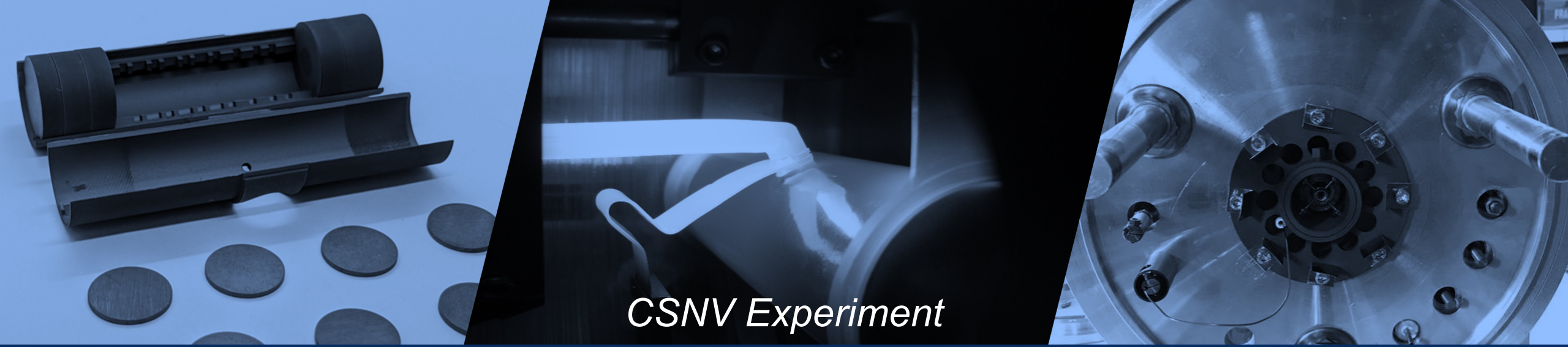


HISOL

High performance ISOL systems for the production of radioactive ion beams

Progress Report 2024

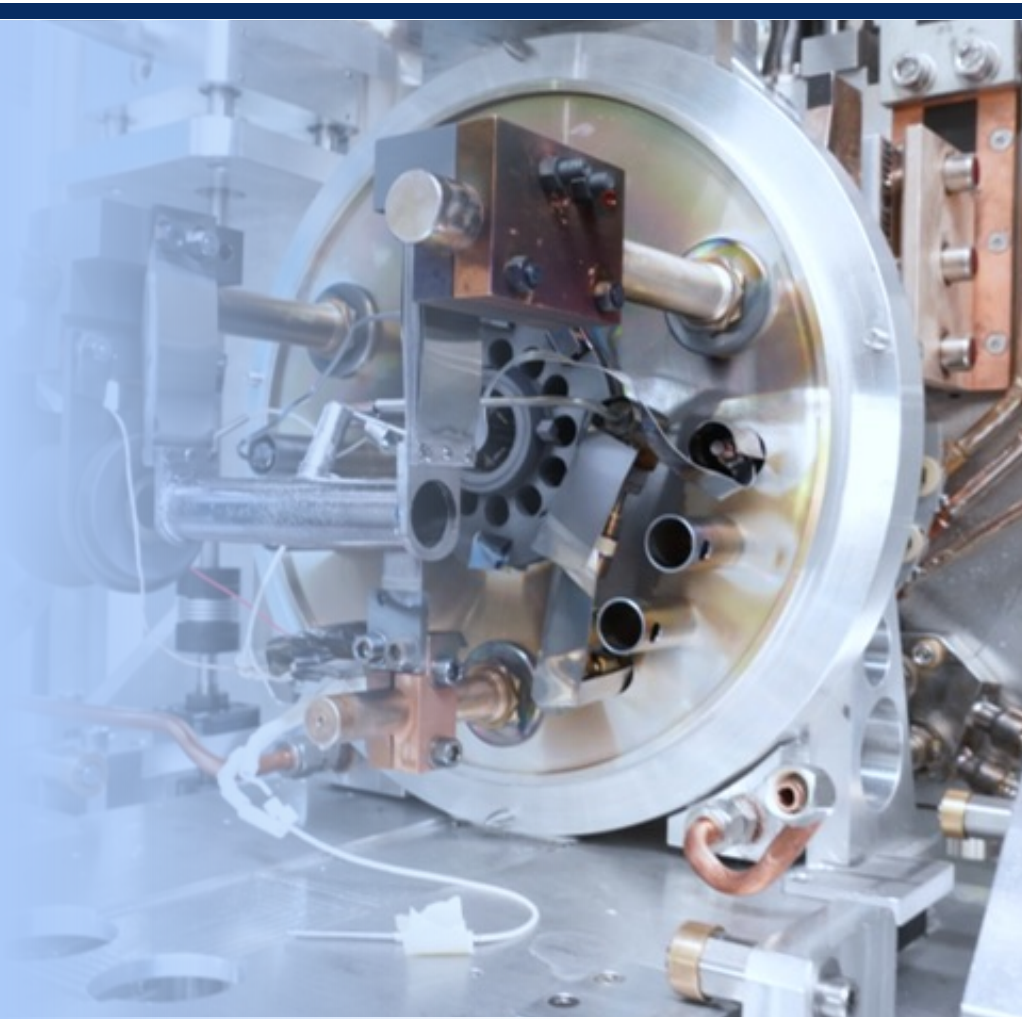
Pietro Rebesan – INFN Sezione di Padova

INFN
Istituto Nazionale di Fisica Nucleare

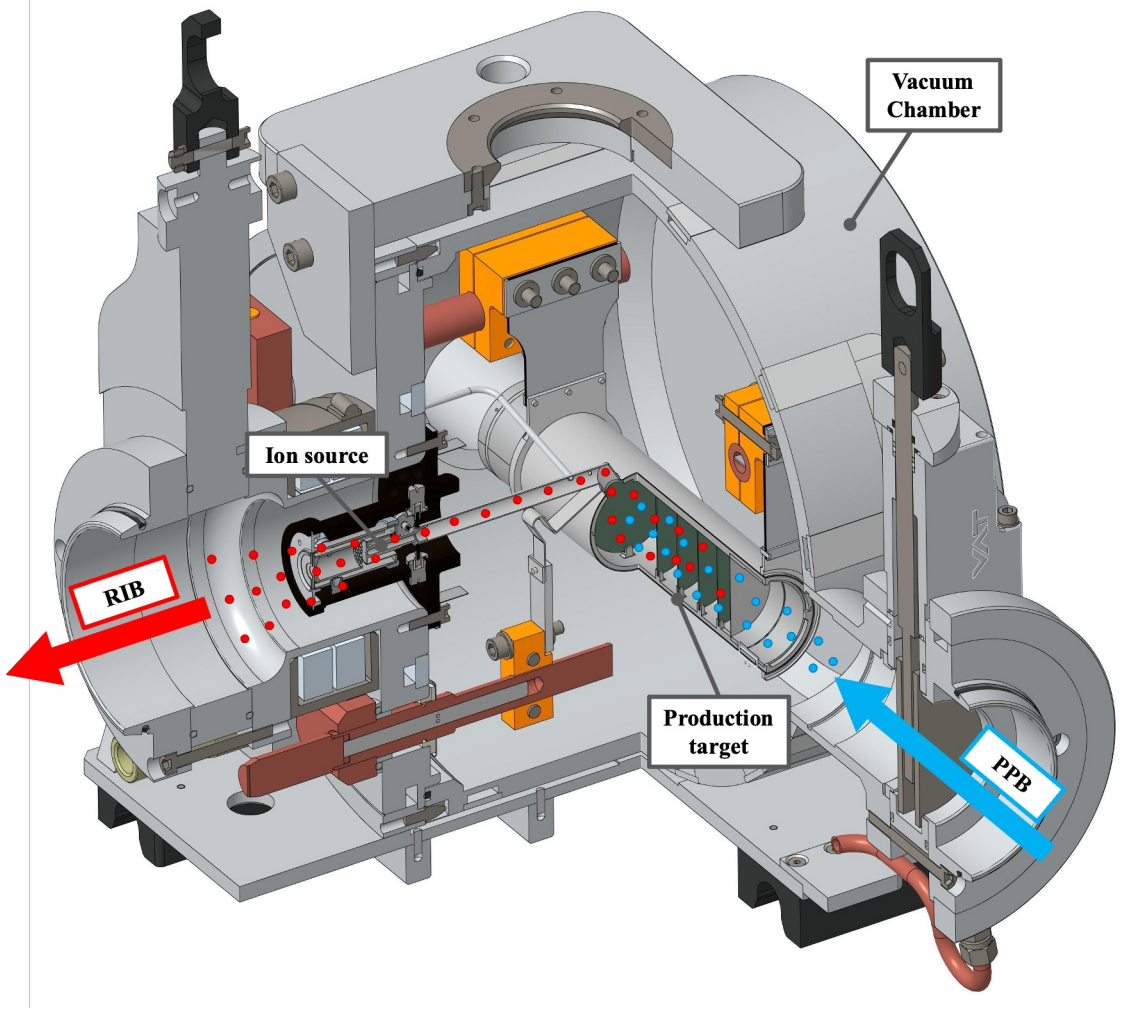
HISOL – 27th June 2024

Outline

- **Introduction – the TIS unit**
  - The SPES target
  - The SPES FEBIAD ion source
- **The HISOL**
  - Project Objectives
  - Research Methodology
  - Timetable and milestones
  - Some Results – WP 2 Examples
- **HISOL_NEXT**



The SPES Target – Ion Source Unit



The **Target – ion source unit** is the **core of an ISOL facility.**

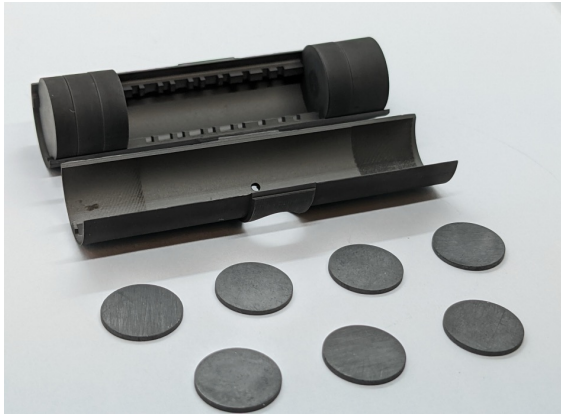
It's composed of the **production target** connected to the **ion source.** Such devices are contained in a **vacuum chamber**.

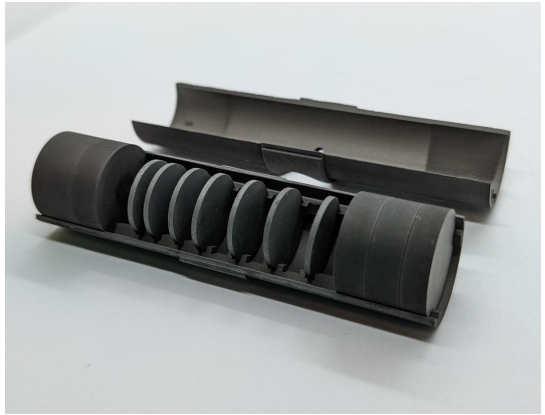
The growing demand for **high intensity** and **pure Radioactive Ion Beams (RIBs)** is pushing to improve the performance of the existing **ISOL Targets** and **Ion Sources**, since these are the objects that most of all affect the **intensity** and the **purity** of **RIBs**.

