COMPARATIVE ANALYSIS OF THE ENERGETIC EFFICIENCY OF LASER THERMONUCLEAR TARGETS WITH SHELL-ABLATOR MADE OF BERYLLIUM MATERIALS.

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Abstract.
Energetic characteristics, including thermonuclear gain, of cryogenic laser fusion targets with beryllium and beryllium deuteride shell-ablators are found and compared basing on the results of numerical simulation by one-dimensional code “DIANA”. The targets correspond to the Nd-laser third harmonics pulse of 1-3 MJ energy.

It was proved that the gain of the targets with beryllium hydride ablator could be brought to a level of the targets with beryllium one due to the variations of the geometrical parameters of BeD₂ targets. It was shown that burning of the ablator, made from BeD₂ or BeDT, can introduce a significant contribution into thermonuclear yield for reactor-scale targets.

1. Introduction and problem statement.

Beryllium is one of the most appropriate materials to be used as a substance for the ablator of direct laser fusion target [1,2]. Its relatively high density (ρ=1.85 g/cm³) for small-charge element and low compressibility provides good hydrodynamic properties of ablator, which compresses thermonuclear fuel, at the high efficiency of laser radiation absorption and small energy losses due to plasma self-radiation. It was proposed in [3] to use deuterides and deuterides-tritides of light elements (BeD₂, BeDT and Li₂BeD₂T₂) as a material of ablator according to the following considerations. The density of such substance is considerably lower than that of the pure beryllium (for example, for BeD₂ − ρ=0,766 g/cm³) and closer to the DT-ice density (it is 0.215 g/cm³ for DT-ice). Therefore the target with such ablator are more stable relatively to hydrodynamic instability. Then, for reactor-scale targets with high gain of 100 and more (at the laser energy 5-10 MJ) burning of the ablator, which contains thermonuclear fuel, can produce a considerable contribution into thermonuclear yield.

In this paper the ablator properties of beryllium deuteride are studied and compared with beryllium ones. Directly irradiated targets with solid ablator and DT-ice layer, frozen on the
inner ablator surface are considered. The gain contributions from burning of the ablator containing thermonuclear fuel are found, also.

The hydrodynamic efficiency (ablator kinetic energy fraction of absorbed energy) of the shell with aspect ratio $\Delta_s/R_s/\Delta_s<100$ grows at the growth of parameter $\alpha = R_s \rho_c / \Delta_s \rho_s$ [4] ($\rho_c$ is the critical density; $R_s$, $\Delta_s$ and $\rho_s$ are the radius, thickness and density of ablator). The beryllium deuteride density is 2.4 times less beryllium density and at the assigned aspect ratio parameter $\alpha$ for beryllium deuteride ablator approximately 2.4 times higher in comparison with beryllium one. This fact determines the higher hydrodynamic efficiency of the beryllium deuteride shell as compared with the beryllium shell at the same aspect ratios. On the other hand the smaller initial density of beryllium hydride leads to the less efficiency of the ablator kinetic energy transfer to the thermonuclear fuel and decreasing of the fuel compression in the target with beryllium hydride ablator in comparison with the pure-beryllium ablator target.

One-dimensional simulations of enough hydrodynamically stable targets with low aspect ratio $\sim 20$ compressed to convergence ratio $C_R = R_o/R_f$ ($R_f$ is the target radius at the moment of maximal compression) not more than 16 were carried out by code “DIANA” [4]. Third harmonics Nd-laser radiation ($\lambda = 0.351 \mu m$) absorption of 60-70% is supposed. So, the absorbed energies $E_{ab} = 0.8 \pm 2.3$ MJ corresponds to the laser energy $E_L = 1 \pm 3$ MJ. Laser pulse was of triangle shape with a maximal power in the end of the pulse.

