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Riga Technical University | 9 – 11 October 2023

IPPAT

# LPBF of pure copper for particle accelerator applications

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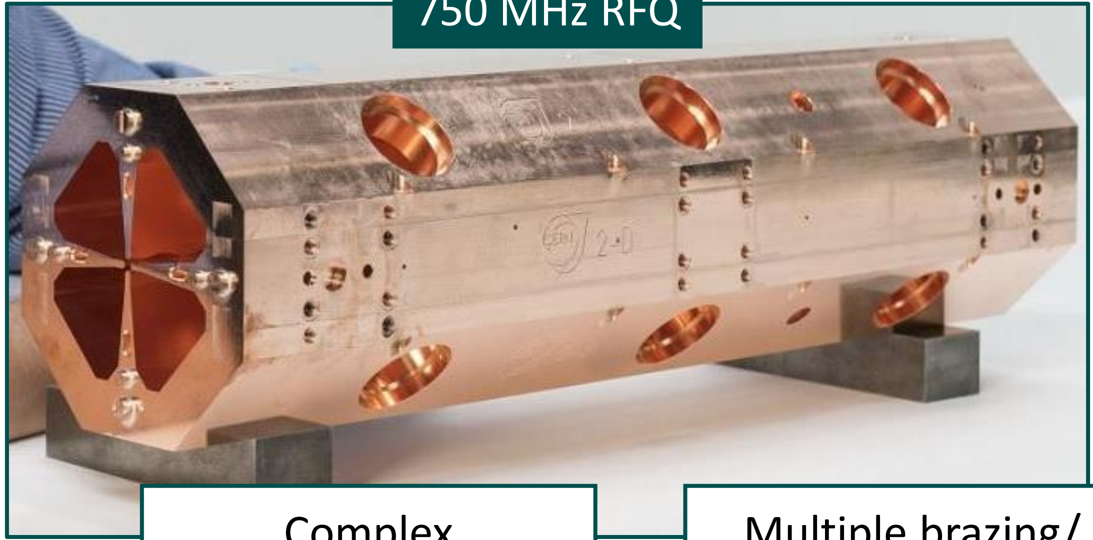
# The use of pure copper in accelerators