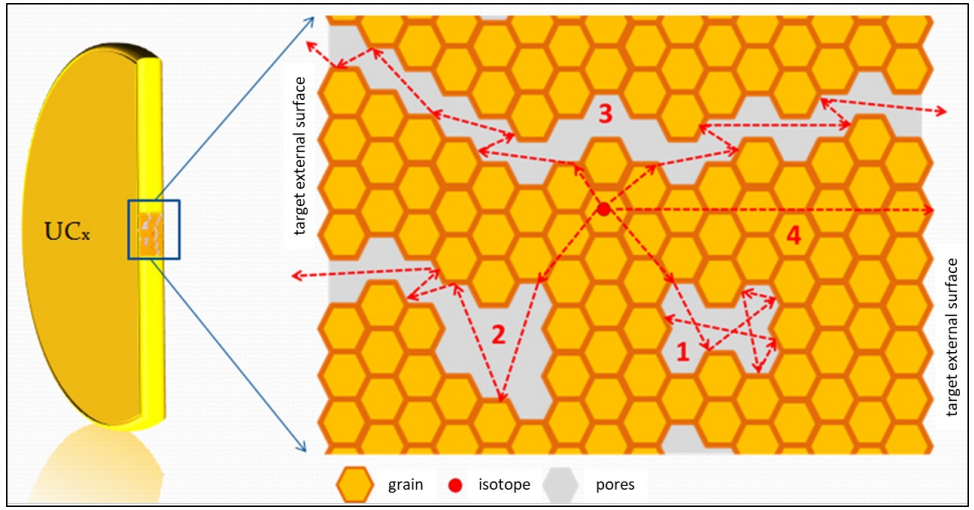
ISOL target requirements

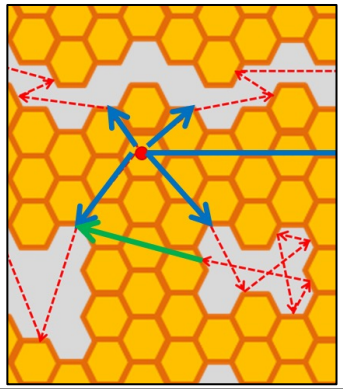
Target requirements:

- open porosity and reduced grain size
- high thermal conductivity
- high mechanical properties
- stability at high temperature
- production of radioisotopes









Total isotope yield deeply affected by **open porosity** (diffusion/effusion processes)

Isotope generation

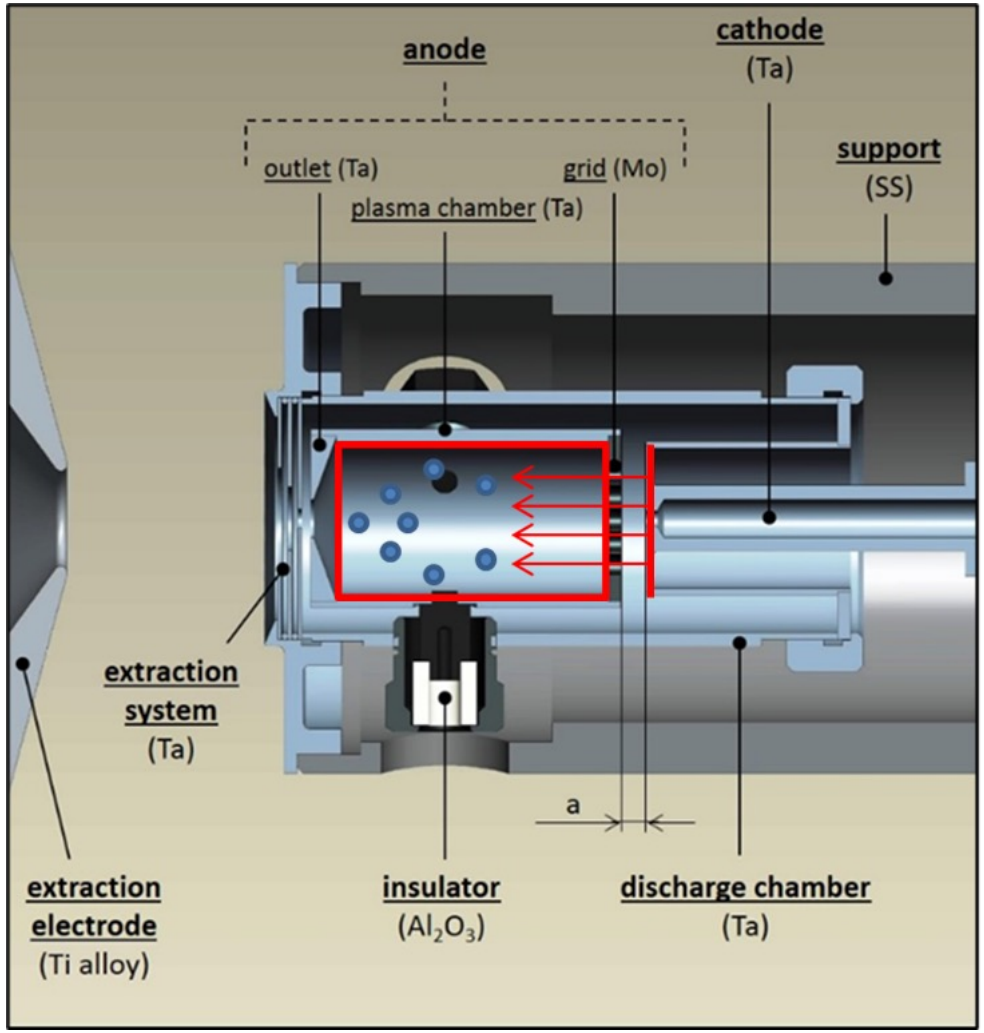
Diffusion paths

Effusion paths

Re-diffusion paths

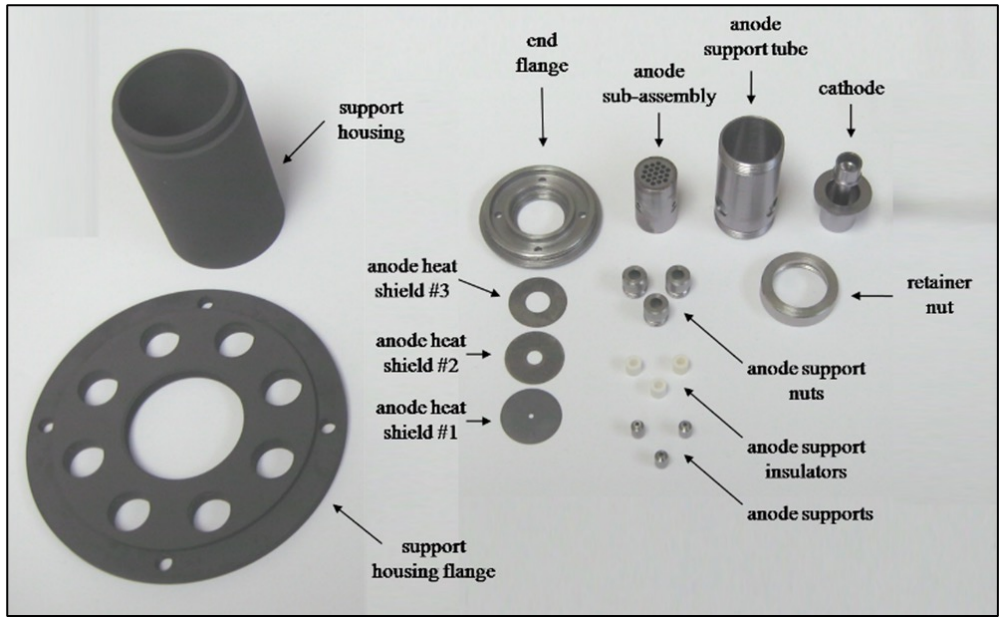
BULK TARGET = BAD RELEASE!!
Need of targets with regular improved microstructure

The SPES FEBIAD Ion Source



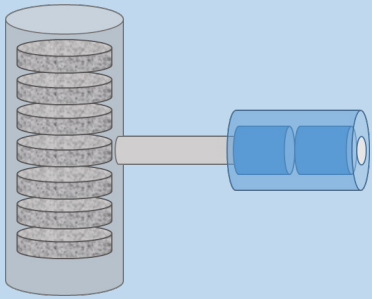
The Standard FEBIAD Ion Source

- more than **20 components**
- long procedure for alignment (manual operation)
- **performance variation** and **reduced reproducibility**



HISOL Objectives

Main goal:
Development of a **new generation of High Performance ISOL Targets and Ion Sources** with cutting edge technologies available within INFN and its collaboration network.



Such aim foresees **three fundamental objectives**:

WP 1 ➚ Study and development of **innovative recipes and methods** to produce **ISOL targets**

WP 2 ➚ Study and development of **innovative methods** to produce and operate **ion sources**

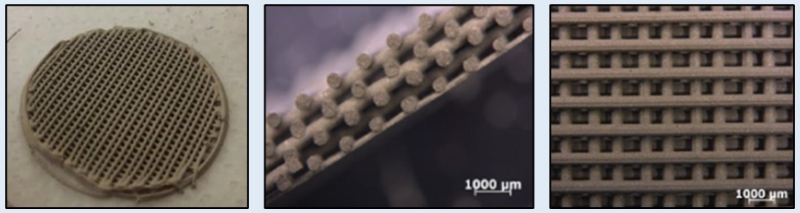
WP 3 ➚ **Characterization** and **multiphysics simulation** of the obtained components by means of advanced techniques

Research Methodology – AM production, Tests, & Characterization

Work package 1: Development of High Performance ISOL Targets

Production of **TiC/SiC samples** with **regular structures** for **characterization** activities

Development of **TiC/SiC disks** with regular structures for **ISOL Targets**



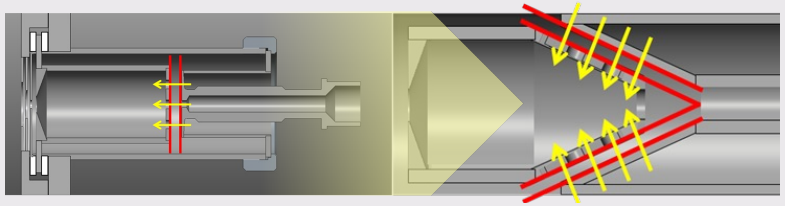
Long term **high temperature test** of a TiC/SiC ISOL Target prototype

Aim: maximize heat transfer and release

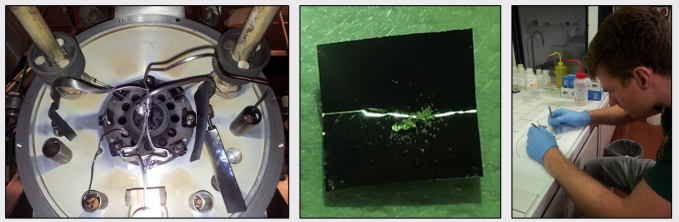
Work package 2: Development of High Performance ISOL Ion Sources

Production and test of **W, Ta and Mo Ion Source components** with **complex shapes**

