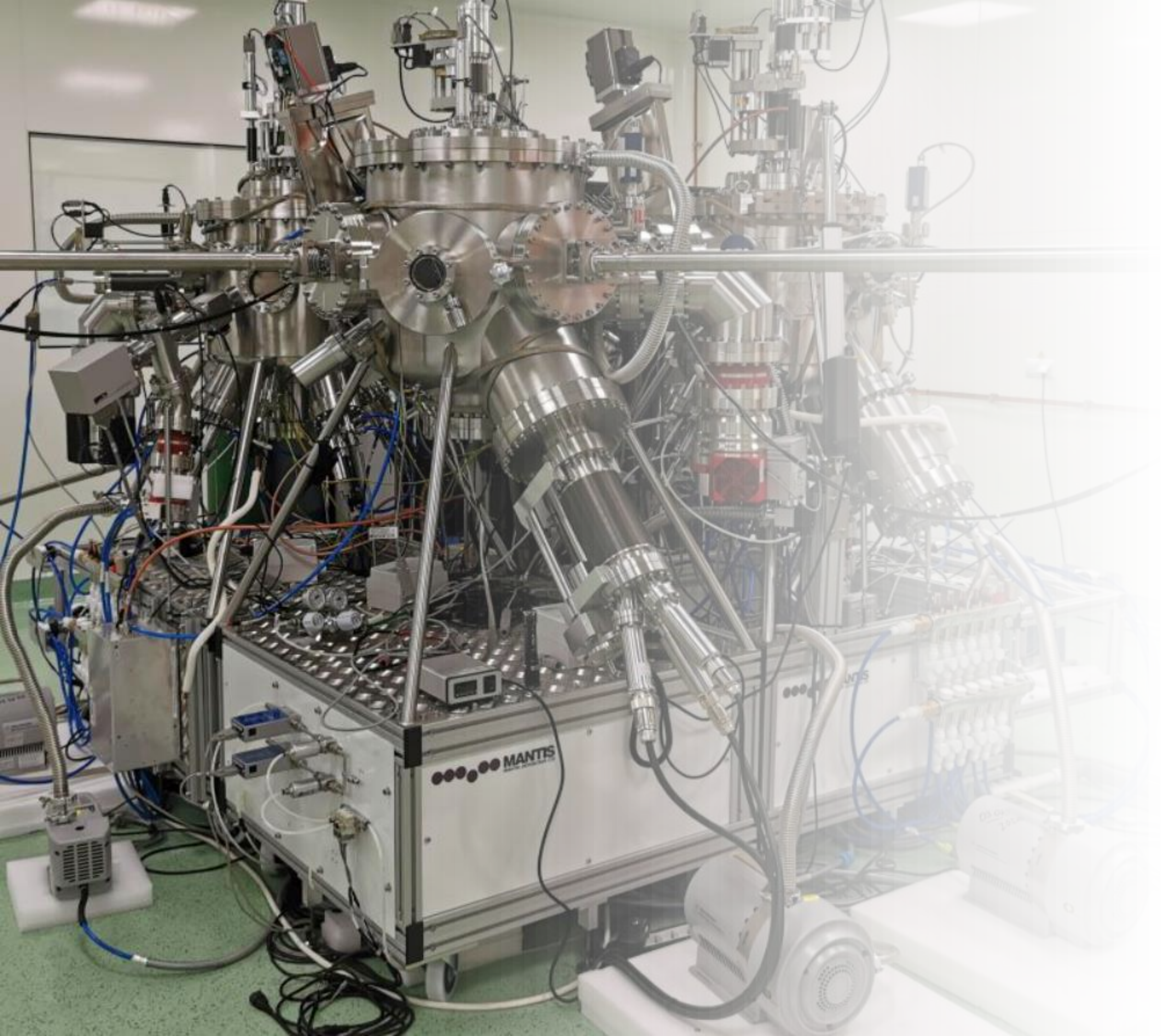
Solid targets fabrication and challenges at ELI-NP

Stefania Ionescu, on behalf of Target Laboratory team, ELI-NP, Magurele, Romania

Frascati, 4-6th of December, 2024

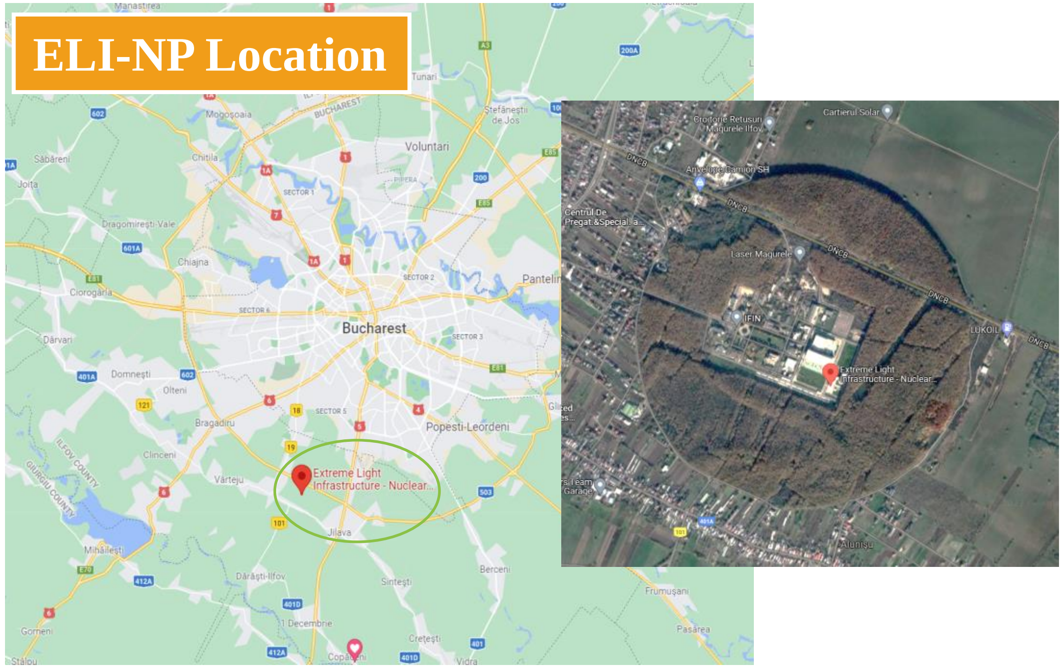


Content

- ELI-NP & Target Laboratory Overview
- Capabilities and equipment
- Research directions

ELI-NP (Extreme Light Infrastructure-Nuclear Physics)

ELI-NP Location



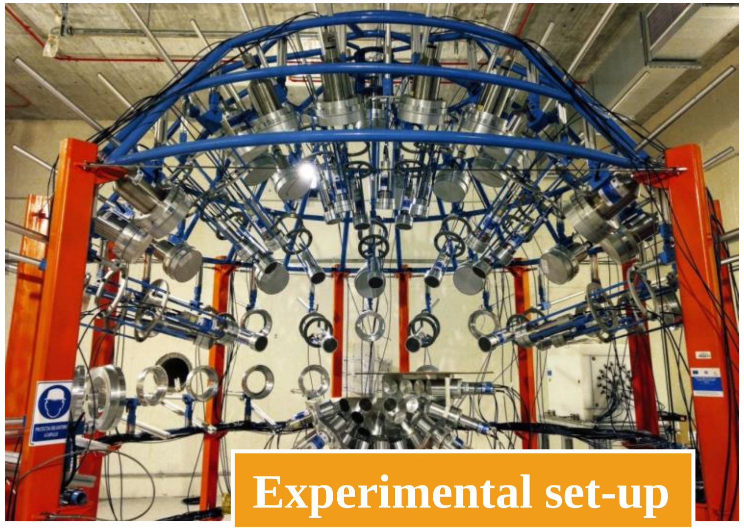
2x10PW High Power Laser System

ELI-NP SCOPE

- Fundamental Research (exotic nuclei and photo-fission; vacuum properties and particle creation; nuclear structure and astrophysics studies)
- Applied Research (materials for space science; management of nuclear materials; industrial tomography; brilliant positron source; radioisotopes for medical applications)

eli-np.ro

Brilliant energy tunable gamma-ray beam system (under construction)



Experimental set-up

ELI-NP Target Laboratory

- ✓ Provide targets – in-house manufacturing and characterization
- ✓ Perform R&D activities – of new target designs with improved performances and materials science