2. Comparison of the targets with ablator made of beryllium and deuteride beryllium.

Firstly the energetic efficiency of targets with shells of beryllium deuteride and beryllium for absorbed energy $E_{ab} = 800 \text{ kJ}$ and fixed fuel mass $M_{DT} = 600 \mu g$ was considered. In this case the target with $\Delta_s = 86$ for the beryllium shell should be close to an optimal one to obtain maximal thermonuclear gain ($G = E_{fu}/E_{ab}$, $E_{fu}$ is the fusion energy) [1]. The passing to smaller aspect ratio targets was realized by the simulations of 5 beryllium targets, one of them possessed $\Delta_s = 86$ and shell radius 2055 $\mu m$, and four others were of the 1717 $\mu m$ radius and insignificantly different thickness of the ablator at the aspect ratio 50-60. In this sequences also the target with the aspect ratio about 50 and same mass as one of the beryllium shells, but supplied with a beryllium deuteride ablator. The beryllium deuteride ablator possessed considerably greater radius of the shell equal to 2300 $\mu m$ if compared to the beryllium targets.

Calculations of the beryllium target with $\Delta_s = 86$ presented the gain $G = 84$, what matches well with the results of [1]. Decrease of the beryllium target aspect ratio to 50-60 leads to the diminution of the gain to the value $G = 64-68$. The gain of beryllium deuteride ablator-targets insignificantly decreases to the value 58.

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Energetic efficiency of the target with beryllium deuteride ablator.

Two last sequences of calculations were devoted to the targets with a beryllium deuteride ablator at the aspect ratio $A_x = 20$. For equal laser energy, target parameters for both groups differed only by the ratio of the ablator and fuel masses $M_a/M_{DT}$, which was 4.7 and 3.7. Parameters of the targets with $M_a/M_{DT} \approx 4.7$ and laser pulse $\tau_L$ are shown in the Table.

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<td>9</td>
<td>10</td>
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![Graph](image)

Fig.1. Dependencies of thermonuclear gain $G$ of the BeD$_2$-ablator targets on absorbed laser energy $E_{ab}$ for two sequences of targets: G-II – $M_a/M_{DT} = 4.6$ and G-III - $M_a/M_{DT} = 3.7$.

Gain dependencies on the absorbed laser energy varying from 0.8–2.3 MJ for both sequences of calculations are shown in Fig.1. Some other results of simulations are the following: hydrodynamics efficiency is 0.08 -0.09; the average density and temperature of the fuel in the moment of maximal compression are 90 -100 g/cm$^3$ and 2-4 keV; convergence ratio is 14-16.
As for the targets with beryllium shells, energetic efficiency of targets with the beryllium deuteride ablators becomes less with the decrease of the target aspect ratio. Degree of this decrease the greater, the less absorbed energy is. But at the energy $E_{ab} \approx 2$ MJ gain about 50 are attained for the low-aspect targets with the beryllium deuteride ablator.

4. Energy yield in the ablator made of BeDT and BeD$_2$.

Numerical simulation of the target with beryllium deuteride ablator at the absorbed laser energy $E_{ab} = 2.35$ MJ shows that the fusion energy $E_{\text{fus}}^{(a)} \approx 94$ kJ was released at the cost of the deuterium burning, what is approximately 0.07% of the total thermonuclear energy. The same target with BeDT ablator given: $G = 62.3$ and $E_{\text{fus}} \approx 146$ MJ; $E_{\text{fus}}^{(a)} \approx 3.7$ MJ, what is nearly 3% of the total thermonuclear yield, was realized in ablator. The calculations carried out under conditions, far from the optimal ones, show that at the laser energy level 2+4 MJ and $A_s = 20$ the burning in BeDT ablator increases the thermonuclear yield by 4+7%.

Very attractive ablator materials are mixed hydrides of lithium and beryllium (LiBeD$_3$), lithium and boron (LiBD$_4$), and even nitrogen and boron (NBD$_6$) which are more stable relatively tritium $\beta$-radiation or easier obey isotopic exchange, which permit to introduce tritium before laser irradiation [3]. The properties of such substances and beryllium deuteride are close, so our conclusions for beryllium deuteride ablator can be applied to these ablators.

5. Conclusion.

Energetic efficiency of the targets with a beryllium deuteride ablator can attain the energetic efficiency of the targets with a beryllium ablator by means of shell radius increasing. At the absorbed laser energy about 1.5+2 MJ low-aspect-ratio such targets, which better resist the development of the hydrodynamic instability, provides high gain of 50-60.

The first calculations with non-optimized low-aspect targets ($A_s = 20$) for the laser energy 2+4 MJ showed that the ablator containing the thermonuclear fuel increases yield by 4-7%. This result makes possible to project reactor targets with new properties of the ablator-fuel.

References