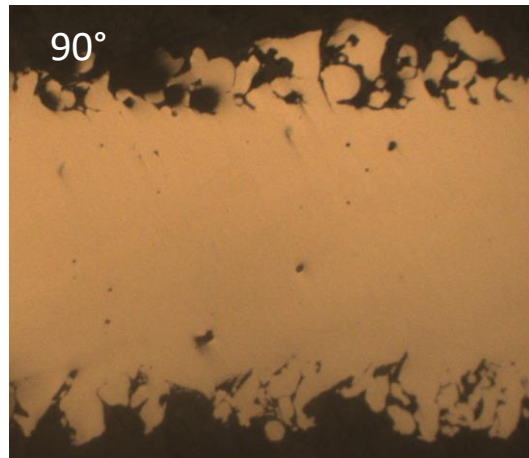


Test passed, threshold value at: $1 \cdot 10^{-10} \text{ mbar} \cdot \text{l} \cdot \text{s}^{-1}$



UHV tests on Cu printed membranes

Only small-thickness membranes at highest angles failed the test due to actual thickness related to roughness

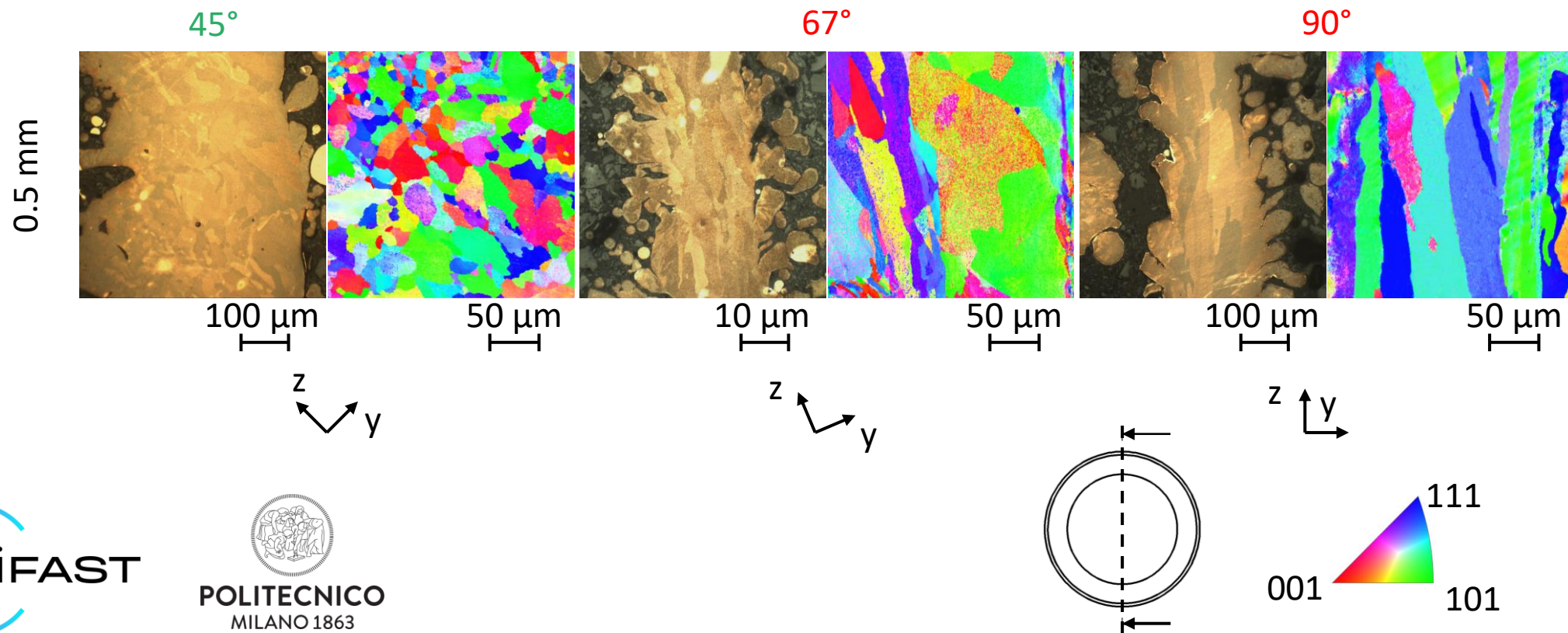


Thickness \ Build angle	He leak rate (mbar·l·s ⁻¹)		
	45°	67°	90°
2,5 mm	Pass	Pass	Pass
2 mm	Pass	Pass	Pass
1,5 mm	Pass	Pass	Pass
1 mm	Pass	Pass	Pass
0,75 mm	Pass	Pass	$1,0 \cdot 10^{-6}$
0,5 mm	Pass	$2,5 \cdot 10^{-3}$	$5,0 \cdot 10^{-2}$