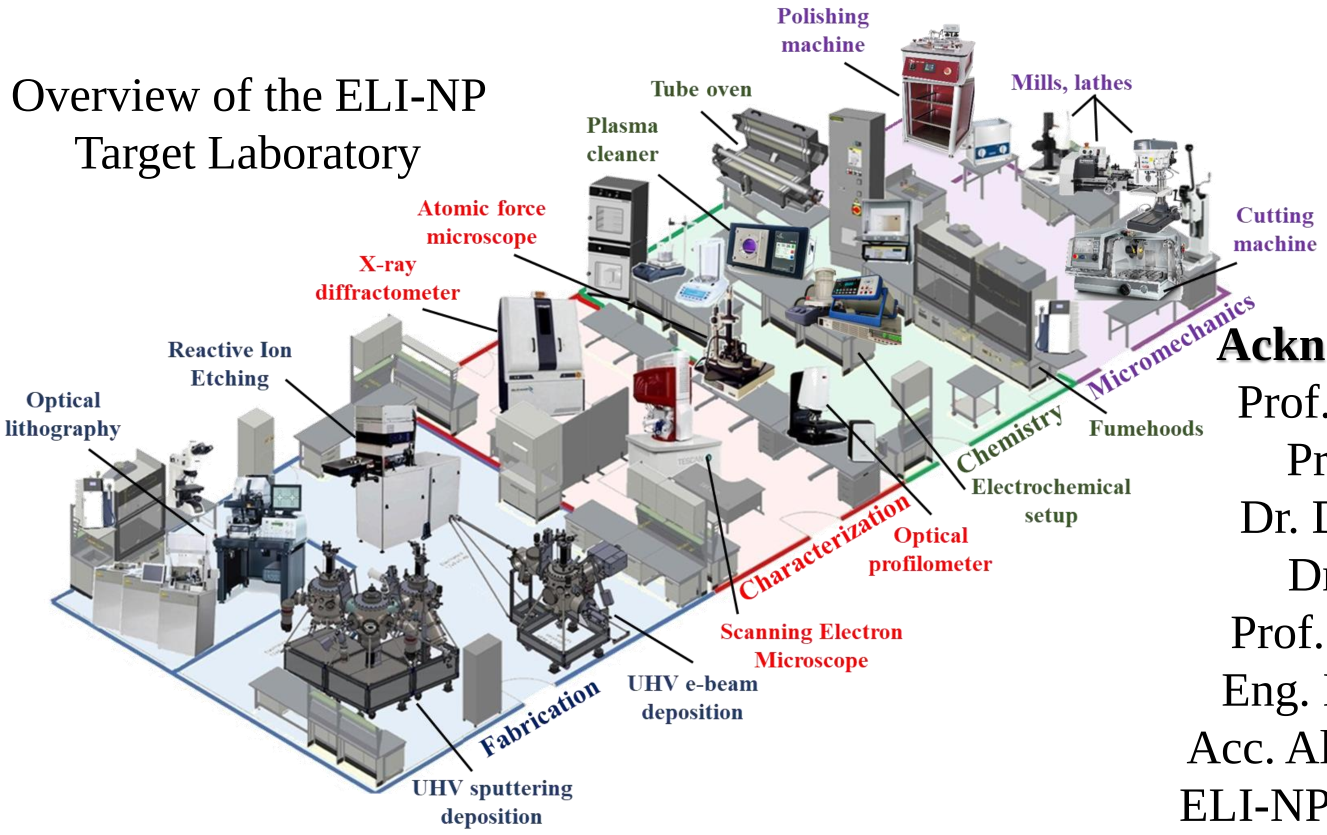
https://www.eli-np.ro/target_lab.php

C. Gheorghiu et al, JIST, 2016

Team:
- Dr. Victor Leca- head
- Dr. Cristina Gheorghiu
- Dr. Karolina Horna
- Dr. Cosmin Jalba
- Eng. Iulia Zai
- Eng. Stefania Ionescu
- Eng. Andrei Giulesteanu
- Tech. Daniel Popa
- Tech. Adrian Vatcu

Types of targets:
- solid (thin/thick/ultra-thin films, multi-layer, foams, nanospheres, snow clusters, NWs, gratings, nanoparticle, micro-cone...)
- cryogenic
- gas jet
- liquid crystals

Overview of the ELI-NP Target Laboratory



- Total surface area 350 m^2
- ISO 7 and ISO 6 cleanliness
- 4 designated rooms: micro/ nanofabrication, characterization, chemistry room, micromachining

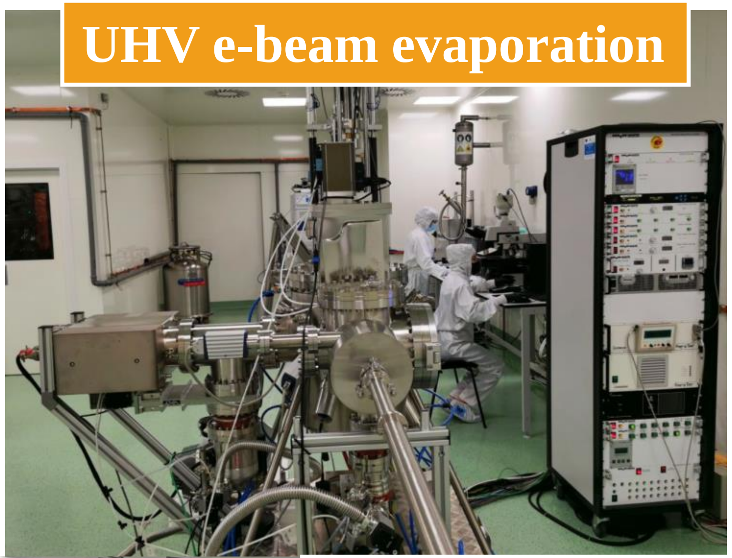
Acknowledgements:

Prof. Sydney Gales
Prof. Calin Ur
Dr. Daniel Ursescu
Dr. Dan Ghita
Prof. Razvan Stefan
Eng. Bogdan Tatulea
Acc. Alexandru Popescu
ELI-NP Acquisition Dep.