Alternative anode-cathode interfaces



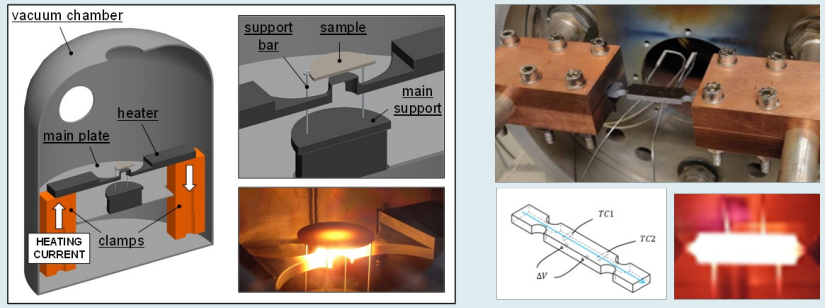
Production of ion beams with the Ion Source prototype (also **molecular beams**)



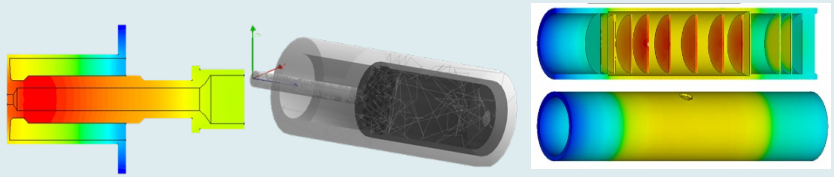
Aim: improve the ionization efficiency, the source stability and reproducibility

Work package 3: Materials Characterization and Multiphysics Simulation

Microstructural, thermal, electrical and structural **characterization**



Multiphysics Simulation of High Performance ISOL Targets and Ion Sources



Aim: component characterization

WP 1 – Timetable & Milestones

		Year 1				Year 2			
		M3	M6	M9	M12	M15	M18	M21	M24
WP1	**Development of High Performance ISOL Targets**								
T1.1	Production of TiC samples with regular structures for characterization activities		MS1.1						
T1.2	Development of TiC disks with regular structures for ISOL Targets				MS1.2				
T1.3	Production of SiC samples with regular structures for characterization activities								
T1.4	Development of SiC disks with regular structures for ISOL Targets							MS1.3	
T1.5	Long term high temperature test of a TiC/SiC ISOL Target coupled with a Plasma Ion Source								MS1.4

WP1 milestones		Date
MS1.1	Production of TiC/SiC samples with regular structures for characterization activities	M06
MS1.2	Printing Test of TiC disks with regular structures for ISOL Targets	M12
MS1.3	Development of TiC/SiC disks with regular structures for ISOL Targets	M21
MS1.4	Long term high temperature test of a TiC/SiC ISOL Target coupled with a Plasma Ion Source	M24

WP 2 – Timetable & Milestones

		Year 1				Year 2			
		M3	M6	M9	M12	M15	M18	M21	M24
WP2	Development of High Performance ISOL Ion Sources								
T2.1	Study, optimization and production of W, Ta and Mo Ion Source Components with Complex Shapes				MS2.1				
T2.2	Thermionic emission tests with Ta cathodes specifically designed for high electron fluxes								
T2.3	Production of stable ion beams with the High Performance Plasma Ion Source prototype				MS2.2				MS2.2
T2.4	Production of molecular beams with the Plasma Ion Source prototype				MS2.4				MS2.5

WP2 milestones		Date
MS2.1	Production of W, Ta and Mo Ion Source Components with Complex Shapes: first prototype	M12
MS2.2	Preparation of the Front-End for stable ion beam production	M12
MS2.3	Production of stable ion beams with the High Performance Plasma Ion Source prototype	M24
MS2.4	Preparation of the Auxiliary Components for the production of molecular beams	M12
MS2.5	Production of molecular beams with the Plasma Ion Source prototype	M24

WP 3 – Timetable & Milestones

		Year 1				Year 2			
		M3	M6	M9	M12	M15	M18	M21	M24
WP3	**Materials Characterization and Multiphysics Simulation**								
T3.1	Microstructural Characterization				**MS3.1**				
T3.2	Thermal and Electrical Characterization								
T3.3	Mechanical Characterization						**MS3.2**		
T3.4	Multiphysics Simulation of High Performance ISOL Targets								**MS3.3**
T3.5	Multiphysics Simulation of High Performance ISOL Ion Sources				**MS3.4**				**MS3.5**

WP3 milestones		Date
MS3.1	Microstructural Characterization	M12
MS3.2	Thermal, Electrical and Mechanical Characterization	M18
MS3.3	Multiphysics Simulation of High Performance ISOL Targets	M24
MS3.4	Definition of the Multiphysics Simulation strategy for High Performance ISOL Ion Sources	M12
MS3.5	Multiphysics Simulation of High Performance ISOL Ion Sources	M24

T2.1 & T3.5: Study, optimization and production of W, Ta and Mo Ion Source Components with Complex Shapes

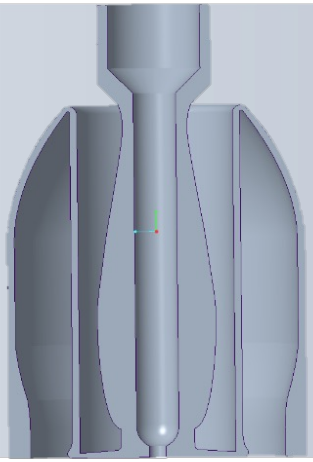
Edoardo Bonigolo's master thesis DTG, UNIPD, Supervisor S. Carmignato - defended 2024

0. Standard cathode
(Cost ~ 1100 €)

1. first AM cathode
(Cost ~ 100 €)

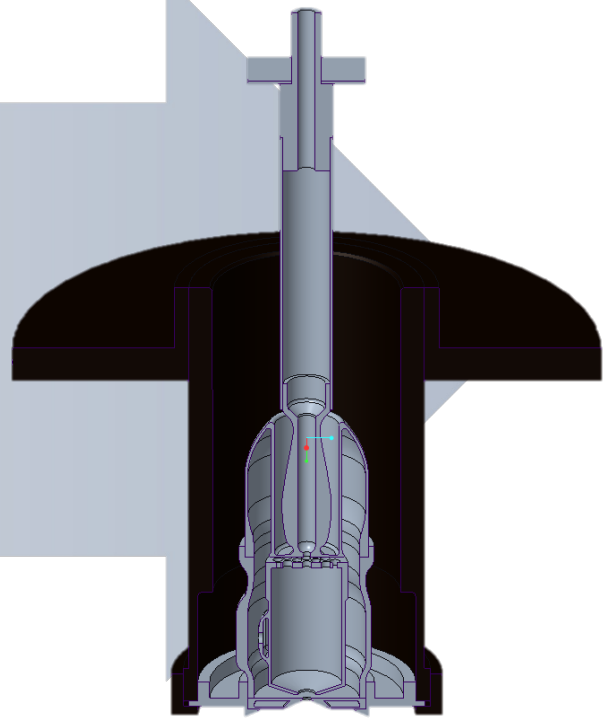
Similar to the standard cathode in both geometry and performances

2. enchanced AM cathode



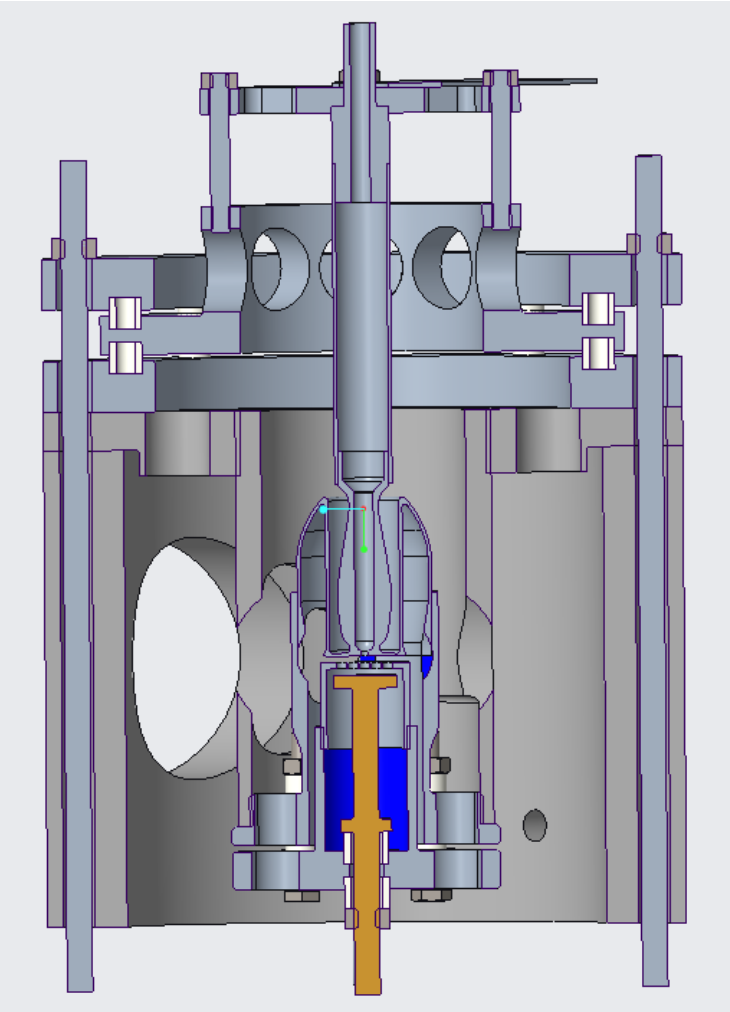
Better temperature homogeneity, easier assembly procedure

3. Fully AM FEBIAD ion source



Edoardo Bonigolo, Master thesis in Products Innovation Engineering, UNIPD, Supervisor S. Carmignato - to be defended March 2024

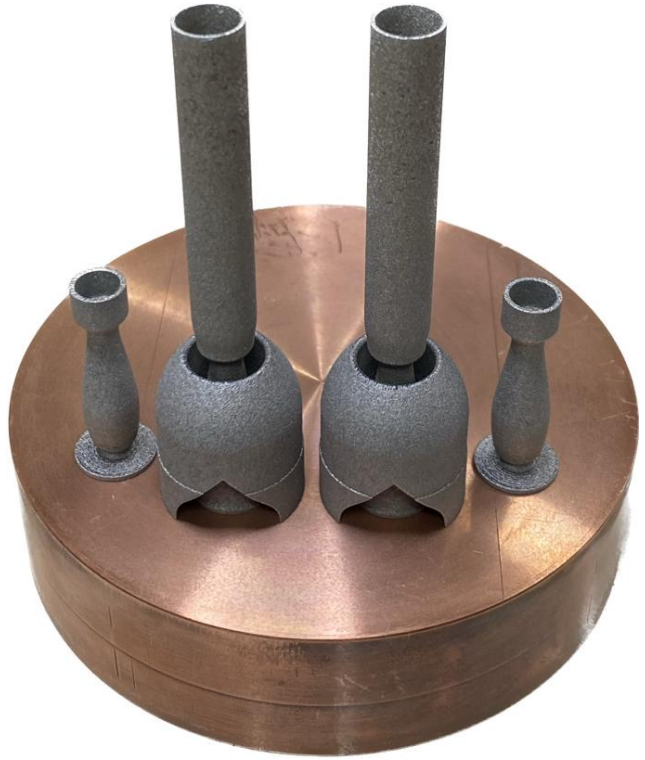
T2.2: Thermionic emission tests with Ta cathodes specifically designed for high electron fluxes

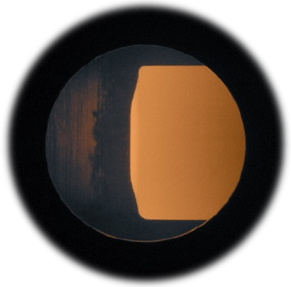


A **dedicated set-up** for the evaluation of the thermionic effect and the high temperature deformation measurement was developed.

