CONFERENCE PRE-PRINT

TARGETS DEVELOPED IN THE 21ST CENTURY AT THE P.N. LEBEDEV PHYSICAL INSTITUTE OF RAS TO STUDY THE EXTREME MATTER PHYSICS USING HIGH-POWER LASER FACILITIES

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Abstract

60 years ago the idea of Laser Thermonuclear Fusion (LTF) was proposed by N.G. Basov and O.N. Krokhin. What is the mission of targets now in the era when experiments have demonstrated several-fold thermonuclear energy yield under NIF irradiation of target? The mission is still to provide the diversity of investigations regarding physics of the extreme matter states in each laser available from the unique Facilities developed in the framework of national programs to the Universities' less scale (energy and cost) installations with its definite parameters, resources, limitations. Well-organized target works allow

for minimum time from hypothesis to the laser irradiation experiments. This makes the relevant scientific field "targets for Laser Thermonuclear Fusion (LTF)" attractive and very important.

1. INTRODUCTION

A wide range of target activities in the thermonuclear target laboratory of the P.N. Lebedev Physical Institute in Moscow [1] in collaboration with several institutes of the Russian Academy of Sciences has been creating for 50 years the targets and the equipment by its own as well as developing techniques for target characterization. The targets have been produced for and have participated in many projects in the Russian Federation and over the world. They are not only thermonuclear experiments, but also different essential studies such as the nature of instabilities, energy absorption, radiation conversion and balance, secondary plasma sources for "accelerator on the table" and for fine invasive medical application and many others, for example [2-3].

The targets worked in the experiments with lasers, heavy-ion driver and on powerful electro-physical installations. The shot experiments provide the new phenomena from novel targets and verify the requirements for the further target works, which sometimes become orders of magnitude easier than the initial theoretic demands.

In spite of microscale (from santi- down to nanometers) the targets are complex and difficult objects and many organizations are involved. Each year the new fabrication methods appear [4-5] as well as the new diagnostics [6], everything being very competitive. Fig. 1 exemplifies the target of the Lebedev Physical Institute currently used in shot experiments of different scale. Many of them are heterogeneous with controllable structures.