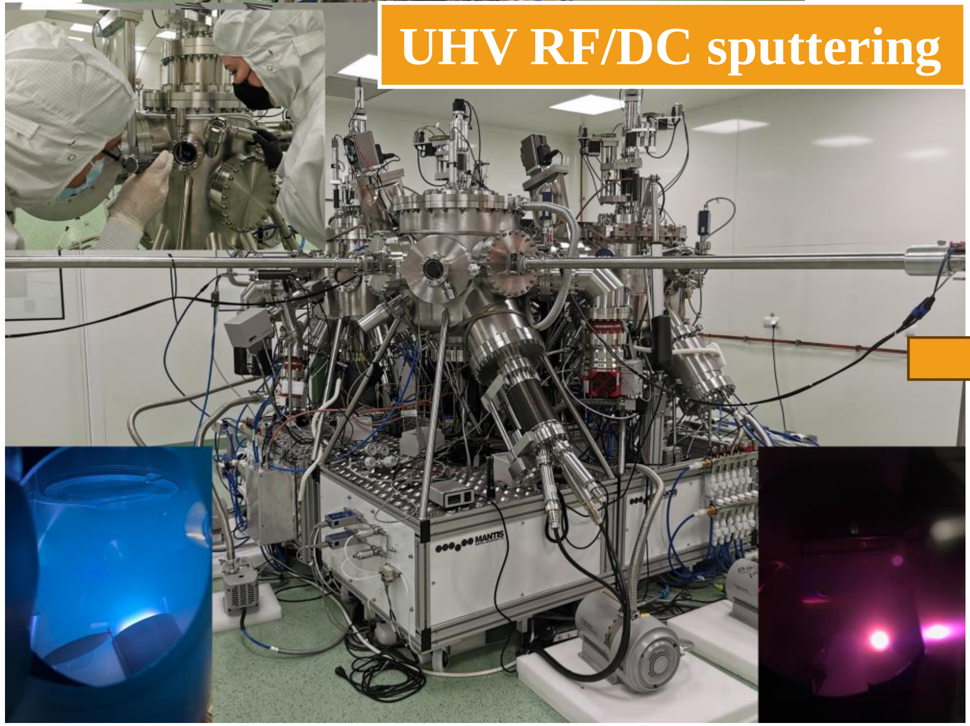
Fabrication capabilities

Deposition techniques

UHV e-beam evaporation



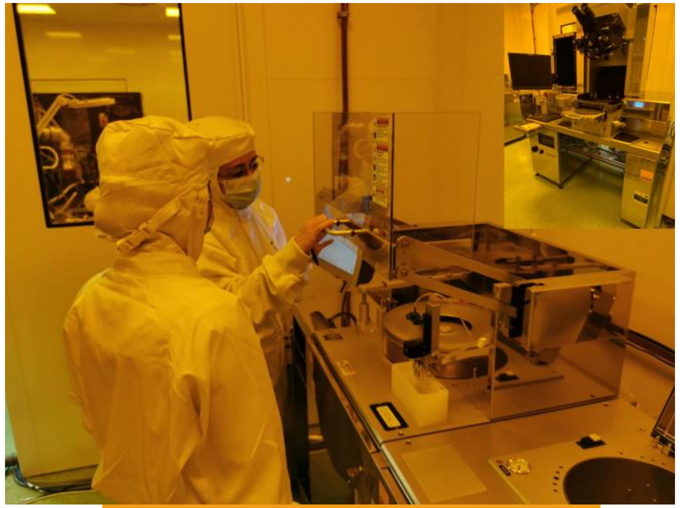
UHV RF/DC sputtering



- metals
- nitrides
- oxides

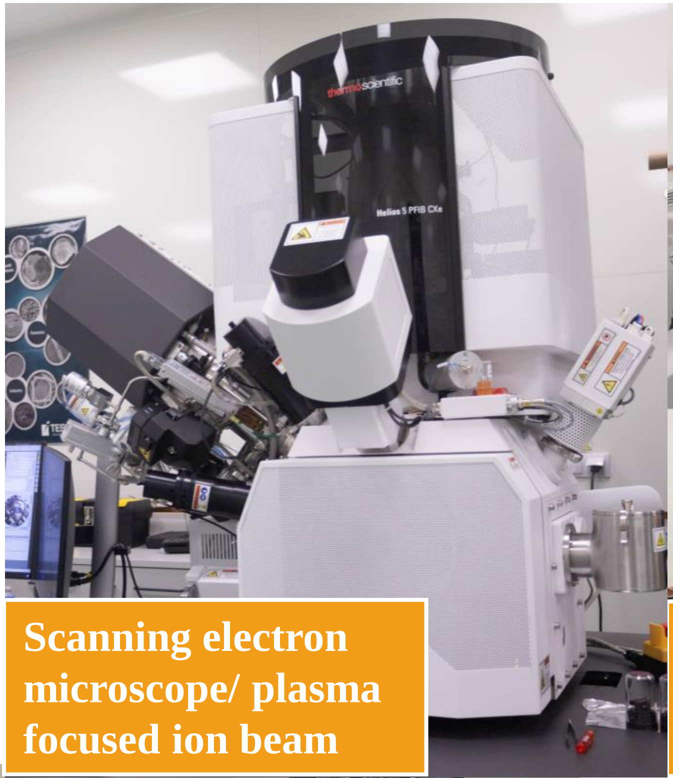
Structuring techniques

Optical / e$^-$ beam lithography

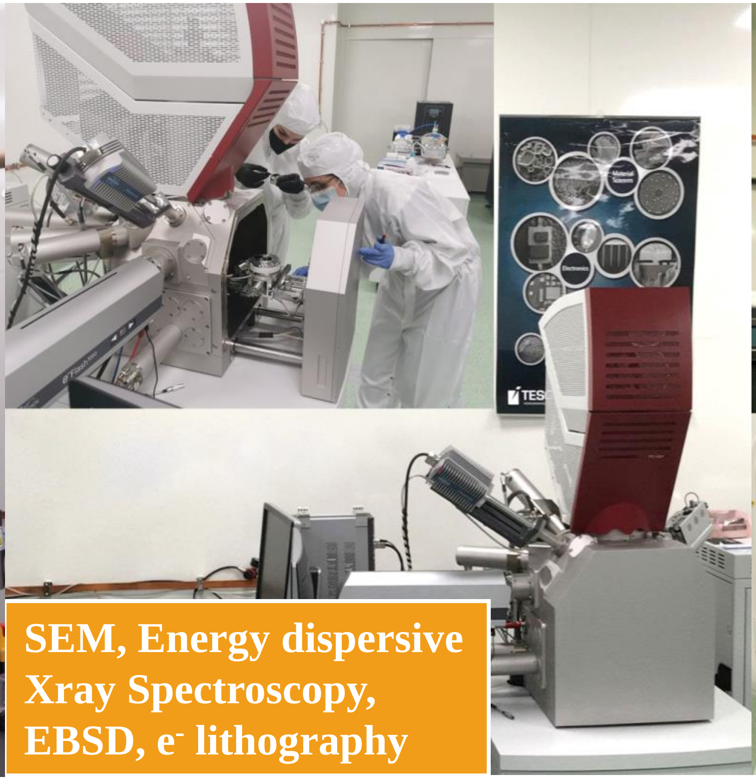


Reactive ion etching

Characterization capabilities

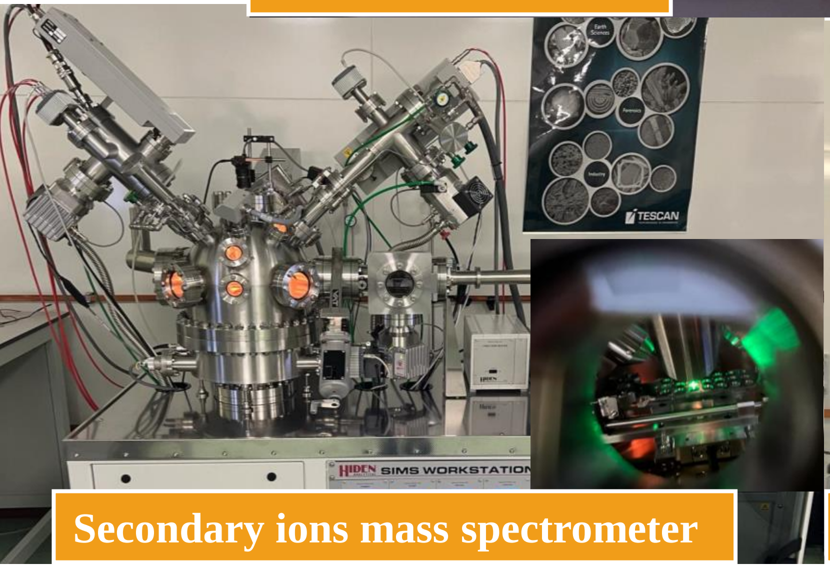


Scanning electron microscope/ plasma focused ion beam

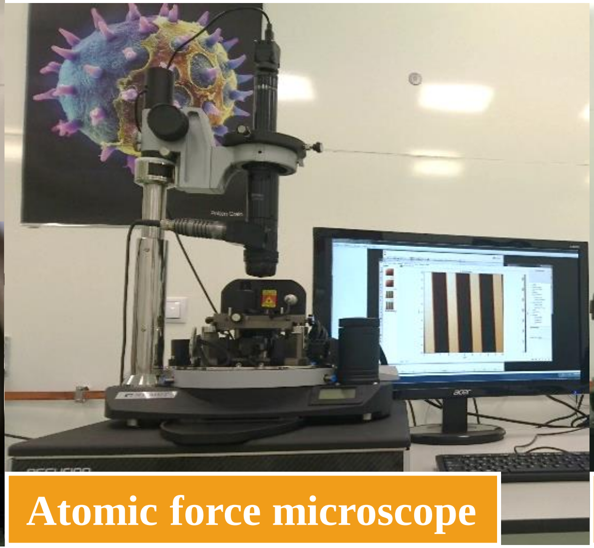


SEM, Energy dispersive Xray Spectroscopy, EBSD, e$^-$ lithography

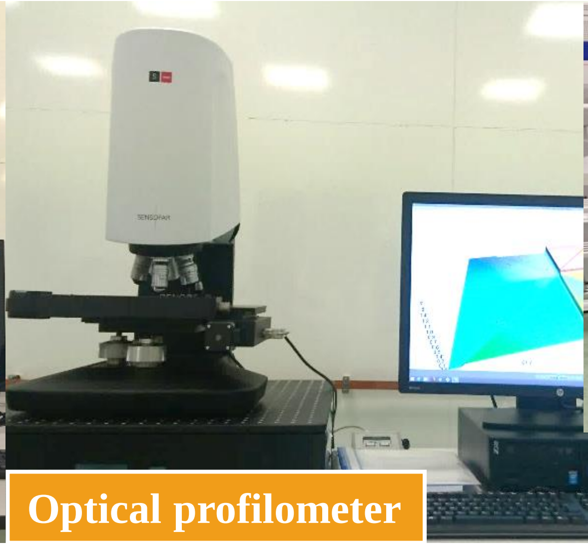
X-ray Diffractometer



Secondary ions mass spectrometer



Atomic force microscope



Optical profilometer

Low temperature physical measurements system

Chemistry laboratory

Micro-mechanical and other equipment

- Plasma (O_2, Ar, SF_6)
- Ion beam (Ar)
- Thermal treatments

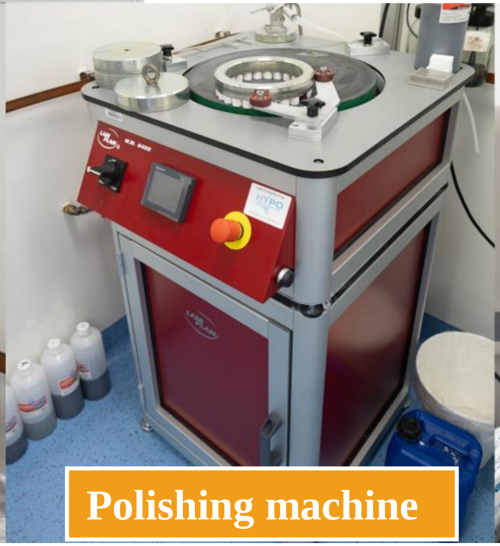
Ion mill

Supercritical dryer

Bonding machine

Benchtop plasma treatment system

Cold roll

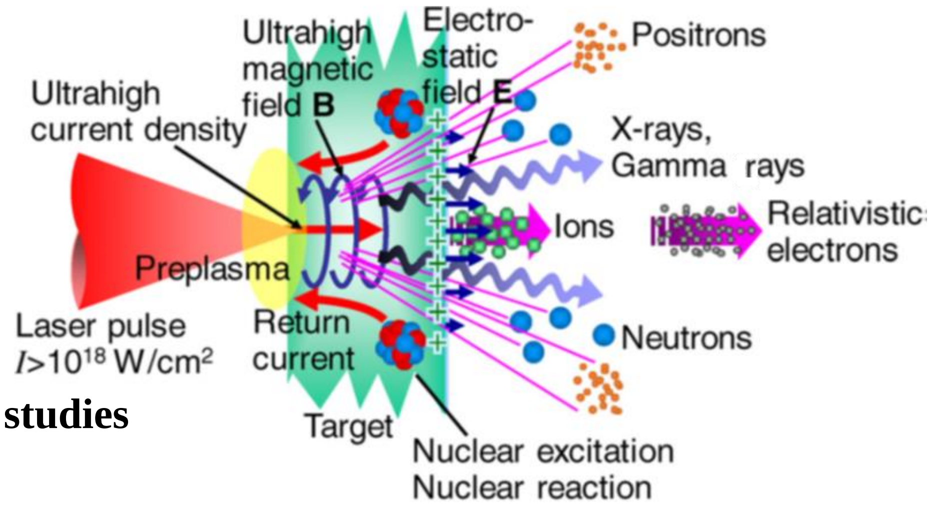


Polishing machine

Cutting machine

Laser bonding machine

Current requirements and proposed strategies



H. Daido et al, Rep. Prog. Phys., 2012

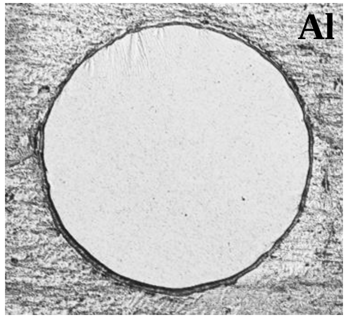