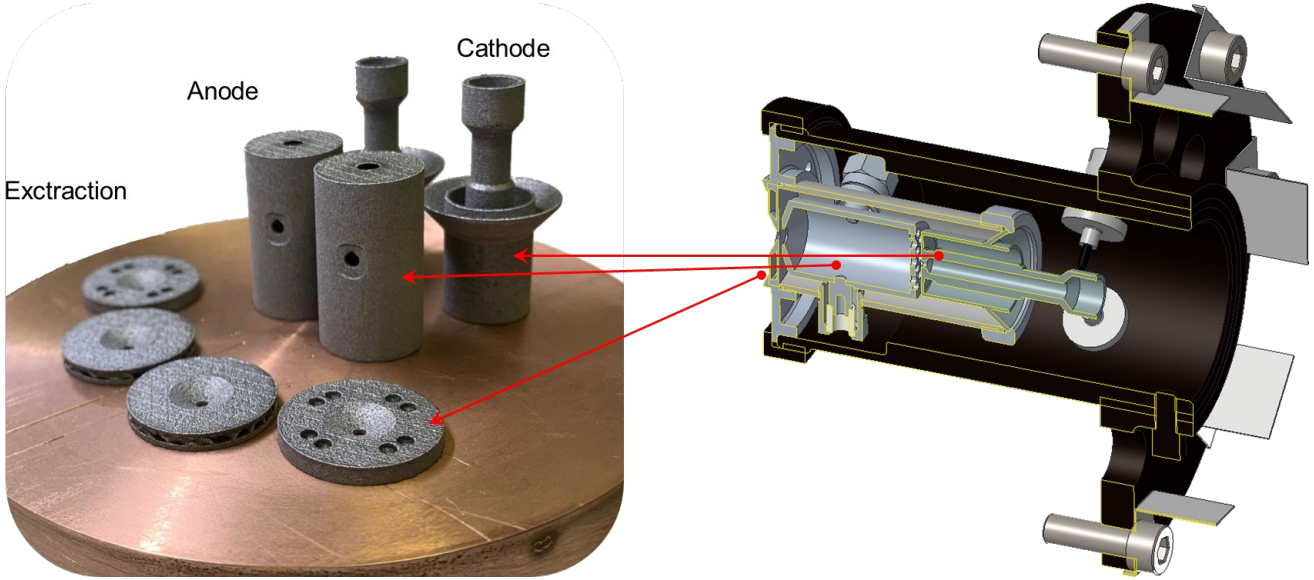
Possible observations:

- Effect of the component **surface finishing**
- Effect of different **anode grid geometries**
- **High temperature deformation** during long term operation

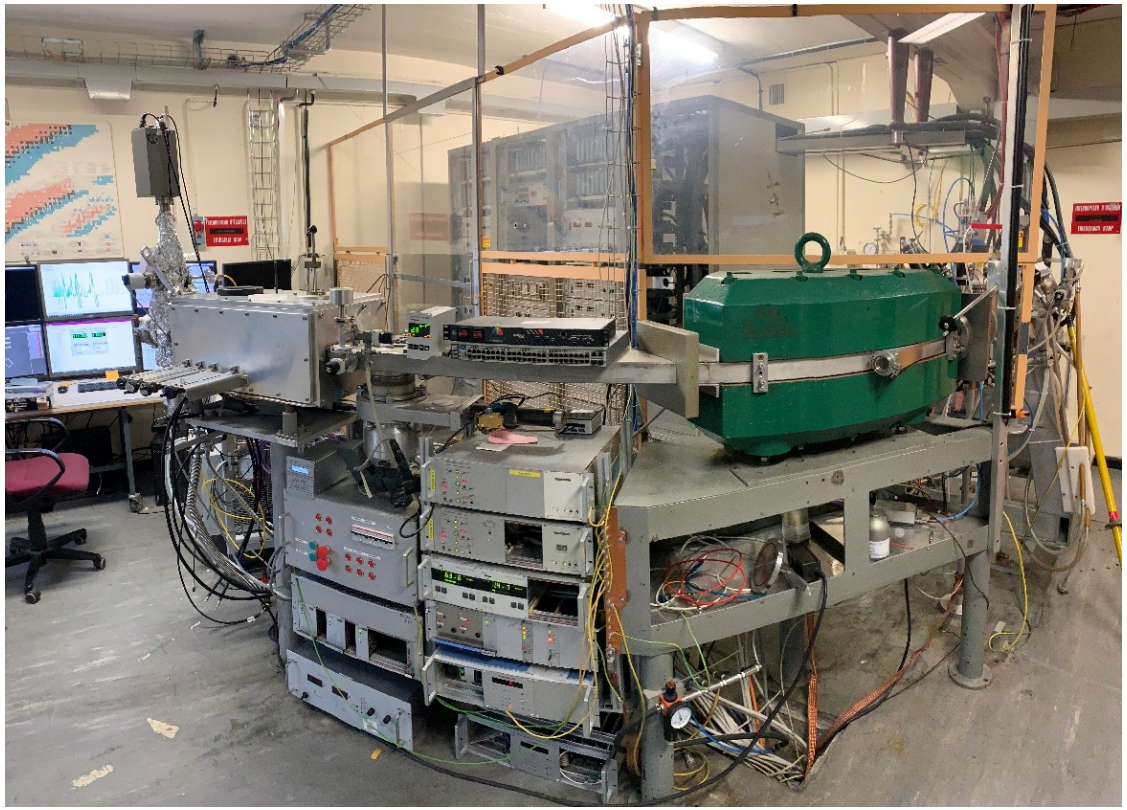




T2.3: Production of stable ion beams with the High Performance Plasma Ion Source prototype



ISOLDE offline 1: <u>ion source reference test facility</u>



Research Group – for INFN PD

INFN-PD			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Adriano Pepato (PD local resp.)	AM of metallic components	2, 3	0.3
Pietro Rebesan	design of components/parts for AM	2, 3	0.1
Massimiliano Bonesso	AM of metallic components	2, 3	0.1
Razvan Dima	design of components/parts for AM	1, 2	0.1
Simone Mancin	thermal characterization	2, 3	0.5
Lisa Biasetto	microstructural characterization	2, 3	0.5
Paolo Gregori	AM of metallic components and microstructural characterization	2, 3	0.5
Matteo Perini	AM of metallic components and microstructural characterization	2, 3	0.5
Total INFN-PD FTE			**2.6**

INFN PD

UniPd

ProM

HISOL_NEXT 2025 - 2028

Development of **H**igh performance **ISOL** target – ion source systems for the **NEXT** on-line operation at SPES

→ **The HISOL_NEXT experiment is designed to continue and finalize the development of ISOL target – ion source systems that began with the HISOL experiment. The goal is to make these systems available for the online commissioning campaign of the ISOL SPES facility.**

Participants: **INFN-LNL, INFN-PD, INFN-PV**

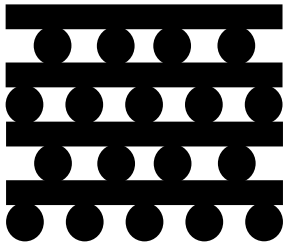
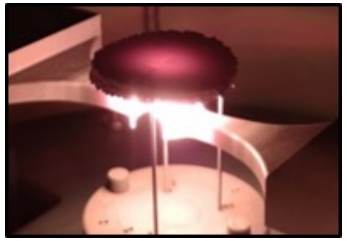
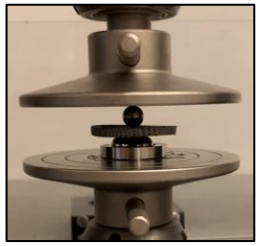
→ **3 years project**

Backup

WP 1 - Developments in HISOL

T1.1 & T1.2: Production of TiC disks with regular structures for characterization activities and long-term high temperature tests

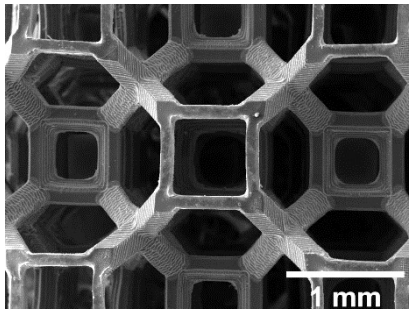
- Production and microstructural, thermal and mechanical characterization of **TiC** disks via **Direct Ink Writing**

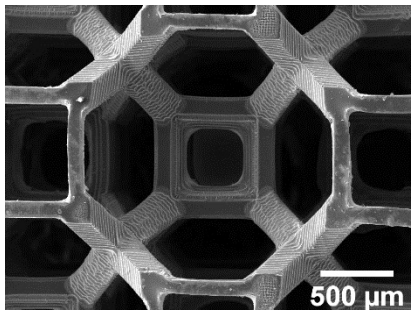





Alessandro Breda's master thesis in Materials Engineering, UNIPD, Supervisor M. Manzolaro - defended April 2023

Gabriele Sala's master thesis in Materials Engineering, UNIPD, Supervisor M. Manzolaro - defended October 2023

- Production, characterization and long-term high temperature tests of **TiC** samples produced via **Digital Light Processing**



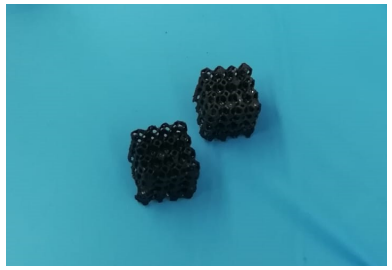


More details in Alice Zanini's presentation

WP 1 - Developments in HISOL

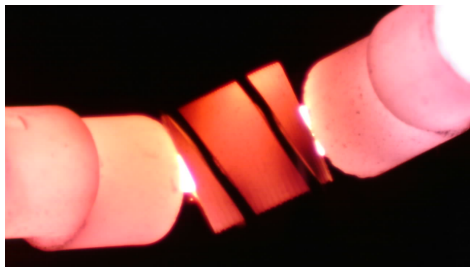
T1.3: Production of SiC samples with regular structures for characterization activities

- Preliminary assessment of the production of **SiC** samples via **Digital Light Processing**



More details in Alice Zanini's presentation

EXTRA: Production and characterization of Oxide insulators with Additive Manufacturing via Fused Filament Fabrication (WP1-WP2 transversal activity)



