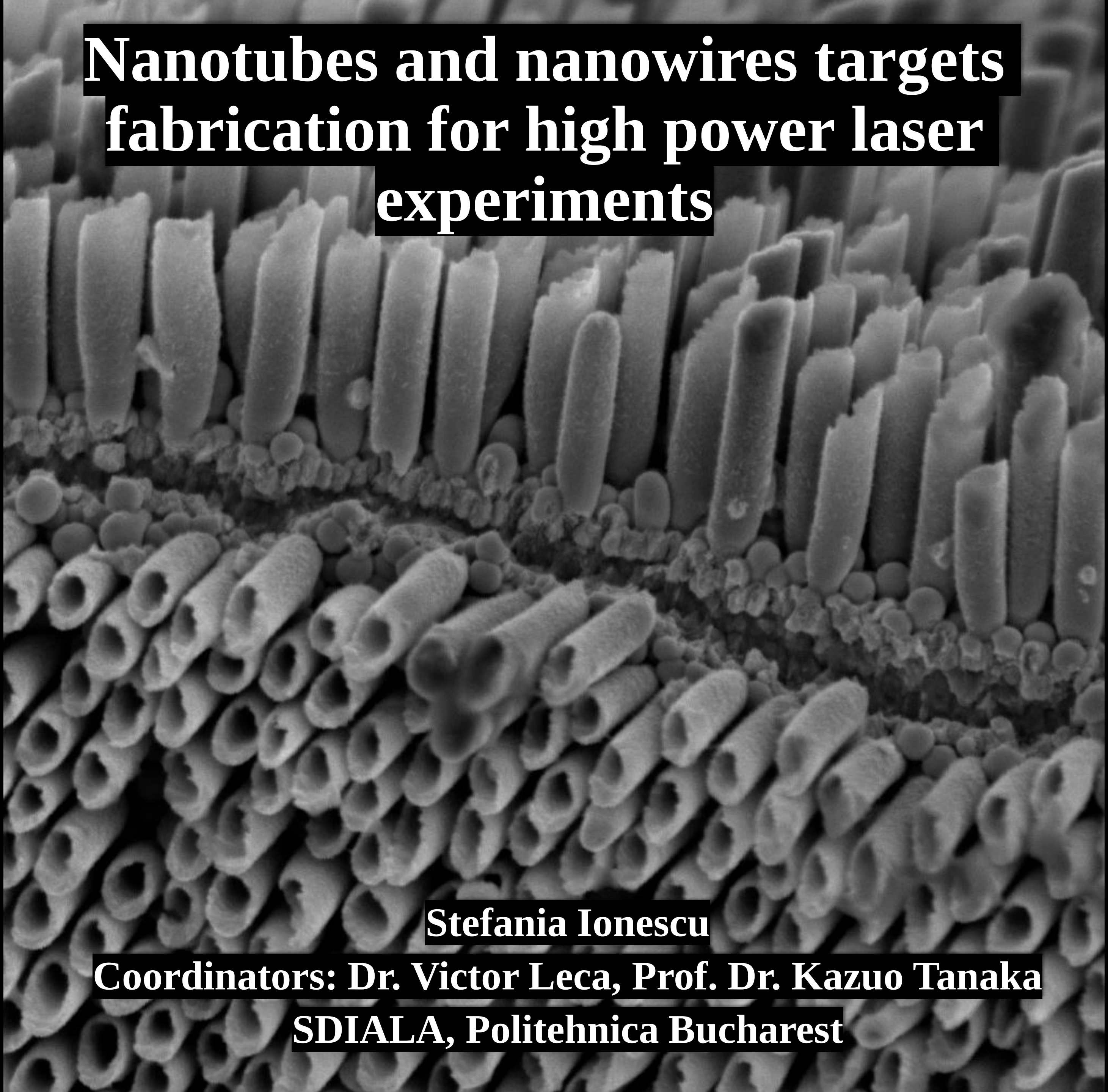
Nanotubes and nanowires targets fabrication for high power laser experiments



Stefania Ionescu

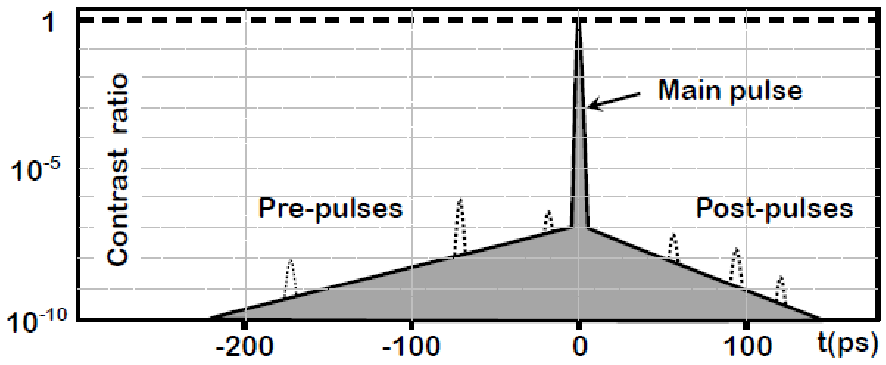
Coordinators: Dr. Victor Leca, Prof. Dr. Kazuo Tanaka

SDIALA, Politehnica Bucharest

Young Researchers & Young Engineers Days,
Măgurele,
30-31 January 2024

Content

Ultra-intense, ultra-short laser-matter interaction

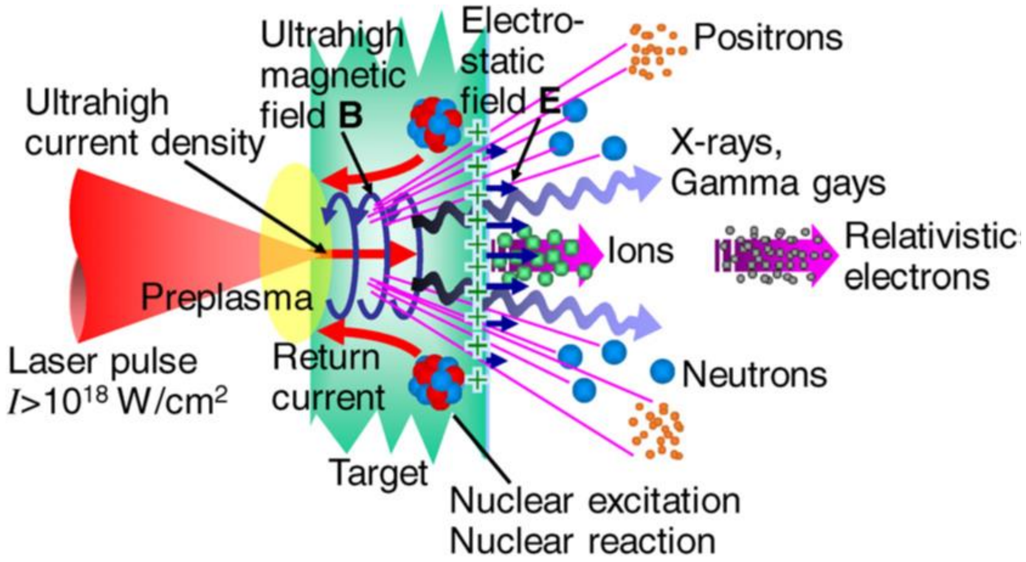


Unifying Physics of Accelerators, Lasers and Plasma, Seryi 2015

INTERACTION

Targets

- solid (thin/thick films, microstructured multi-layer, foams, 3D shapes: micro-cone, nanospheres, snow clusters, NWs, gratings nanoparticle, etc.)
- cryogenic
- gas jet
- liquid crystals



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

How can we improve the interaction?