Targets requirements for high power laser experiments:

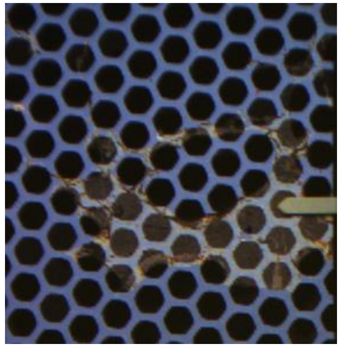
- Thin metallic films (gold, aluminium) **for commissioning and RIT/ RPA/ TNSA studies**
- Thick (commercial) metallic, or multilayer films **for TNSA acceleration**
- Carbon *new → for carbon ions acceleration **for medical projects**

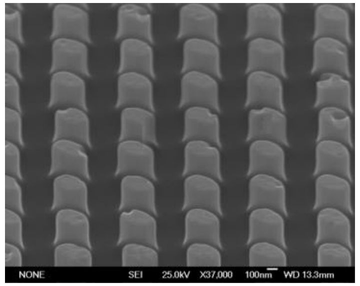
Dense
- Graphene (d = 2.267 g/cm^3)
- Diamond-like carbon (DLC) (d = 2.5 - 3 g/cm^3)

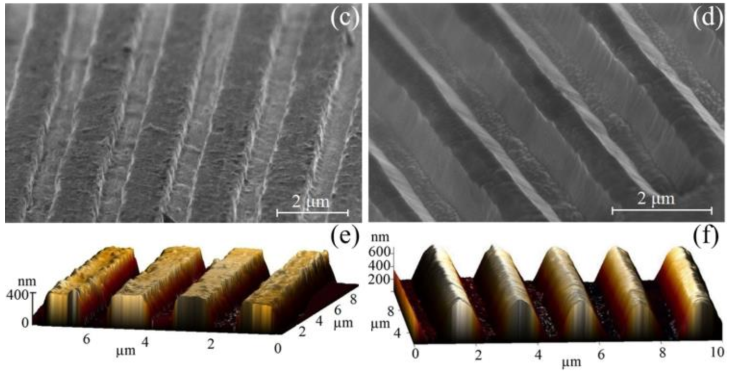
Near critical density
- Carbon nanotubes (CNTs)
- Carbon foams

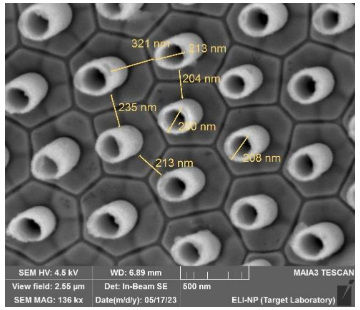
- *new Boron (boron thick films, boron nanoparticles and nanostructures) → **for proton-boron fusion experiments**
- Structured targets (gratings, nanodots, nanospheres, nanowires, nanotubes, etc.) → **for enhanced laser-matter interaction**
- Future developments: high repetition rate targets

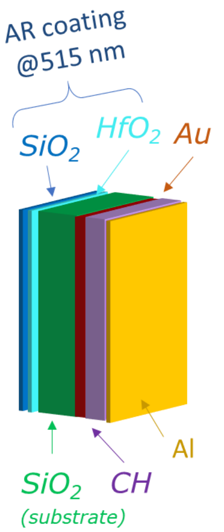








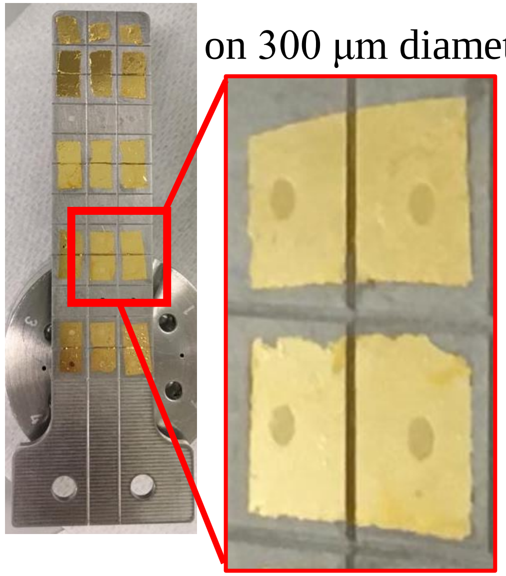




Freestanding metallic targets

- for 1 PW laser experiments – commissioning | to improve ion acceleration, high Z ions *(LDED collab: D.Doria, P.Ghenuche, M.Cernaianu)*

on 300 μm diameter hole



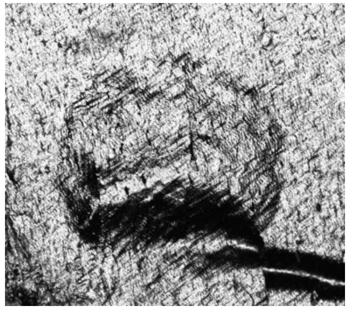
on 1.3 mm diameter hole

Gold foils
(thick: 10 nm - 400 nm)

