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Overview on the target fabrication facilities at ELI-NP and ongoing strategies

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ABSTRACT: Along with the development of petawatt class laser systems, the interaction between high power lasers and matter flourished an extensive research, with high-interest applications like: laser nuclear physics, proton radiography or cancer therapy. The new ELI-NP (Extreme Light Infrastructure - Nuclear Physics) petawatt laser facility, with 10PW and $\sim 10^{23}$W/cm^2 beam intensity, is one of the innovative projects that will provide novel research of fundamental processes during light-matter interaction. As part of the ELI-NP facility, Targets Laboratory will provide the means for in-house manufacturing and characterization of the required targets (mainly solid ones) for the experiments, in addition to the research activity carried out in order to develop novel target designs with improved performances. A description of the Targets Laboratory with the main pieces of equipment and their specifications are presented. Moreover, in view of the latest progress in the target design, one of the proposed strategies for the forthcoming experiments at ELI-NP is also described, namely: ultra-thin patterned foil of diamond-like carbon (DLC) coated with a carbon-based ultra-low density layer. The carbon foam which behaves as a near-critical density plasma, will allow the controlled-shaping of the laser pulse before the main interaction with the solid foil. Particular emphasis will be directed towards the target's design optimization, by simulation tests and tuning the key-properties (thickness/length, spacing, density foam, depth, periodicity etc.) which are expected to have a crucial effect on the laser-matter interaction process.

KEYWORDS: Lasers; Manufacturing; Targets (spallation source targets, radioisotope production, neutrino and muon sources); Wake-field acceleration (laser-driven, electron-driven)

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Contents

1 Targets Laboratory

Targets Laboratory was designed within the ELI-NP infrastructure to ensure the fabrication and characterization of targets that will be used for experiments with high power lasers and gamma beams [1–4]. Among the solid targets, particular emphasis will be given to thin and thick films (nm-μm thick, μm-mm lateral dimensions) of metals, nitrides and oxides. In order to cover the production of a large variety and number (high repetition rate experiments require thousands of targets per day) of the aforementioned targets, in a reproducible way, the following equipment will be used: ultra-high vacuum (UHV) deposition cluster (for the preparation of metals/oxides/nitrides films and metal nanoparticles by DC/RF sputtering), UHV e-beam deposition (for ultrathin and ultrapure metallic films), reactive ion-etching (RIE) and optical lithography for structuring the samples; while the characterization will be performed by means of X-ray diffraction (XRD), scanning electron microscopy (SEM) with microanalysis, and atomic force microscopy (AFM). All the equipment are distributed over 4 cleanroom areas (ISO7 cleanliness) (figure 1): a room dedicated to the fabrication by film-deposition technologies, which also includes a separate room for photolithography (ISO6 cleanliness), a room for diagnosis and characterization of the obtained targets, and a room assigned for chemical/thermal treatments and micro-assembly; extend over a total lab surface area of 220 m^2.

Beside targets fabrication and characterization, the role of Targets Laboratory will also be to anticipate the future target advances and develop novel ones through a continuous research activity. Particular attention will be dedicated to nanostructured targets development.

2 Available equipment and specifications

Among the equipment for targets fabrication, UHV sputter deposition system (from Mantis Deposition), which also includes a cleaning unit by Ar ion-milling and nano-particle deposition set-up “NanoGen”, will be used for film deposition by DC/RF sputtering of metals, oxides and nitrides, on wafers up to 6 inch and temperatures up to 1000°C (for oxides and metals; 800°C for metals). The second UHV deposition system by e-beam evaporation of metals allows 6 inch wafers and deposition temperatures up to 800°C for (ultra)pure metals. RIE tool (Oxford Instruments), which will handle the structuring of the targets by chemical and physical etching, includes Bosh (selectivity to photoresist $> 250 : 1$, etching rate $> 2.5\ \mu$m/min) and Cryo (etching rate $> 5\ \mu$m/min, selectivity to photoresist $> 100 : 1$) etching technologies, with deep silicon etch (DSiE), for 8 inch wafers. Structuring by optical lithography includes tools like mask aligner, hot palates and spin coater (Süss MicroTec), for 8 inch wafers and with lateral resolution down to 500 nm. As for the characterization of the films, XRD (Rigaku) will be used to perform the microstructural and reflectivity analysis, at SAXS/USAXS, in-plane/out-of-plane diffractions, in 0D, 1D and 2D modes. Morphological analysis will be ensured at microscopic scale by high resolution (1 nm) SEM (Tescan), with Bruker EDS (energy dispersive x-ray spectroscopy) unit, for 6 inch wafers; by optical profilometer (Sensofar), with white light interferometry and 0.2 microns for XY resolution; and at atomic scale by AFM (NT-MDT) on samples up to 8 inch.