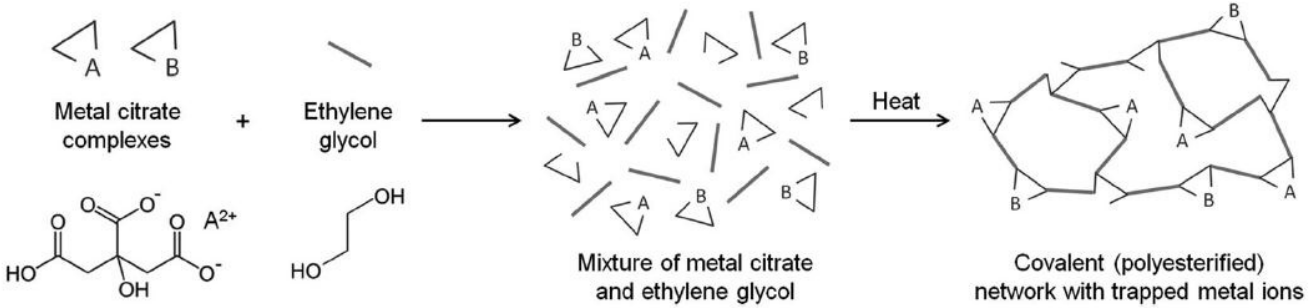
Alessandro Testolin's master thesis in Materials Engineering, UNIPD, Supervisor G. Franchin - defended October 2023

More details in Giorgia Franchin's presentation

EXTRA: LaCx and UCx sample production with Digital Light Processing (activity performed at JRC-Karlsruhe)

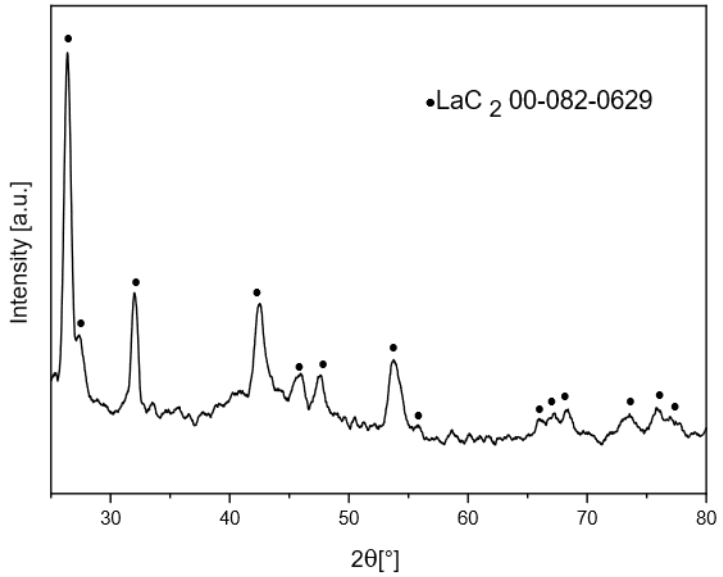
WP 1 - Additive manufacturing of LaC_2 components via DLP

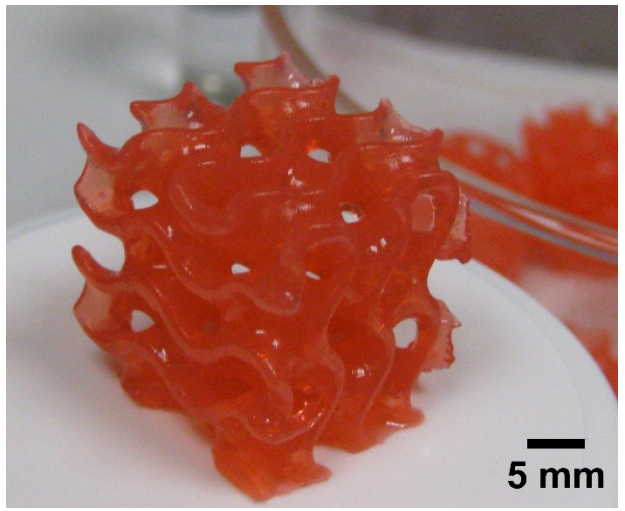
Pechini method -> metal element entrapped in a polymeric network



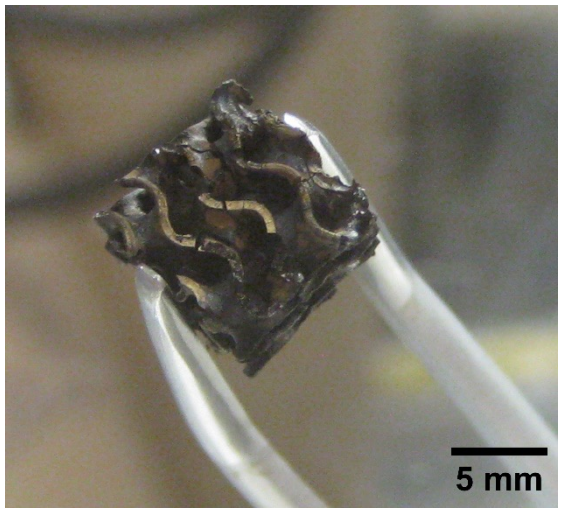
- La source: lanthanum nitrate
- Complexing agent: citric acid
- Polymerization agent: PEG 400 + sucrose
- Photopolymer: Pegda M_n 575

La:CA:PEG 400:sucrose = 1:2:2:0.79 -> photocurable sol-gel formulation for DLP





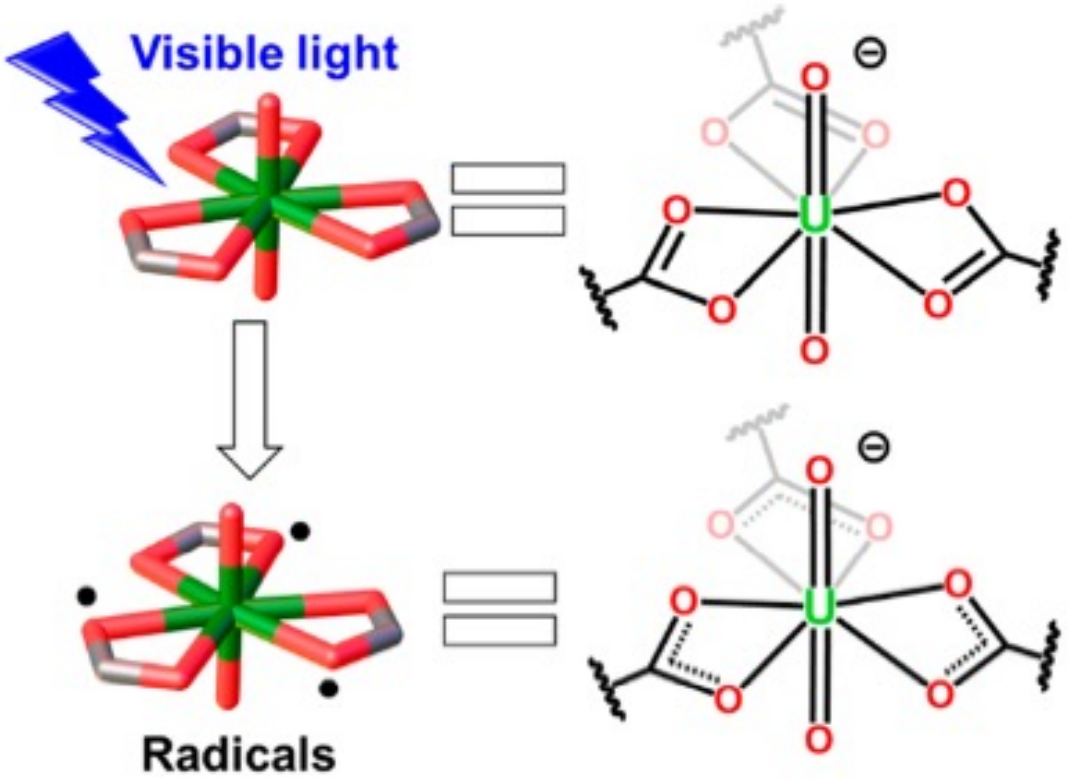
as printed



after sintering 1700°C 2h

WP 1 - Additive manufacturing of UC_2 components via DLP

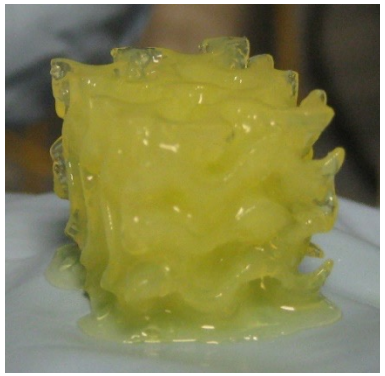
Uranyl cations exhibit high photosensitivity -> photoexcitation of uranyl cation under UV-vis light leads to the formation of uranyl radical species that can act as photoinitiator for photopolymerization processes

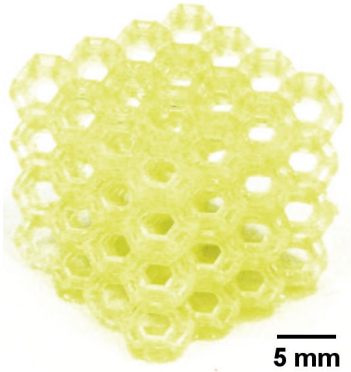


U:CA:sucrose = 1:2:0.5

- U source: uranyl nitrate
- complexing agent: citric acid
- polymerization agent: sucrose
- photopolymer: Pegda M_n 575

