Progress towards Pressurized Flow in Capillary Porous Structures

WPPRD-LMD End of Year Meeting 2025

V.F.B. Tanke & T.W. Morgan

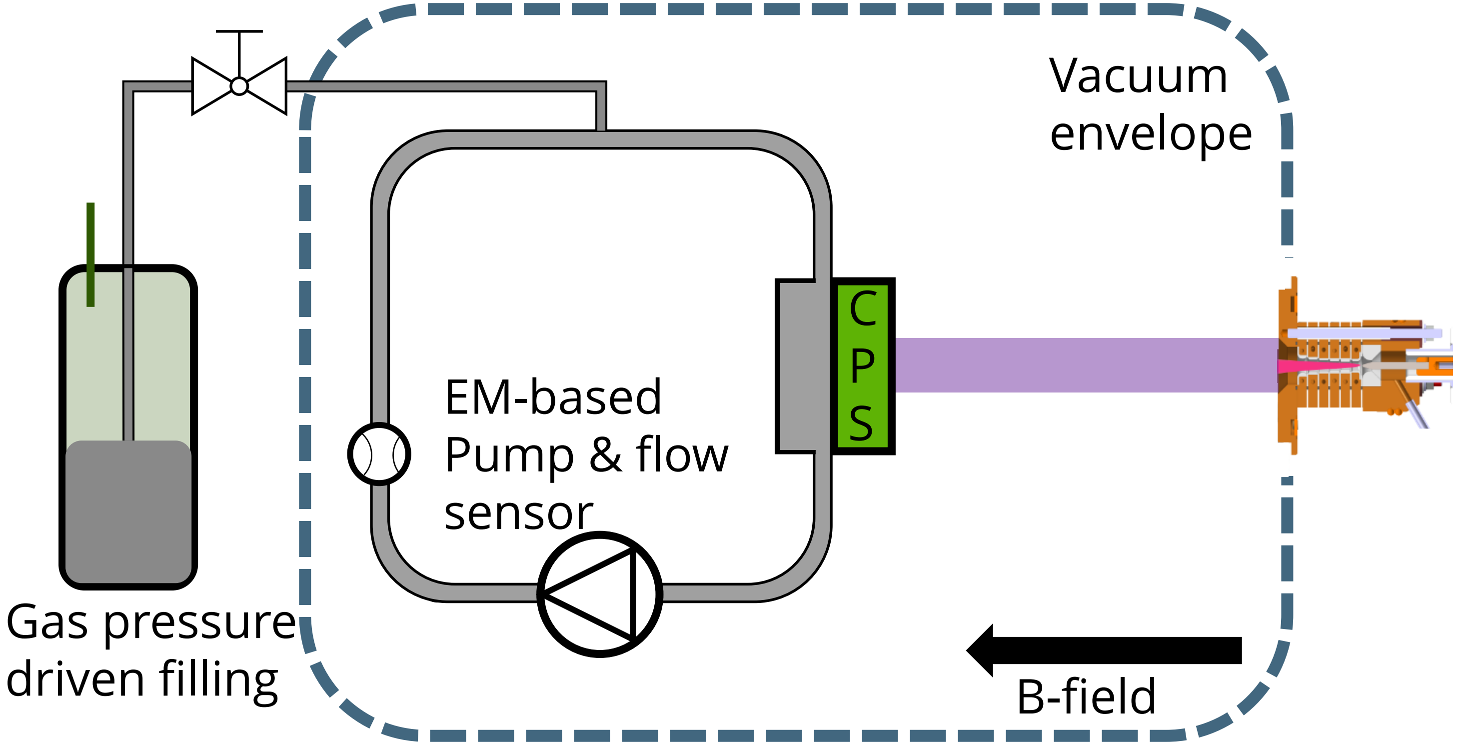
DIFFER

DIFFER Goal

“To develop and demonstrate a circulating liquid metal loop with Capillary Porous Structure (CPS) based Plasma facing component (PFC) within the environment of Linear Plasma Generator (LiMeS-PSI).”