RF cavity

750 MHz RFQ



RF gun cathode plugs

Electron gun electrodes

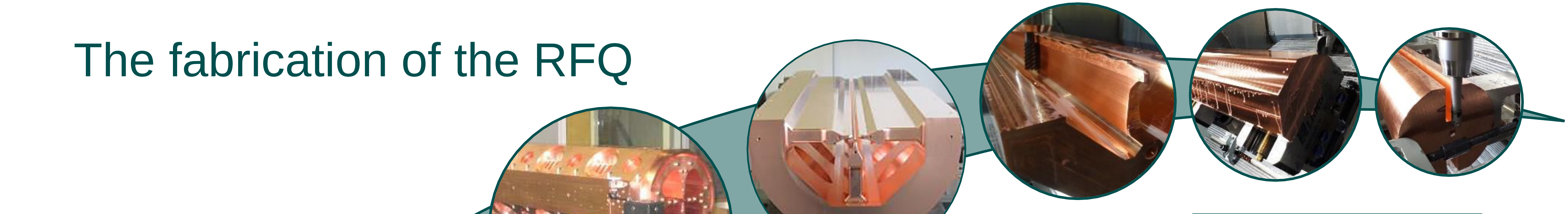
Complex design

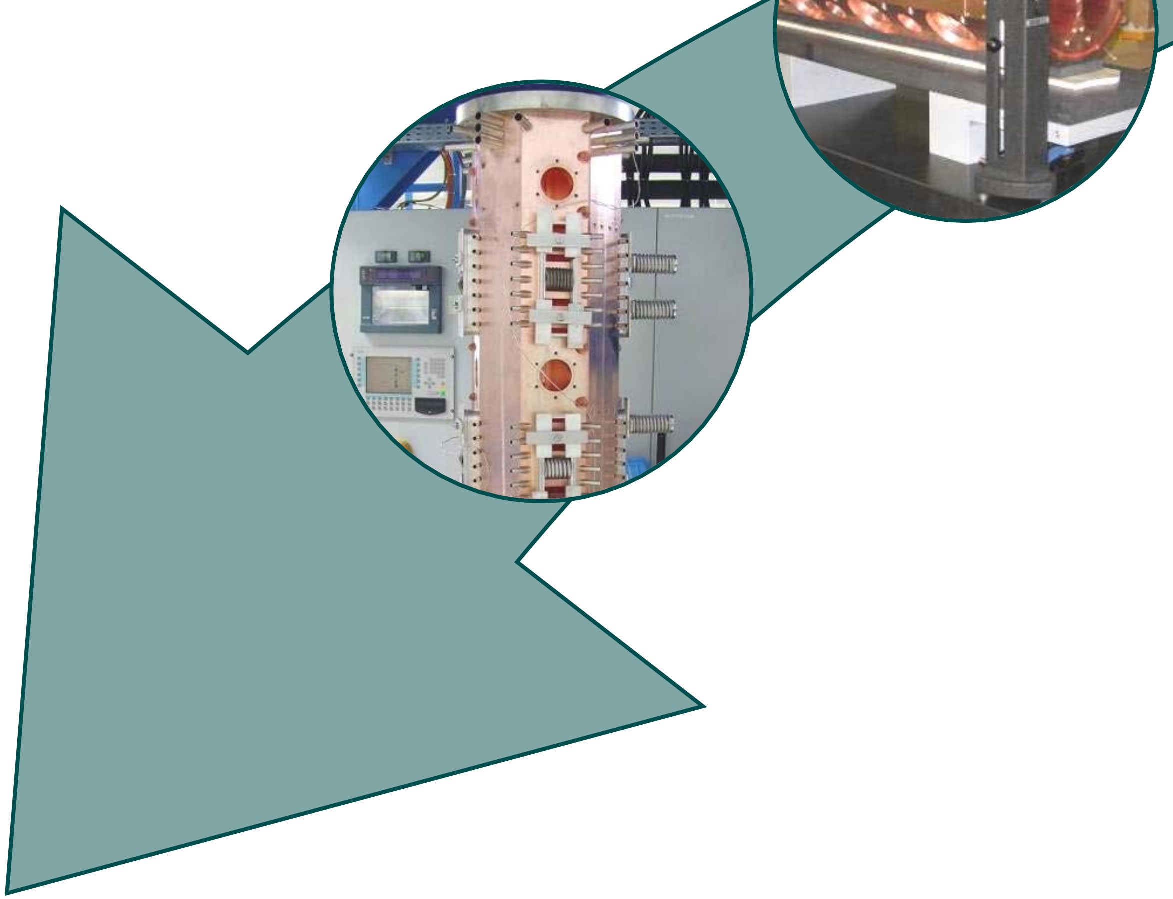
Multiple brazing/ machining steps

High costs and long lead times

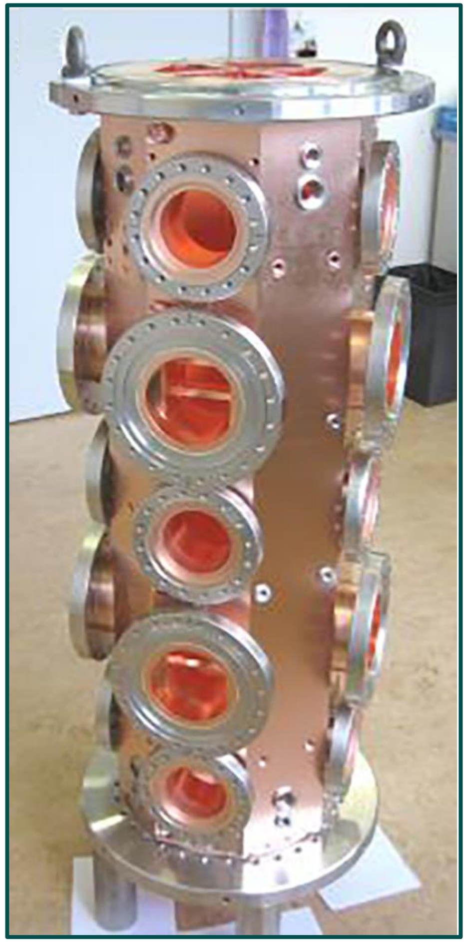

Lain Amador et al., Electrodeposition of copper applied to the manufacture of seamless superconducting rf cavities
A Miniature Linear Accelerator for Cancer Therapy, https://kt.cern/success-stories/miniature-linear-accelerator-cancer-therapy
Schietinger et al., Commissioning experience and beam physics measurements at the SwissFEL Injector Test Facility
Stancari et al., Conceptual design of hollow electron lenses for beam halo control in the Large Hadron Collider

# The fabrication of the RFQ



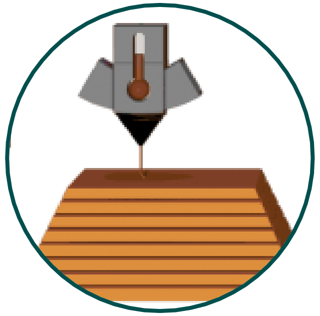


| | |
|---|---|
| Machining | >30x |
| Heat treatment | 4x |
| Vacuum brazing | 2x |
| Metrology | 6x |



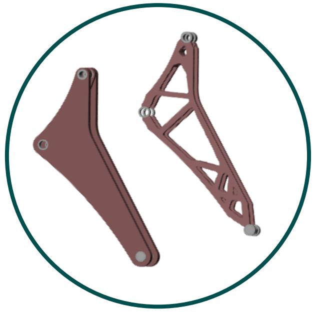
Mathot et al., The CERN PIXE-RFQ, a transportable proton accelerator for the machina project
Scibor et al., PIXE-RFQ modulation and cavity machining
Mathot, RFQ vacuum brazing at CERN