-> photocurable sol-gel formulation for DLP





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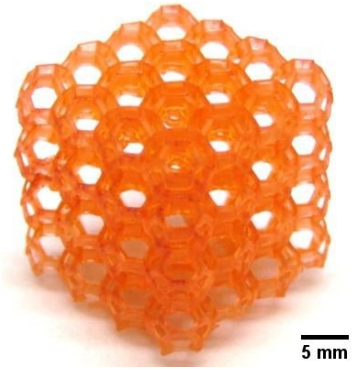
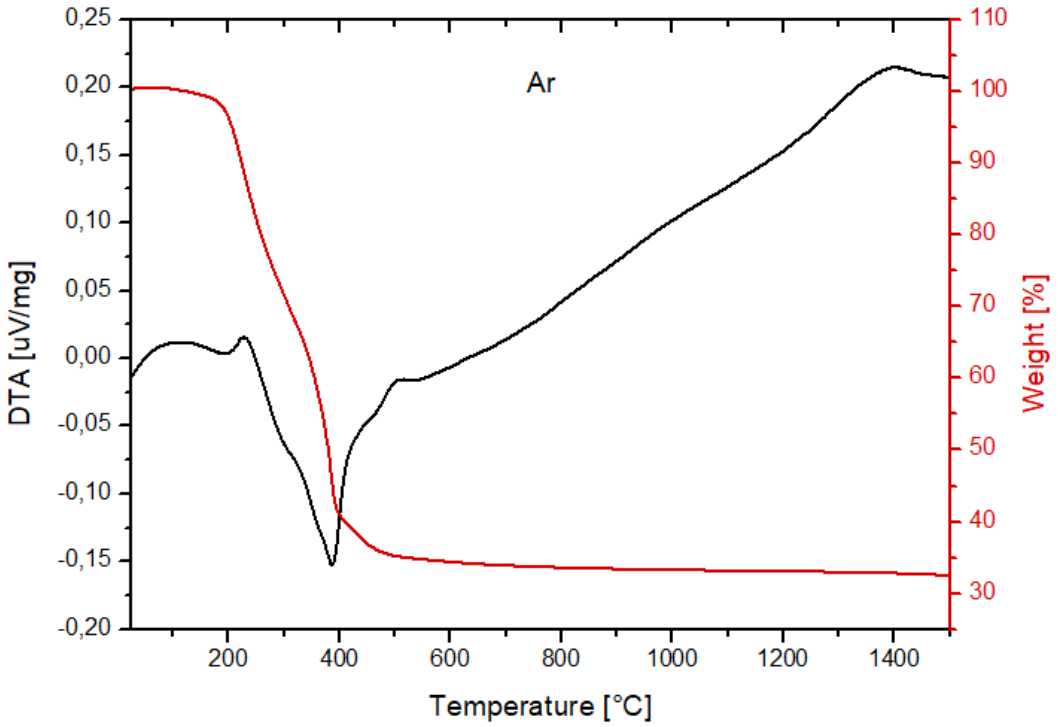
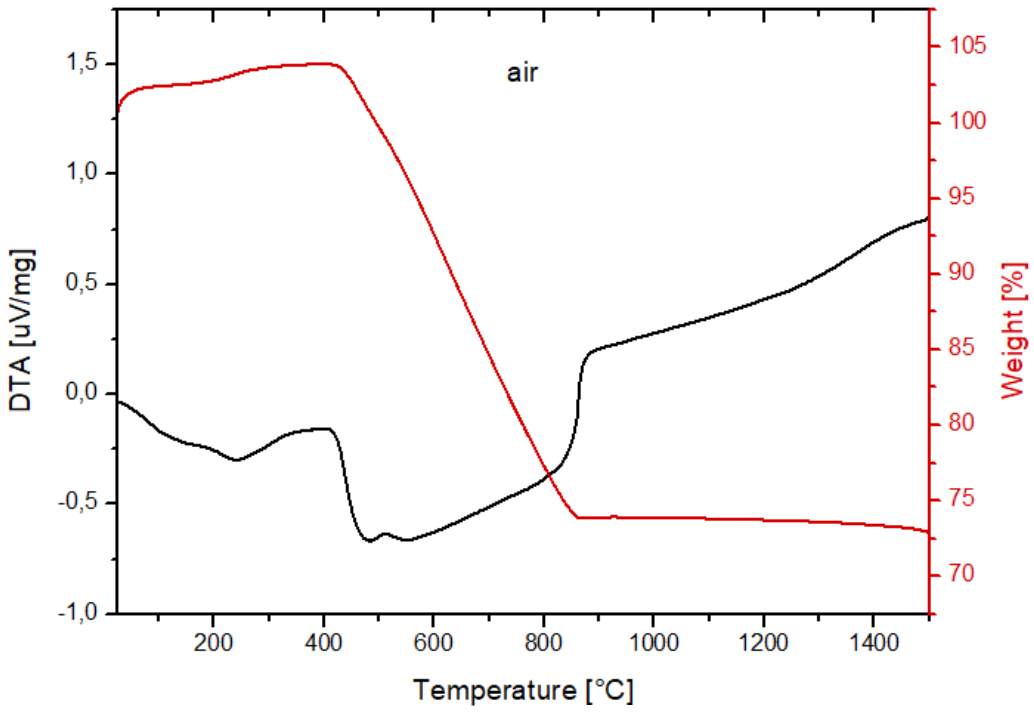


as printed
+ photoabsorber to improve printing quality

WP 1 - Additive manufacturing of UC_2 components via DLP

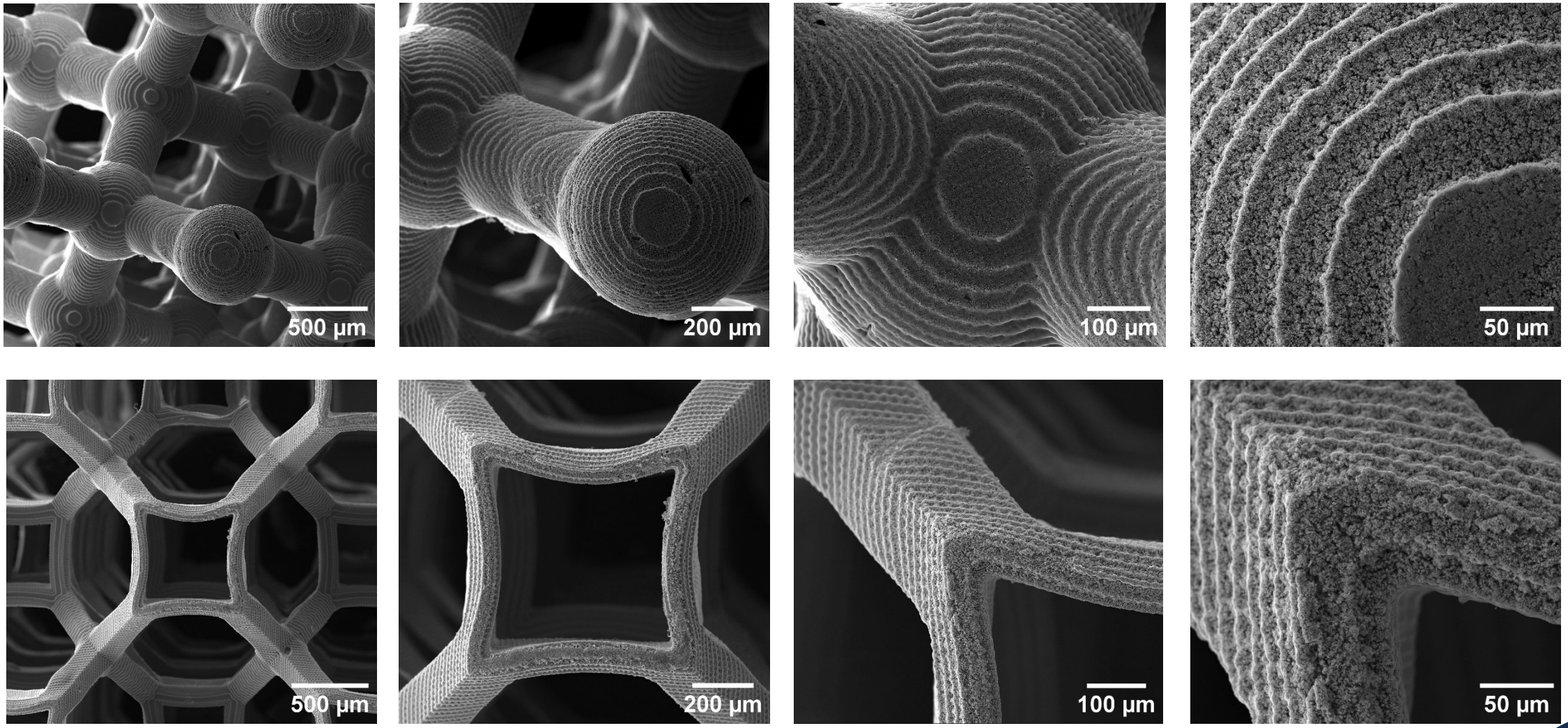




- estimated C/U = 8 → higher content than the proposed (C/U = 6)

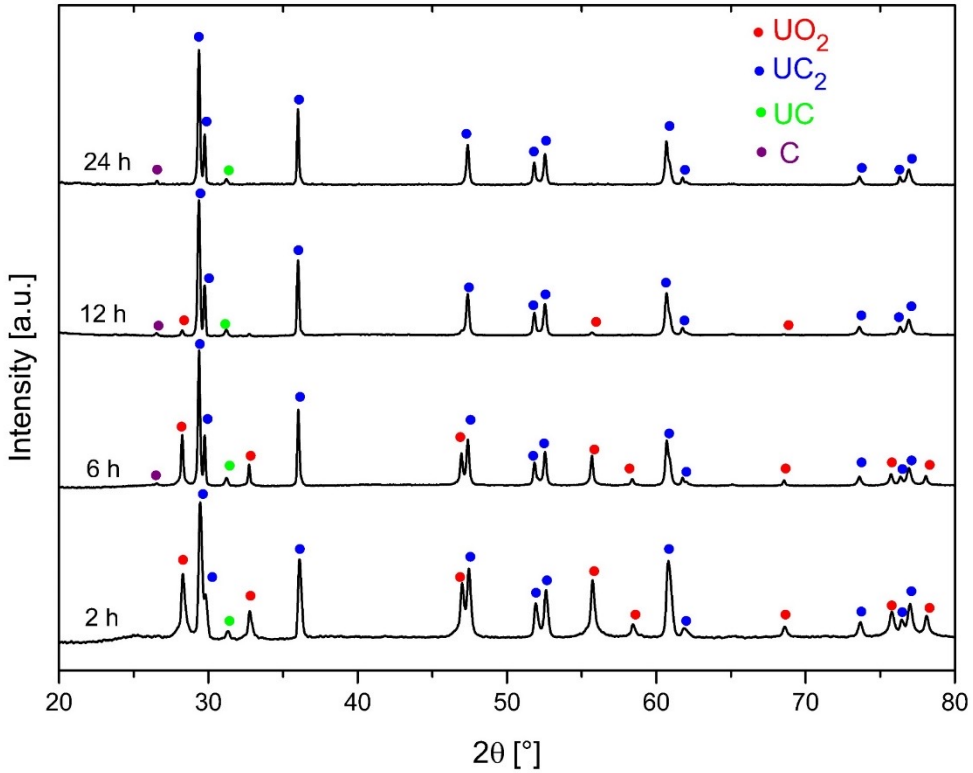
UC_2: $UO_2 + 8C \rightarrow UC_2 + 4C + 2CO$

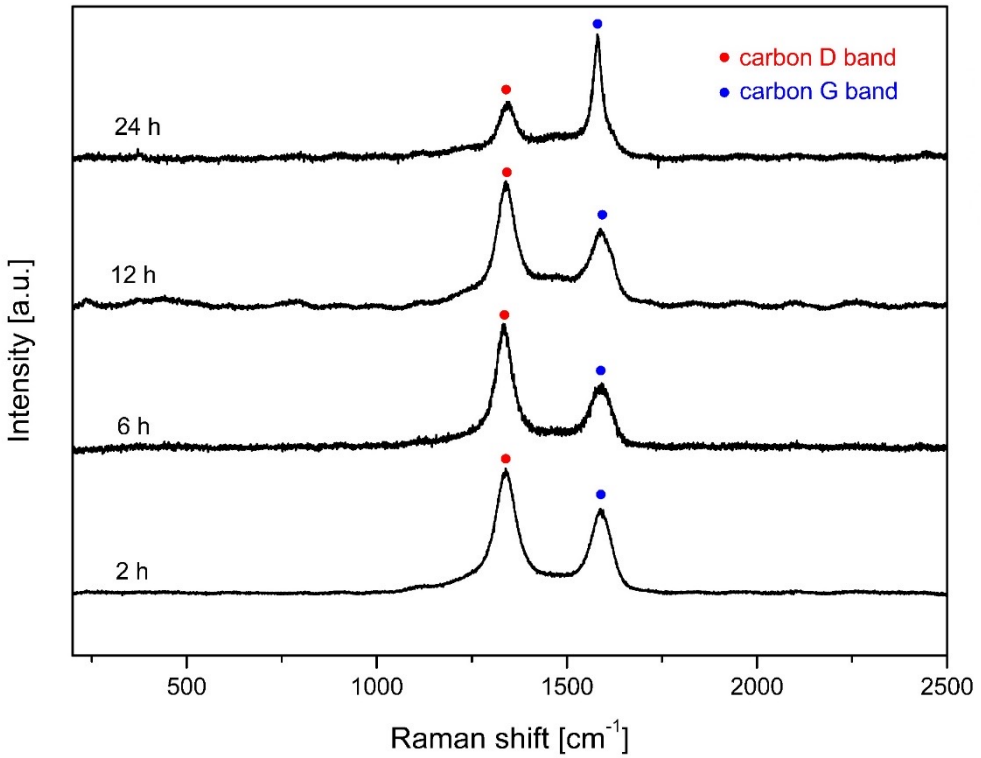
WP 1 - Additive manufacturing of UC_2 components via DLP