- **laser (contrast, ultra short pulse)**
- **or target**

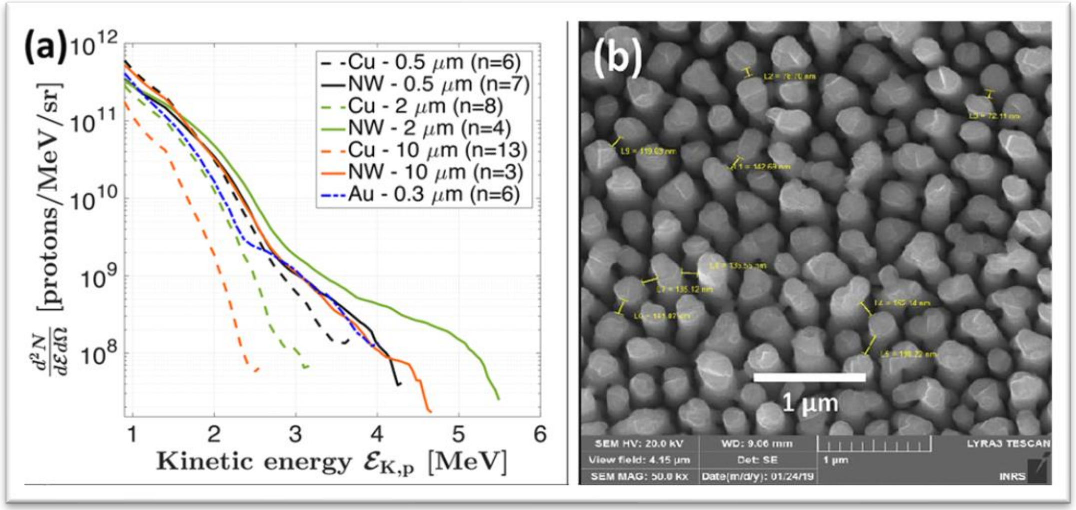
Targets Characteristics

- Chemical composition → High Z/ low Z
- Volume; Thickness → mass limited/ freestanding
- Density → foams
- Micro/ nanostructuring
- state of aggregation

Motivation

➡ Nanowires (NWs)

Proton acceleration



S. Vallieres et al, Nature Scientific Reports, 2021

NW targets for laser experiments may increase:

- ✓ **Maximum resulted particle energy**
- ✓ **Volumetric heating**
- ✓ **Laser absorption on the target**
- ✓ **Conversion efficiency**
- ✓ **Xray emission**

A. Macchi et al, Review of modern physics, 2013

Ultra High energy density matter + Tbar pressure

8x10^{10} Jcm^{-3}; 0.35 terabar

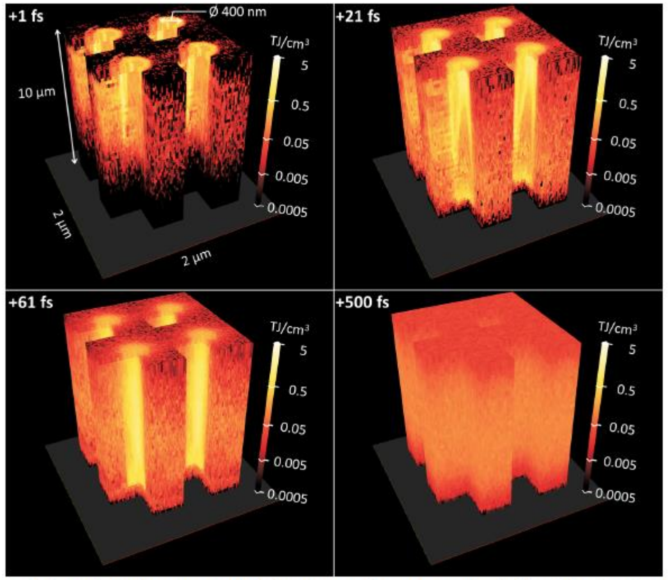


Fig. 7. PIC-simulated energy density distribution in an array of vertically aligned 400-nm-diameter Au nanowires irradiated with an intensity of 1×10^{22} W cm^{-2} ($a_0 = 34$) using a 400-nm wavelength pulse of 30-fs duration. The average atomic density is 12% of solid density. Each frame corresponds to a different time with respect to the peak of the laser pulse. The laser pulse impinges into the array from the top at normal incidence.

C. Bargsten et al., Science Advances, 2017

Scope: widen the range of target characteristics, followed by simulations and experiments, to improve interaction, for fundamental studies and applications.

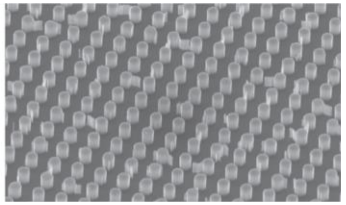
Some challenges: - target fabrication
- laser contrast and pulse duration
- diagnostics

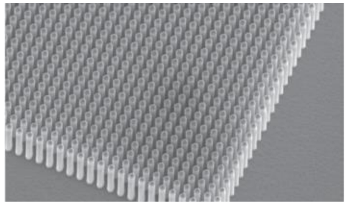
Methods for NW synthesis

Bottom-Up

- Vapor-Liquid-Solid
- Chemical Vapor Deposition
- Hydrothermal
- Molecular Beam Epitaxy
- Electrodeposition

Advantages:
- wide range of tunable parameters
- low-cost equipment and materials





Top-Down

- Reactive Ion Etching
- Metal Assisted Chemical Etching
- Lithography

Equipment

Electrochemical set-up

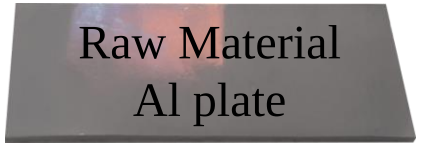
Characterization techniques

Scanning electron microscopy (SEM) +energy-dispersive X-ray spectroscopy (EDS)