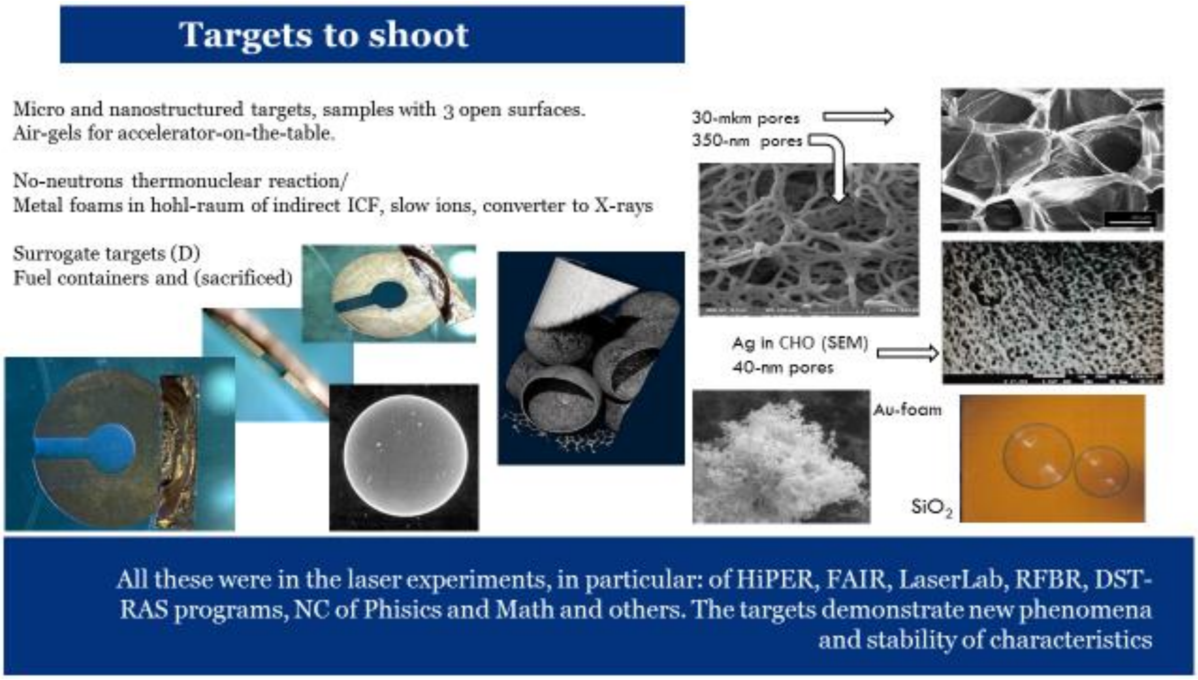

FIG. 1. Types of targets.

The joint laser experiments within the programs DST-RFBR, FAIR, HiPER, National Center for Physics and Mathematics, European experiments within LaserLab Proposals, on such Facilities as LULI, PALS, LIL and others demonstrated many essential hot plasma features and excellent plasma parameters due to targets. The latter become high-technology samples precisely made and measured.

Nowadays the target activity on the research (non-commercial and not reactor targets) falls mainly in the following:

— Spherical shells for fuel thermonuclear research, H_2-containers, sacrifice shells;
— Cryogenic module for the fuel research target formation and supply to the laser focus;
— Low-density plastic air-gels and metal foams as research targets;
— Measuring, mounting and characterizing the targets before the laser (or other driver) irradiation;

— Interaction experiments with targets prepared.

The main volume of targets' configuration and supply is presented on Fig. 1 altogether.

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2. SPHERICAL SHELLS

The activity in shell research and development is a key for the fusion experiments.