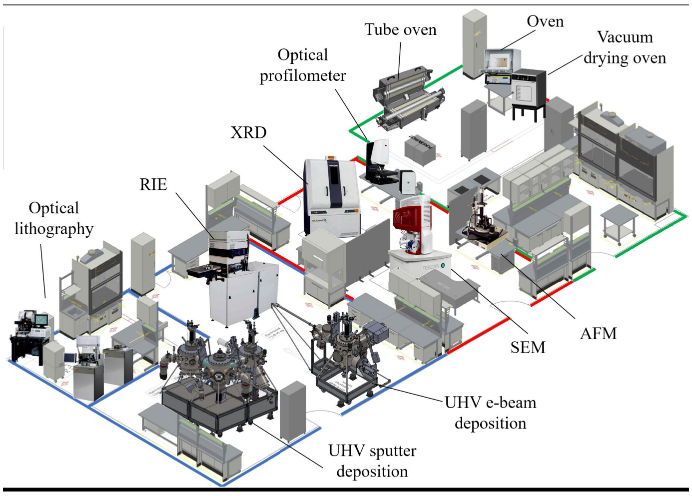

Figure 1. Configuration of the ELI-NP Targets Laboratory.

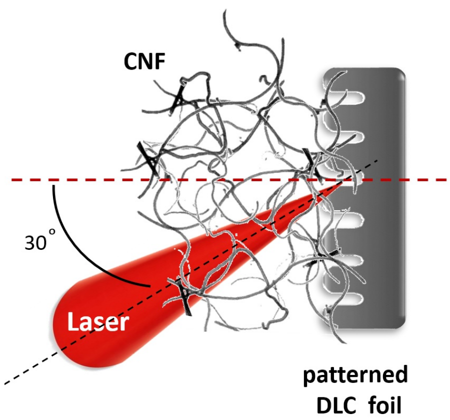

Figure 2. Spaghetti-like carbon nanotubes grown on patterned DLC.

3 Current requirements and proposed strategies

Current targets needs includes not only thin/thick films (SiN, metallic foils Al, Cu. . .) but also targets with more complex shapes (micro-cone targets [5, 6]) or decorated with nanostructured features (nanosphere [7–10], snow clusters [11], nanowires [12–14], gratings [15], nanoparticles [16]) which showed enhanced laser energy absorption and coupling by controlling the laser-matter interaction phase. Moreover, carbon foams used as near-critical density layer attached on thin foils, allowed to optimally shape the laser pulse, leading to increased energy conversion [17–21]. In this context, an interesting route to be developed at ELI-NP, for proton acceleration, consists in coating the irradiated side of an ultra-thin micro-structured patterned foil (DLC, by means of diffraction gratings) with a near-critical density layer of carbon nanotubes (with controllable density profile and length, which need to be tuned in order to reach the optimal properties), figure 2. Irradiation of CNF foam results in its immediate ionization, leading to the formation of a uniform near-critical density plasma that acts as a nonlinear medium, where the laser pulse can be modulated (both temporal and spatial profile) by relativistic self-focusing and self-phase-modulation, obtaining high intensity, steepened laser pulses. Therefore enhanced ion acceleration performances can be achieved by optimal control of laser-matter interaction phase.