Threshold value at: $1 \cdot 10^{-10}$ mbar·l·s⁻¹

UHV tests on Cu printed membranes

- For fine-thickness membranes, building orientation plays a role on grain shape (equiaxed vs. elongated)
- Fine and homogeneous grain structure can reduce the risk of leaks

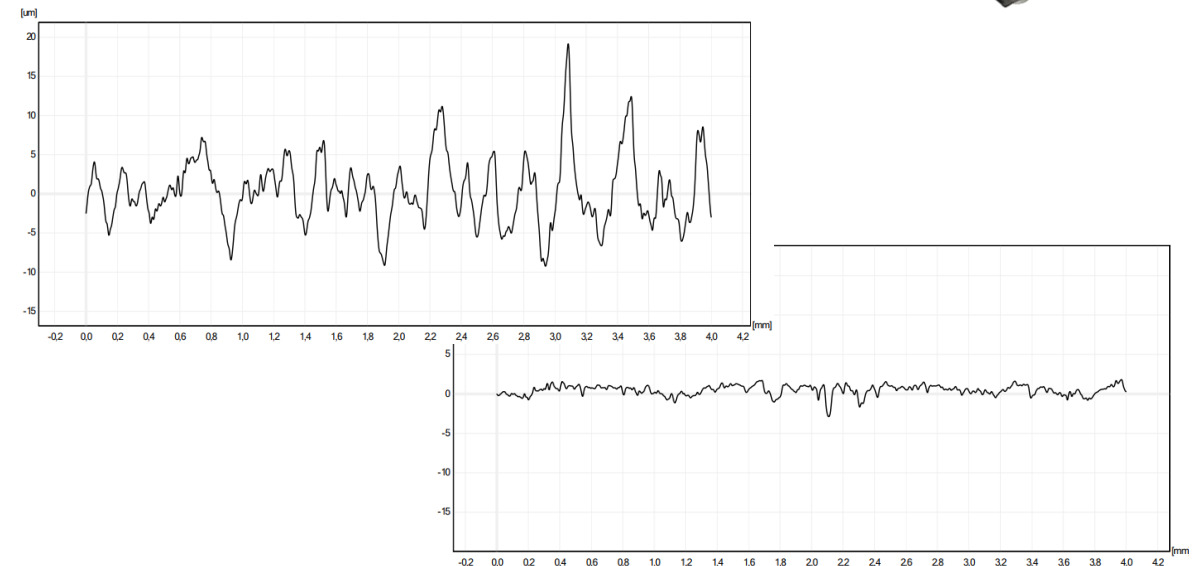


Surface finishing - Mass finishing

Based on mechanical abrasion (chemically assisted) provided by media under vibration.

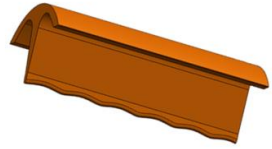
Automatic /semi-automatic process tunable through many parameters

- Type, size, shape of media
- Water and chemical compounds
- Operating conditions
- ...