# The advantages of additive manufacturing

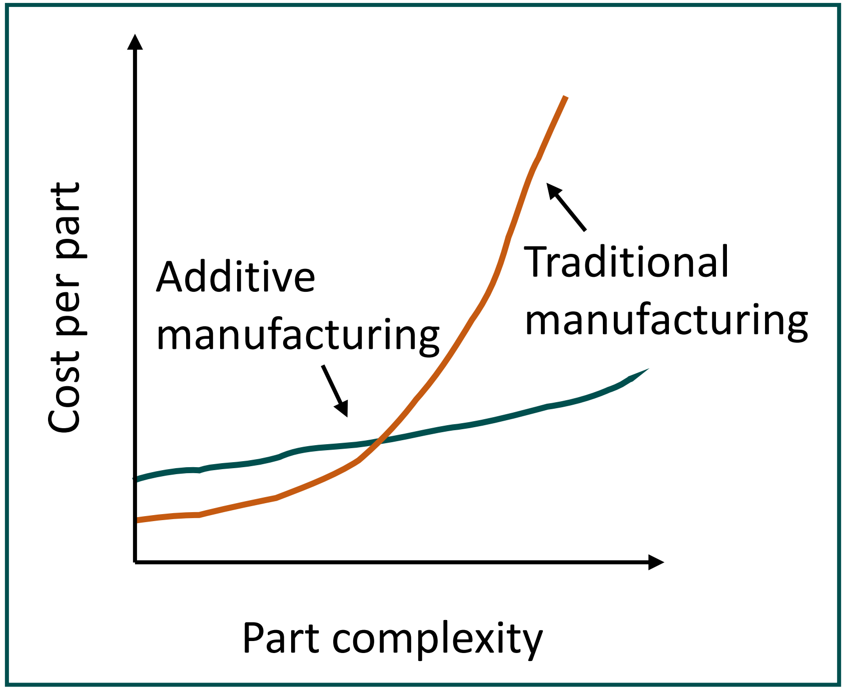


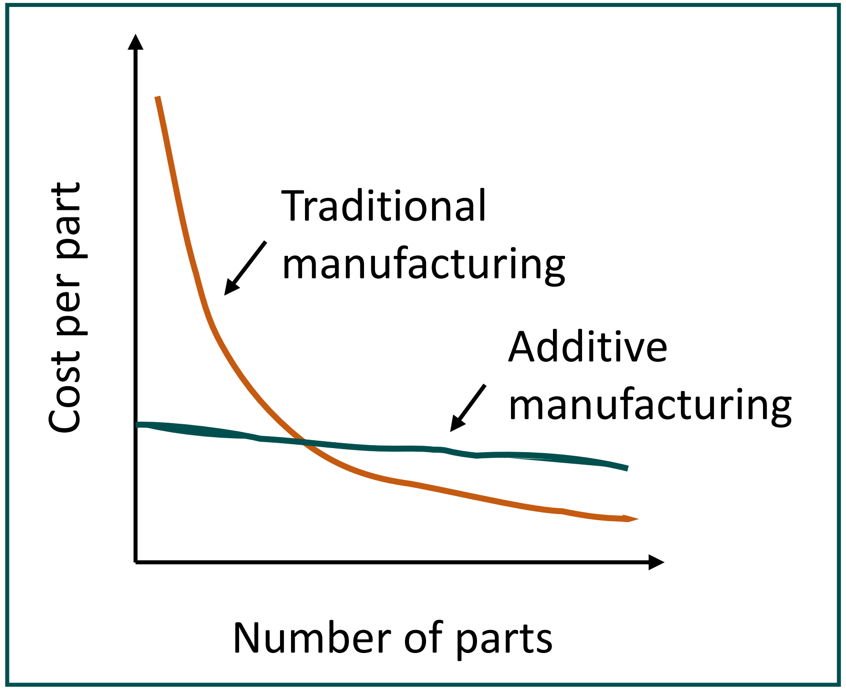
One-step printing

Design freedom



Topology optimization

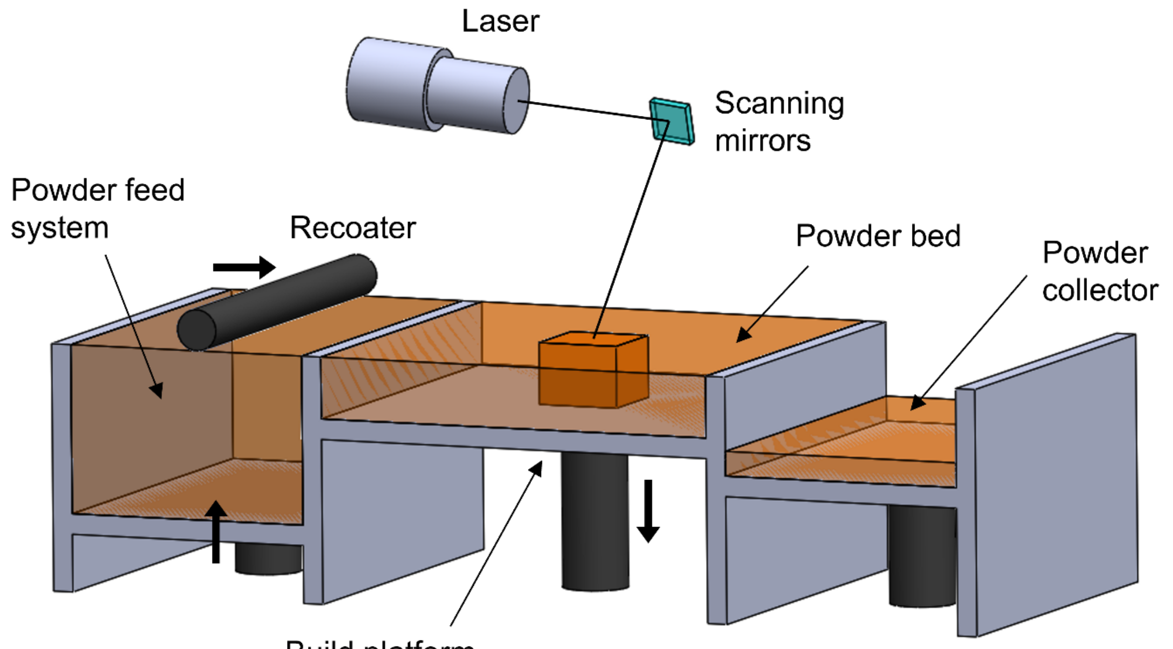



García-Gascón et al., Minimal Surfaces as an Innovative Solution for the Design of an Additive Manufactured Solar-Powered Unmanned Aerial Vehicle (UAV)