Pre-processing

50 mm

20 mm

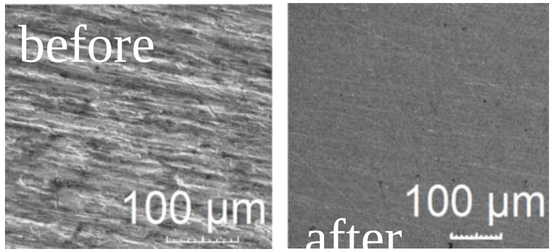


Thickness: 1 mm

Thermal treatment

enhances grain size **for** homogeneous pore growth

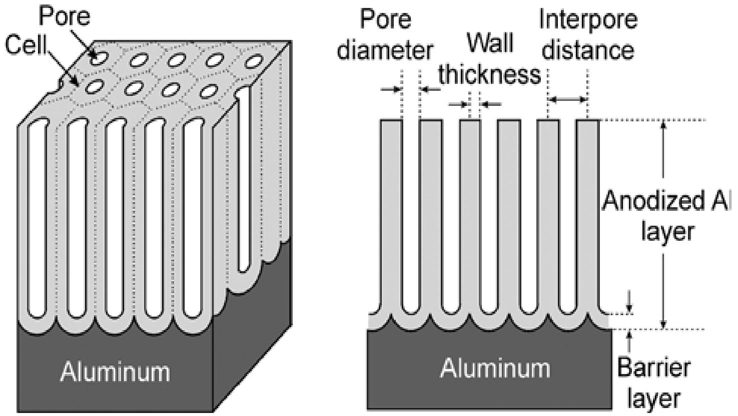
Mechanical polishing



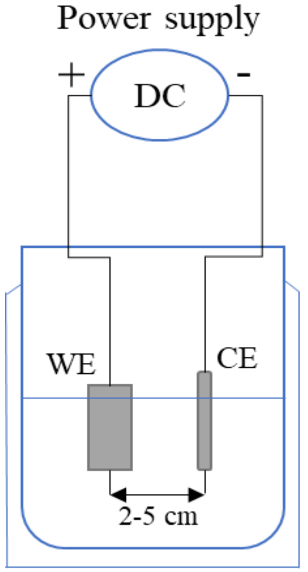
Reduce roughness

Anodization process

- Al anodization transforms Al in anodized aluminum oxide (**AAO**), which is porous alumina.



G. Sulka, Nanostructured Materials in Electroch. 2008

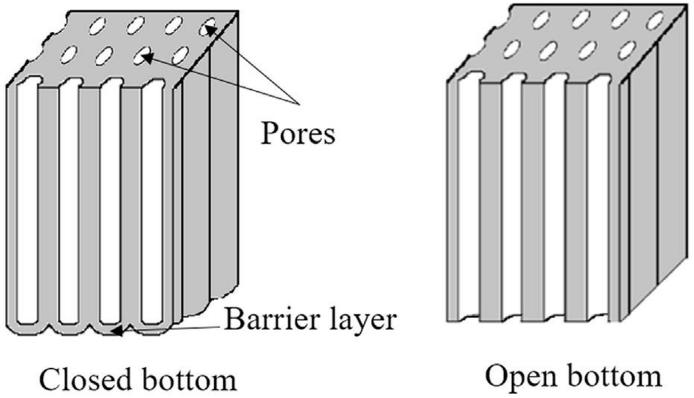


Electrochemical cell

AAO Characteristics

- Pore Diameter: 40-500 nm
- Interpore distance: 40-500 nm
- Thickness: 500 nm- tens of um

- Free-standing AAO: by detaching the anodized layer from the aluminum substrate or by dissolving the aluminium in HCl, $CuCl_2$ mixture.

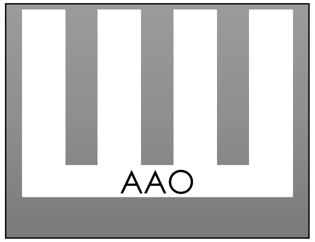


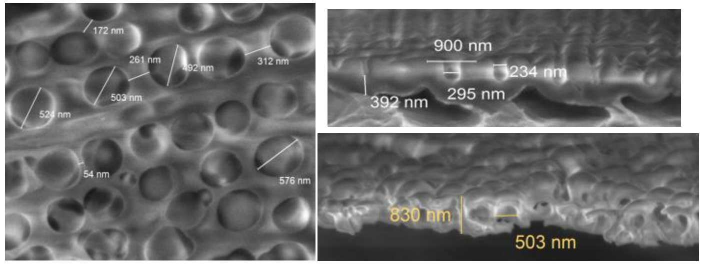
C. Gheorghiu et al., Frontiers in Physics, 2021

Process Parameters	
Electrolyte	Oxalic, Citric, Phosphoric, Ethanol
Type	1 step (mild-high) 2 steps
Voltage	40-400V
Time	Gives the thickness

