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AND A COMPARISON WITH ULTRA THIN SHELLS

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September 20, 1977

MASTER

Presented at the 19th Meeting of the American Physical Society/Division of Plasma Physics, Atlanta, Georgia, November 6-11, 1977.

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LOW ASPECT RATIO DOUBLE SHELL TARGETS FOR HIGH DENSITY AND
HIGH GAIN AND A COMPARISON WITH ULTRA THIN SHELS*

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ABSTRACT

Double shell targets may have decisive advantages over single shells for achieving a number of goals in the laser fusion program. With 0.2 μ light, such designs achieve 500-1000 times liquid density at 2 kJ absorbed; 10% or more of breakeven at 15 kJ absorbed, and gains of 10 or more at 200 kJ absorbed. These targets are relatively insensitive to preheat, laser pulse shape, and hydrodynamic instability. A double shell in which the outer pusher is fuel may achieve a gain of 1000 for lasers in the 1-10 megajoule size. Ultra thin targets have only about a factor of two reduction in power over shells with aspect ratios of 2-4 while requiring about the same input energy and achieving about the same gain. Their extreme sensitivity to preheat, symmetry, and hydrodynamic instability makes them unattractive for targets in advanced lasers systems.

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*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48.

Double shell type targets,^{1,2,3} for laser fusion may have decisive advantages over single shell type designs. A simple double shell target is shown schematically in Figure 1. The outer shell is composed of a low-Z ablator layer and a pusher-preheat shield layer. The material between shells is gas or a low density foam. The inner shell is made of high-Z, high density gas or solid. The advantages of this target over a single shell are:

1) Relative insensitivity to preheat: Because of the high density, high-Z layer surrounding the fuel at a small radius, high energy x-rays and electrons are kept away from the fuel which remains on a good adiabat. A high-Z layer of comparable thickness and shielding effectiveness at the radius of the outer shell would typically have a mass 10-30 times that of the inner shell and could not reach the required implosion velocity.

2) Insensitivity to laser pulse shaping: Pulse shaping is provided largely by the gas or foam between shells and the high density pusher of the inner shell.

3) Low intensity-low velocity implosion: Because of velocity multiplication when the more massive outer shell collides with the inner shell, the velocities required for the outer shell are reduced.

There are several unique features of the design in Fig. 1:

1) Low density outer pusher density matched to the low-Z ablator. This is necessary to control fluid instability at the pusher ablator interface and allows the possibility of a large volume, low power stable implosion of the outer shell.

2) Use of preheat to produce a shallow density gradient in the outer shell to further reduce sensitivity to fluid instability.

3) Low density gas fill between shells. This minimizes mass between the shells and allows the large volume low density outer shell to act as an effective pusher on the inner shell.

4) Use of thermal electron conduction smoothing to reduce asymmetry and sensitivity to fluid instability of the inner shell. This occurs because of preheat and also when the outer shell compresses the gas between shells.

Relative to single shell targets, double shell targets appear more complicated to fabricate. However, elimination of the requirement of a solid DT layer may more than compensate for the increased number of parts and the levitation requirement in designs with gas between shells.

Double shells have a relatively larger convergence ratio, defined as the ratio of initial radius of the outer shell to final radius of the compressed fuel. Typical designs have convergence ratios of close to 100 and hence require uniformity in implosion pressures of better than 1%. This puts a premium on designs with a high degree of symmetry and on understanding the details of energy transport. One way to achieve such symmetry is to use a long wavelength laser early in the implosion. This long wavelength light would be absorbed in a low density corona, produced by exploding a low mass shell outside of the main target.

By controlling the amount of preheat, the outer shell of the double shell design can be made quite insensitive to fluid instability. The

inner shell is more sensitive to fluid instability and in high performance designs may have to have 50-100 Å surface finishes. This shell can be made somewhat less sensitive to instability by coating with lower density materials to produce a density gradient, and by allowing some preheat to decompress the outer portion before collision with the exterior shell.

Such designs using 0.2 μ light achieve the following calculated performance levels for the listed absorbed energy:

- 1) 500-1000 times liquid density at 2 kJ
- 2) 10% or more of breakeven at 15 kJ
- 3) Gains of > 10 at 200 kJ.

With 1 μ light, the absorption efficiency is lower and preheat is more severe. These effects result in reduced performance although designs have not yet been optimized. For example, 500-1000 times liquid density might require a SHIVA sized laser (15 kJ) instead of an ARGUS sized laser (2 kJ).