# Powder bed fusion technologies

## Laser

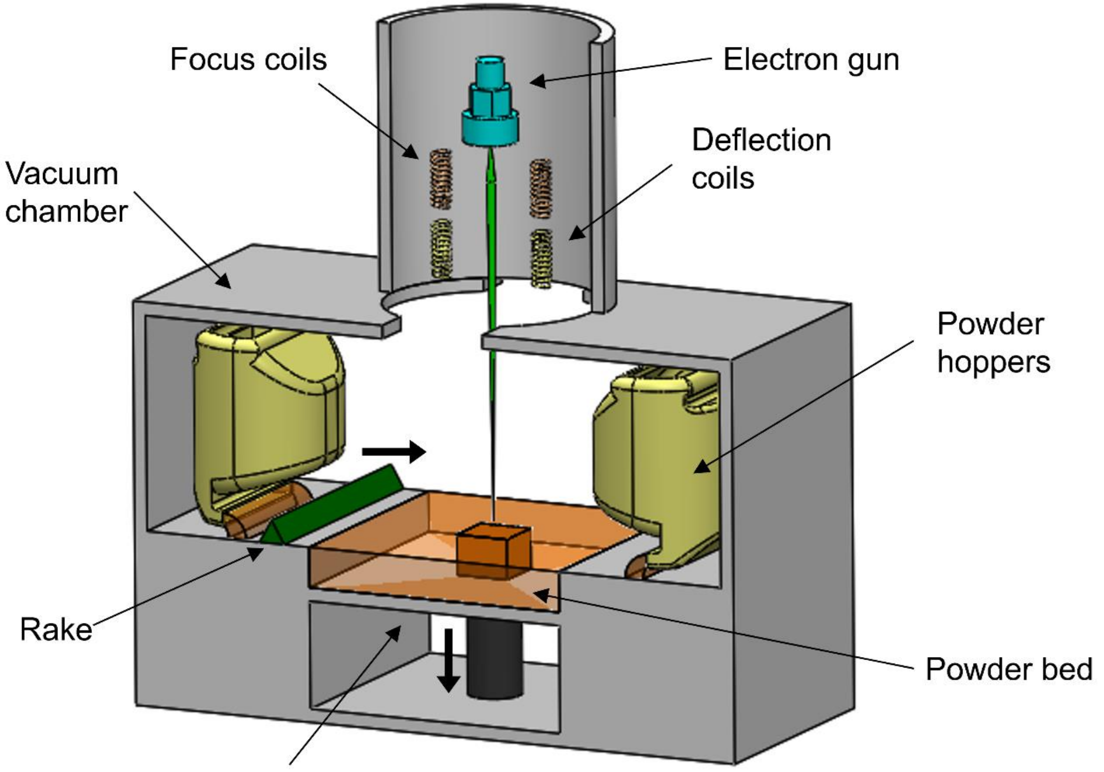



Good resolution

Inert atmosphere

Laser reflection

## Electron beam




Absorption rate

Vacuum chamber

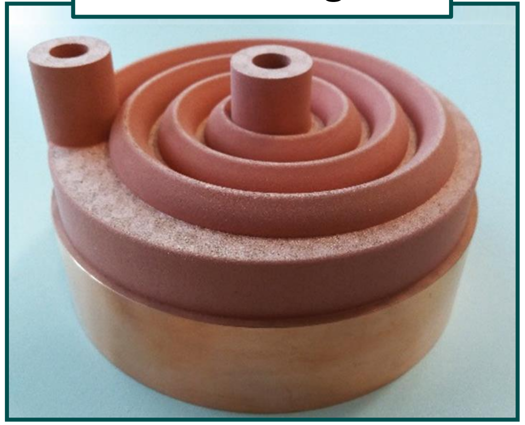
Low accuracy

Romano & Vedani, Additive Manufacturing of Pure Copper: Technologies and Applications

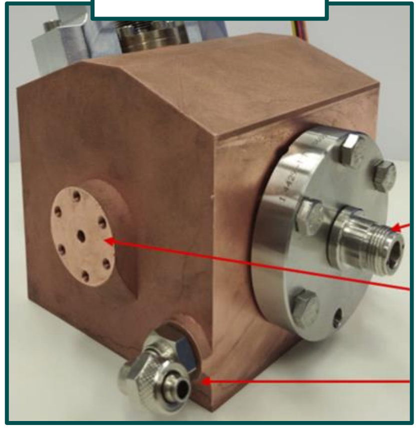
# Copper accelerator components made by powder bed fusion