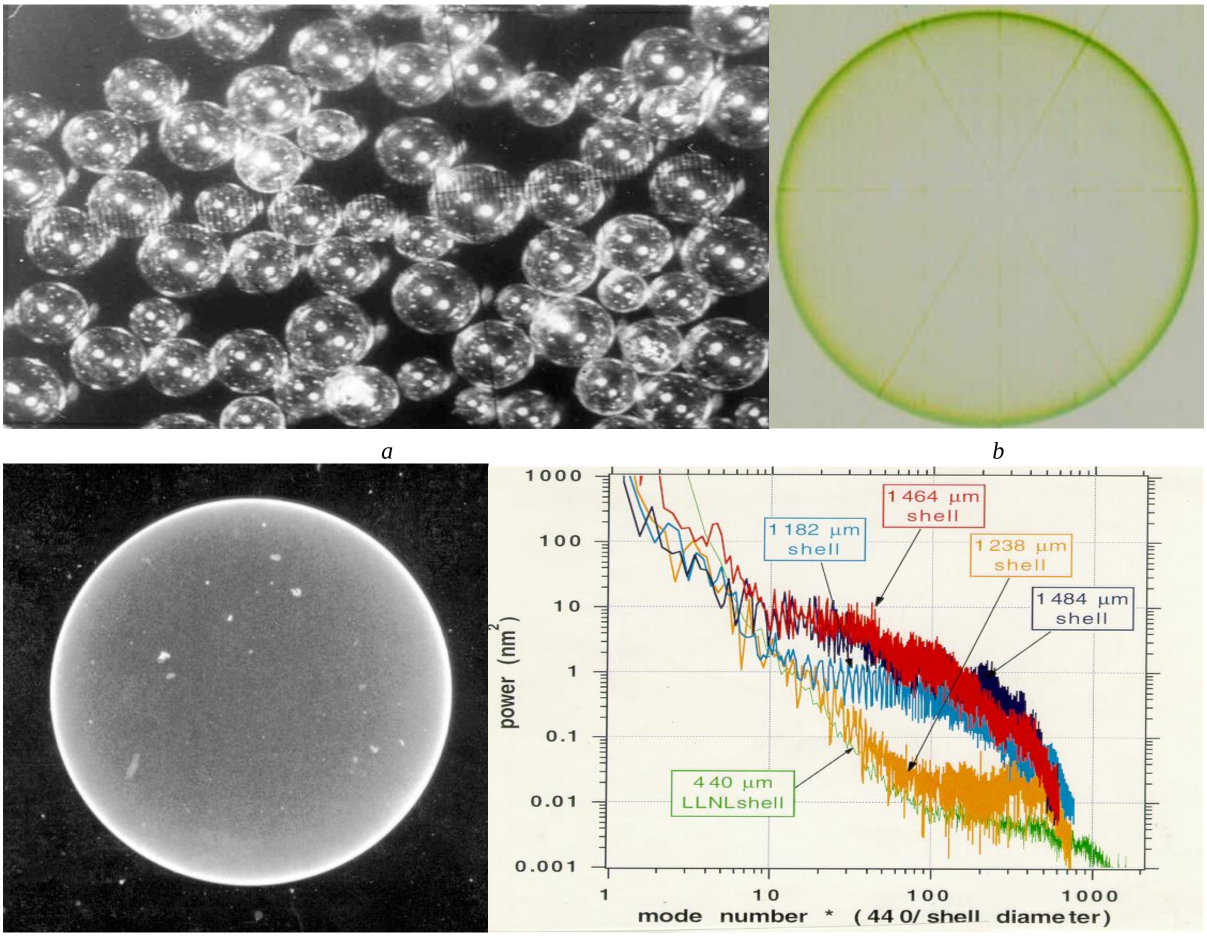

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FIG. 2. Polystyrene microshells produced in vertical furnace and in the ballistic furnace.

Fig. 2 presents a batch of thin hollow spherical shells (a) and quality characterization: (b) interferometer and (c) x-ray images proving shell's high symmetry: (d) surface analysis of selected shells showing their quality. Being strong and convenient for fuel containers, they gave way for another microencapsulation technique to fabricate the affordable shells of exactly the same sizes as illustrated on Fig. 3.