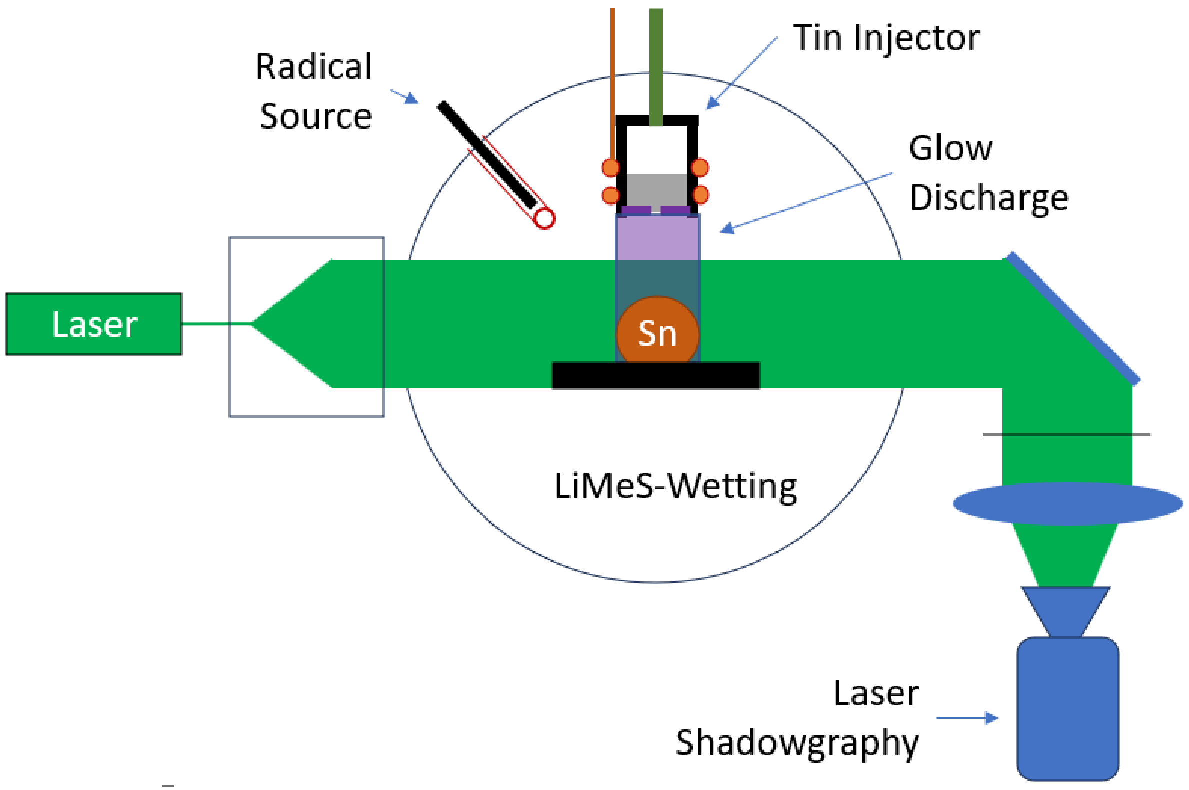
Main Objective 2025: Evaluation of effective CPS capillary pressure to enable pressurized flow

- Liquid tin – substrate wetting improvement via surface treatment
- Tungsten sample infiltration by liquid tin to produce capillary stabilized samples.
- In-situ evaluation of capillary stability during different operating conditions.



LiMeS-Wetting: Sn Contact angle on substrates

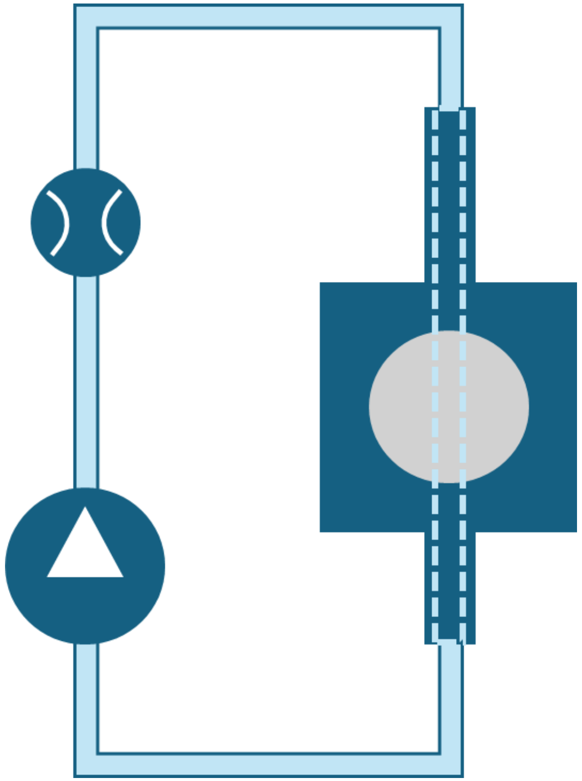
- LiMeS-Wetting commissioned June 2025.
- Contact Angle measured on solid AISI304 and TZM samples exposed to different surface treatments.
- System down due to vacuum leaks. Continue with Tungsten and 3D printed “solid” tungsten in next year.
- Tin contact angle measured on AISI304 CPS samples exposed to different cleaning methods.
  - No Wetting or Infiltration observed up to 750 °C using either glow discharge or radical cleaning.
  - Continue with Tungsten CPS samples next year.



Evaluation of CPS capillary stability

Observe capillary stability as function of pressure behind CPS component in a two phased approach:

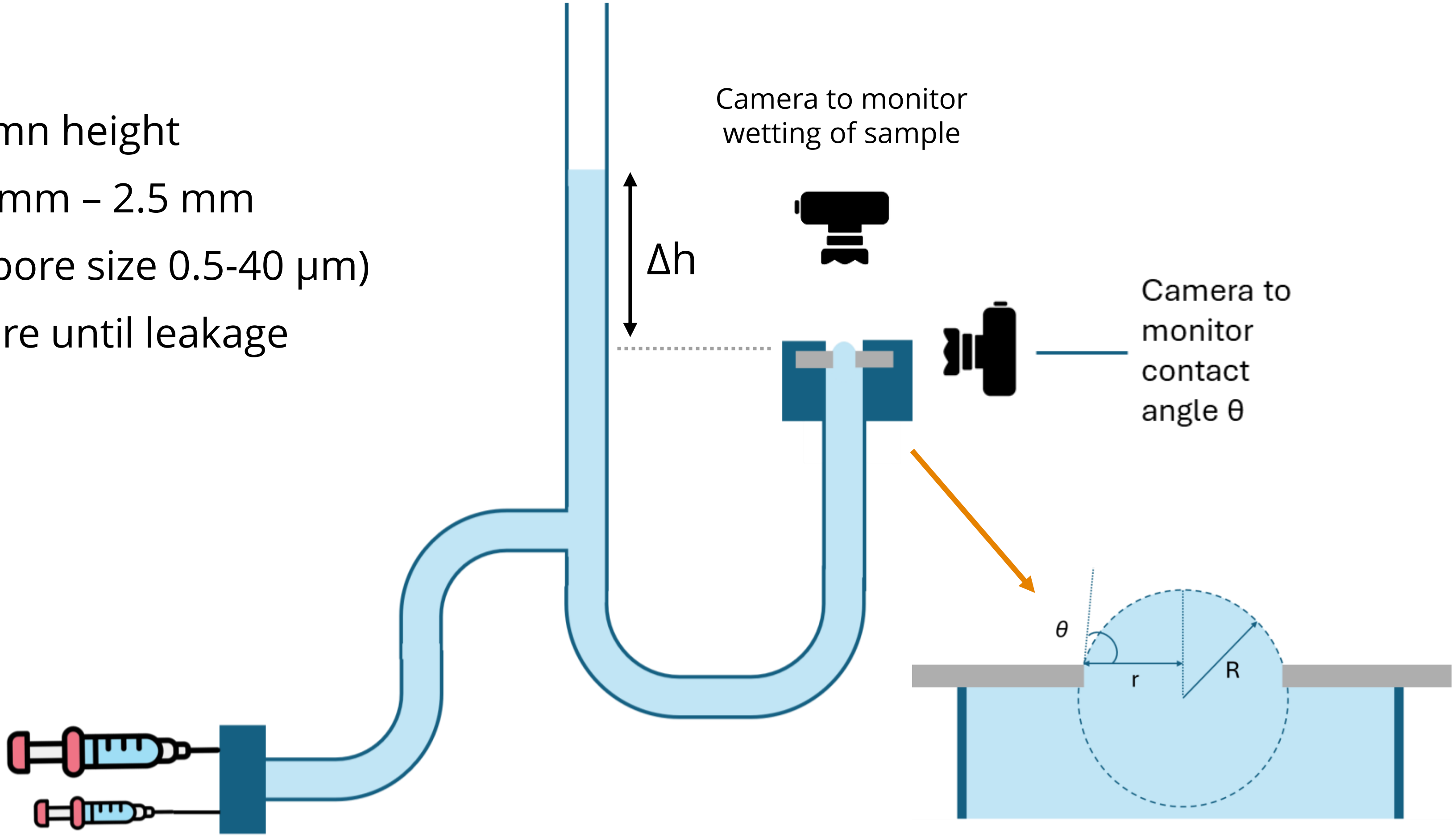
1. Start with a static evaluation using water in simple test setup: Hydrostatic pressure generated by liquid column is balanced by capillary pressure due to curved meniscus at pore exit.
2. A functioning closed loop setup for liquid Gallium circulation to develop plasma facing components in static and flowing conditions, requiring:
   - Sample holder for CPS style samples
   - Flowmeter
   - Pump (PMP or DC-EM)
   - Filling and draining system



Maximum static pressure sustained by single pore

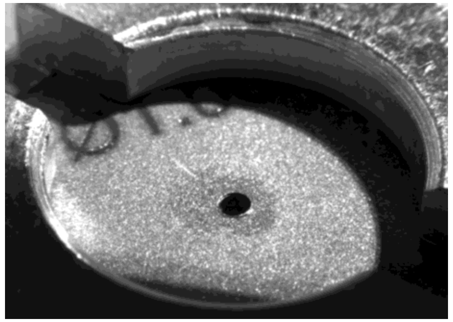
Setup:

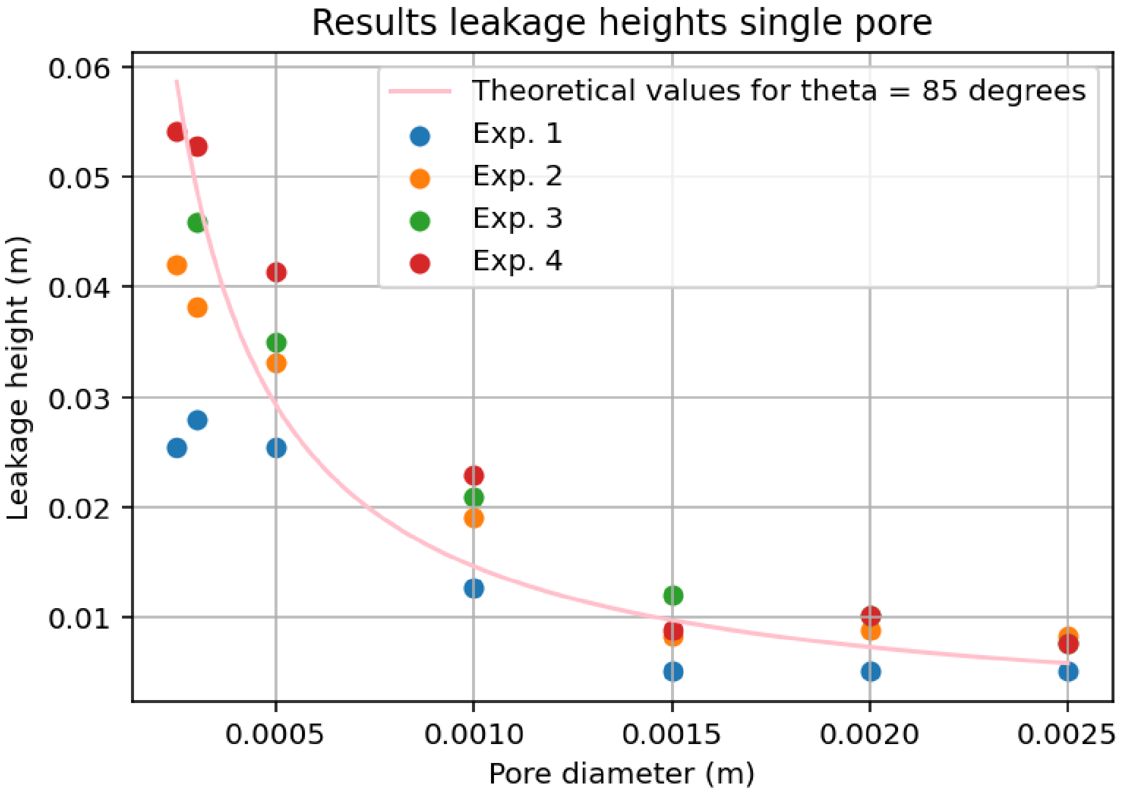
- Syringes to vary liquid column height
- Single pore samples Ø0.25 mm – 2.5 mm
- 4 CPS samples (mean flow pore size 0.5-40 µm)
- Increase hydrostatic pressure until leakage through pore occurs