Target 1/ Template: Nanochannels

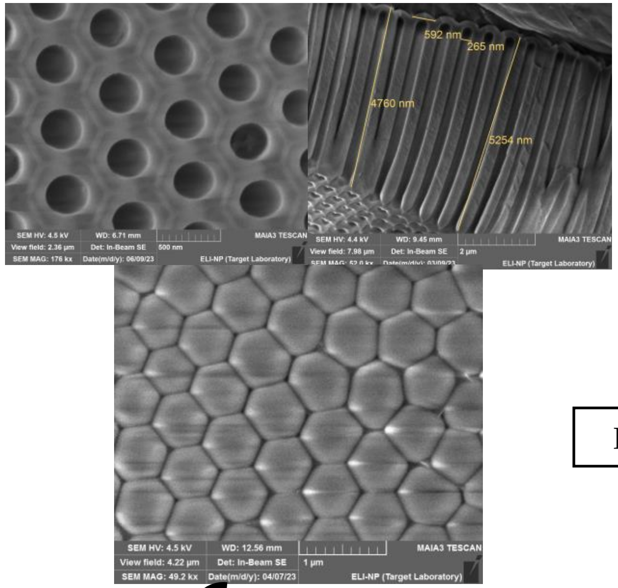
Testing method's limits





Diameter: **500nm**

400V



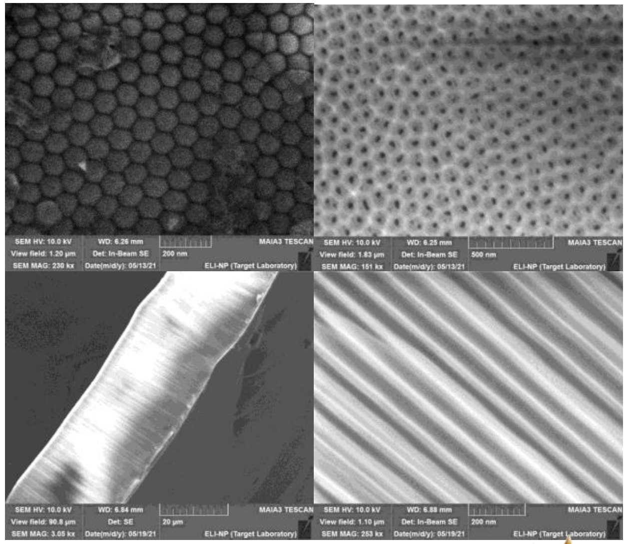
Diameter: **200nm**

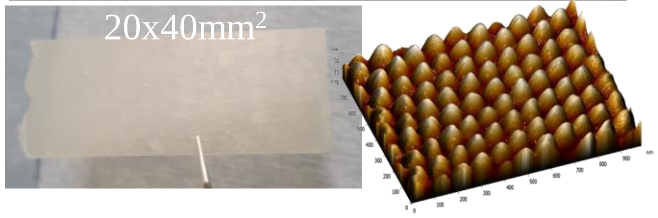
250V

Aluminum plate

40-80V

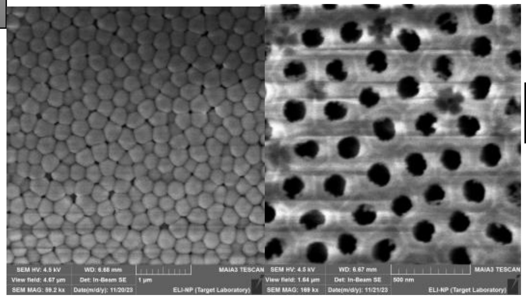
Diameter:**40-100nm**





120V

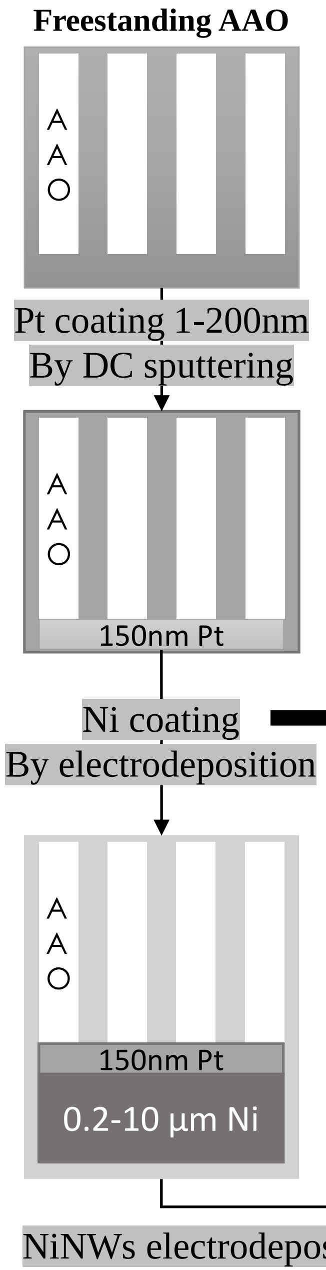
Used for nanotubes and nanowires



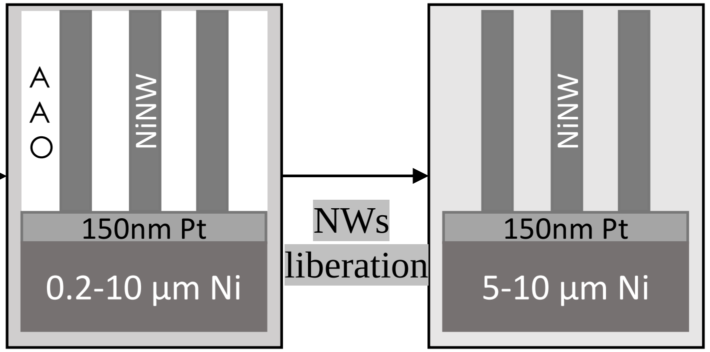
Diameter: **1-200nm**

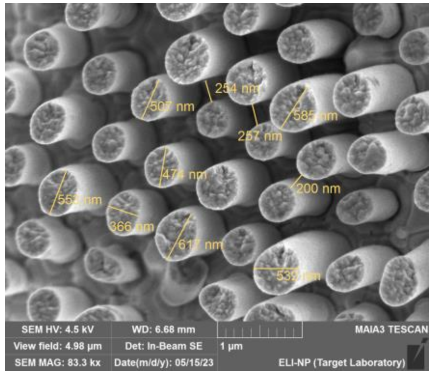