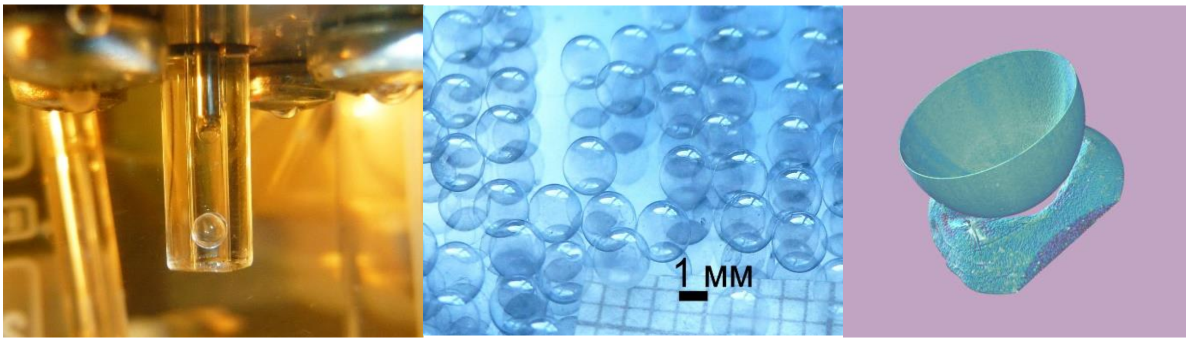

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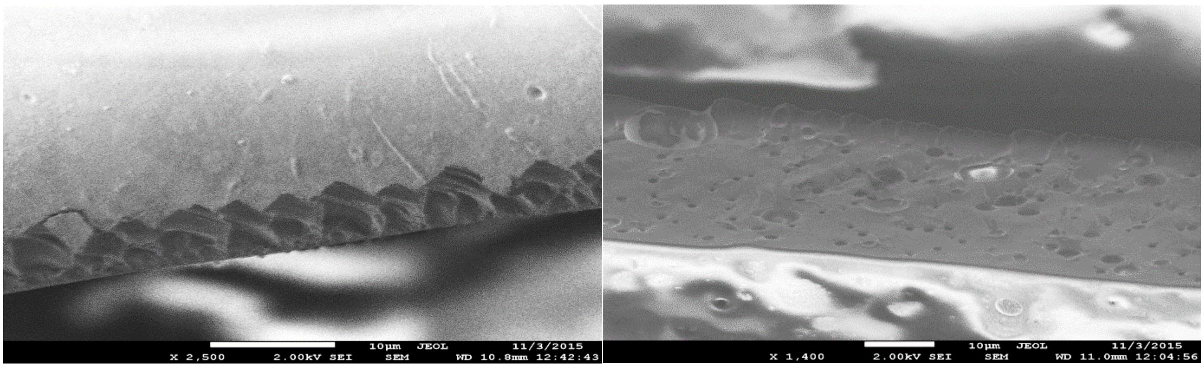
FIG. 3. LPI-made Drop generator, a batch of microshells by encapsulation and x-ray microtomography shell reconstruction.



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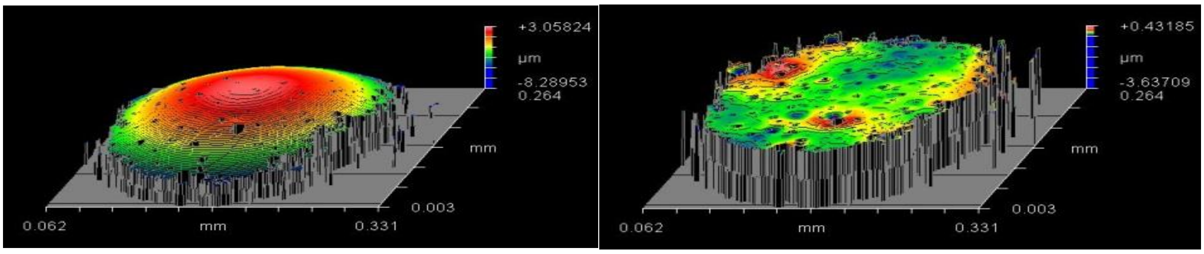

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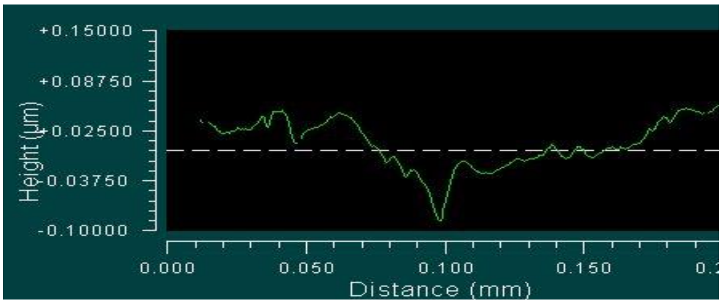

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FIG. 4. SEM of the shell cross-section and interferometer profilometric shell surface data.

Fig. 4 presents study of the shell's wall cross-sections and surface mapping proving the height of relief as low as 40 nm. This microcapsulation technology is now prevailing everywhere, though the strength is moderate.

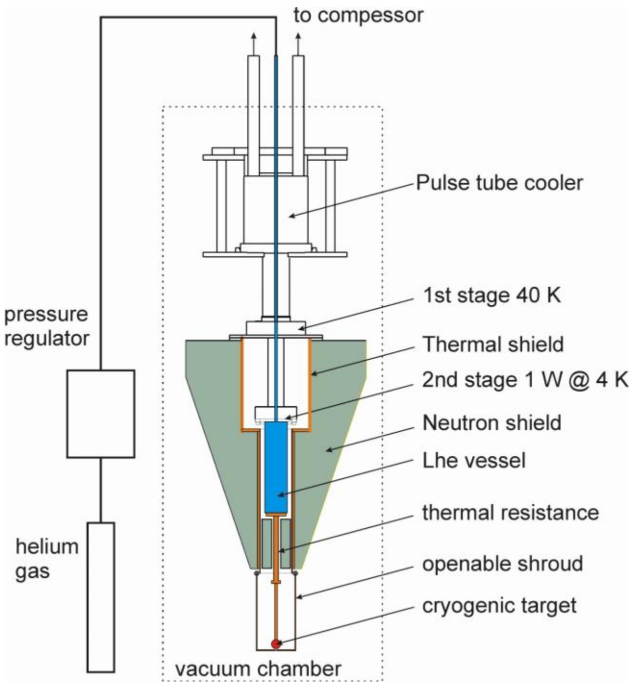


FIG. 5. Cryogenic setup for MJ class laser targets.