WP 1 - Additive manufacturing of UC_2 components via DLP

- thermal treatment in Ar at 1700°C, different dwelling times tested





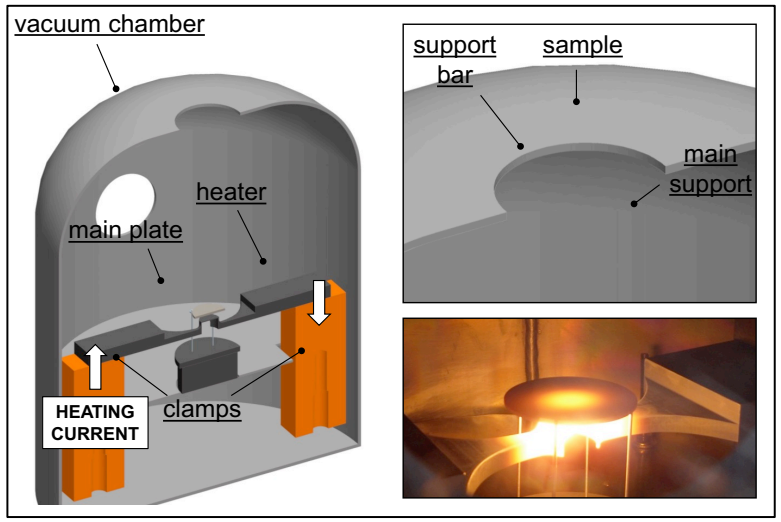
- disappearance of UO_2 peaks at 24 h
- graphite free carbon peak

- G band > D band -> ordered graphite domains at 24 h
- noisy signal but relevant peaks for carbon phase

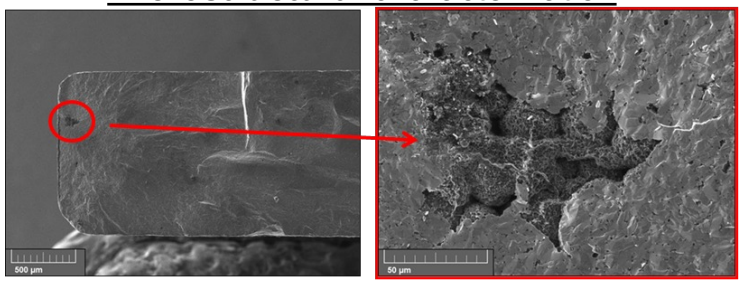
Work package 3 organization

Work package 3: Materials Characterization and Multiphysics Simulation

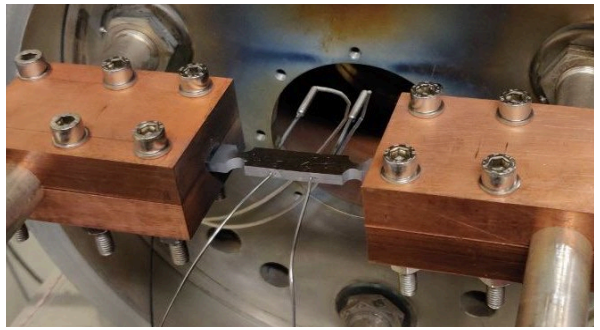
emissivity and **thermal conductivity** measurements

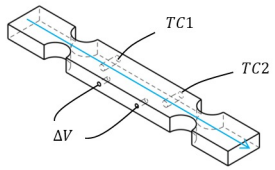


microstructural characterization



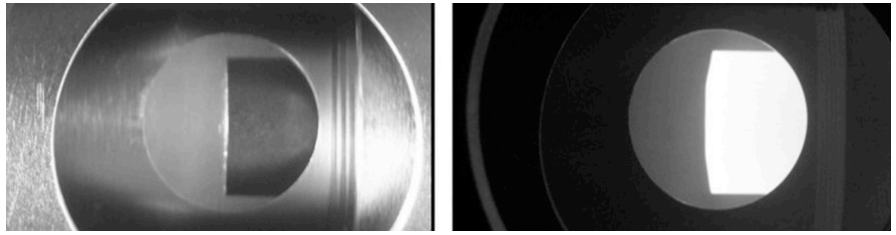
electrical resistivity measurements





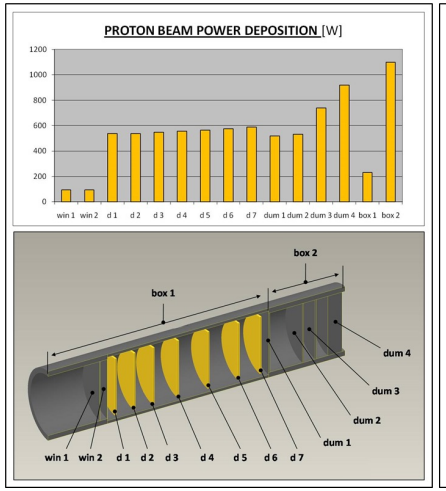
Reliable Material Property Data at High Temperature are required for **Robust Multiphysics Simulation** of ISOL Targets and Ion Sources

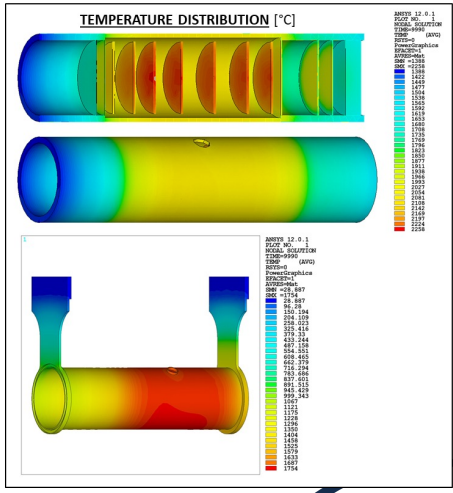
thermionic emission measurements



multiphysics simulations

Proton beam thermal load: 40 MeV, 0.2 mA (≈ 8 kW) (power density input for the Finite Element model calculated by means of particle physics MonteCarlo codes)





T3.1: Material development and microstructural characterization

PhD Candidate Leoanrdo Salvò training in ProM, Trento

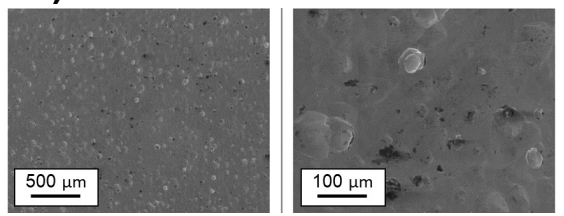
First LPBF Nb samples produced at ProM

Luca Da Tos's master thesis DTG, UNIPD, Supervisor S. Carmignato - defended 2024

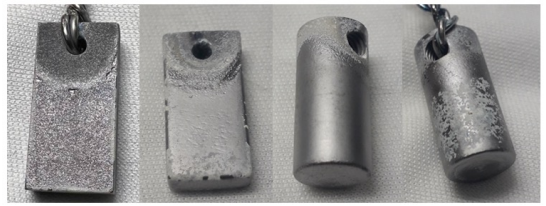
Surface treatment on Ta sample to decrease roughness

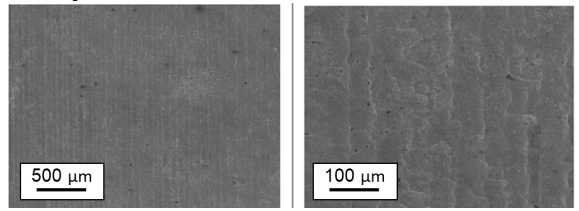
(collaboration with Surface Technologies and Superconductivity Service at INFN-LNL)

- **Buffered Chemical Polishing (BCP)**

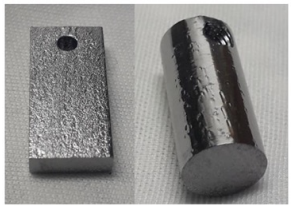


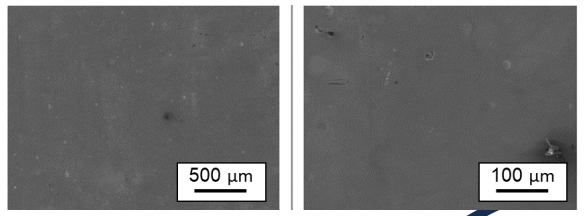
- **Plasma Electrolytic Polishing (PEP)**