AAO=anodized aluminum oxide

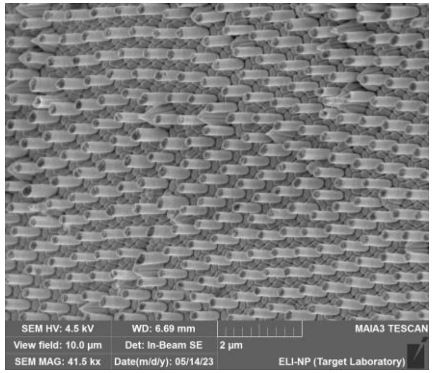
Target 2: Nanowires

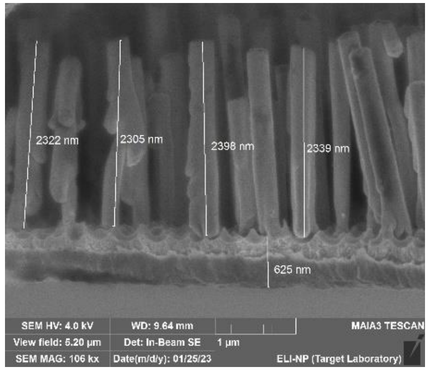


- **W.E. (AAO) -**
- **C.E. (Ti/Pt) +**
- **$NiSO_4$+ $NiCl_3$+ H_3BO_3**









Nanowires Characteristics

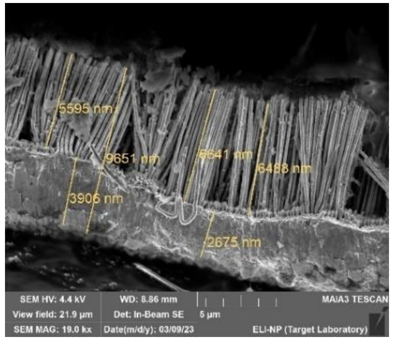
Diameter: 100-500 nm

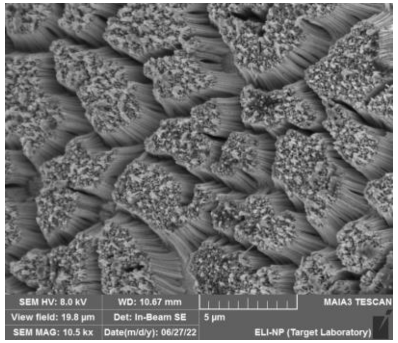
Height: 500 nm-10s of µm

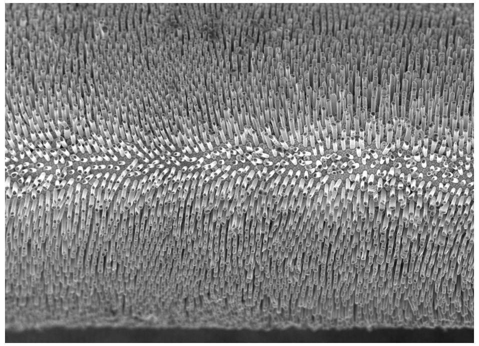
Interpore distance: 40-500 nm

Material: **Cu, Ni, Co, Au, Pd** (Ag, Zn, Nd, Tb, combinations)