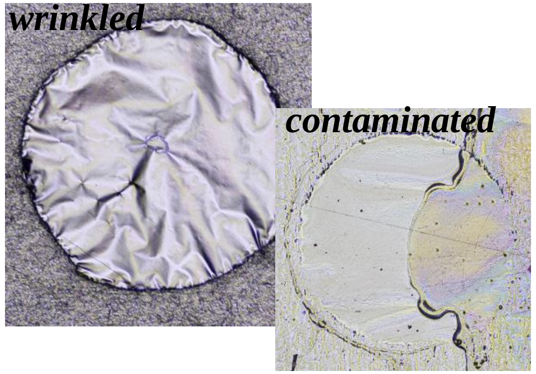
Aluminium foils
(8 nm - 400 nm)

Importance of fishing process

Glued commercial Au foil

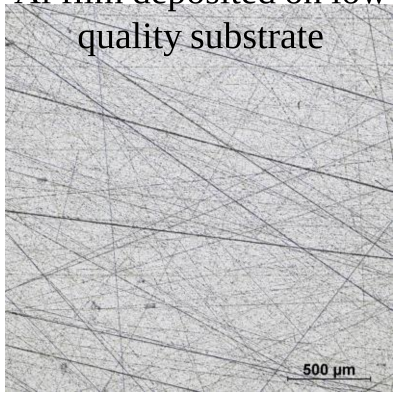


Un-optimized free-standing Au foil

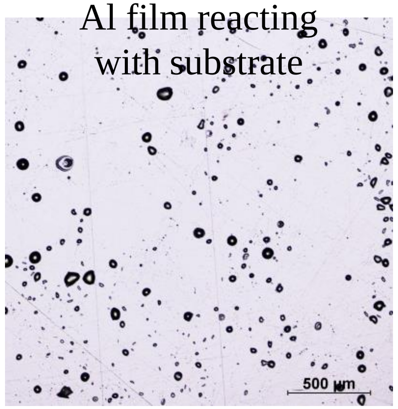


Importance of substrate

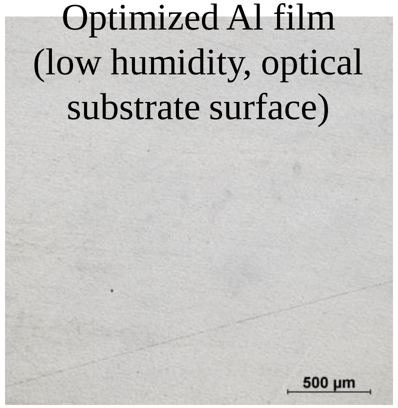
Al film deposited on low quality substrate



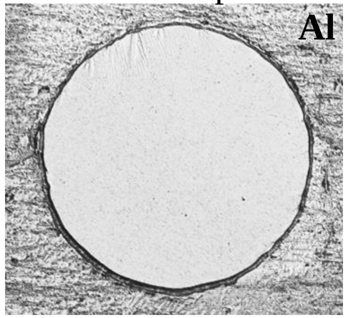
Al film reacting with substrate

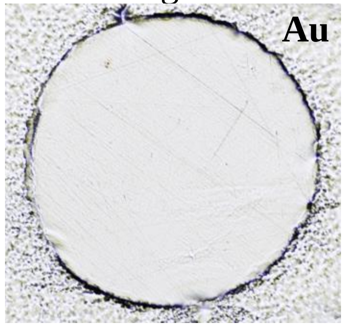


Optimized Al film (low humidity, optical substrate surface)



Optimized free-standing



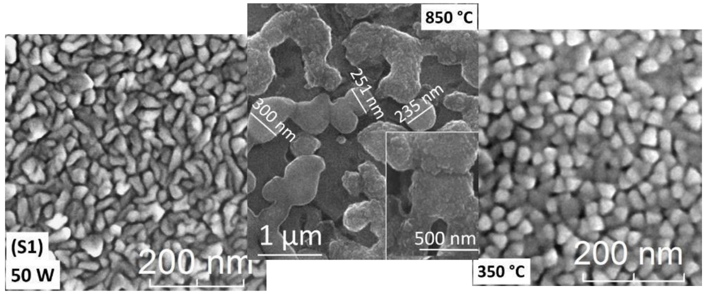


Research done by: Cristina Gheorghiu, Victor Leca

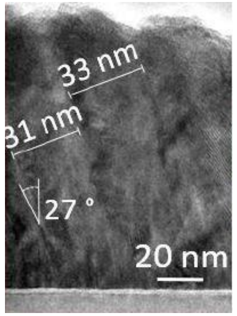
Targets on support

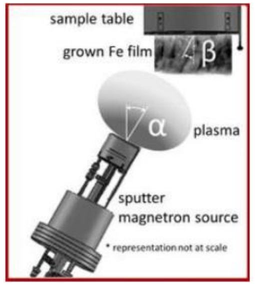
- **Nanoscale control of structure and composition of thin films**

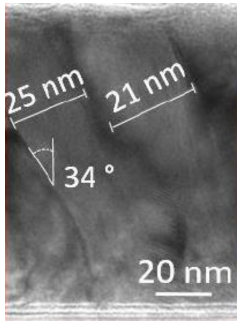
Oblique angle deposition technique gives:
(limited surface diffusion, and with atomic-scale ballistic shadowing)



- Controlled surface morphology and topography





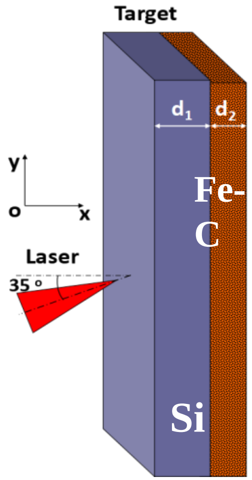


Materials, 6134 (15) (2022)

- **Multicomponent solid targets for spatial/ radiobiological applications**

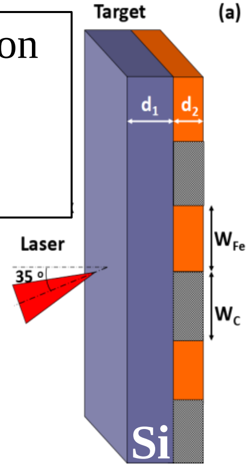
(Univ. Politehnica collab, and LDED collab: D. Sangwan)

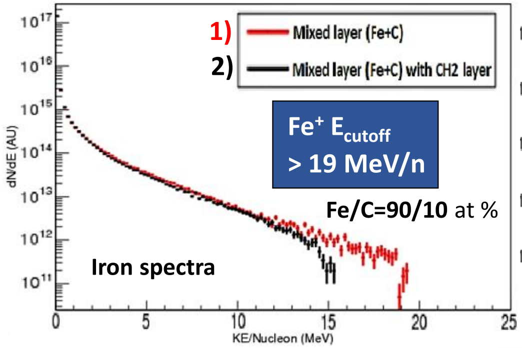
Homogeneous Fe-C film

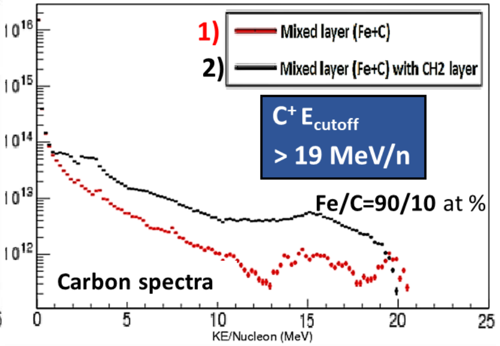


1) without contamination
2) with CH_2, 10 nm
Si thickness:
d_1 = 1 µm, d_2 = 200 nm

