Target fabrication technologies and noncontact delivery systems to develop a free-standing target factory operating in the repetition mode at the IFE relevant level

Irina Aleksandrova, Elena Koresheva, Eugeny Koshelev

P.N.Lebedev Physical Institute of Russian Academy of Sciences, Moscow, Russian Federation;
e-mail for contacts: koreshevaer@lebedev.ru

In the context of the inertial fusion energy (IFE) programme, the researches have embarked on a new stage which provides an opportunity to produce pure fusion ignition and burn by using power laser facilities and appropriate-scale targets. The ignition and high-gain target design requires free-standing cryogenic target with an isotropic hydrogen fuel on the inside surface of a spherical polymer shell. This is due to the fact that the progress in plasma implosion up to intensive fusion reactions lies in formation of a given fuel structure that must be isotropic for reaching fusion conditions. Our approach to this issue is based on the development of structure-sensitive methods resulting in the bulk homogenisation of fuel (hydrogen isotopes and their mixtures). Guided by general rules of crystallography, they also take into account the peculiarities inherent in the hydrogen isotopes as quantum molecular solids. These methods allow forming isotropic hydrogen layers by using high cooling (q = 1−50 K/s) combined with fuel doping (tritium, neon, argon) which results in creation of stable ultimate-disordered structures with a high defect density or isotropic medium (Figure1). As applied to cryogenic solid layering the conception of isotropic layer structure comprises a certain level of its dispersity providing the required quality of layer surface finish. This is nano-layering technology for which the grain size is scaled back into the nanometer range.

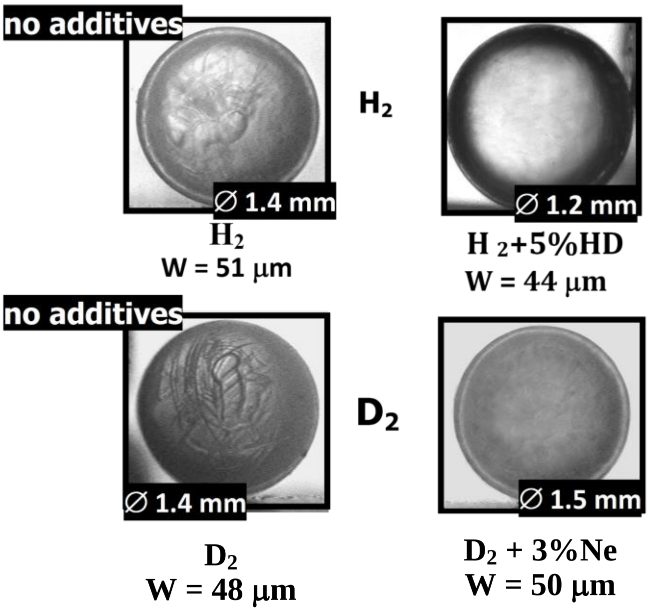


Figure 1. Isotropic ultrafine layers obtained by FST.

A unique feature of the experimental procedure is the following: a batch mode is applied and high cooling rates are maintained in the FST layering module (Figure 2a) inside free-rolling targets that has no analogue in the world's practice of IFE Cryogenics. This is precisely the condition which, in many respects, has defined a successful course of research. The obtained isotropic ultrafine layers have enhanced mechanical strength and thermal stability. For D-T mixture, tritium T_2 is considered as a high-melting additive with respect to D_2 and deuterium tritide. This is a significant factor for the processes: (1) layer quality survival during target delivery; and (2) regular propagation of the shock wave, the front of which has to be extremely smooth.

Thus, the technical approach based on the free-standing target (FST) layering method in line-moving spherical shells is a credible pathway to a reliable, consistent, and economical target supply. So fast fuel layering is a necessary condition in-line target production [1] due to the following reasons: tritium inventory minimization, the producing targets in the massive numbers, and obtaining fuel as isotropic ultrafine layers. Multiple target protection methods are also used in the FST approach [2]. Among them are outer protective cryogenic layers, metal coatings of different configurations and compositions, nano-coatings for specific applications, co-injection of a special protective cover ahead of the target, etc.

As fusion reactions must occur approximately ten times a second, then a free-standing target (FST) factory becomes an integral part of any IFE reactor. Additionally, the high-power laser experiments with repetition rates between 1 and 10 Hz require developing noncontact delivery systems for safe, stable and friction-free target transport at the laser focus. In this area our approach is the target transport with levitation. The operational principle is based on a quantum levitation effect of type-II high-temperature superconductors (HTSC) in the magnetic field [2].