Total target area: few cm^2

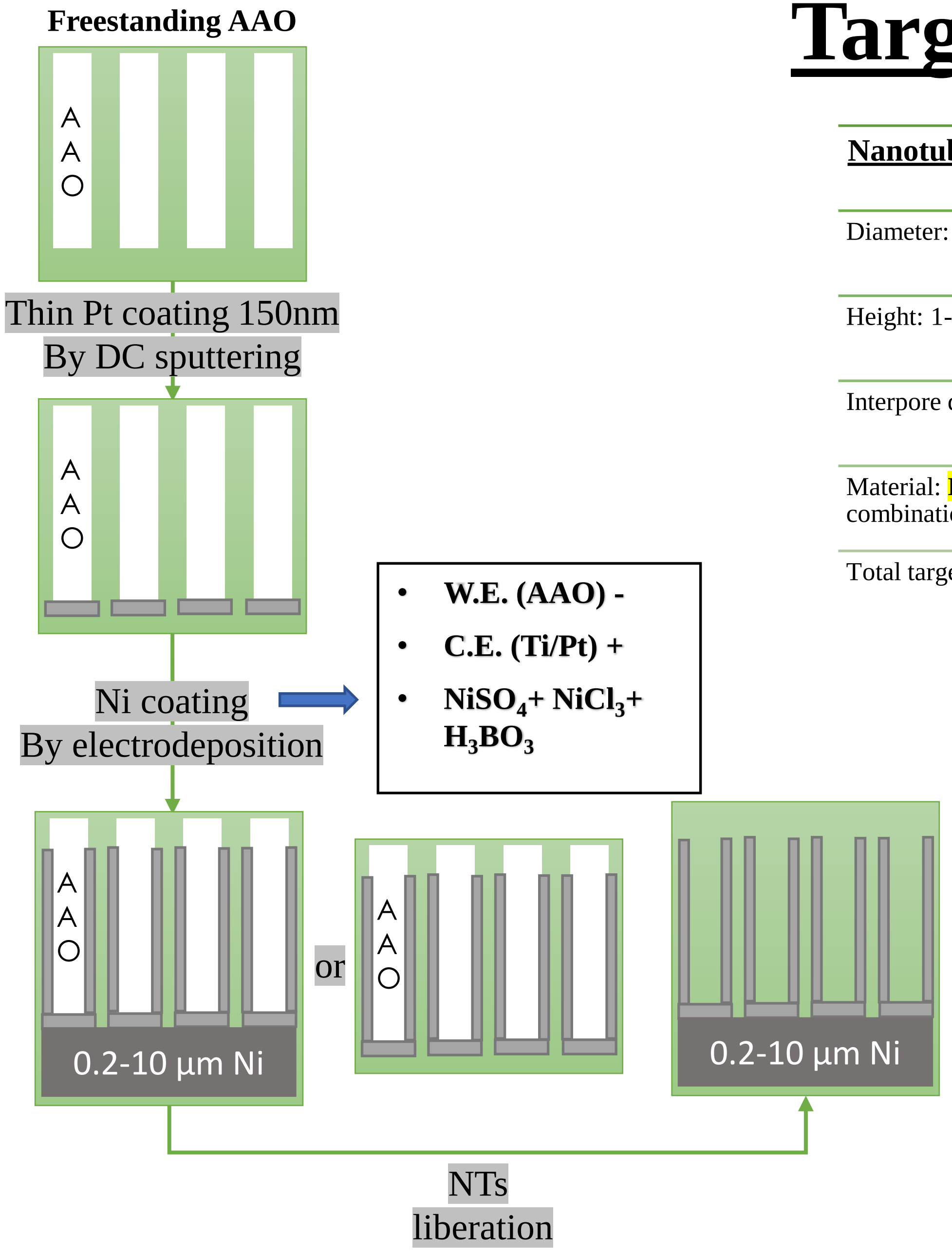


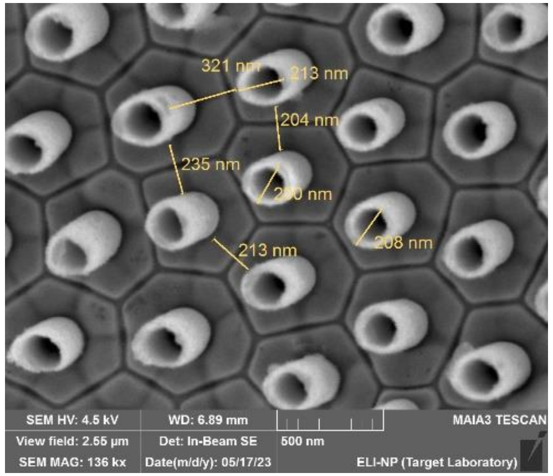


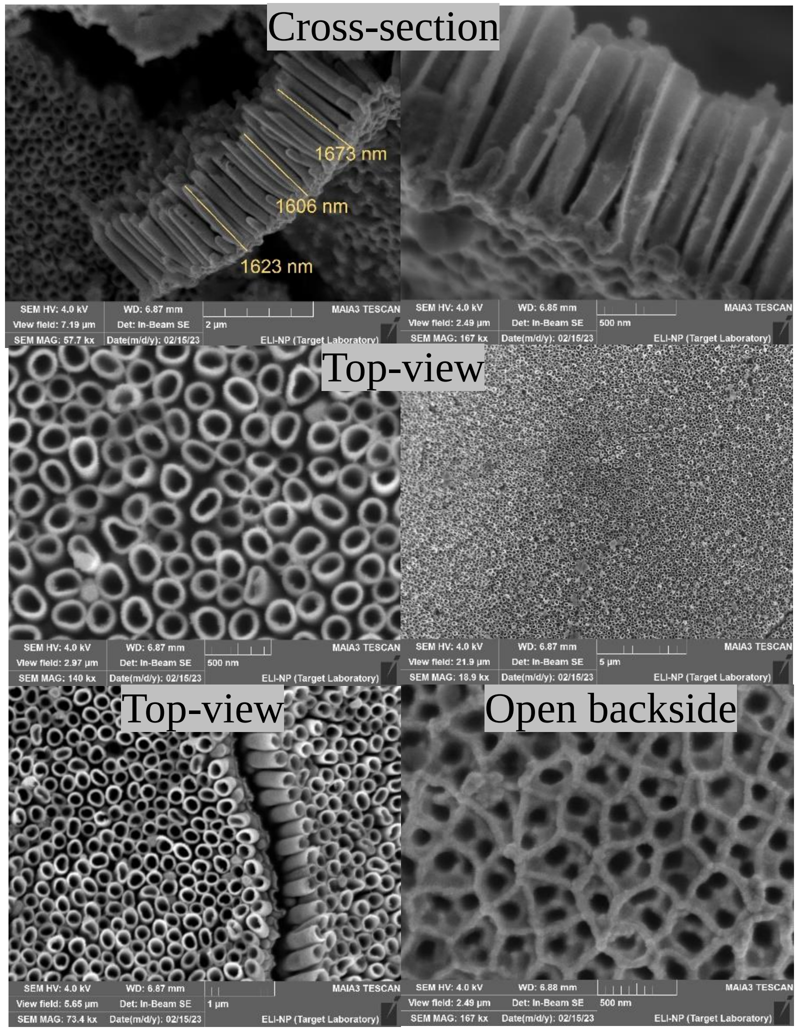


<u>Target 3</u>: Nanotubes

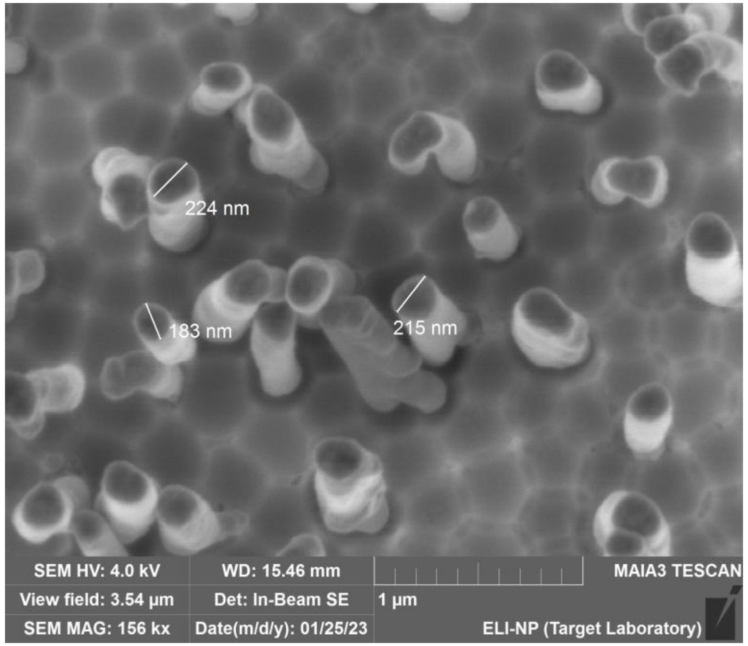
<u>**Nanotubes Characteristics**</u>
Diameter: 200-300 nm
Height: 1-3μm
Interpore distance: 40-300 nm
Material: **Ni, Cu, Co, Au, Pd** (Ag, Zn, Nd, Tb, combinations)
Total target area: few cm^2