The final stage of the research-class fusion target's life cycle is the shot performance in the interaction chamber of the laser facility under laser irradiation being preliminary placed, DT-filled and stabilized inside the cryogenic setup for MJ-class targets. as on the scheme of Fig. 5. According to the Monte-Carlo simulation results the neutron shield reduces a flux of 14.1 MeV neutrons a 2 orders of magnitude but the total neutron flux only from 3 to 20 times due to slowed neutrons affects also. LPI designed, created the setup for actual facility, and is ready to make a series of setups (to be replaced after several full-energy shots). The shields are simulated and designed so that liquid He is not fully evaporated after shot and thermonuclear microexplosion of the DT-target [8].

3. LOW-DENSITY MATERIALS AND TARGETS

Low-density parts and targets cover the whole world of plasma experiments with high energy density in the matter. Some of the sound directions are thermonuclear research (neutron and no-neutron), secondary plasma sources of particles, fuel and plasma preheat prevention, stability of driver beam and implosion, energy conversion and transfer, non-linear optics and properties, strong applications and many others. Materials and samples for irradiation are permanently being designed, developed and characterized for irradiation with driver. Selected recent samples are exemplified below.

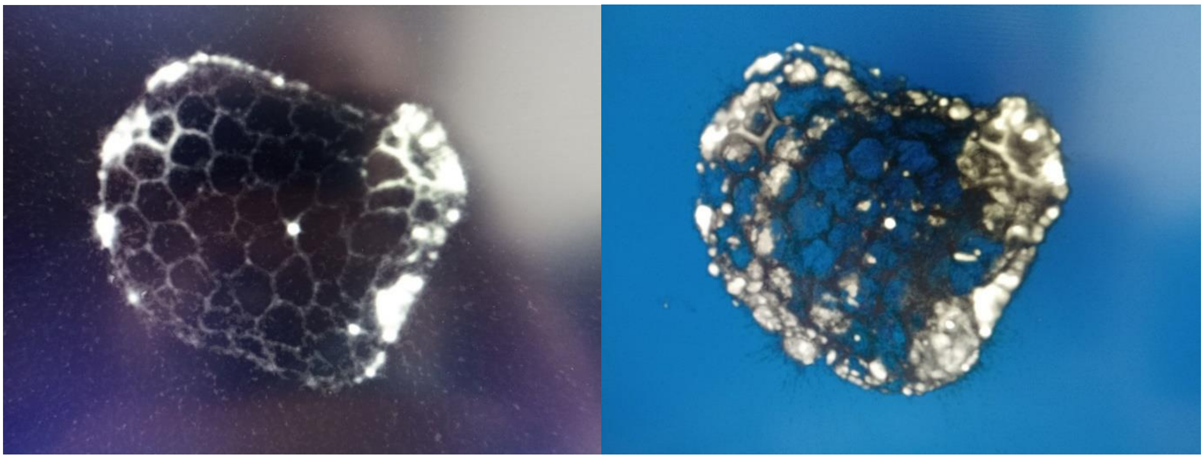


FIG. 6. Crosslinked chitozane with recovered silver in the polymer network. Pores are 200 micron large. Neoscan N80.

Fig. 6 presents the crosslinked biopolymer structure with huge regular pores required by physicists. X-ray microtomography by Neoscan N80 allowed the 3D reconstruction and demonstrated even Ag-distribution over volume network.

The next two Figures 7 and 8 show the nanostructured materials from microtomography on the basis of synchrotron PETRA III [6].