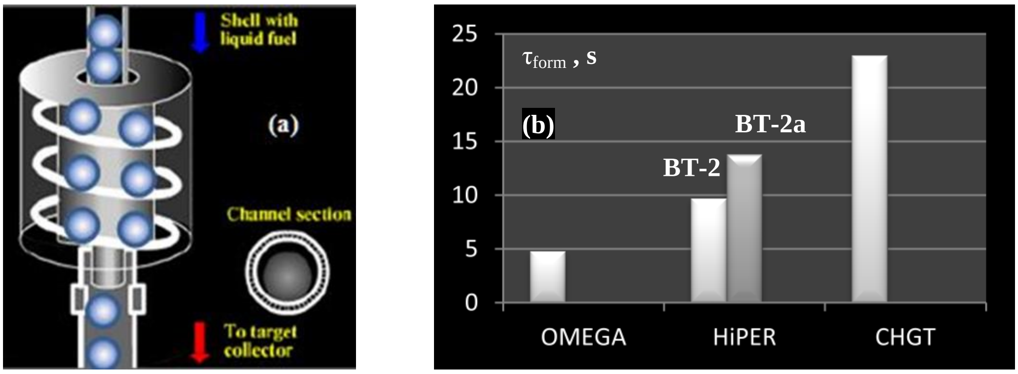
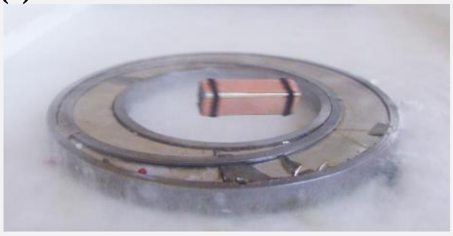


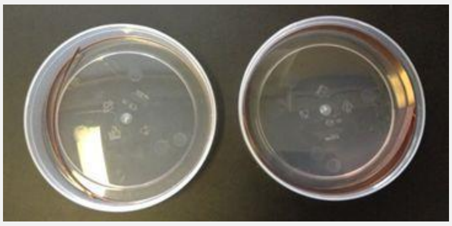
Figure 2. Schematic of the FST-layering module (a) for repeatable target fabrication and the FST layering time (b) for several direct-drive target designs calculated using the computational codes developed at the LPI.

Significant progress has been made in the development of the hybrid electromagnetic accelerator, which is a combination of the acceleration system (field coils generating the traveling magnetic waves) and the levitation system (permanent magnet guideway (PMG) with a magnetic rail or magnetic track).

(a) Linear PMG



(b) Circular PMG



(c) HTSC tapes used for manufacturing the sabot (see the above figures)

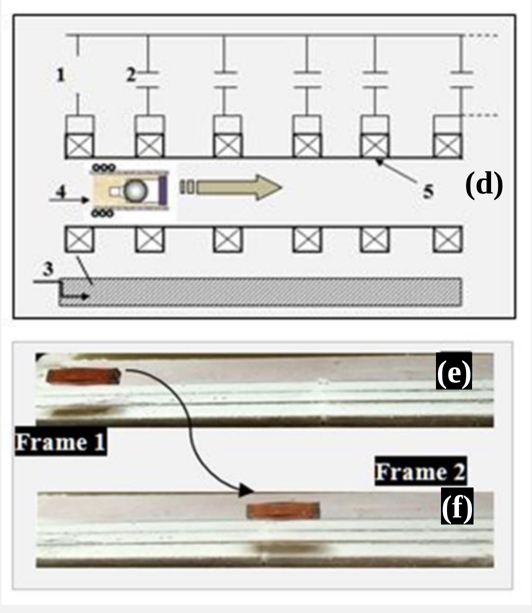


Figure 3. Target transport with levitation (a, b, c); (d) − linear accelerator scheme (1 − key to swith on the traveking electromagnetic wave, 2 – capacitor, 3 – permanent magnet guideway (PMG), 4 – HTSC-sabot with cryogenic target inside it, 5 – coil) and (e, f) − experimental results at T = 80 K on HTSC-sabot linear movement over the PMG under the action of electromagnetic pulse of one coil.

The obtained results have shown that the HTSCs can be successfully used to maintain a friction-free motion of the HTSC-sabots (target carriers) over the PMG, and also to provide a required stability of the levitation height over the whole acceleration length due to a pinning effect. Additionally, using the driving body from MgB_2 superconducting coils as a sabot component (critical current 5000 A at magnetic induction 0.25 T) allows reaching the injection velocities 200 m/s under 400g overload at 5-m-acceleration length. Recent results obtained at the LPI may help improving the actual design of HTSC-maglev linear accelerator be using a circular one. Significant reduction of the accelerator dimensions and the number of the field coils can be obtained in a circular accelerator, in which only several field coils are arranged in a circle in the PMG-system.

Our objective of the study was to develop conceptual designs of the FST factory including IFE target muss-manufacturing followed by their rep-rate delivery at the reactor chamber. In this report, the detailed modeling and proof-of-principle (POP) experiments are outlined and discussed.

Acknowledgements

The presented results have been obtained in the frame of the IAEA Research Contracts #11536, #13871, and #20344 as well as in the frame of the State Task of the government of Russian Federation.

References

1. Irina Aleksandrova, Eugeniy Koshelev, Elena Koresheva. *In-line target production for laser IFE.* Applied Sci. 2020, **10** (2), 686 (pp. 1-17)
2. I.V. Aleksandrov, E.R. Koresheva, E.L. Koshelev. *Multilevel system for protecting the cryogenic target during its delivery to the focus of high-power laser facility at high repetition rate*. Physics of Atomic Nuclei, 2019, **82** (7), 1060–1071