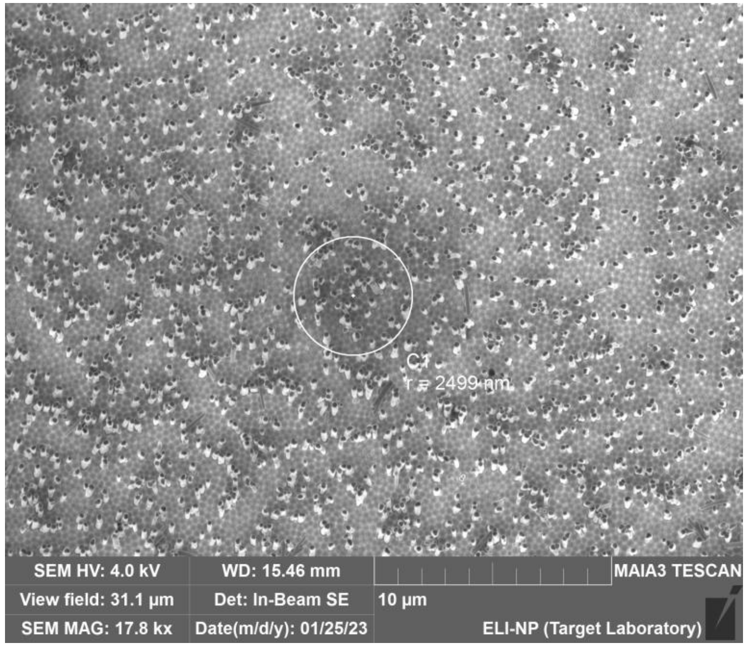


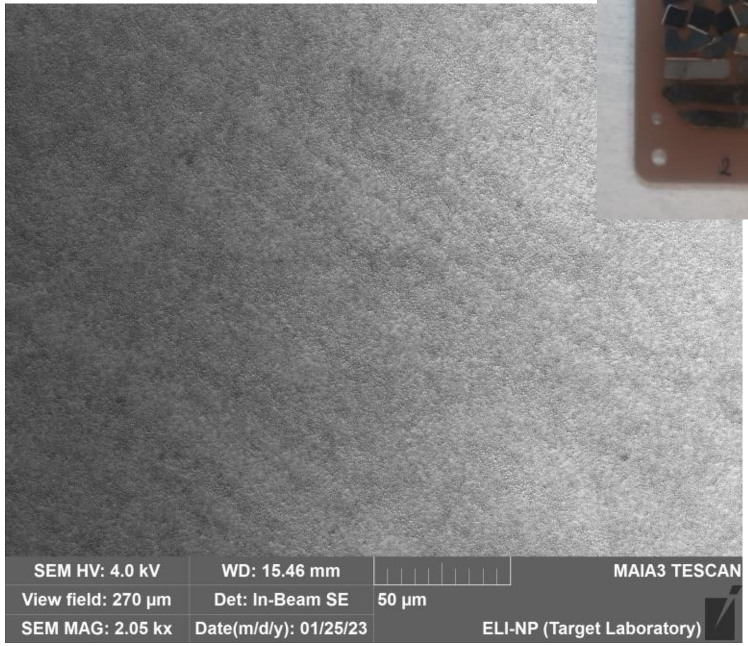


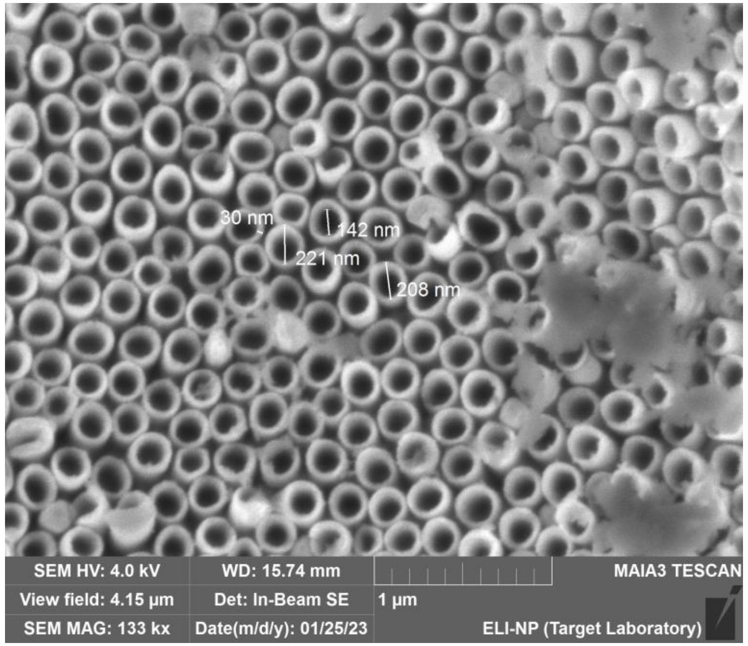


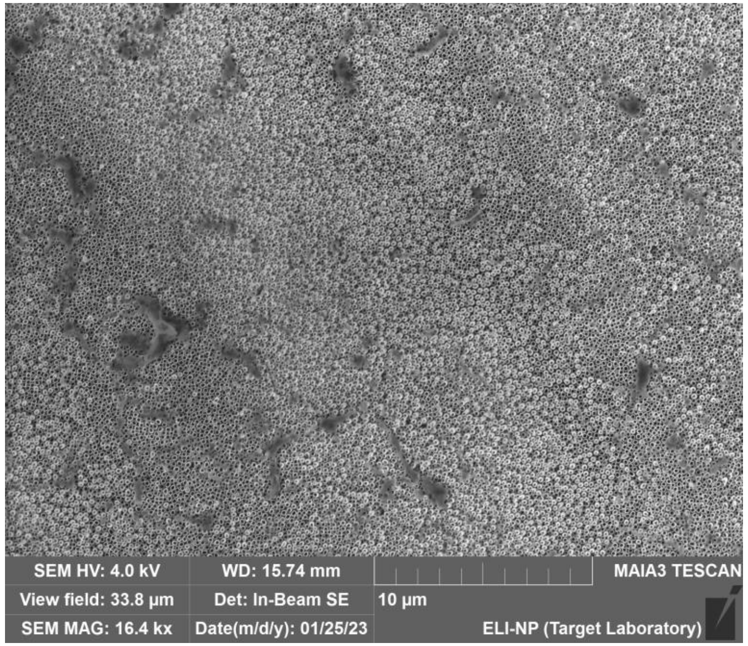
Targets surface area – few cm^2

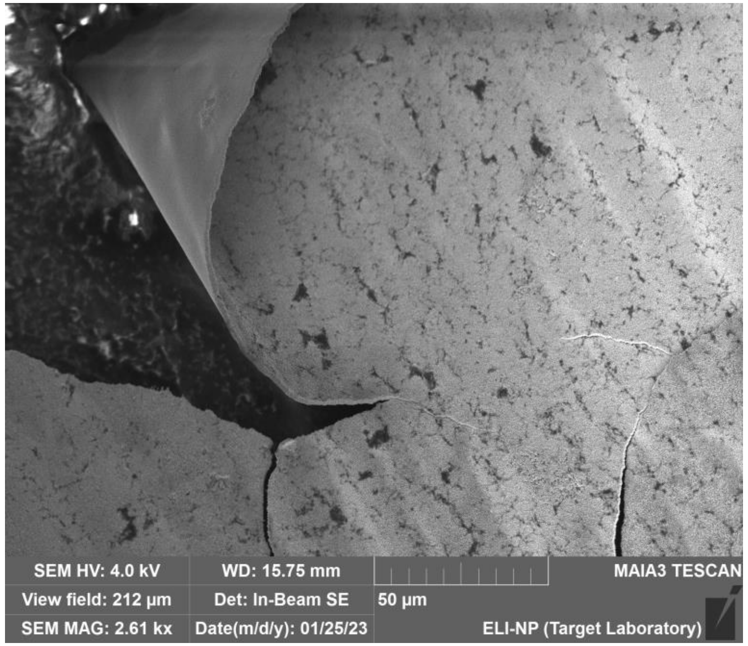












Conclusions

The following has been achieved:

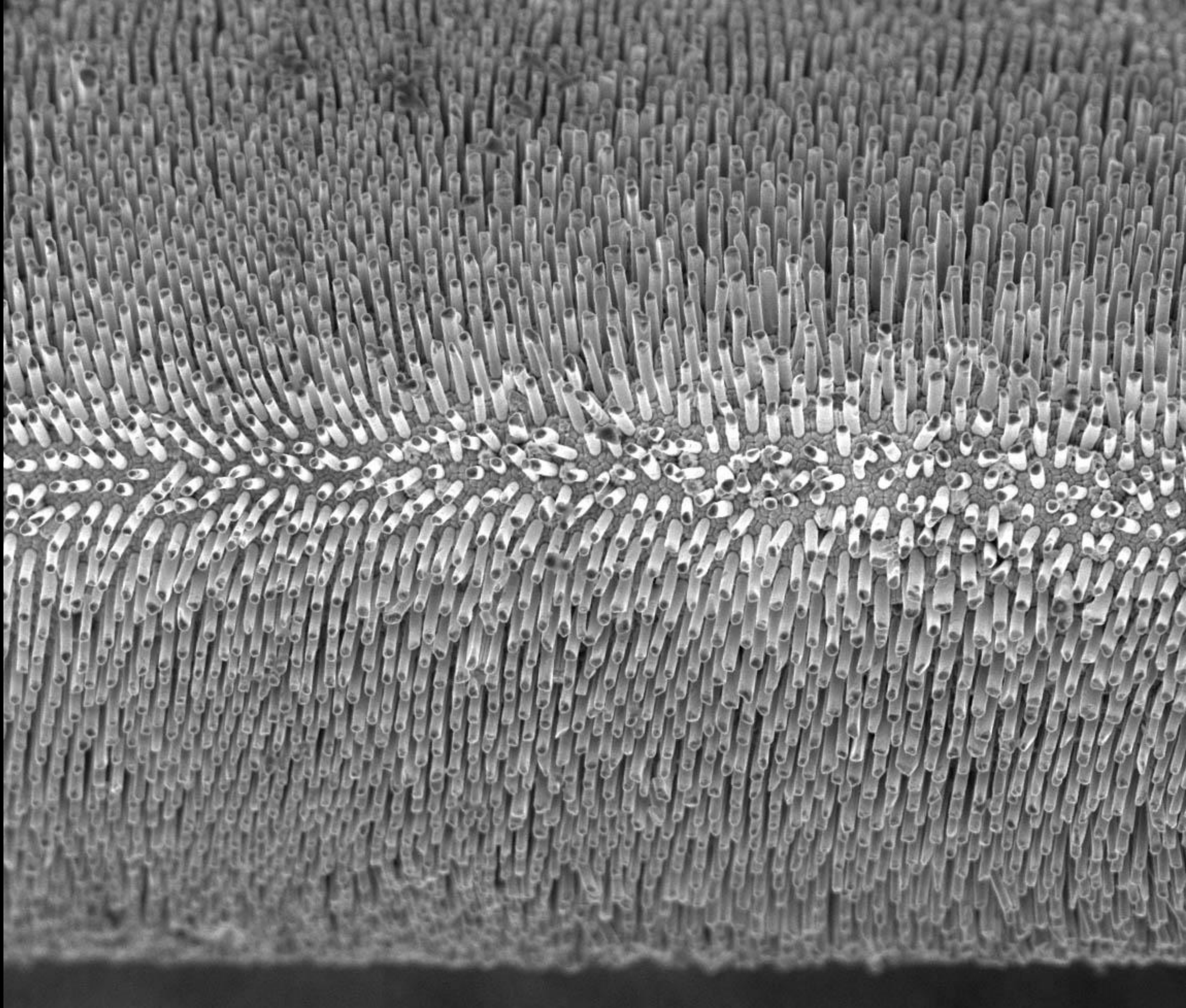
✓Synthesis of NiNWs and NiNTs on very thin Ni substrate

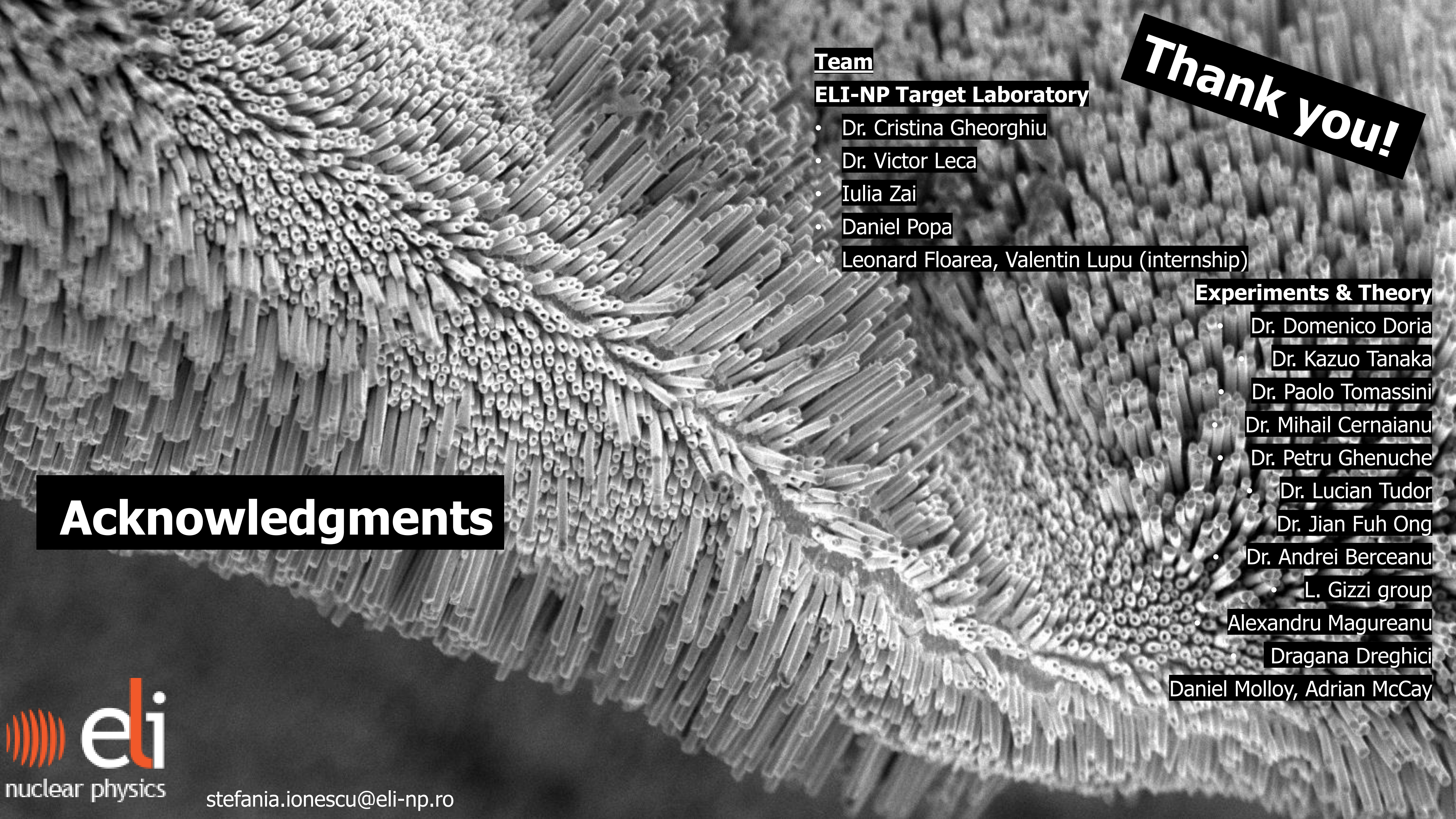
✓Increasing of target parameters intervals (dimeters, interpore distances, substrate thickness)

✓Laser experiments to study proton acceleration and x-ray emission from nanostructured targets

Regarding further work, next directions are of interest:

- Synthesis of longer NWs by supercritical drying
- **Increasing the interpore distance**
- Obtaining other metallic NWs (Co, Ni, Au, Pd, or mix)
- Si NWs by RIE+ EBL (Top-Down method)
- **Target testing in high power laser experiments**
- **PIC simulations for NWs & AAO targets**





Team

ELI-NP Target Laboratory

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- Daniel Popa
- Leonard Floarea, Valentin Lupu (internship)

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