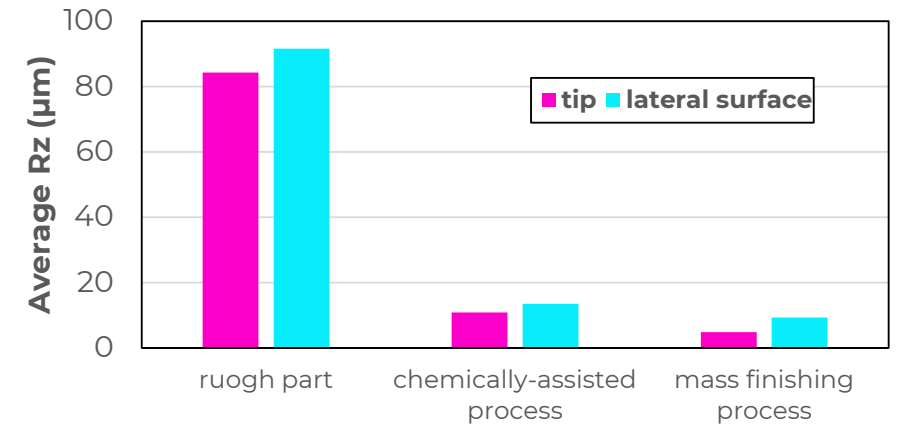
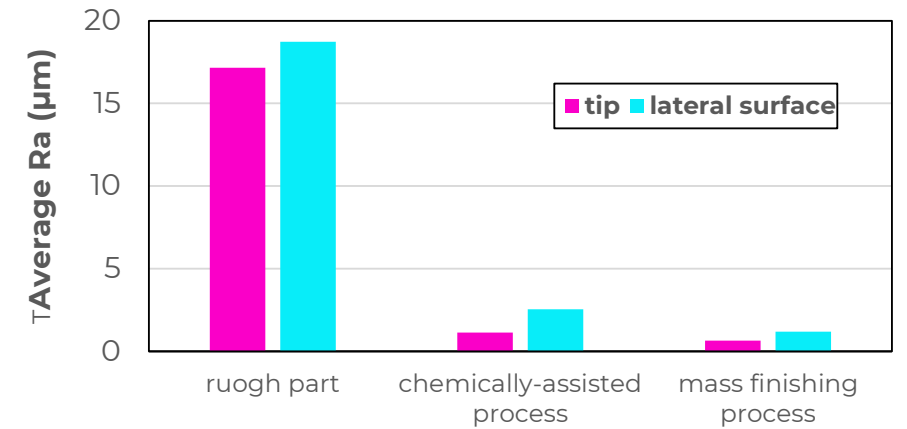


Surface finishing

Mass finishing can effectively improve the as fabricated surfaces. Care must be taken to homogenize material removal and compensate for size tolerances