Double shell designs which have all of the fuel inside the inner shell have a limitation of 30-50 on the possible gain. This occurs because the massive high-Z pusher must be accelerated to velocities high enough to achieve ignition of the DT fuel, yet the pusher itself does not burn. Although required implosion velocities are typically reduced by about a factor of 2 by the high-Z pusher, and burn efficiency is increased by the tamping effect, the factor of 20-100 in pusher mass results in about an order of magnitude reduction in peak gain for targets in the 1-10 megajoule size. However, it may be possible to combine the velocity

multiplication effect of a double shell target with the large fuel mass of a single shell to achieve very high gain. This would be achieved by making most of the pusher of the outer shell out of DT as shown schematically in Figure 2. The outer shell would still have a low-Z ablator and a preheat shield, but for large sizes, the preheat shield can be thin enough that most of the imploded mass can be DT. By appropriate pulse shaping, the DT can act as a pusher for the inner shell. For targets with a fuel mass of about a milligram, velocities of $1.0 - 1.5 \times 10^7$ cm/sec are sufficient, in Fermi degenerate DT, to achieve the density required for efficient burn. Yet, implosion velocities of $2.5 - 3.0 \times 10^7$ are typically required to get ignition temperatures as well as sufficient density. Ignition of only a small fraction of the total fuel mass (about 1% at these sizes) is sufficient to get a propagating burn so one would like to accelerate only that fraction of the mass to 2.5×10^7 cm/sec and accelerate the rest of the mass to much lower velocities. Because of velocity multiplication between shells, a double shell target allows this possibility. Calculations to demonstrate the feasibility of such a scheme are currently underway. If successful, the outer fuel would be imploded at one half the currently required velocity, requiring one fourth of the energy, giving an increase in the gain of a factor of four. Gains of greater than 1000 might be possible. Such gains require high absorption efficiency and 10-15% hydrodynamic coupling efficiency to the fuel. They will probably require a 0.2μ wavelength laser although work is continuing on designs which could use longer wavelengths.

Claims for very high gains have been made in the recent Russian literature. The paper by Afanas'ev et al.,⁴ claims that gains of 80 are possible at 10 kJ and that gains of 1000 are possible at 10^6 joules using ultra-thin shells. The 10 kJ target could be tested on SHIVA. A number of LASNEX calculations have been done on the design shown in Figure 3 to compare with the Russian design claims at 10 kJ. The aspect ratio of the beryllium ablator is 55. Because the Russian designs were sketchy, the design in Figure 3 probably does not match them in detail. But a comparison can still be useful because several conclusions of the LASNEX results do not depend on target detail. Table 1 gives a comparison of LASNEX 1-D calculations, using both a 3-T and multigroup electron transport model, with Russian design claims. In 3-T, the power required in LASNEX calculations is 30 TW instead of 5 TW and the input energy is 40 kJ instead of 10 kJ. The discrepancies could probably be somewhat reduced by design changes, but the important column is that using multigroup electron transport and an electron spectrum derived from current experiments. When the effect of energetic electrons is included, this target is seen to act essentially like an exploding pusher and achieve about 3×10^{-3} of breakeven.

Even then, the calculations are optimistic because they assume complete absorption of the incident laser light. Because of the relatively high intensity of nearly 10^{15} W/cm², inverse bremsstrahlung is relatively inefficient and actual absorption might only be 20-30%.

Even in 3-T, the performance of these shells is not radically different from that of much thicker shells which are less sensitive to preheat and two dimensional effects. For example, a 2-1 DT shell has about the same gain and energy requirements as these thin shells and requires only a factor of two more power.

Larger thin shelled targets might be able to survive the preheat but then must survive the symmetry and fluid instability requirements.

Figure 4 shows the result of a LASNEX fluid instability calculation on a thin beryllium shell, 100 μ thick at 1 cm radius with an initial perturbation amplitude of 100 $\text{\AA}$. The calculation was for a spherical harmonic with $\ell = 1000$, zoned 16 zones per wavelength. As seen, the shell is badly broken up after moving only 300 μ . A calculation at 24 zones per wavelength looked the same. Two questions that can be asked about these perturbation calculations are:

- 1) Does LASNEX calculate the growth rates correctly? This question cannot be definitively answered until experiments are done because of the complicated physics involved. However, we have made extensive studies to check for zoning and amplitude independence of growth rates and have checked the code results against analytical theory for acceleration of incompressible matter in both planar and spherical geometry.

- 2) What stabilization techniques are available for suppressing the growth of perturbations?