Preliminary Static Results

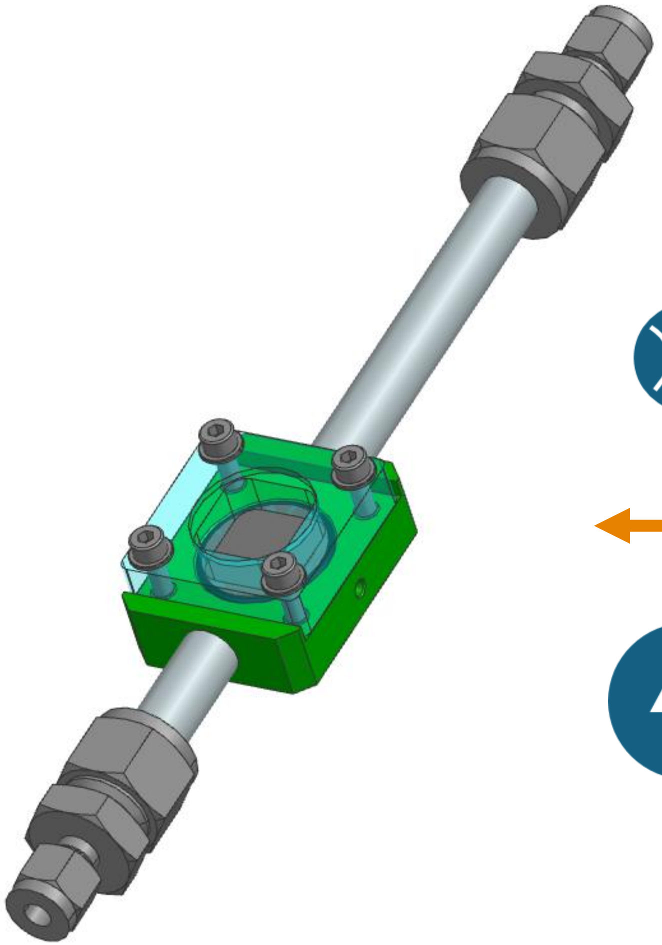
- Time-dependent formation of ‘precursor film’ results in earlier onset of leakage (Exp 1) in single pore experiments
- When minimizing influence of time: results follow theory quite well (Exp 2 – 4)
- Current experiments with CPS samples ongoing, completed in January 2026.

