Gas shell target for laser initiation of thermonuclear reactions

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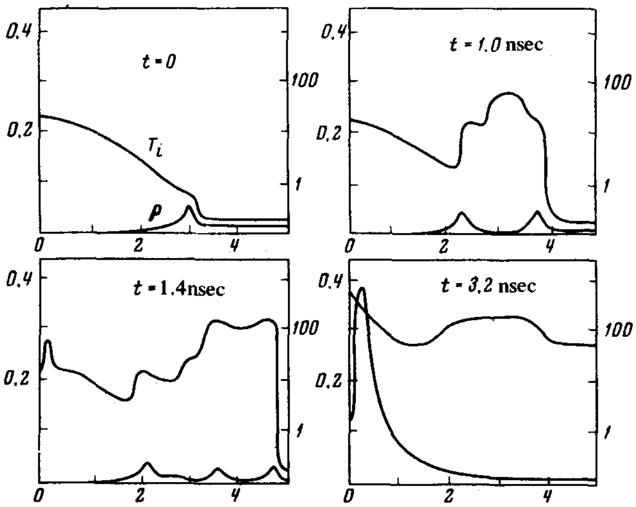
Principal attention has been paid in recent research on laser thermonuclear fusion to the study of different variants of shell targets. Numerous calculations show that besides having many useful properties, the customarily considered target types have also major shortcomings.[1-4] An appreciable fraction of the shell target is the inert matter of the shell, and this results in a lowered energy amplification. The thin shells, which are the most effective in this respect, exhibit strong instability upon compression, and this limits their practical application. In view of the stringent requirements with respect to the sphericity, mass production of complex shell targets is a difficult technical task. Finally, many complicated problems arise, as is well known, in the development of the reactor and of the system for the conversion of the reaction-product energy into electricity.[5] All these difficulties justify the search and investigation of new variants of laser targets. One of the interesting possibilities, from our point of view, is proposed in this article.

In contrast to the previously investigated model, the



Distribution of the density and of the ion temperature over the radius of the drop at various instants of time. The radius is in units of 10^{-2} cm, the density (left-hand scale) is in g/cm^3, and the temperature (right-hand scale) is in electron volts.

model proposed here "produces itself" during the course of the experiment. To this end, optical breakdown is produced in the deuterium and tritium gas mixture. The spherical shock wave propagating from the location of the breakdown forms a highly inhomogeneous density profile, namely, practically all the matter initially occupying the volume enclosed by the shock wave is on the periphery, forming a relative cold plasma shell with relative thickness about 10%. The density of the matter at the center is very small, and the energy density, in view of the high temperature, is commensurate with the energy density on the shock-wave front.[6] The shell produced in this manner serves as the target. It is irradiated symmetrically by a pulse or by a series of pulses. The ensuing shell collapse differs greatly from the usual picture[1–4] because of the presence of a gas atmosphere. We shall describe the collapse dynamics in greater detail later on.

The described approach eliminates the difficulties connected with the preparation of an ideally spherical target, its transport to the focus of the optical system, the shielding of the chamber walls against the neutron flux, the x-ray flux, and the charged-particle flux. Many other problems arise, however. First, the irradiation flux must be chosen such that the energy of the laser pulse be directed into the shell produced by the diverging shock wave without causing uncontrolled gas breakdown ahead of the shock-wave front. This condition obviously limits the maximum laser-radiation intensity; however, this limitation is not excessively stringent.[7,8] For picosecond pulses, the hydrogen breakdown at atmospheric pressure exceeds 10^{13} W/cm^2. Using targets of sufficiently large size and a suitably chosen pulse waveform (or train of picosecond pulses) it is possible, as shown by preliminary numerical calculations, to obtain a thermonuclear yield equal to the laser-energy input at a level on the order of several kilojoules. However, calculation of a regime with large gains calls for a more substantiated analysis of the problem of gas breakdown ahead of the shock-wave front. In the calculations we started from estimates and experimental data on the breakdown of gases by a single pulse under conditions of sharp focusing, which does not correspond fully to the situation in question. It is difficult to take into account in the numerical calculations all the factors that influence the breakdown. Under this condition, an experimental investigation of shock waves converging in a gas and produced by a series of laser pulses becomes particularly important. Bearing experiments of this kind in mind, we have carried out detailed numerical calculations of the process of implosion in a DT mixture for laser energies on the order of 100 J. We describe below some of the results of such calculations.

We used a one-dimensional two-temperature hydrodynamic model with allowance for the absorption of the laser radiation, the classical electron thermal conductivity, and the thermonuclear reactions. The equations were solved by a variant of Harlow's method,[9] which is convenient at compression degrees on the order of a hundred or less, as it typical of the variants under consideration. The figure shows the profiles of the density and of the electron and ion temperatures for a typical calculation variant. The sequence of events begins with gas breakdown in a small volume near the point $r = 0$. The energy of the breakdown pulse is 0.2 J. The initial density corresponds to a DT mixture pressure 70 atm. When the shock wave reaches a radius 0.03 cm, a second laser pulse is turned on, with an energy 12.5 J and a duration 300 psec. The shell breaks up into two layers. The internal one begins to move towards the center, and the outer one continues to expand and to enclose an additional mass. A third pulse of energy 100 J and of the same duration is absorbed by this expanding layer, as a result of which one more shell is formed and converges towards the center. The time when the third pulse (and if necessary also more successive pulses) is turned on is chosen such that the collision of the shells takes place near the center. A simplified gasdynamic calculation gives for the energies of the successive pulses the expression

$$E_i \approx E_0 (1 - {}^{t_i}/_{t_0})^{-2} (1 + {}^{t_i}/_{t_0})^4 \quad ,$$

where t_i is the time when the i-th pulse is turned on and t_0 is the time during which the first converging shock wave reaches the center. In the described variant, the thermonuclear yield is naturally small. The total number of neutrons is approximately 10^9. By slightly changing the durations of the pulses and of the switching instants it is possible to increase the neutron yield by several times. Much better results are obtained when the pulse is programmed.

Interesting additional possibilities are uncovered by addition of other gases to optimize the absorption, to vary the density, or to raise the breakdown threshold. The presence in the considered targets of a relatively smooth density profile gives grounds for hoping for sufficient stability of the compression process.

The calculations show that the proposed target is hardly inferior in its main parameters to the simple shell targets of solid hydrogen, and at the same time offers a number of substantial advantages.

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