Layered Fe-C target
Fe/C=90/10 at %

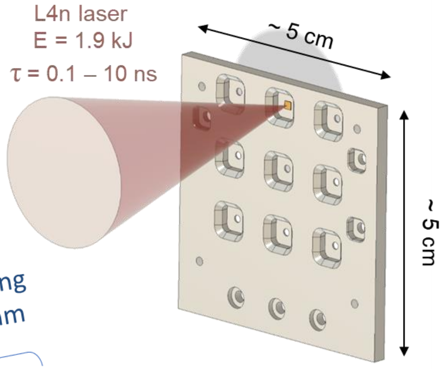


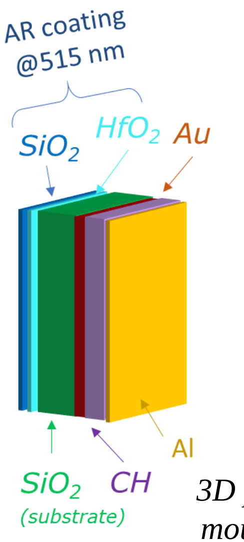




- **Multilayered targets**

(ELI-Beamlines collab – for X-Ray generation)

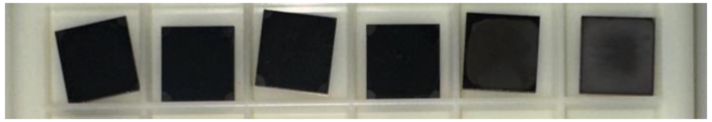




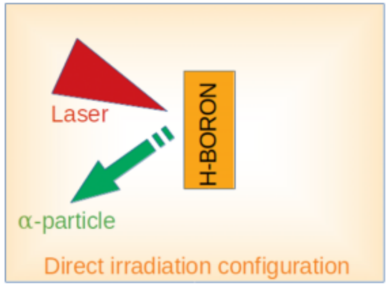
3D printed plastic frame with mounted multilayered targets

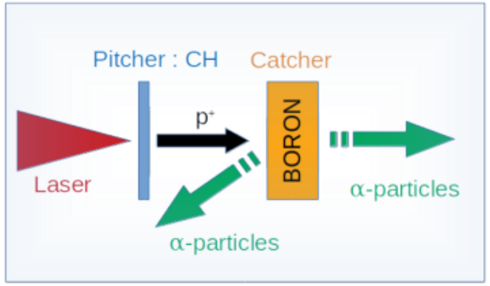
Research done by: Cristina Gheorghiu, Victor Leca

Boron target fabrication for proton-boron fusion

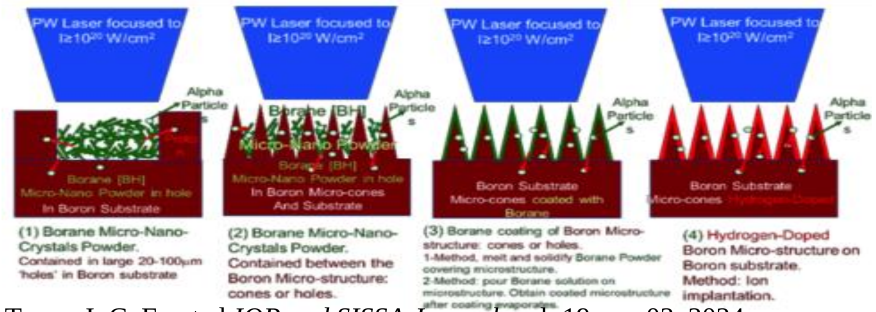


Boron Nanoparticles on Si(100)

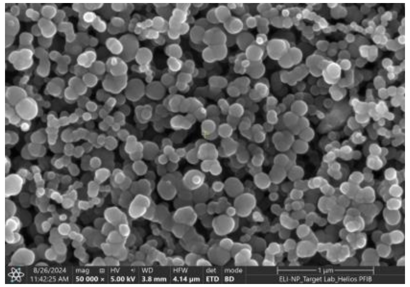




Batani, K., JIST, 2023



Turcu, I. C. E., et al *IOP and SISSA Journal*, vol. 19, no. 03, 2024



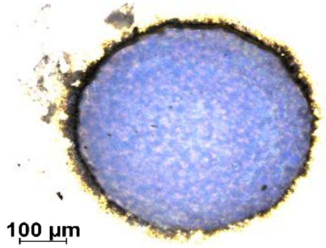
Regarding further work, next directions are of interest:

- Boron films by RF Sputtering (Top-Down method)
- Finding the best solution for B nanoparticles dispersion
- Target testing in high power laser experiments
- Applications to Fusion Energy
- Applications to Medical Radioisotopes

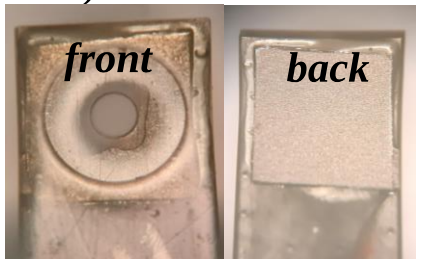
Commercial foam targets and carbon targets directions

Solid targets for the 2024 May 10 PW experimental campaign:

- Commercial foams (General Atomics, RAL):
  - ✓ CH, SiO2, 6 - 50 mg/cc:
    - on plastic washer
    - on metallic washer
    - with foil as support



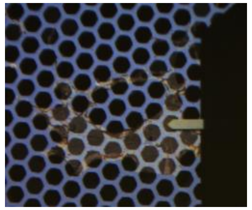
SiO_2 foam on Cu washer

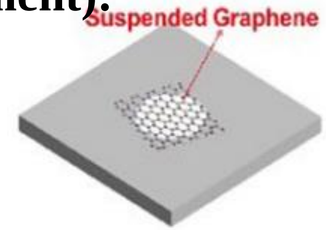


CH foam on Ni foil

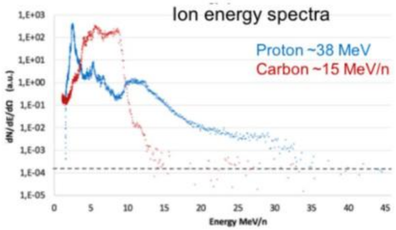
Carbon targets strategies (under development):

- Graphene by CVD growth and transfer on substrates with holes





- DLC (diamond like carbon) by pulsed laser deposition (collab.)



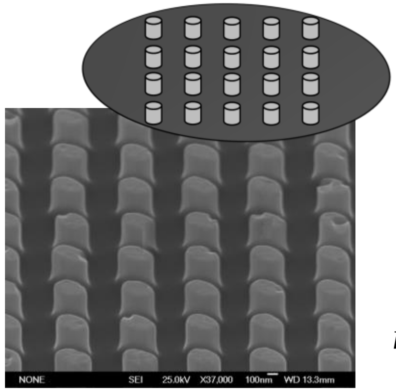
- Carbon foams by chemical methods and supercritical drying/ freeze drying

Research done by: Andrei Giulesteanu, Cosmin Jalba, Karolina Horna, Cristina Gheorghiu

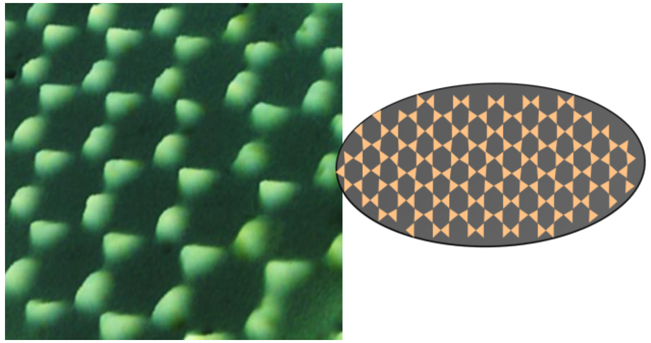
Microstructured targets - bigger surface area