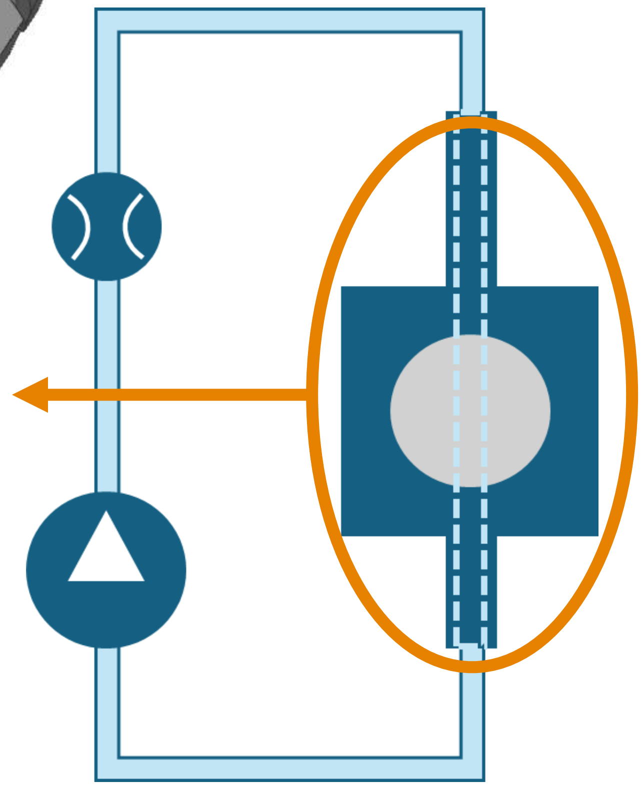




Gallium Experiment Development: Sample Holder

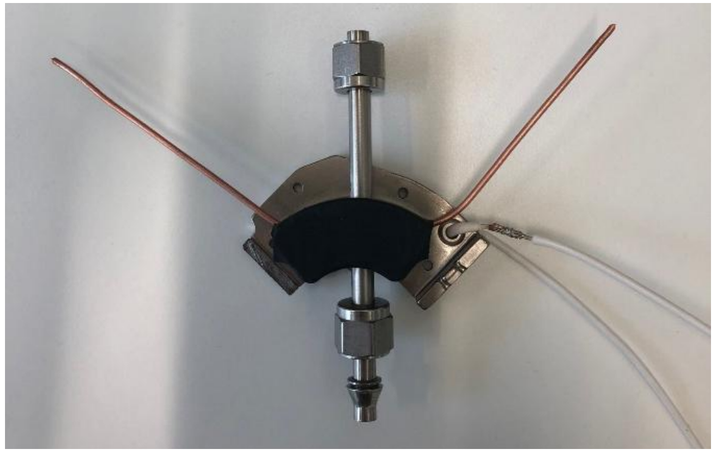
- Development of CPS sample holder with liquid Gallium flow channel below CPS. To be used in:
  - Static experiment
  - Gravity driven open loop experiment
  - Pump driven closed loop experiment
- 4x4 mm square channel with undisturbed length of 100 mm before and 50 mm after the CPS sample.
- Transparent plastic sample clamp to observe surface.
- In 2026: Start with open loop experiments while acquiring pump to create the closed loop.

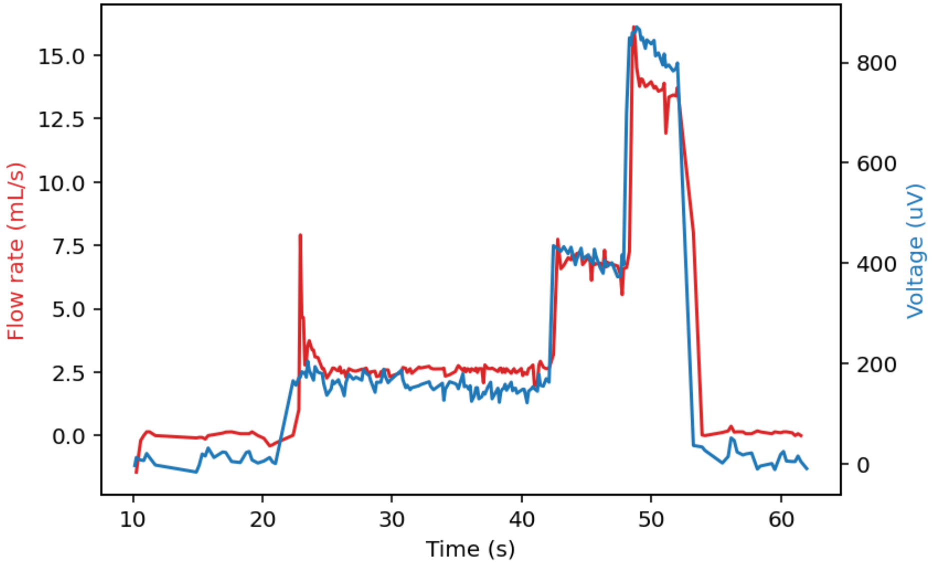


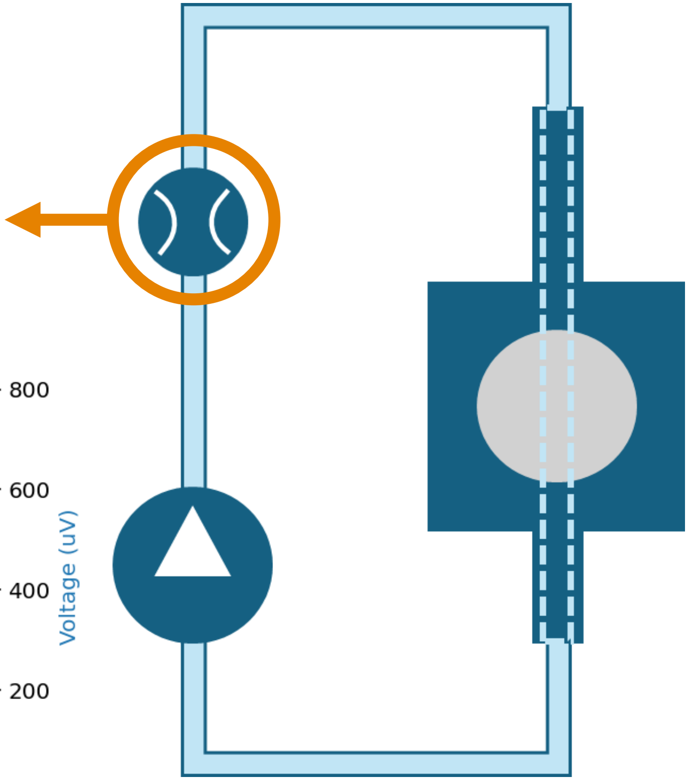


Flowing Gallium Experiment: Flowmeter

- Development of transverse magnetic field potentiometer as gallium flowmeter.
- Initial prototype made and tested in gravity driven open loop.
- Calibration using a mass balance which measured change in weight.
- In 2026 extend sensor to include more electrodes to produce more stable result and calibrate in closed loop against other sensors.







Activities in 2026

First half of 2026:

- Start/Continue with the investigations of wetting and infiltration in the Tin-Tungsten system.
- Construct gallium test loop, followed by experiments on capillary stability of liquid gallium containing CPS.
- Finish construction of LiMeS-TDS and quantify performance of machine.