Laser

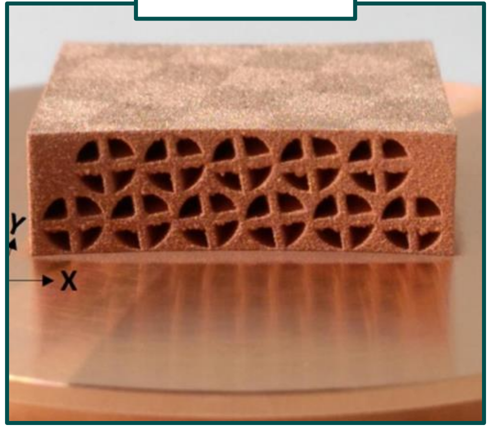
WR10 waveguide



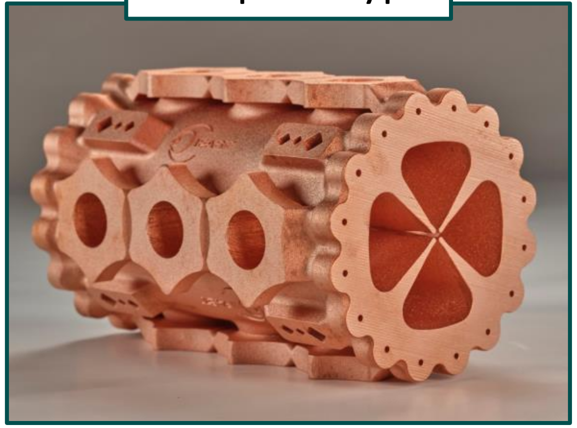
Drift tube



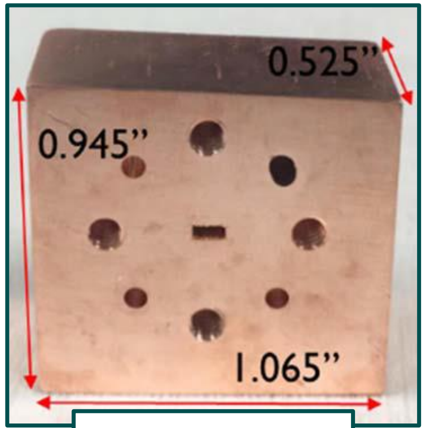
Heat sink



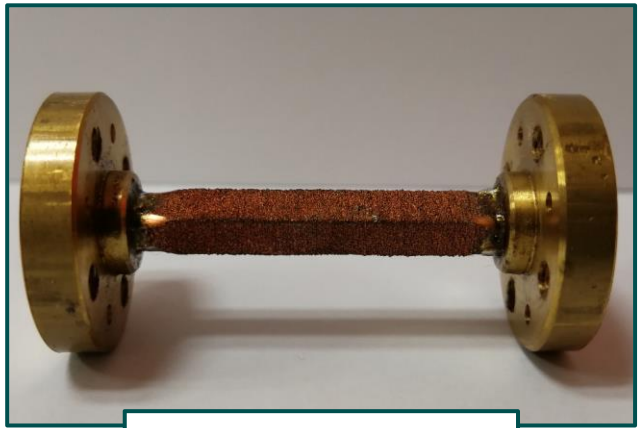

RFQ prototype



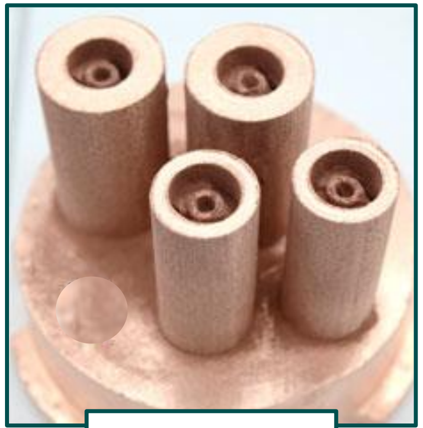
Electron beam



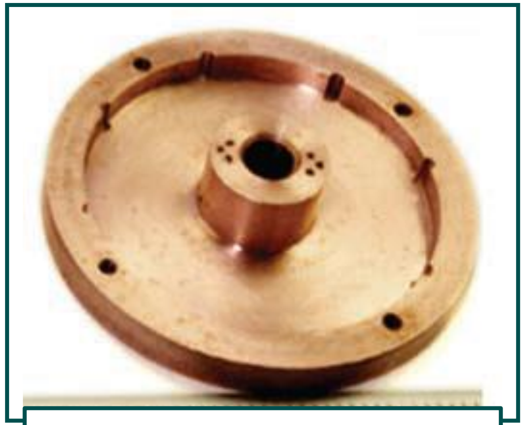

Beam dump



WR12 waveguide



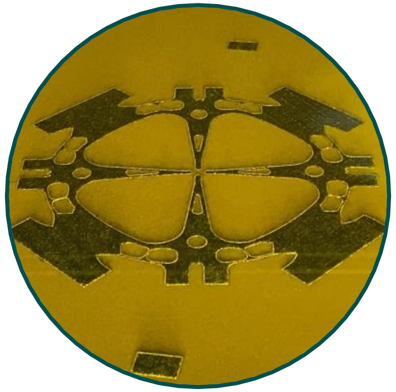
RF cavities

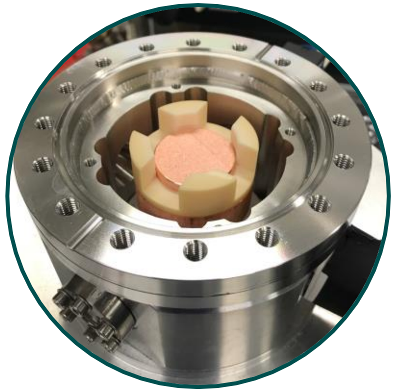


Photoinjector cathode

Sinico et al. (2019), Mayerhofer et al. (2022), Sciacca et al. (2023), Torims et al. (2022)
Horn et al. (2018), Lomakin et al. (2019), Nantista et al. (2020), Frigola et al. (2014)

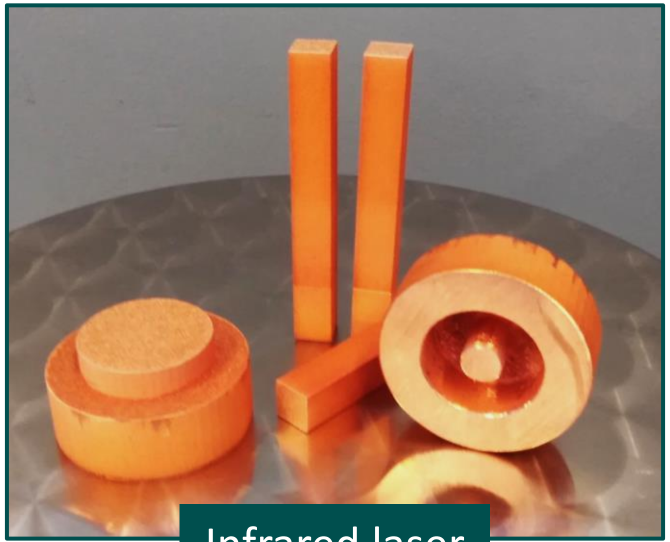