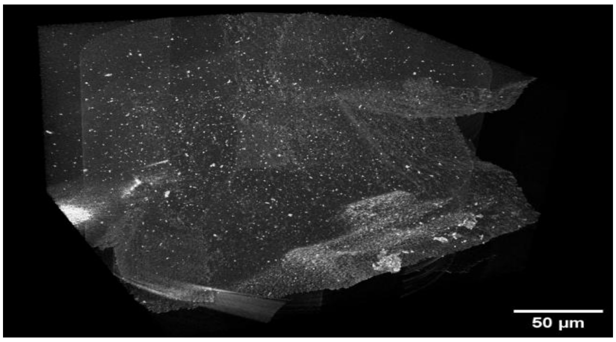
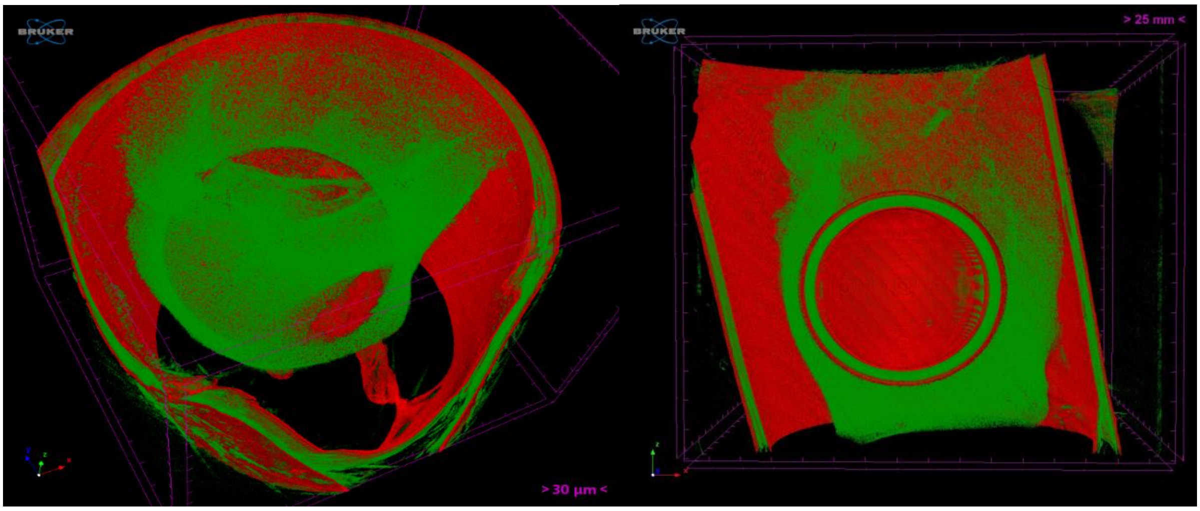


FIG. 7. Synchrotron microtomography of gold clusters in plastic aerogel of 10mg/cc.

Fig. 7 demonstrates the regular distribution of ^{0}Au formed from $^{+3}$Au inside the 3D network of synthesized aerogel.



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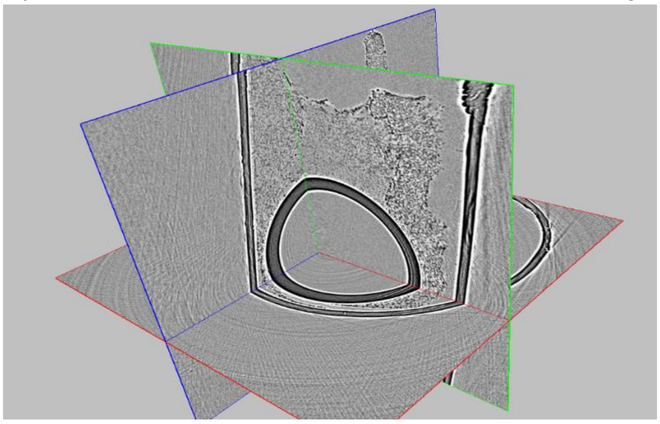

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FIG. 8. Microtomography by PETRA III.

Fig. 8 presents the complex object of fuel container SiO_2 thin shell of 400 micron dia fixed by low-density foam (colored green) inside 600 micron dia thin wall cylinder. Several cuts show details of the parts differing in Z and densities (10-2500 mg/cc) orders of magnitude.