Table 2 gives a list of potential methods for reducing target sensitivity to hydrodynamic instability. Density gradient stabilization

has proved to be uniformly effective for reducing the classical amplitude by about a factor of 100 for implosions driven by laser, electron beams, and ion beams. This technique requires a spread in the energy deposition near the critical surface to produce a shallow density gradient. For lasers, this is achieved by making use of the properties of superthermal electrons generated by plasma collective processes. Impulsive acceleration uses a series of shocks instead of a continuous pulse to accelerate a shell. If the ratio of shock pressures between succeeding shocks is less than about a factor of 3, the increase in entropy is small and perturbation amplitudes are reduced about a factor of 10. These are the only techniques that we have found to be useful for low intensity, low entropy laser driven implosions. A number of other techniques have been proposed. Some have been tested calculationally and others remain to be tried. Firepolishing, proposed by Bodner and Leith,^{5,6} does not occur for laser driven implosions. Rapid ablation, in which the ablation front moves through the shell at a velocity $V_A > \frac{Y}{K}$, also proposed by Bodner, cannot be achieved for low entropy implosions. Boris⁷ has proposed dynamic stabilization, similar to that which stabilizes an inverted pendulum, but no calculations showing its feasibility have appeared. Material strength is another possibility. If ignition conditions can be achieved with implosion pressures of 1 megabar or less, materials such as beryllium with a large shear strength could stabilize short wavelength modes.

A final possibility is the use of initially decompressed or very low density material. The material in a thin shell would be preheated and

decompressed prior to implosion by use of long range ions, or electrons. This does not necessarily reduce the growth rate of any perturbations, but it gives a much thicker shell for a given mass of material and hence increases the wavelength of the most serious modes. Since growth rate is inversely proportional to the square root of the wavelength, this technique effectively reduces the growth rate of the most serious modes. Although the possibility of imploding very thin shells cannot be completely ruled out, it would seem very risky to base the future of a program on their success. This is particularly true since they show relatively little improvement in performance over much thicker shells.

SUMMARY

Double shell targets may have decisive advantages over single shells for achieving a number of goals in the laser fusion program. With 0.2 μ light, such designs achieve 500-1000 times liquid density at 2 kJ absorbed, 10% or more of breakeven at 15 kJ absorbed and gains of 10 or more at 200 kJ absorbed. These targets are relatively insensitive to preheat, laser pulse shape, and hydrodynamic instability. A double shell in which the outer pusher is fuel may achieve a gain of 1000 for lasers in the 1-10 megajoule size. Ultra thin targets have only about a factor of two reduction in power over shells with aspect ratios of 2-4 while requiring about the same input energy and achieving about the same gain. Their extreme sensitivity to preheat, symmetry, and hydrodynamic instability makes them unattractive for targets in advanced laser systems.

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**COMPARISON OF RUSSIAN CLAIMS AND LASNEX CALCULATIONS
FOR THIN SHELL TARGETS AT THE SHIVA SIZE**

	Russian claims	Lasnex 3-T	Lasnex multigroup electrons
Input energy	10 kJ	40 kJ	25 kJ
Yield	800 kJ	400 kJ	100 J
Gain	80	10	0.004
Coupling efficiency (%)	8.5	5.8	5.9
Power	5 TW	30 TW	30 TW
Average fuel density	1160	1070	1.5

50-05-1277-3125

TABLE 1

POTENTIAL METHODS FOR REDUCING SENSITIVITY TO HYDRODYNAMIC INSTABILITY

Method	Requirements	Growth reduction
Density gradient	$L \gtrsim 1/k$ ⇒ thick shells	100
Impulsive acceleration	Acceleration time much less than implosion time	10
Firepolishing	Not observed for laser driven implosions	
Rapid ablation	Not applicable to low entropy implosions	
Dynamic stabilization	Achievable? Low entropy?	
Strength of materials	Effective?	
Initial decompression of ablator to reduce shell aspect ratio	Source of preheat appropriately timed before main pulse	Shifts most severe modes to longer slower growing modes ~100

7/77

TABLE 2

CANONICAL DOUBLE SHELL TARGET

1/77

Figure 1

HIGH GAIN DOUBLE SHELL TARGET WITH SPLIT FUEL MASS

7/77

Figure 2

THIN SHELL DESIGN AT THE SHIVA SIZE

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Figure 3

**IMPLOSION OF A 100 μm THICK, 1 cm RADIUS
BERYLLIUM SHELL WITH A 200 TW LASER**

Figure 4