- **Electropolishing (EP)**

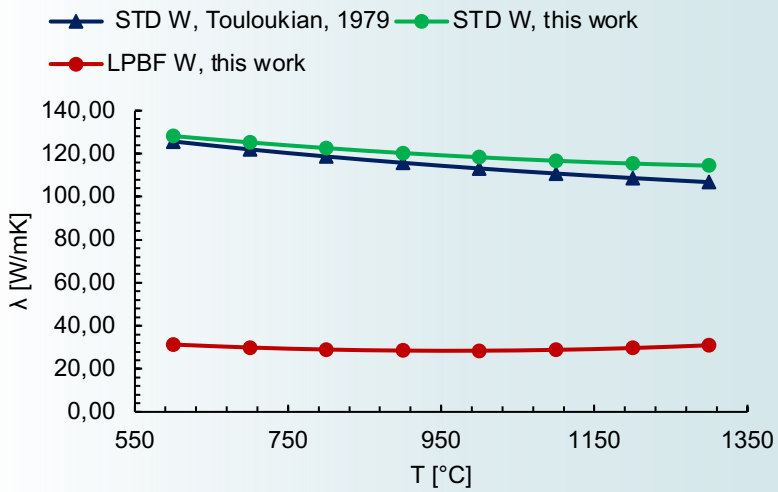


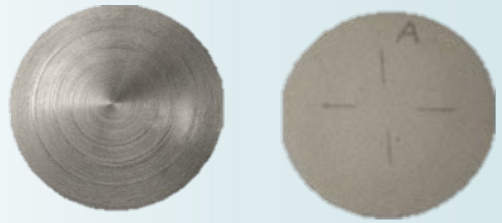


T3.2: Thermal and Electrical Characterization

Thermal and electrical characterization of LPBF W

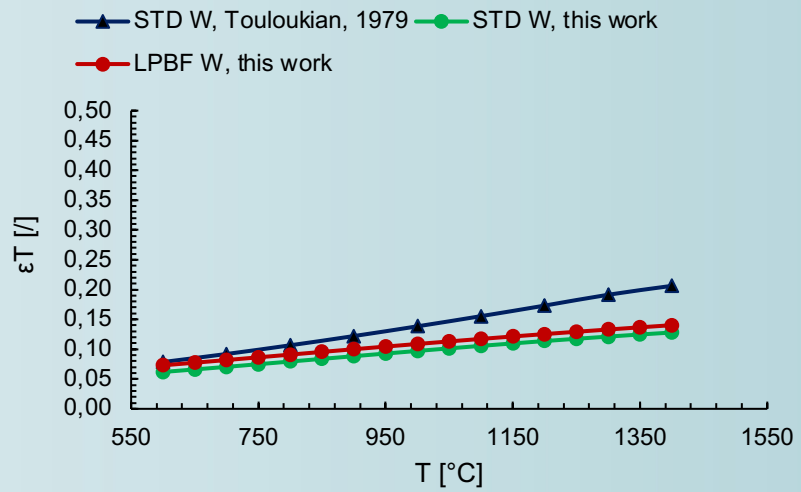
Thermal Conductivity - W



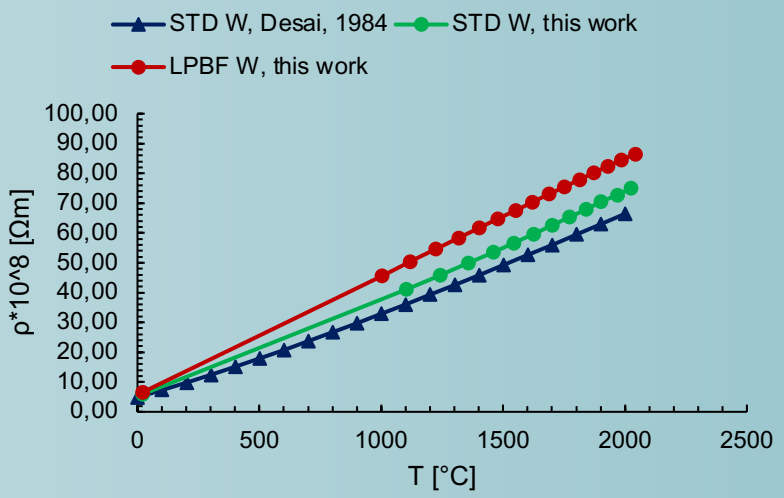


STD W sample LPBF W sample

Global Emispferical Emissivity - W



Electrical Resistivity - W



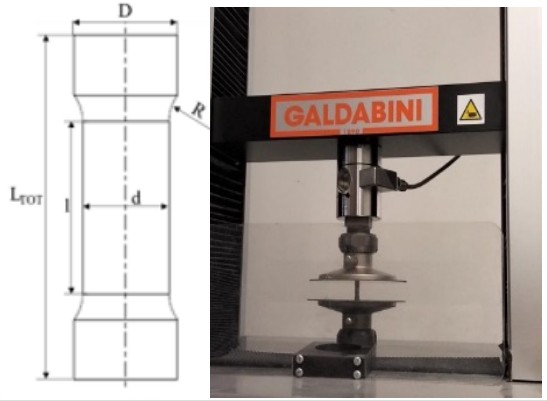
Davide Cester, Master thesis in Materials Engineering, UNIPD, Supervisor M. Manzolaro - defended July 2023

T3.3: Mechanical Characterization

More details on Pietro Rebesan's thematic update

LPBF Tungsten compression tests

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE



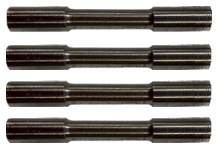
Geometry	D [mm]	d [mm]	L_{TOT} [mm]	l [mm]	R [mm]
Uniaxial	6	5	20	10	2.5

	Uniaxial 1	Uniaxial 2	Uniaxial 3	Uniaxial 4	Uniaxial 5	Uniaxial 6
E [MPa]	18519	19617	19679	18125	17894	17719
σ_R [Mpa]	1038	1101	1083	1079	1090	1051

Davide Cester, Master thesis in Materials Engineering, UNIPD, Supervisor M. Manzolaro - defended July 2023

LPBF Tantalum tensile tests

Horizontal LPBF Ta



Vertical LPBF Ta

Standard Ta (Plansee bar)

	E [GPa]	UTS [MPa]	A [%]
Vertical AM	193.7 ± 3.2	512.2 ± 4.3	17.0 ± 1.0
Horizontal AM	181.6 ± 0.5	459.4 ± 1.2	23.8 ± 1.2
Standard	180.2 ± 2.6	337.6 ± 2.3	27.5 ± 0.6

Leonardo Salvò, Master thesis in Materials Engineering, UNIPD, Supervisor M. Manzolaro - defended October 2023

T3.4: Multiphysics Simulation of High Performance ISOL Targets

A complex multistep simulation process

Monte Carlo simulations:
Particle transport and interaction with matter

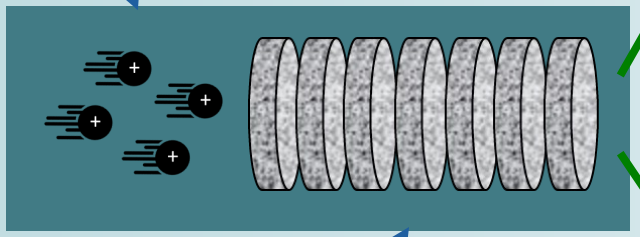
PHITS Particle and Heavy Ion Transport code System

FLUKA

Multiphysics FEM simulations:
Thermal and structural analyses

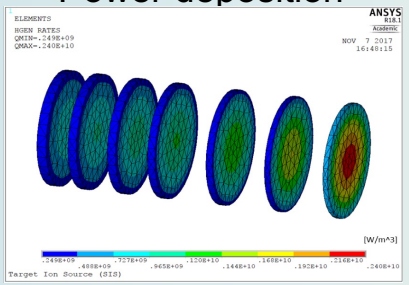
Ansys

Proton Beam Properties
(energy, intensity, profile)

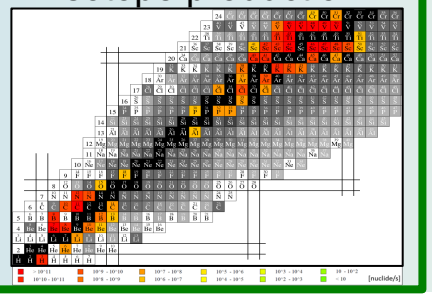


Target characteristics
(composition, geometry, density)

Power deposition

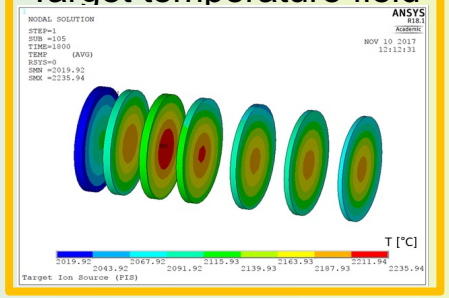


Isotope production



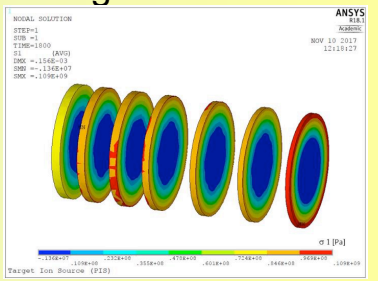
Thermal analysis
required material properties:
- **k** (thermal conductivity)
- **ε** (emissivity)

Target temperature field



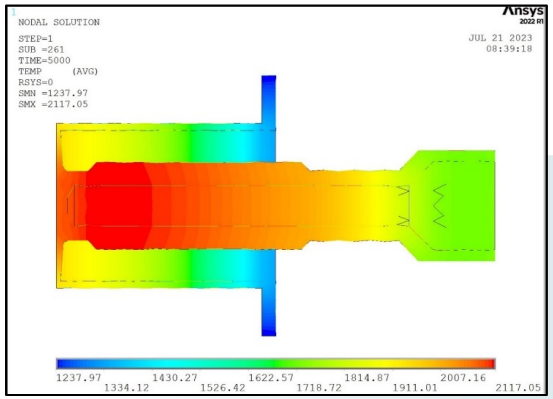
Strucutral analysis
required material properties:
- **E** (Young's modulus)
- **ν** (Poisson's ratio)
- **α** (coeff. of th. expansion)

Target stress field



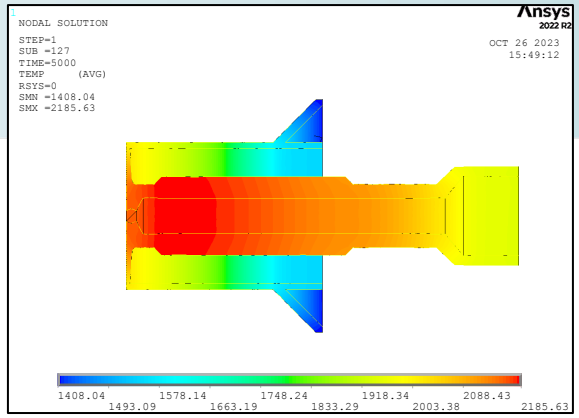
T3.5: Multiphysics Simulation of High Performance ISOL Ion Sources

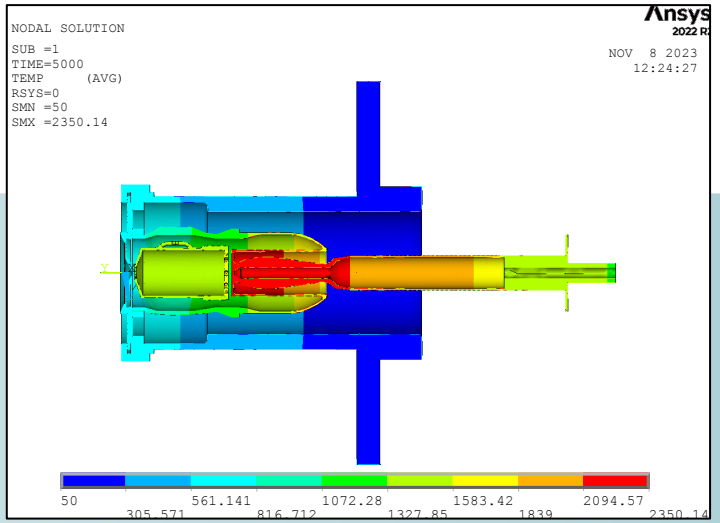
A path towards a FEBIAD ion source with enhanced performances benefitting of the flexibility of the LPBF technology



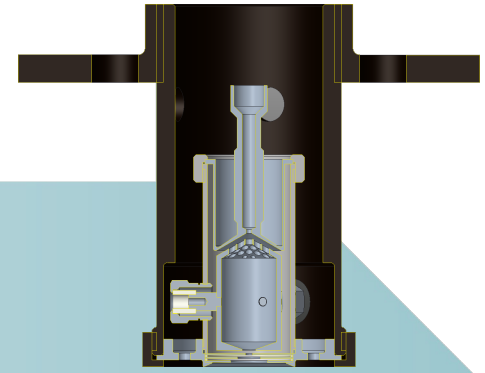
Step 0:
Standard FEBIAD source (cathode)

Step 1:
First AM FEBIAD source component (cathode)





Step 2:
Enhanced AM FEBIAD source



Step 3:
Innovative anode-cathode interfaces