- **Surface film nanopatterning**

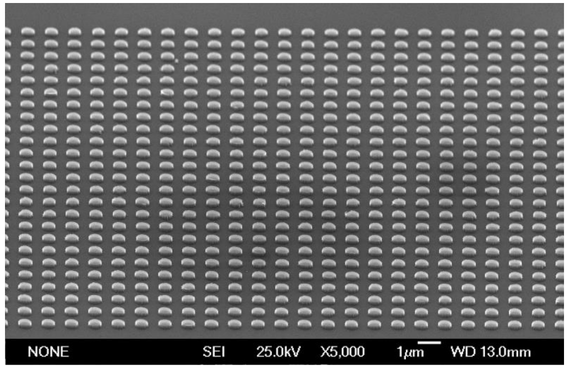
Suitable for high repetition rate applications.
Fabricated by means of:
- electron beam lithography (EBL)
- reactive ion etching (RIE)
- optical lithography
- Ar ion milling

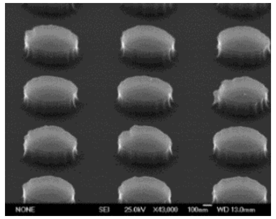


nano-rods



metallic triangle array nanostructures



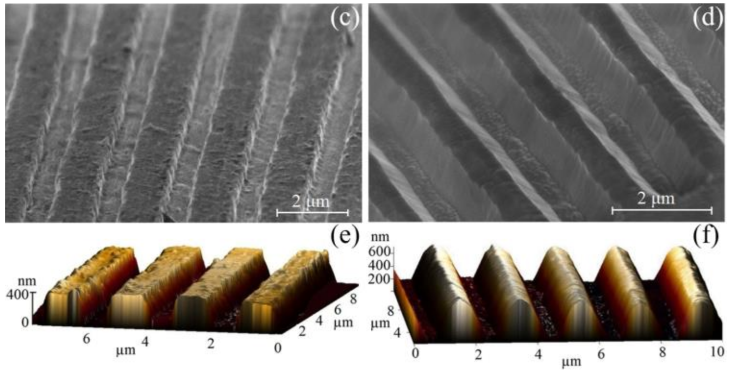


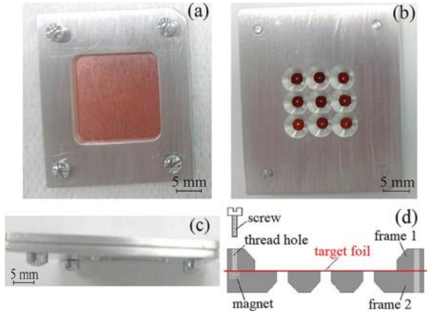
metallic (Au, Cr) nano-dots

C. Gheorghiu et al., Frontiers in Physics, 9, 727498 (2021)

- **Periodic gratings on Au and Cu foils (3 µm, 10 µm)**

- for ion acceleration experiments, High Harmonic Generation and X-ray generation *(collab. Laser and Plasma Physics Institute/Duesseldorf)*

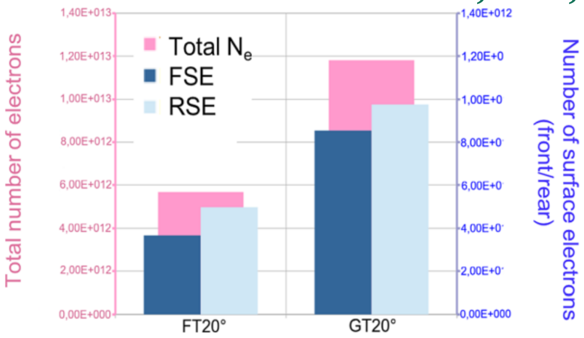




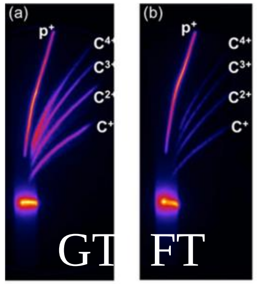
Al-frame with Cu patterned foil

Enhanced laser energy absorption, higher efficiency in accelerating charge particle beams (compared to planar foils)

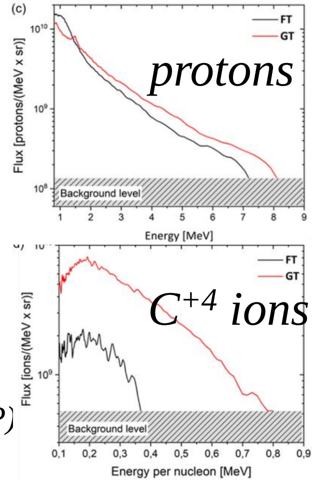
Arcturus laser: I=10^{20} W/cm^2, 30 fs, 5-9 um spot size



N° of accelerated electrons (E > 0.8 MeV) gold FT (thin flat), GT (grating target)



Proton and ion traces (Thomson parabola/MCP) for Cu targets.

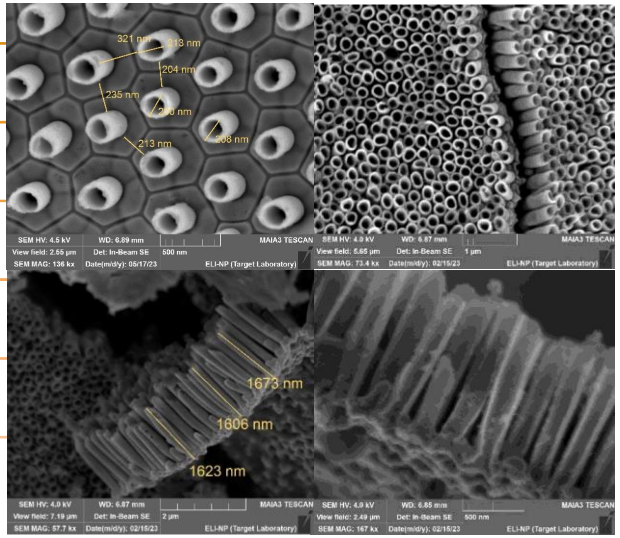


C. Gheorghiu et al., High Power Laser Science and Engineering 10 (2021)

Research done by: Cristina Gheorghiu, Victor Leca

Nanostructures: Metallic Nanowires and Nanotubes

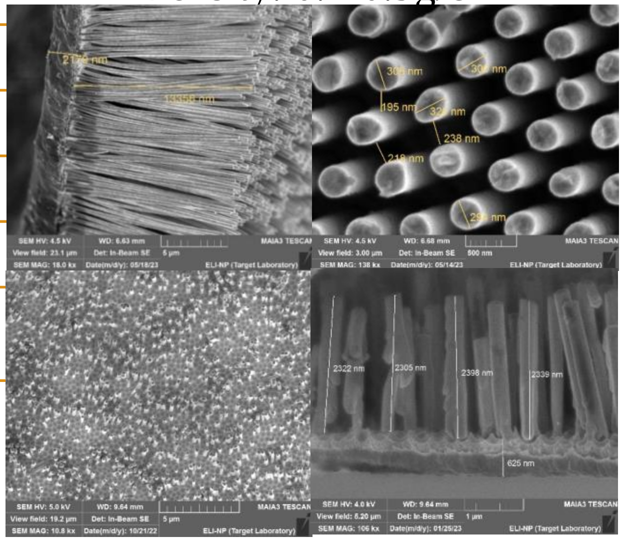
Nanotubes Characteristics
Diameter: 200-300 nm
Height: 1-3µm
Interpore distance: 40-150 nm
Substrate thickness: 200nm-tens of microns
Material: **Ni, Cu, Co, Au, Pd** (Ag, Zn, Nd, Tb, combinations)



Filling factor: 8-10%

Density: 0.7-0.9g/cm^3

Nanowires Characteristics
Diameter: 100-300 nm
Height: 500 nm-10 µm
Interpore distance: 40-300 nm
Substrate thickness: 500nm-tens of microns
Material: **Cu, Ni, Co, Au, Pd** (Ag, Zn, Nd, Tb, combinations)