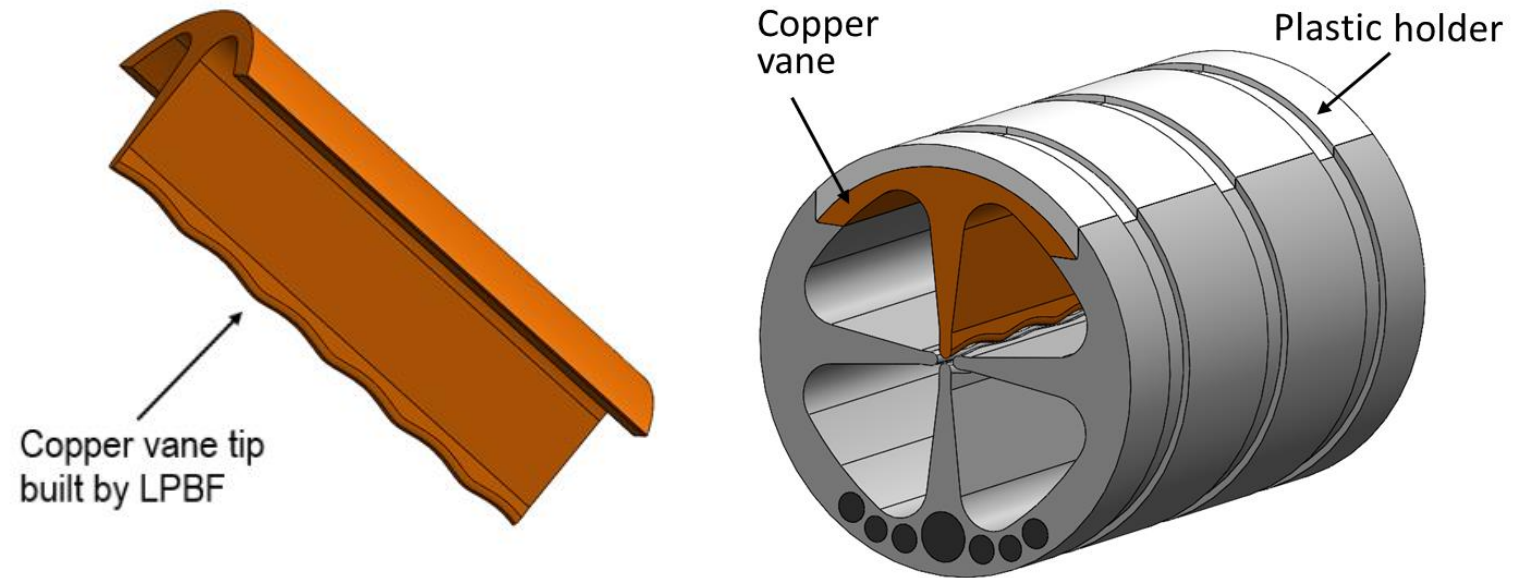
	Tip		Lateral surface		Overall mass loss	
	Ra (µm)	Rz (µm)	Ra (µm)	Rz (µm)	Δm (g)	Δm%
As built vane	17,16 ± 2,84	84,30 ± 16,20	18,73 ± 3,59	91,59 ± 11,28		
Chemically assisted process	1,14 ± 0,43	10,87 ± 5,71	2,55 ± 0,77	13,49 ± 3,77	278	2,05
+ Mass finishing process	0,65 ± 0,08	4,85 ± 0,57	1,19 ± 0,39	9,33 ± 2,74	448	3,30



Prototype for surface finishing tests

Activities planned for near future:

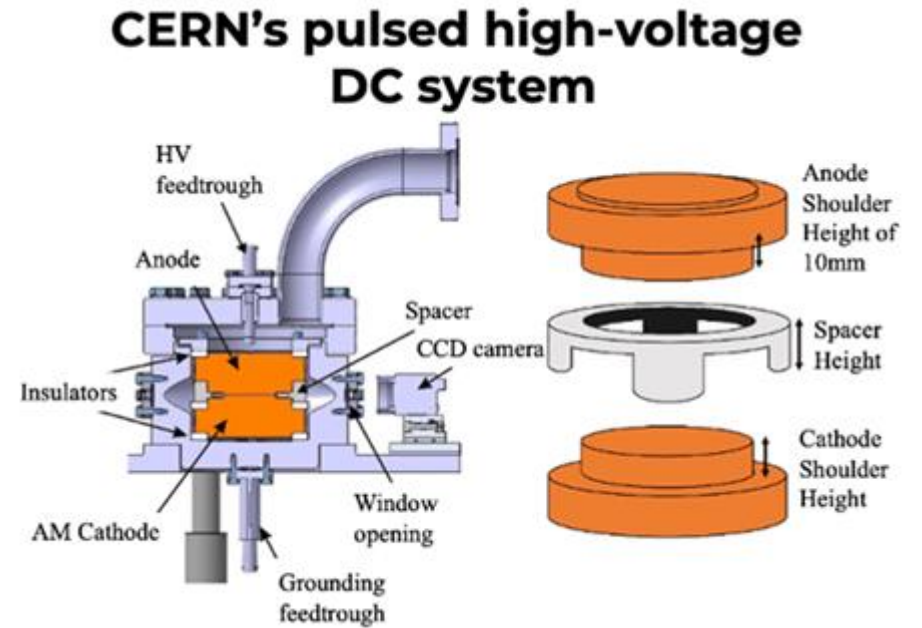
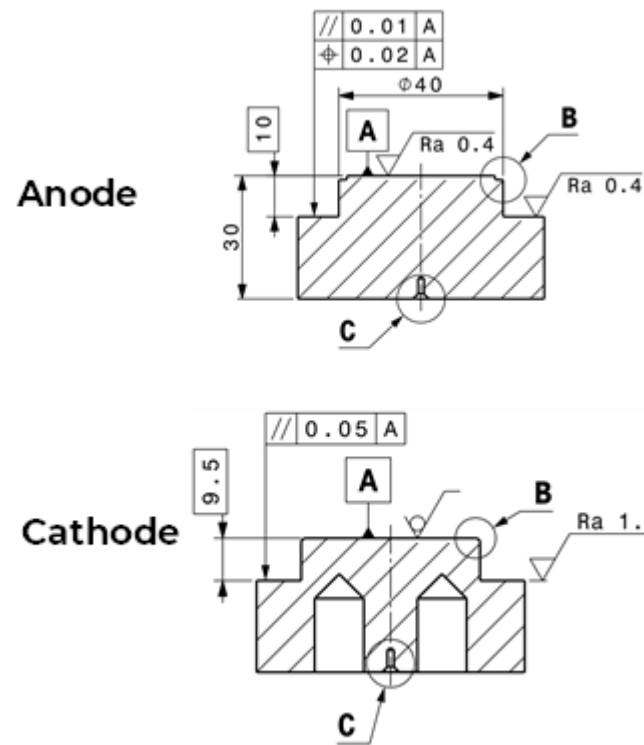
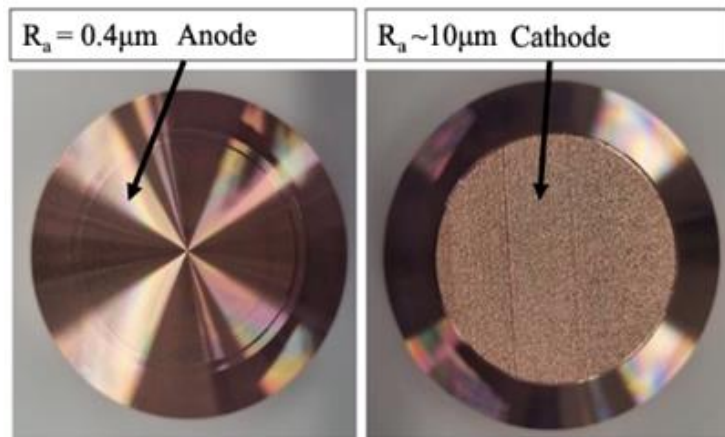
- «in situ» surface finishing tests with different combinations of chemical solutions and abrasive media
- Objective: evaluate achievable roughness and effect on vane tip modulation profile