4 Conclusions

Targets Laboratory at ELI-NP possesses all the necessary tools and technologies to provide in-house manufacturing and characterization of required targets for laser-driven experiments, along with delivering novel target designs with improved properties and performances, through an intense research activity and by anticipating the future developments for more complex targets.

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References

[1] N.V. Zamfir, *Nuclear Physics with 10 PW laser beams at Extreme Light Infrastructure - Nuclear Physics (ELI-NP)*, *Eur. Phys. J. ST* **223** (2014) 1221.

[2] F. Negoita et al., *Laser driven nuclear physics at ELI-NP*, *Rom. Rep. Phys* **68** (2016) S37.

[3] N. Djourelov et al., *Positron production by gamma beam at ELI-NP*, *Rom. Rep. Phys.* 68 (2016) S735.

[4] N. Djourelov et al., *Source of slow polarized positrons using the brilliant gamma beam at ELI-NP. Converter design and simulations*, *Nucl. Instrum. Meth.* **A 806** (2016) 146.

[5] K.A. Flippo et al., *Increased efficiency of short-pulse laser-generated proton beams from novel flat-top cone targets*, *Phys. Plasmas* **15** (2008) 056709.

[6] S.A. Gaillard et al., *Increased laser-accelerated proton energies via direct laser-light-pressure acceleration of electrons in microcone targets*, *Phys. Plasmas* **18** (2011) 056710.

[7] D. Margarone et al., *Laser-driven high-energy proton beam with homogeneous spatial profile from a nanosphere target*, *Phys. Rev. ST Accel. Beams* **18** (2015) 071304.

[8] D. Margarone et al., *Laser-Driven Proton Acceleration Enhancement by Nanostructured Foils*, *Phys. Rev. Lett.* **109** (2012) 234801.

[9] J. Limpouch et al., *Efficient ion beam generation in laser interactions with micro-structured targets*, *EPJ Web of Conferences* **59** (2013) 17011.

[10] V. Floquet et al., *Micro-sphere layered targets efficiency in laser driven proton acceleration*, *J. Appl. Phys.* **114** (2013) 083305.

[11] T. Palchan et al., *Efficient coupling of high intensity short laser pulses into snow clusters*, *App. Phys. Lett.* **90** (2007) 041501.

[12] S. Jiang et al., *Effects of front-surface target structures on properties of relativistic laser-plasma electrons*, *Phys. Rev.* **E 89** (2014) 013106.

[13] S. Jiang et al., *Microengineering Laser Plasma Interactions at Relativistic Intensities*, *Phys. Rev. Lett.* **116** (2016) 085002.

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[14] S. Jiang et al., *Enhancing Bremsstrahlung production from ultraintense laser-solid interactions with front surface structures*, *Eur. Phys. J.* **D 68** (2014) 283.

[15] T. Ceccotti et al., *Evidence of Resonant Surface-Wave Excitation in the Relativistic Regime through Measurements of Proton Acceleration from Grating Targets*, *Phys. Rev. Lett.* **111** (2013) 185001.

[16] M. Dalui et al., *Preferential enhancement of laser-driven carbon ion acceleration from optimized nanostructured surfaces*, *Sci. Rep.* **5** (2015) 11930.

[17] T. Nakamura et al., *Interaction of high contrast laser pulse with foam-attached target*, *Phys. Plasmas* **17** (2010) 113107.

[18] A. Sgattoni et al., *Laser ion acceleration using a solid target coupled with a low-density layer*, *Phys. Rev.* **E 85** (2012) 036405.

[19] I. Prencipe et al., *Development of foam-based layered targets for laser-driven ion beam production*, *Plasma Phys. Control. F.* **58** (2016) 034019.

[20] J.H. Bin et al., *Ion Acceleration Using Relativistic Pulse Shaping in Near-Critical-Density Plasmas*, *Phys. Rev. Lett.* **115** (2015) 064801.

[21] M. Passoni et al., *Energetic ions at moderate laser intensities using foam-based multi-layered targets*, *Plasma Phys. Control. F.* **56** (2014) 045001.

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