# Validation of LPBF for accelerator applications





| Material | Process | Operating conditions |
| --- | --- | --- |
| Chemical purity | Parameter setting | UHV compatibility |
| Microstructure/anisotropy | Part orientation | High voltage holding |
| Defects/porosity | Dimensional accuracy | Radio-frequency properties |
| Mechanical properties | Surface roughness | Response to irradiation |
| Electrical properties | Print-to-print reproducibility | Cryogenic properties |

# Specimen fabrication



Infrared laser


Green laser

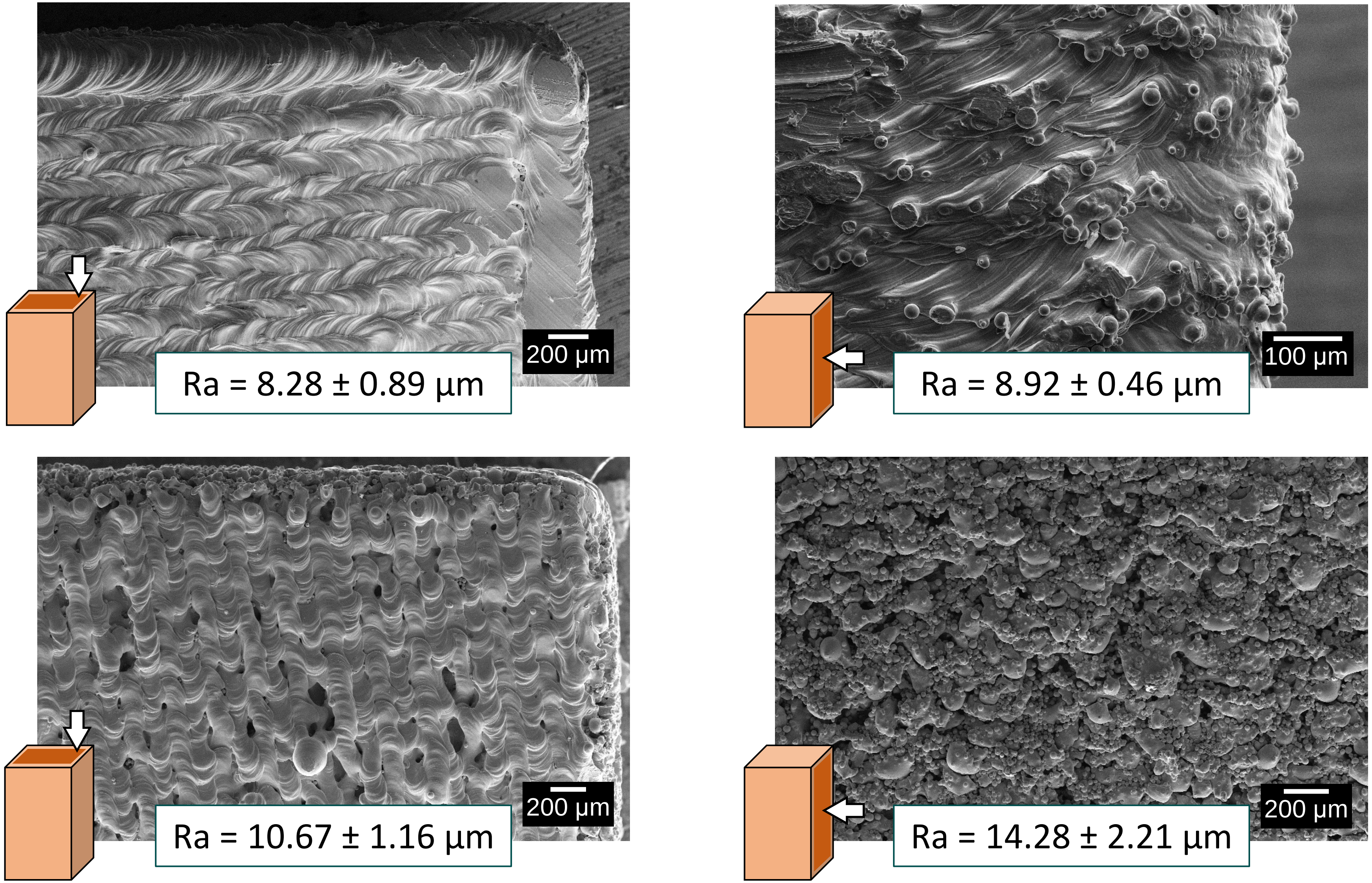
- EOS M 280
- Laser wavelength: 1070 nm
- 99.95% pure Cu powder
- Particle size: 15 – 38 µm