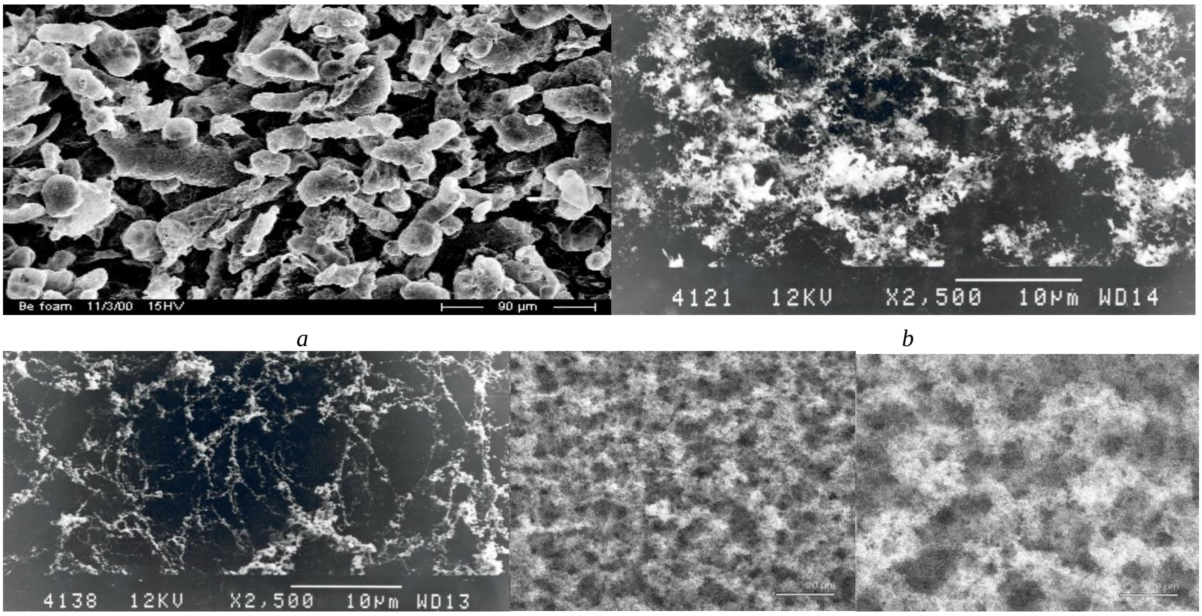

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FIG. 9. Metal foams for laser irradiation experiments.

Pure metal foams that participated in laser irradiation experiments are presented on Fig. 9. Here (a) Be-foam, (b) Cu-foam, (c) Au aerogel, (d) Sn aerogel on the scale of 20 and 10 micron.

4. SELECTED TARGETS' USE

The targets from the thermonuclear targets laboratory of LPI have been used in laser experiments in many laboratories involved in IFE research and plasma studies. All the materials and targets developed have been shortly used in the laser shots [9-17]. The spherical targets have been applied for thermonuclear research of DT-filled targets, as H_2-containers, and sacrifice shells for Be-targets. Additional efforts allowed to influence stability, turbulence and energy transfer effects for ICF-IFE applications. A lot of time has been devoted to create a low-density and microheterogeneous materials and targets. They proved effective for the direct and indirect LTF and in the interdisciplinary research. The invented targets demonstrated the active governing role to calm the negative effects of unstable plasma and to ensure the smooth operation of laser-plasma interaction in the desired mood. The use of low-density foams for controllable long-scale sub-critical, near critical and overcritical plasmas played decisive role in successful accelerated particles secondary beams from laser plasma and their applications.

5. CONCLUSION

Laser thermonuclear target is a universal instrument of scientific research: for ICF/IFE, for astromodelling, it also allows for almost arbitrary scaling for natural and artificial phenomena with high energy density in the matter.

Independent of energy prospects targets provide an interesting research opportunity with almost every laser already existing [2, 9, 10].