Second half of 2026:

- After Gallium loop, take lessons learned and develop high temperature tin loop for use in vacuum and determine capillary stability.
- Work on infrastructure and components for the LiMeS-PSI tin loop, such as:
  - Flowmeters
  - DC electromagnetic pump using device magnetic field.

Additive manufacturing of CPS's

Clement Heitz[1], J.A.W. van Dommelen[1], T.W. Morgan[1,2], N. Ur Rahman[3]

1Eindhoven University of Technology

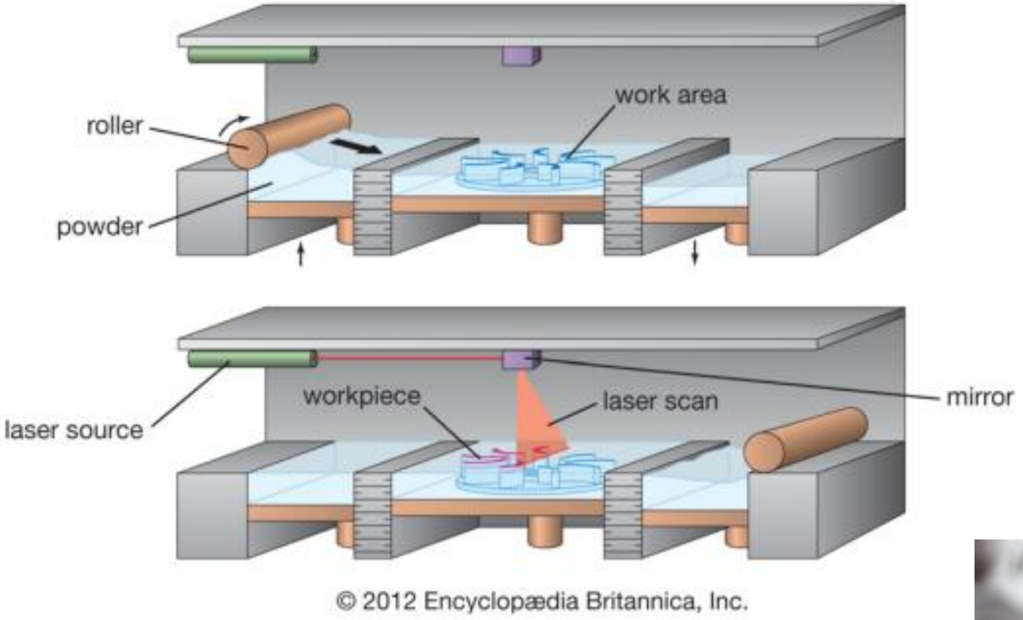
[2]DIFFER

[3]Philips

Design, Manufacturing and testing of liquid metal shielding concepts

Improve bulk part properties	2026
Design, manufacture and test porous surface	2027
Design, manufacture and test internal structures	2028
Gradient in architecture and composition	2029

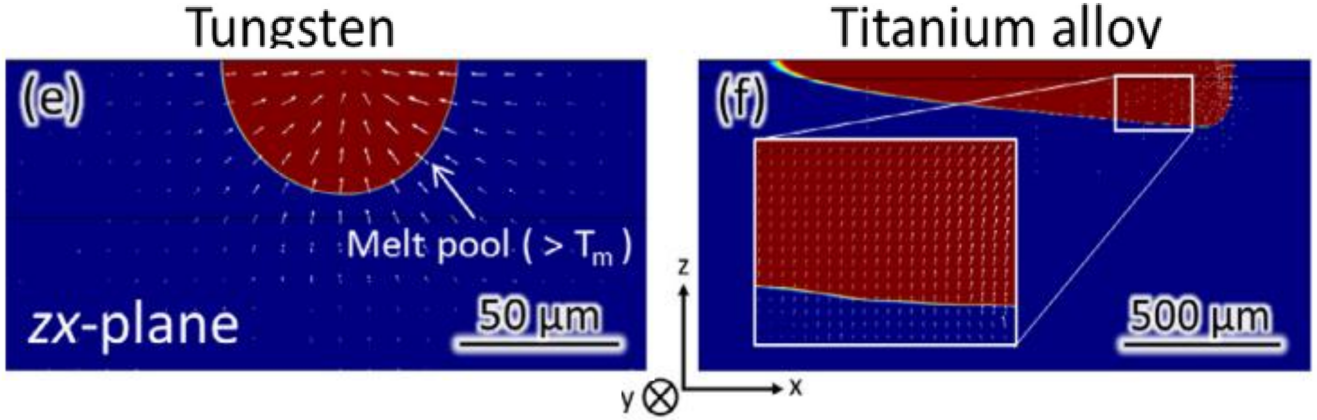
Laser Powder Bed Fusion machine: Aconity MIDI



- High speed scan
- Thin scan lines (100 µm)
- 10µm accuracy

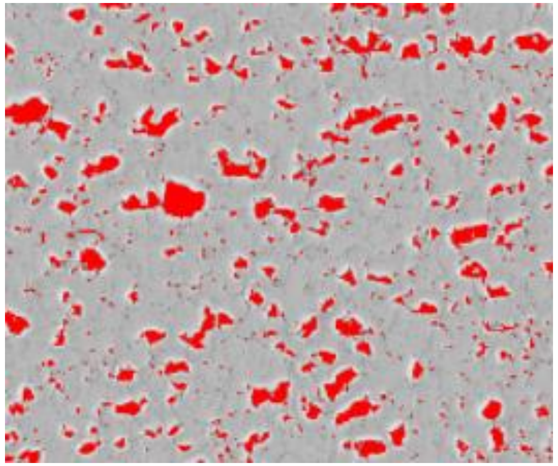
- High power laser
- 50µm spot size
- 800°C preheating
- Low O_2 content