- TRUMPF TruPrint 1000 Green Edition
- Laser wavelength: 515 nm
- m4pTM PureCu powder (>99.95%)
- Particle size: 10 – 45 µm

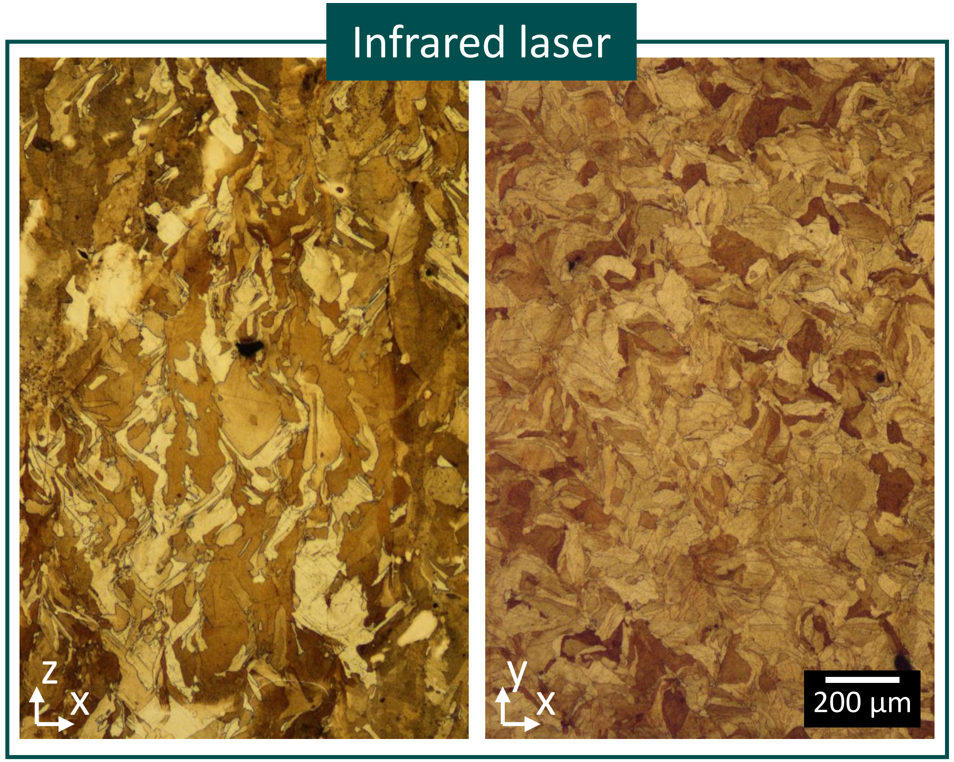
# As-printed surface morphology

Infrared laser

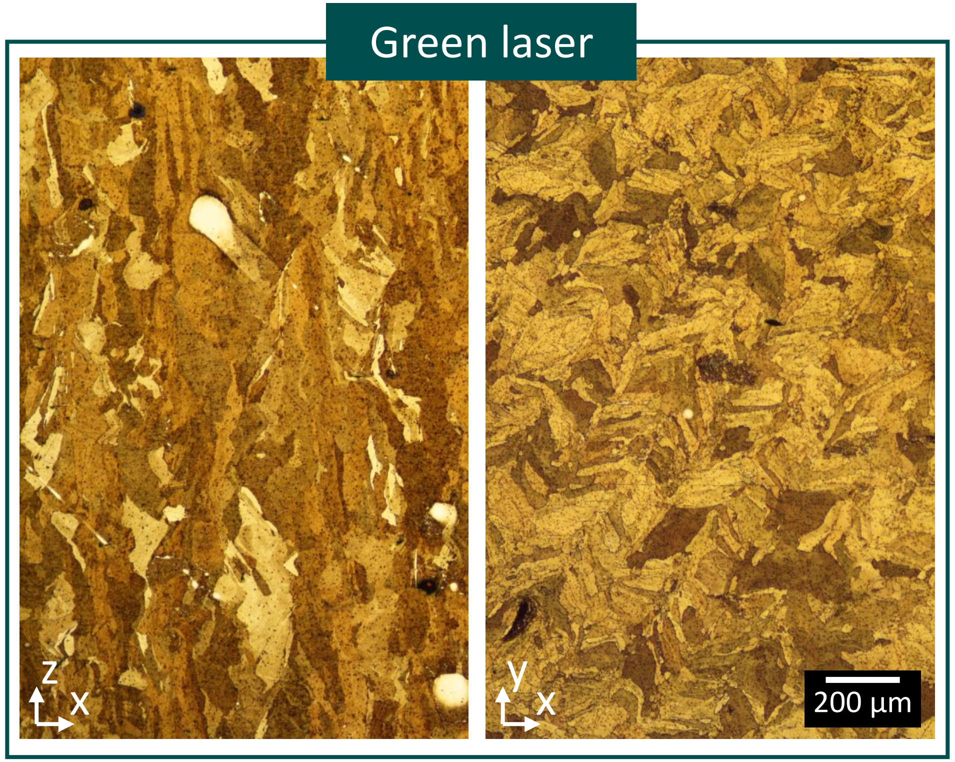
Green laser



# Microstructure and hardness



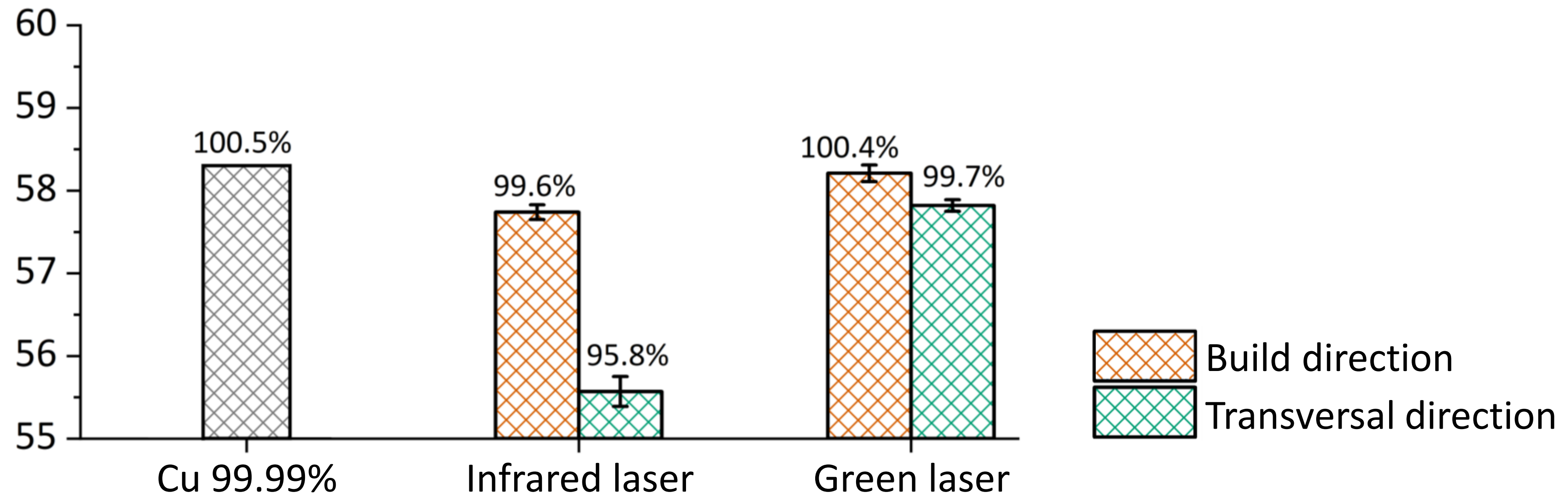

- Oxygen content: 0.041 ± 0.003 wt.%
- Density: ~99.8%
- Microhardness: 78.2 ± 1.9 $HV_{0.05}$



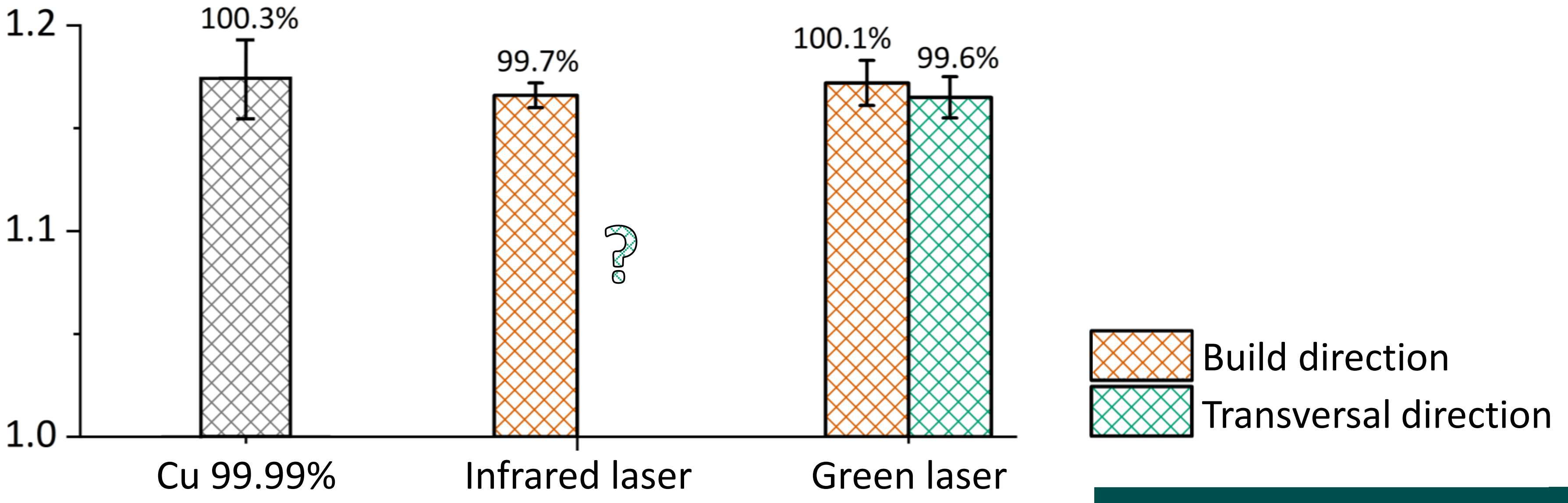

- Oxygen content: 0.044 ± 0.004 wt.%
- Density: ~99.6%
- Microhardness: 75.5 ± 3.2 $HV_{0.05}$