Material aspects are of special interest and difficulty for the researchers involved. The successful target gives rise to several scientific schools at once. It becomes necessary worldwide.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] BASOV, N.G., KROKHIN, O.N., Conditions for heating plasma by radiation from an optical generator, JETP **46** 1 (1964) 171-175.

[2] GYRDYMOV, M., CIKHARDT, J., TAVANA, P. et al., High-brightness betatron emission from the interaction of a sub picosecond laser pulse with pre-ionized low-density polymer foam for ICF research, Sci Reports **14** 1 (2024) 14785.

[3] CIKHARDT, J., GYRDYMOV, M., ZAHTER, S. et al., Characterization of bright betatron radiation generated by direct laser acceleration of electrons in plasma of near critical density, Matter Radiat. Extremes **9** 2 (2024) 027201.

[4] PASTUKHOV, A.V., Magnetic carbonaceous adsorbents derived from nanocomposites of hypercrosslinked polystyrenes, Mat. Today Comm. **39** (2024) 109043.

[5] PASTUKHOV, A.V., PERVAKOV, K.S., AKUNETS, A.A. et al., Fabrication of hollow poly(alpha-methylstyrene) shells for inertial confinement fusion targets, J. Appl. Polymer Sci. **139** 41 (2022) e52997.

[6] ARTYUKOV, I., BORISENKO, N., BURENKOV, G. et al., X-ray 3D Imaging of Low-Density Laser-Target Materials, Photonics **10** 8 (2023) 875.

[7] BORISENKO, N.G., AKUNETS, A.A., BORISENKO, L.A. et al., “Noizy” low-density targets that worked as bright emitters under laser illumination, JPCS **1692** 1 (2020) 012026.

[8] RYBAKOV, A.S., DEMIKHOV, E.I., KOSTROV, E.A. et al., Cryogenic setup for MJ class laser targets, Laser and Particle Beams **37** 1 (2019) 24-29.

[9] ZVORYKIN, V.D., BORISENKO, N.G., PERVAKOV, K.S. et al., Explosion and Dynamic Transparency of Low-Density Structured Polymeric Targets Irradiated by a Long-Pulse KrF Laser, Symmetry **15** 9 (2023) 1688.

[10] KAUR, C, CHAURASIA, S., BORISENKO, N.G. et al., Demonstration of gold plasma as bright x-ray source and slow ion emitters, Plasma Physics and Controlled Fusion **61** 8 (2019) 084001.

[11] KHALENKOV, A.M., BORISENKO, N.G., KONDRASHOV, V.N. et al., Experience of micro-heterogeneous target fabrication to study energy transport in plasma near critical density, Laser Part. Beams **24** 2 (2006) 283.

[12] DEPIERREUX, S., Pesme, D., Wrobel, R. et al., Experimental investigation of the interplay between optical and plasma smoothing induced on a laser megajoule beamline, Phys. Rev. Research **5** (2023) 043060.

[13] NICOLAÏ, Ph., OLAZABAL-LOUMÉ, M., FUJIOKA, S. et al., Experimental evidence of foam homogenization, Phys. Plasmas **19** 11 (2012) 113105.

[14] BORISENKO, L.A., BORISENKO, N.G., MIKHAILOV, Yu.A. et al., Time evolution of the distribution function for stochastically heated relativistic electrons in a laser field of picosecond duration, Quantum Electron. **47** 10 (2017) 915.

[15] ANDREEV, N.E., POPOV, V.S., ROSMEJ, O.N. et al., Efficiency improvement of the femtosecond laser source of superponderomotive electrons and X-ray radiation due to the use of near-critical density targets. Quantum Electronics **51** 11 (2021) 1019.

[16] GÜNTHER, M.M., ROSMEJ, O.N., TAVANA, P. et al., Forward-looking insights in laser-generated ultra-intense γ-ray and neutron sources for nuclear application and science, Nat. Commun. **13** (2022) 170.

[17] OREKHOV, A.S., AKUNETS, A.A., BORISENKO, L.A. et al., Modern trends in low-density materials for fusion, J. Phys.: Conf. Ser. **688** (2016) 012080.