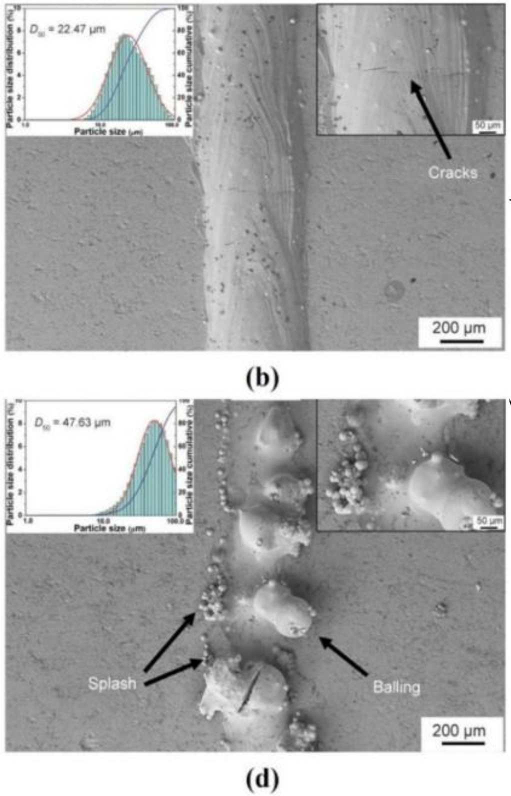
Improve bulk part properties in W



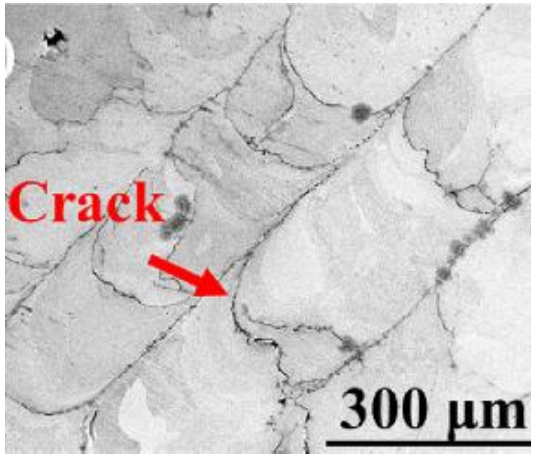
Melt pool comparison [Todo et al 2022]

- High power density required
- Balling phenomena
  - Low density
  - $\tau_{Solidification} < \tau_{Wetting}$
- Crack formation
  - Crossing Brittle to Ductile Temperature
  - At grain boundaries


W LPBF cross section [Burger 2024]



Scan line comparison [Mudda et al 2025]



Cracks in W LPBF [Hu et al 2023]

Literature review of obtained Density

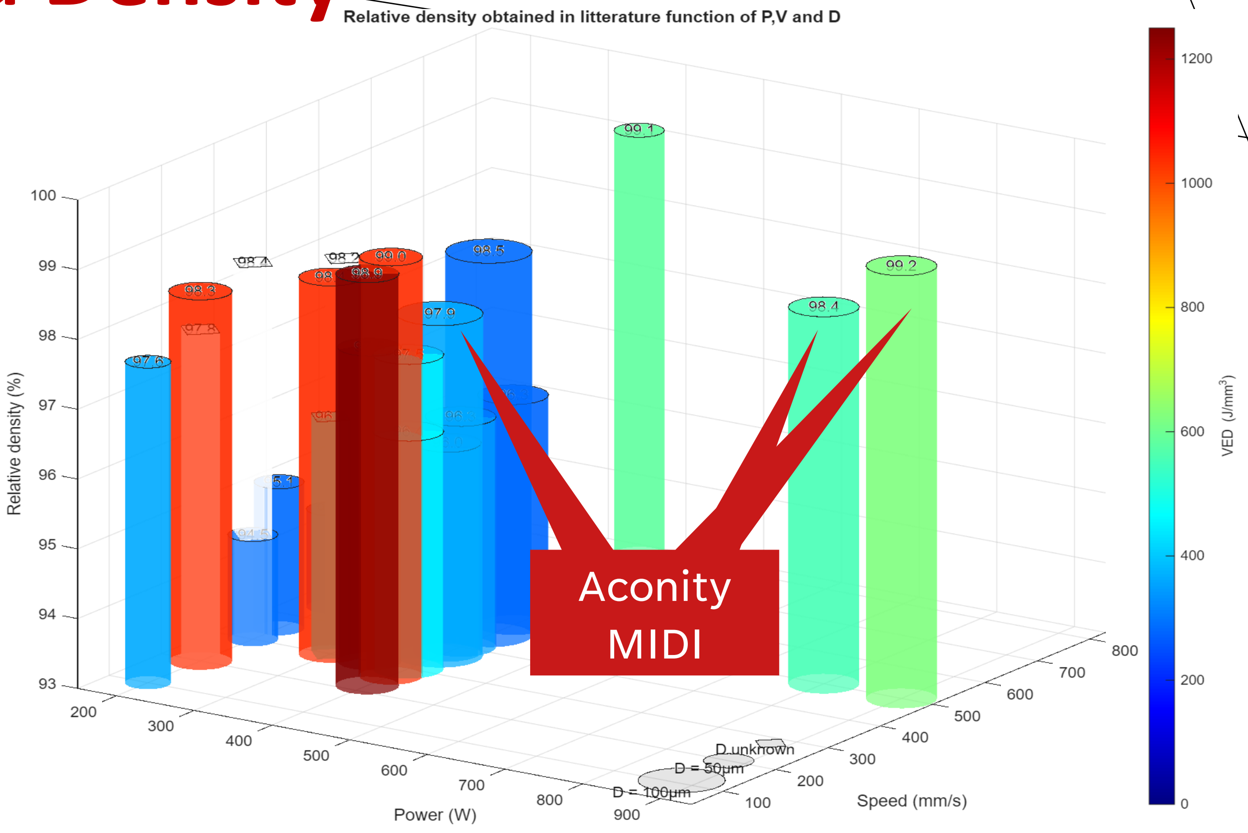
- Plot **Density** in **P-V** plan
- Diameter → spot diameter
- Height → Density
- Colour → $VED = \frac{P}{V\ e\ h}$