# Physical properties

Electrical conductivity (MS/m)

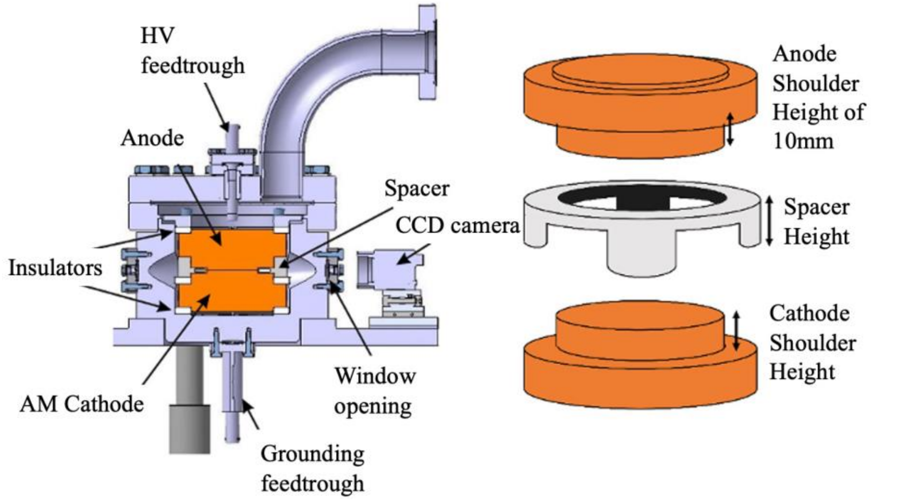


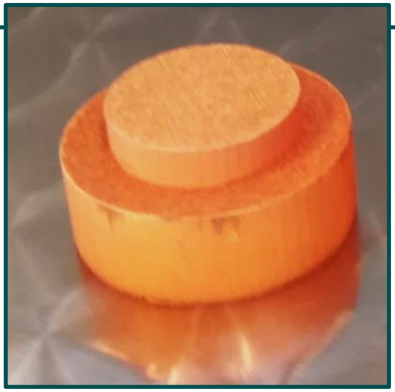

Thermal diffusivity ($cm^2/s$)

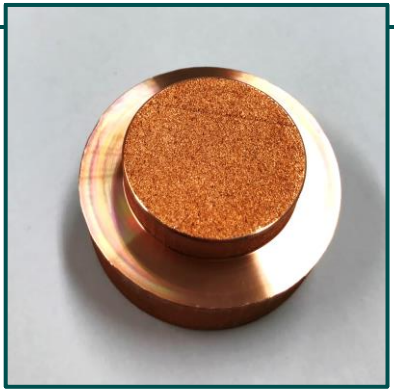


# High-voltage and UHV testing

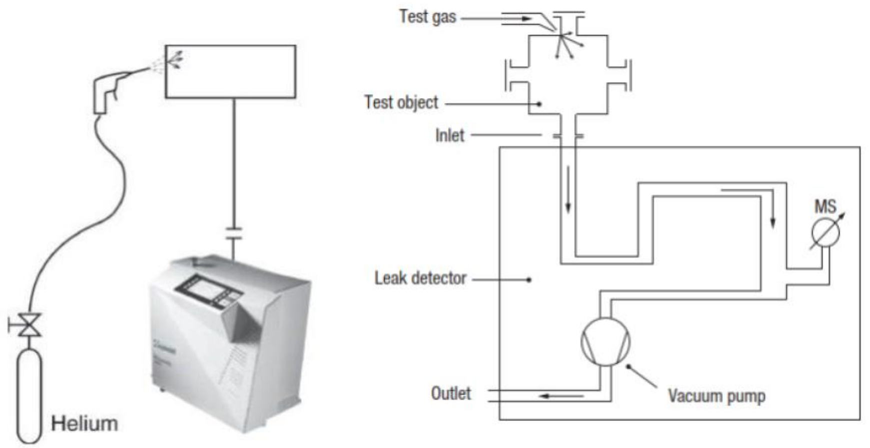
## Vacuum arc breakdown test





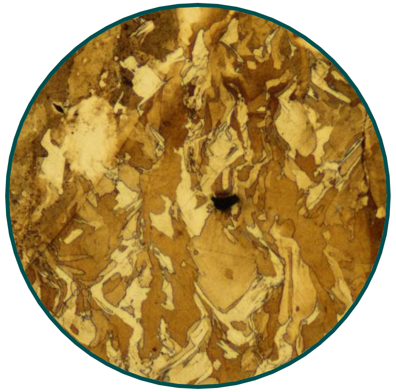
## Helium leak test




Peacock, Experimental Investigation of Vacuum Breakdown Triggering Mechanisms in a DC Electrode System
Rorison, A study of the effectiveness of Cold-Spray additive manufacturing for Ultra High Vacuum

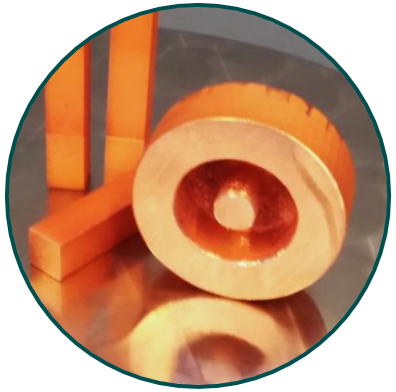
# Conclusions and future work

| | | | |
|---|---|---|---|
| Low oxygen content | Low residual porosity | Adequate hardness | >90% electrical conductivity |



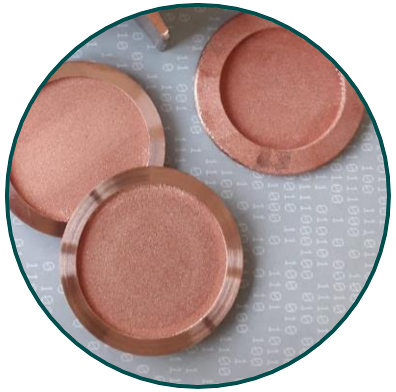
***As-printed material***

Effects of anisotropy on material properties



***HV cathodes***

Surface features produced by breakdown



***UHV membranes***

Structural features causing helium leakage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