High-voltage behaviour of AM Copper

Different surface conditions have been investigated

- smooth / smooth
- smooth / post processed
- smooth / as built

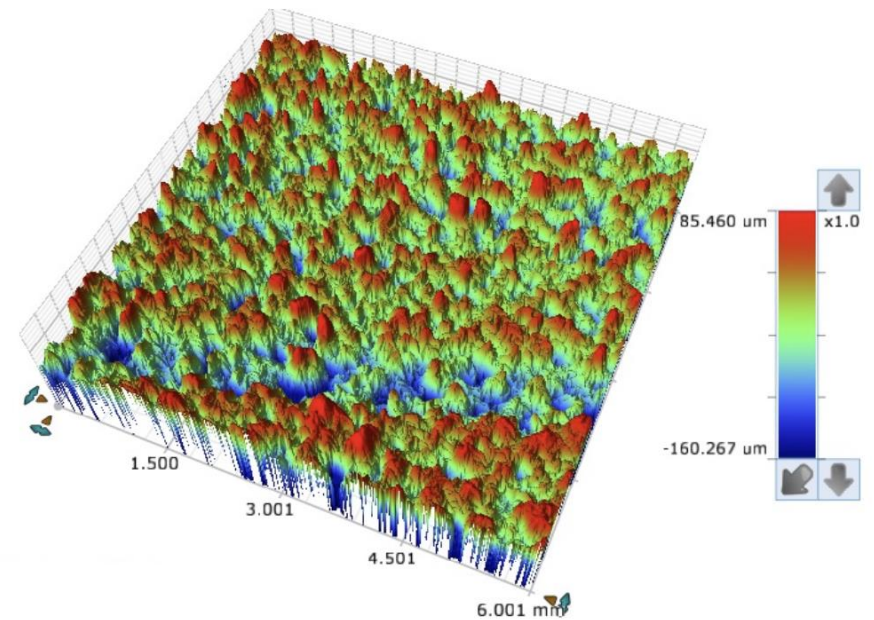


thanks to CERN SY-RF team W. Wuensch and V. Bjelland

High-voltage behaviour of AM Copper

The HV testing procedure requires samples with higher dimensional accuracy

- The roughness profile peaks and valleys are comparable to electrode gap
- LPBF printing distortions and material loss due to finishing add further dimensional errors (planarity)

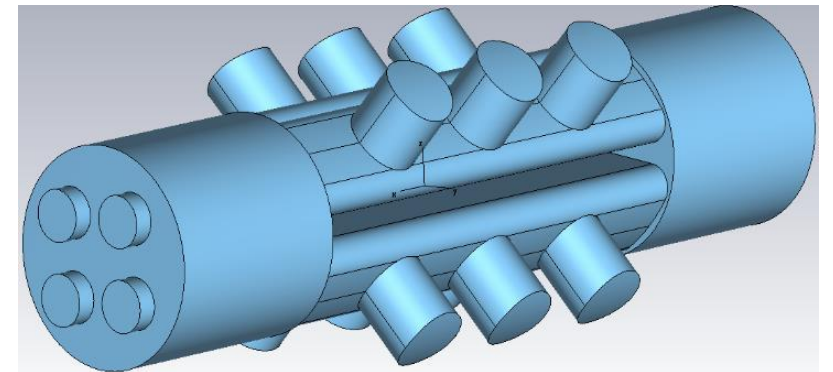
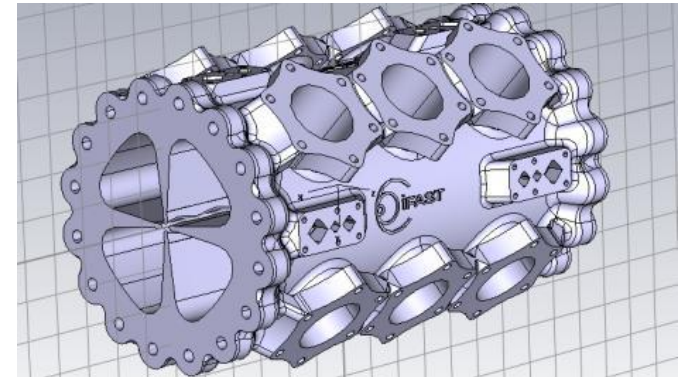