Power

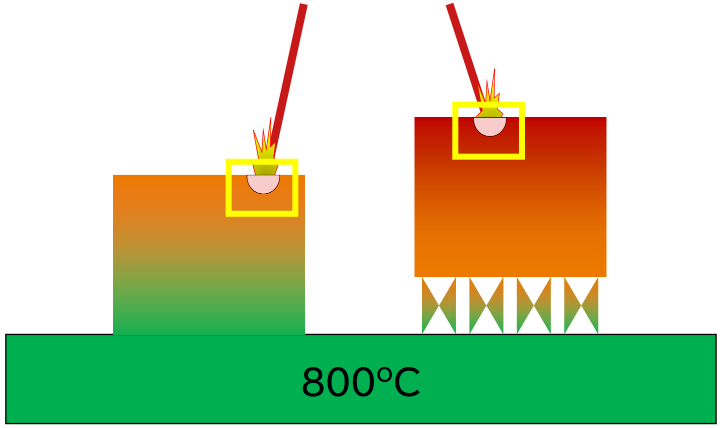
Scan speed

Layer height

Hatch distance



- ➢ *High VED*
- ➢ *Global heat accumulation*
- ➢ *Local heat accumulation*

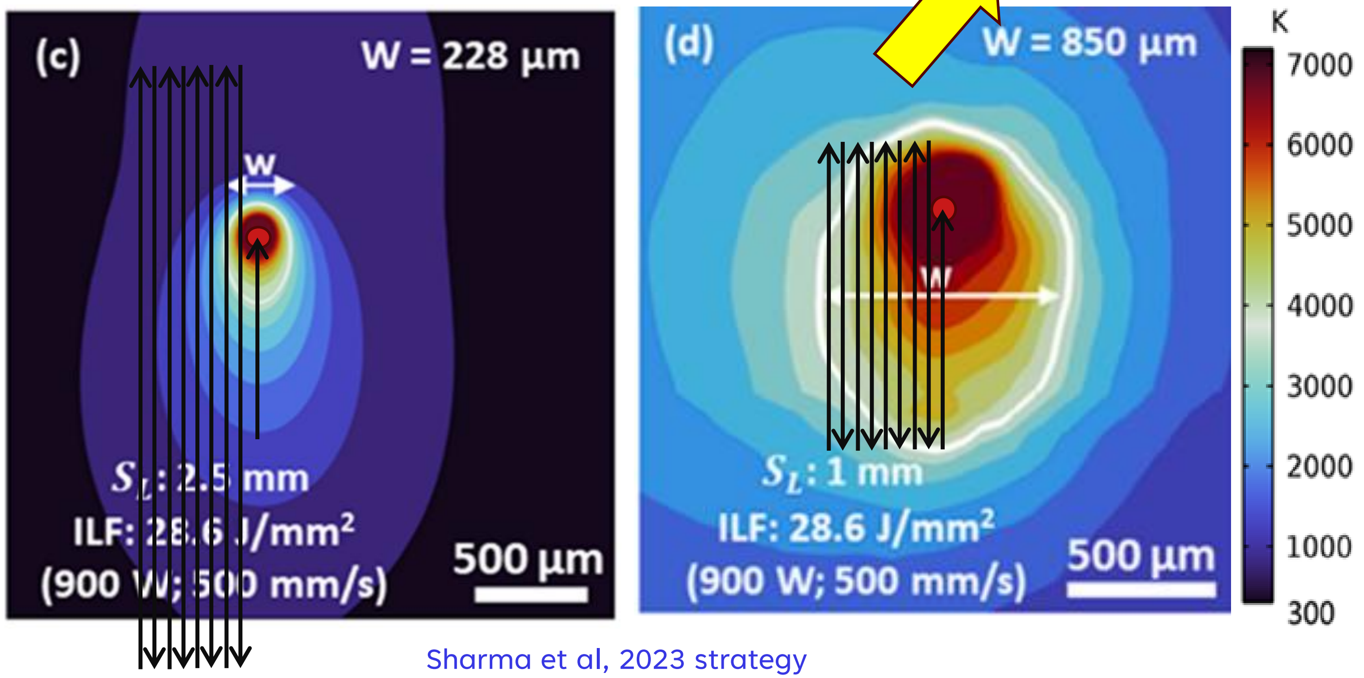


Local heat accumulation

- **Short lines / Sine wave / helicoidal** scan strategies
  - Less thermal gradient
  - Longer solidification time
  - Higher productivity

$\tau_{\text{Solidification}} \sim 1 \rightarrow 20 \text{ ms}$

99,2 % density



Sharma et al, 2023 strategy