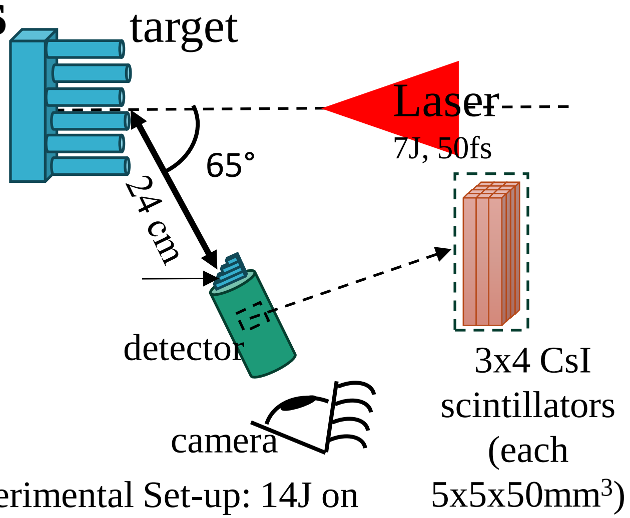
Filling factor: 10-30%

Density: 0.9-2.8 g/cm^3

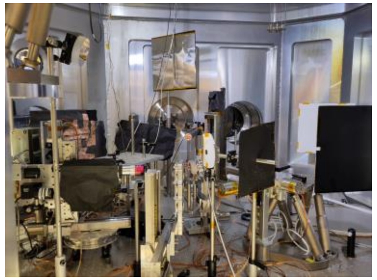
• Laser experiments

➢ Gemini 2023/2024

- Laser set-up and properties: DPM, 50fs pulse duration; 2um FWHM focal spot, ~7J on target;
- Diagnostics: RCF, TP, ToF, CsI, X-ray pin-hole camera;



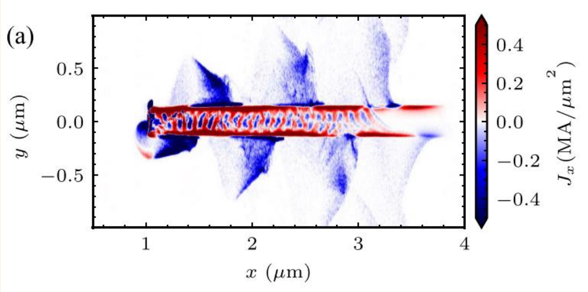
➢ ELI-NP E5 1PW 2024



- Experimental Set-up: 14J on target, 28fs, 4 µm focal spot, 15deg, single plasma mirror
- Diagnostics: TP, RCF, CsI, bubble detectors, ionization chamber

• PIC simulations

In collaboration with theory and simulation group



Ong, J.F., et. al,PRR 3, 2021

Ong, J.F., et. al,PRE 107, 2023

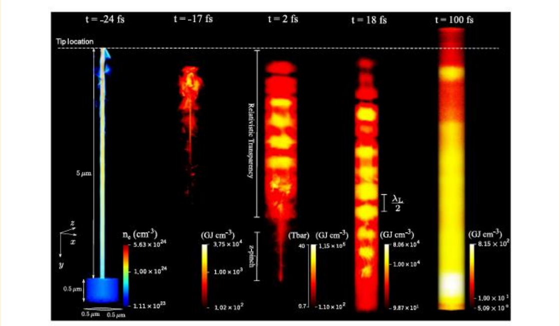


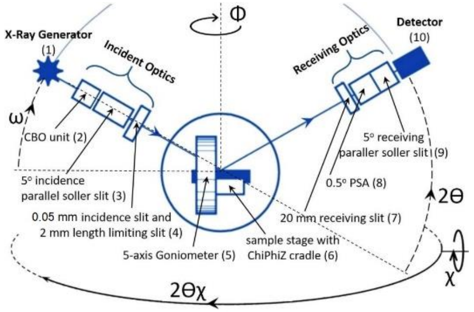
FIG. 2. The 3D density and kinetic energy density distribution of 100-nm-diameter Cu nanowire irradiated by a laser with intensity 10^{23} W cm^{-2} at $t = -24, -17, 2, 18$, and 100 fs. The peak of the laser pulse reaches the tip of the nanowire at $t = 0$, indicated by the dashed line. The laser pulse is propagating in the $+y$ direction. The RT regime led to the plasma modulation with a period of $\lambda_L/2$ which is stable throughout the duration of the laser pulse. The pressure scale at $t = 2$ fs is an estimation based on Ryu *et al.* [29] in ultrarelativistic and nonrelativistic limits.

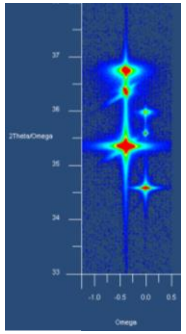
Research done by: Stefania Ionescu, Cristina Gheorghiu

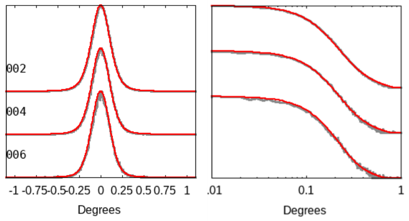
Materials science – structural defects and structure simulations

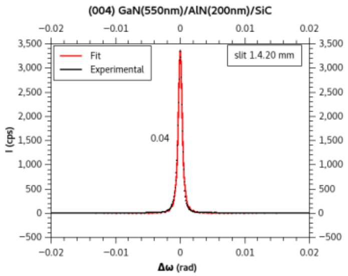
• Threading dislocations studies with XRD

(Faculty of Physics, Univ. Politehnica collab)

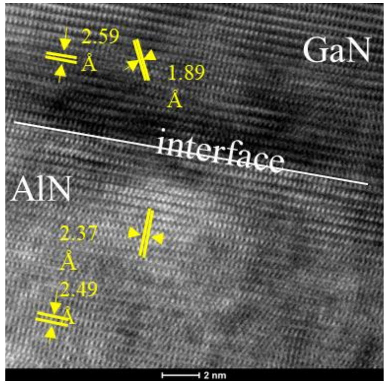








Kaganer method



TEM - high quality of AlN buffer layer and GaN layer

• Metallic hydrides: Ab initio & DFT calculations

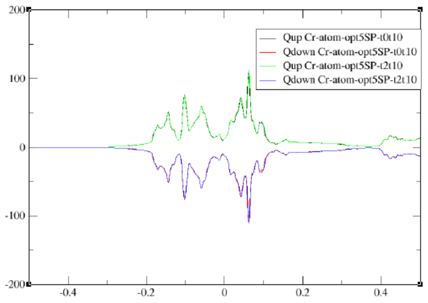
(Faculty of Physics collab: Conf. Alex. Nemnes, Prof. Lucian Ion)

Aim:

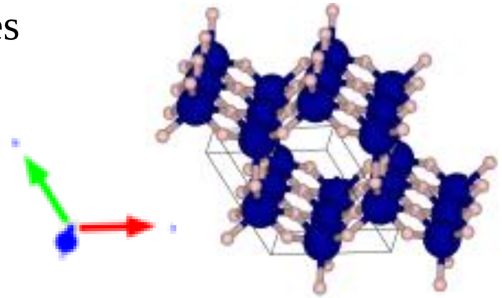
- *find stable structures of metallic hydrides which can be stabilized/grown as thin films, for fabrication of metallic hydrides films*
- *obtain stability conditions and structural investigations for metallic films, as a function of pressure*

Programs: **SIESTA** → **CALYPSO** → **ELK**

1. CALYPSO Code → identify most promising hydrides structures
– crystal structure prediction using evolutive algorithms (PSO)
– the resulted structures found with CALYPSO are then relaxed with SIESTA to find the optimal, stable structure
– the atomic coordinates found after relaxation will be used in ELK
2. SIESTA Code → structural optimization
3. ELK Code → material physical properties



Cr TDOS spin-polarisation



Simulated structure of $\mathbf{Cr_2H_3}$ @ 160 GPa (P6/mmm)

Nanomaterials, 11(5) (2021); Nanomaterials, 10, 197 (2020)
Materials 12, 4205 (2020)

Research done by: Iulia Zai, Victor Leca

Conclusions and perspectives

- In targets fabrication process undestanding of the materials properties is critical for developing targets with desired characteristics;
- This requires ongoing materials science studies for target development;
- Exploration of new methods for fabrication of nanostructured targets in order to widen their parameters range;
- Need for high rep targets;
- On the metallic hydrides:
  - improving DFT simulation parameters for yielding new stable structures
  - Improving the experimental methods that will allow for better stabilization of hydrides that can be applied also to new systems, such as LuHN

EUROPEAN UNION

Extreme Light Infrastructure-Nuclear Physics
(ELI-NP) - Phase II

Structural Instruments
2014-2020

Thank you for your attention!

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IFIN-HH

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We welcome any collab.