Electromagnetic behaviour of the RFQ module

The original design of the RFQ module targeted an operating frequency of 750 MHz

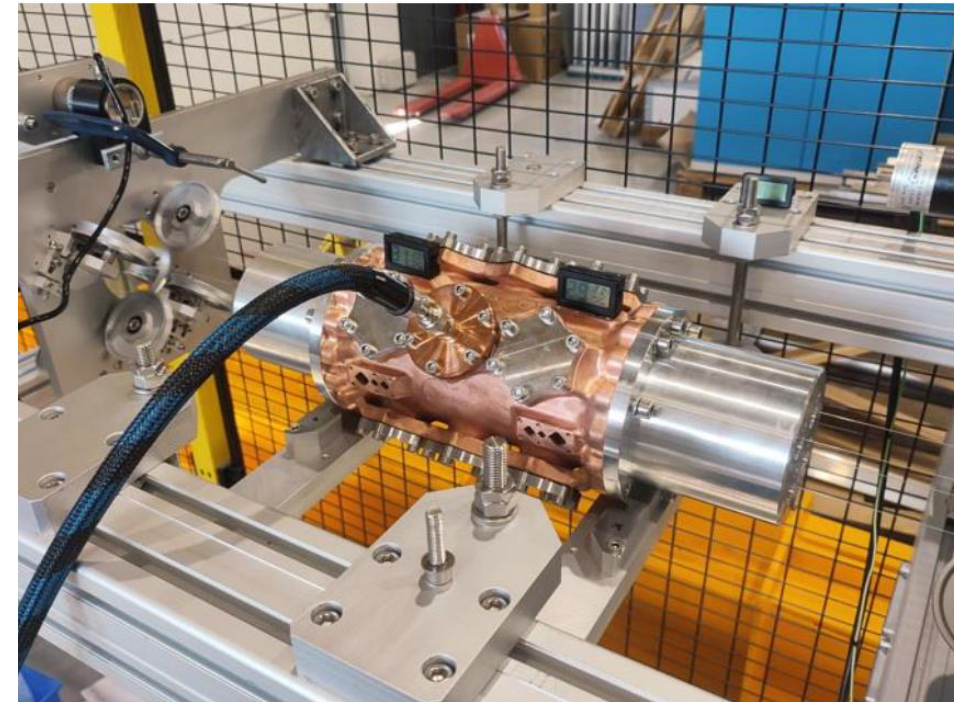
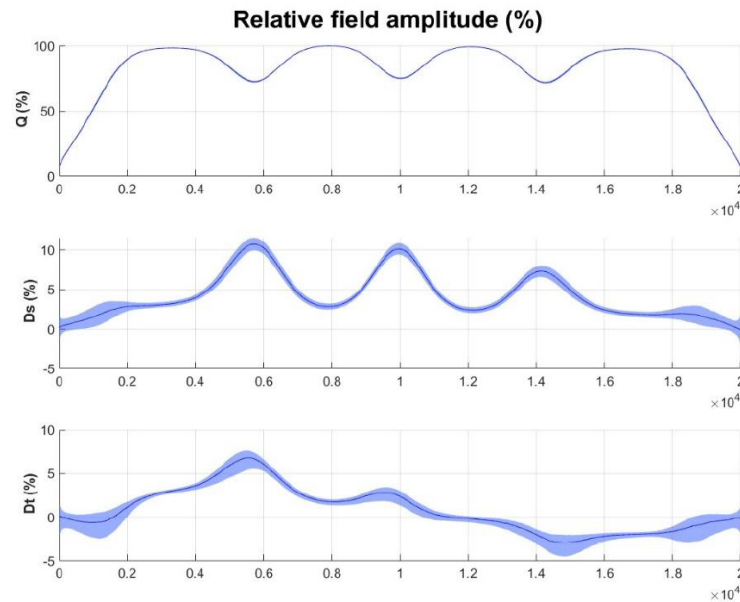
- Due to printing and post processing, a «shrinkage» of around 200 μm was assumed
- Supposing a uniform loss of material from surfaces, the new RFQ geometry was modeled to test expected cavity frequencies
- TE210 (quadrupolar) resonant mode: 749,41 -> 778,27 MHz
- TE110 (dipolar) resonant modes: 714,12 -> 742,10 MHz
715,09 -> 742,86 MHz

Experimental measurement highlighted further shift to 820,89 MHz for the TE210 mode



Electromagnetic behaviour of the RFQ module

Bead-pull measurements allowed measuring the phase shifts of the cavity as the bead interacts with field (with respect to resonance values) from which the quadrupole and dipole components are calculated



The Bead-Pull System for RFQ-AM at CIEMAT

Special thanks to CIEMAT Accelerator Unit G. Moreno and P. Calvo

Final remarks

The results achieved so far show that design and manufacturing by AM of the RFQ module is feasible and deserves further research and technological development to reach a higher TRL (of 6 or 7)

- The design should be improved and more finely matching the needs of following steps
- LPBF process should also be optimized to achieve improved (starting) surfaces and compensate for dimensional changes
- Finishing of surfaces showed further margin of improvement, especially focussing on most critical surfaces of the RFQ

iFAST

Thanks for your kind attention !



This project has received funding from the European Union's Horizon 2020
Research and Innovation programme under GA No 101004730.