Direct drive targets for the megajoule facility UFL-2M

V B Rozanov, S Yu Gus'kov, G A Vergunova, N N Demchenko, R V Stepanov, I Ya Doskoch, R A Yakhin and N V Zmitrenko

1 P.N. Lebedev Physical Institute of RAS, 53 Leninskij Prospekt, Moscow 119991, Russia
2 M.V. Keldysh Institute of Applied Mathematics of RAS, 4 Miusskaya Sq., Moscow 125047, Russia

E-mail: rozanov@sci.lebedev.ru

Abstract. Development of direct drive target schemes for the megajoule facility is a topical problem of up-to-date inertial fusion physics. The choice of possible schemes and solutions depends essentially on the irradiation conditions. The installations both running (NIF) and under construction (LMJ) are destined to the \(3\omega\) irradiation in PDD (polar direct drive) configuration. The UFL-2M installation that is under construction is based on \(2\omega\) irradiation and a symmetrical scheme of direct drive target irradiation. Under these conditions possible schemes for direct drive targets demonstrating the ignition and the achievement of gain \(G=10\text{ to }20\) are considered in this report. At the same time, the possibilities are analyzed for the target compression and ignition with a reliability reserve at the conditions that can deviate from the standard ones, and if our understanding of the physics of the processes is not completely adequate to the physics of the real processes.

1. Introduction

In 2012 a decision has been made to build up a megajoule laser facility UFL-2M at the Russian Federal Nuclear Centre, All-Russian Research Institute of Experimental Physics, VNIIIEF [1]. One of the problems connected with the creation and further application of the facility concerns the development of direct drive targets, since the design of the targets strongly depends on the parameters of the facility. The parameters of the facility specified up to the present moment are listed in table 1.

| Table 1. Basic characteristics of the UFL-2M facility. |
|---------------------------------------------------------|
| **Main dimensions** | **Parameters of the irradiation system** | **Irradiation symmetry** |
| Size – 322.5×67 m\(^2\) | Number of laser beams – 192 |  |
| Laser bay length – 130 m | Laser beam cross-section – 400×400 mm\(^2\) |  |
| Laser bay height – 17.6 m | Laser operating wavelength \(\lambda_0 = 1053\) nm |  |
| Interaction chamber – \(\varnothing 10\) m | Target irradiation wavelength \(\lambda = 527\) nm |  |
| Chamber bay height – 34 m | Output laser energy on \(\lambda_0 = 4.6\) MJ |  |
| Clean rooms area – 16800 m\(^2\) | Laser energy on the target – 2.8 MJ |  |

An important difference in choosing the target design for UFL-2M, as compared to the available NIF and LMJ facilities, lies in the following: \(2\omega\) (\(\lambda=0.53\) \(\mu\)m) is taken as the working (main) wavelength and the system and geometry of irradiation are close to spherically symmetrical (in...
contrast to the NIF and LMJ, where the irradiation comes from the poles). The main feature of irradiation geometry in UFL-2M facility is also shown in table 1: the irradiation over the planes of the cube – each of the 6 planes contains 8 modules consisting of 4 beams. It is also of importance that for λ=0.53 μm one can expect within the target area higher energy of the laser pulses (about 2.8 MJ).

The problem of direct drive targets for megajoule pulses has been considered repeatedly, and, at first sight, seems to be easy. However, the experience gained from the National Ignition Campaign at the NIF laser shows that the problem of target design is a difficult one, and the choice of target parameters (size, mass, composition of the layers) needs serious approach. One of the solutions may be based on choosing the design, which would be low-sensitive to the irradiation and compression conditions, and our possible ignorance of some details of the processes taking place in the targets.

The present paper covers the results obtained from the analysis and 1D simulations of direct drive targets under the conditions of UFL-2M facility. The simulations have been made with the help of DIANA-code [2]. The choice of direct drive target scheme is based on the analysis of calculation results for direct drive targets under conditions of the NIF facility [3].

2. The choice of target parameters

Irradiation of the target by a smooth growing pulse from [3] (see figure 1) has been considered. It is assumed that 1.48 MJ is absorbed (for 2ω and 3ω) at the critical surface, and later we’ll define the laser pulse energy under which the absorbed energy is 1.48 MJ. In the table 2, the comparison of 2ω and 3ω irradiation regimes is made: target dynamics was simulated with account for the α-particle energy deposition and without it (i.e. a pure gasdynamic compression case). The results show that moderate decrease in ρR and η for 2ω as compared to 3ω (by 30-40%) leads to a significant drop in G.

![Figure 1. Baseline direct drive target design (a) and pulse (b).](image)

### Table 2
The comparison of 2ω and 3ω irradiation regimes. Here G is gain, η - hydrodynamic efficiency, E\textsubscript{DT} - energy of DT (gas + ice layers), and W\textsubscript{α}E\textsubscript{DT} product yields the energy of α-particles.

|                   | 2ω             | 3ω             | 2ω             | 3ω             |
|-------------------|----------------|----------------|----------------|----------------|
| α-particle energy deposition is switched on |                 |                |                |                |
| G                 | 2.73           | 38.7           | 7.22           | 1.59           |
| ρR                | 0.719 g/cm\(^2\) | 1.109 g/cm\(^2\) | 0.815 g/cm\(^2\) | 1.128 g/cm\(^2\) |
| η                 | 7.39%          | 9.54%          | 7.39%          | 9.54%          |
| E\textsubscript{DT} | 0.087 MJ       | 0.132 MJ       |                |                |

Additionally, the calculations have been performed for various descriptions of the EOS of CH and DT contained in targets: Thomas-Fermi (TF) approximation, empiric cold curve + equilibrium ionization, empiric cold curve + non-equilibrium ionization, empiric cold curve + TF approximation. For 2ω the sensitivity range is G=1.28±18.1, and G=27.7±44.2 for 3ω. The target with higher critical
density (shorter laser wavelength, $\lambda=0.35 \mu m$) is less sensitive to the lack of knowledge of EOS details.

The simulations have shown that the target given in figure 1a turns to be too heavy (CH + DT-ice mass is approximately 2670 $\mu g$) for the irradiation at the wavelength $\lambda=0.53 \mu m$. In the calculations with the target of the mass reduced to about 2150 $\mu g$ (the proportions given in figure 1a being conserved) one observes a maximum energy yield $G=18$, $G=10$ for $m=1850 \mu g$, and $G=13$ for $m=2400 \mu g$. The illustration of the optimized target compression and burn dynamics is given in figure 2. The dimensions of this modified baseline target are shown in figure 3. It is seen in figure 2a that thermonuclear burn grows from 10.9 to 11.1 ns, i.e. it starts before the moment of maximum compression and affects the collapse dynamics, while the fuel remains relatively "cold" during implosion, as it is indicated by the behaviour of the adiabat (figure 2b).

![Figure 2](image_url)

**Figure 2.** The behaviour of the modified baseline target: (a) - R-t diagrams of the DT layer bounds (dashed grey lines) and time dependence of the ion temperature $T_i$ (black lines); (b) – time dependence of the adiabat $\alpha$. The observation points are taken at mass coordinates of 20% (#1, solid black lines) and 90% (#2, dotted black lines) from the centre of the target.

![Figure 3](image_url)

**Figure 3.** The sketch of the modified baseline target.

![Figure 4](image_url)

**Figure 4.** The dependence of gain $G$ (solid line) and maximum fuel density $\rho$ (dotted line) on the DT layer initial aspect ratio.

3. The sensitivity of modified baseline target to different variations of experimental conditions

As far as different models of EOS are concerned, the range of $G$ variations turned to be moderate, $G=8\sim21$. The laser pulse variation being $E_l=1.38\sim1.58$ MJ (pulse duration, $\tau=10$ ns) $G=18\sim22$,
\(\rho R = 0.85 \div 0.96 \text{ g/cm}^2\), hydrodynamic efficiency \(\eta = 6.83 \div 6.4\%\). Under the change of pulse duration \(\tau_L = 9 \div 11\text{ ns}\) \((E_L = 1.48 \text{ MJ})\) the thermonuclear yield changes insignificantly \(G \sim 21 \div 18\), \(\rho R = 0.9\text{ g/cm}^2\), \(\eta = 7.2 \div 6\%\). The presence of an area (possibly areas) of the result \((G)\) weak sensitivity within the space of the EOS, \(E_L\) and \(\tau_L\) parameters is an interesting fact. The possibilities of utilization of this fact are to be still evaluated. The calculations for different aspect ratios of DT layer (at the given target mass) have revealed more sharp dependences; they are shown in figure 4. For the aspect ratio \(A_{\text{DT}} = 5.96\) the prediction gives \(G = 49.7\), and \(G = 13.9\) for \(A_{\text{DT}} = 5.06\). This decrease is due to the decrease in the DT-gas temperature and the worsening of ignition conditions. Under large values \(A_{\text{DT}} > 12\) the compression and the DT layer density decrease. A possible conclusion here may be as follows: when choosing the target design one should avoid the variants, which make use of maximal values of thermonuclear gain.

4. Conclusions
- For UFL-2M conditions different variants of 1D optimization give \(G = 4 \div 45\).
- In our opinion special attention should be paid to the search for the "rough" target design that would be low-sensitive to probable deviations from "standard" condition and possible drawback in the description of physical processes in ICF target.

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