Observation of the compression of laser-bombarded two-shell targets

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The first experiments have been carried out on the compression of two-shell targets with an ablative acceleration of the outer shell. The energy transfer from the outer shell to the inner shell has been measured, and the volume compression of the inner shell has been found to be $\delta \simeq 150$.

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One of the primary experimental tasks in the laser fusion program[1] is to simulate in existing devices (with a laser energy $E_{\text{las}} \simeq 10^2$–$10^4$ J) typical reactor-plasma conditions, i.e., the conditions which will prevail for targets and lasers at the megajoule level. One possibility here is to use two-shell targets,[2] i.e., targets consisting of two concentric shells. In this approach, the compression velocity of the inner shell can be increased in a collision with the heavier outer shell to values $u_2 > 200$ km/s (which are required to heat the compressed fuel to fusion temperatures), while a high plasma density is maintained.[3] The heating and compression of multishell targets have received absolutely no experimental study, however. The most important question here is the stability of the compression in a real, spherically asymmetric (a deviation from spherical symmetry is necessary to provide mechanical support for the inner shell). Other questions of fundamental importance are the efficiency at which the energy of the outer shell is converted into kinetic energy of the inner shell and the possible energy "loss" in the "inelastic" collision of the shells.

The present experiments were carried out in the Kal'mar nine-beam laser device[4] (wavelength $\lambda_0 \simeq 1.06\ \mu$m, energy $E_{\text{las}} \simeq 200$ J, pulse length $\tau_{\text{pulse}} \simeq 1$ ns, power density $q_0 \lesssim 2 \times 10^{14}$ W/cm^2). The target (Fig. 1, a and b) was fabricated in the following manner: A glass (SiO_2) inner shell, with a diameter $2R_2 \simeq 100\ \mu$m and a wall thickness $\Delta_2 \simeq 0.8$–$2.0\ \mu$m, was placed between two thin films ($\sim 5 \times 10^{-6}$ cm) of cellulose nitrate. A polystyrene $[(C_8H_8)_n]$ outer shell, with a diameter $2R_1 \simeq 150$–$300\ \mu$m, was cut into two hemispheres with the beam from a nitrogen laser; these hemispheres were cemented to the film in a position concentric with the inner shell. The quality of the resulting target was monitored by optical methods and x-ray microradiography.[5] The thickness of the outer shell was chosen such that at least half the mass of this shell remained unevaporated at the time at which the shells collided.

The compression of the target and the characteristics of the resulting plasma were studied with a diagnostic complex,[6] including x-ray, optical, particle-beam, and other pieces of diagnostic equipment.

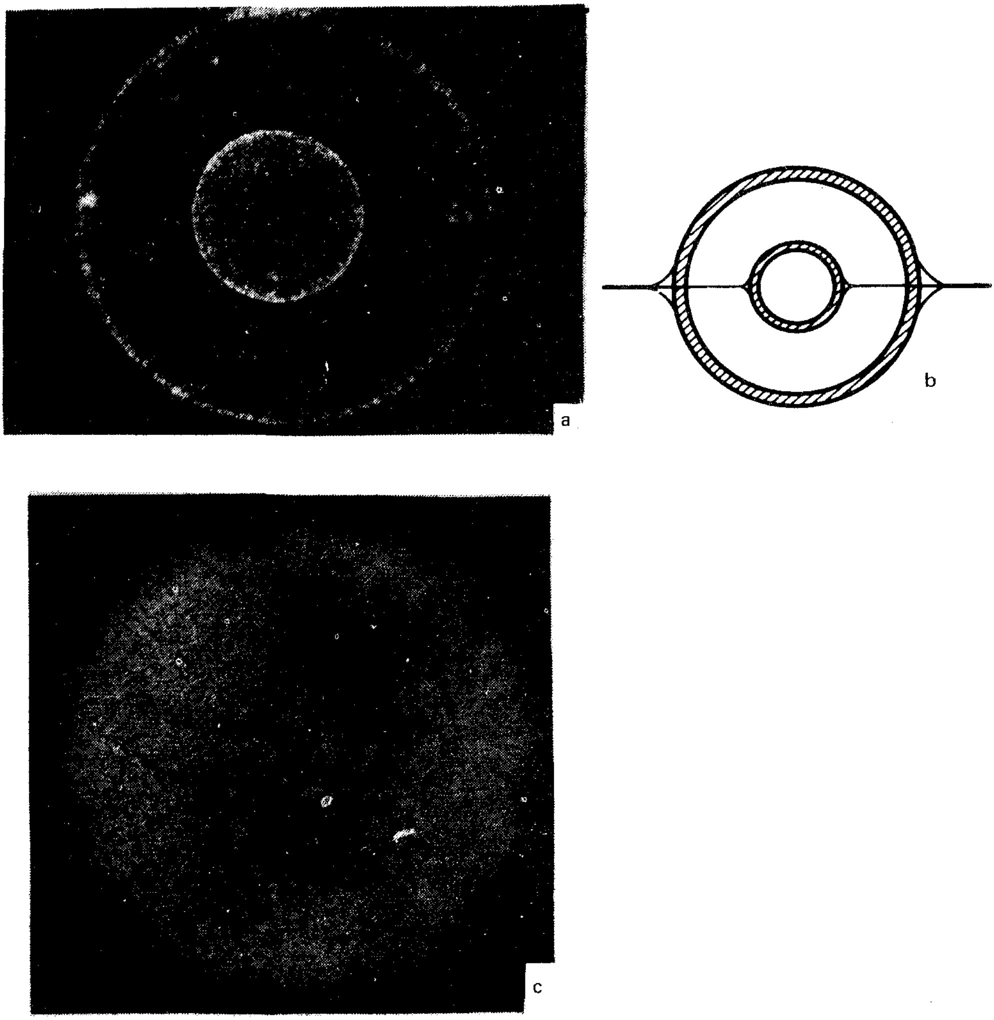

FIG. 1. a—Photograph of a two-shell target; b—arrangement for supporting the target; c—pinhole photograph. The $(C_8H_8)_n$ outer shell has a diameter $2R_1 \simeq 276\ \mu m$, and the SiO_2 inner shell has a diameter $2R_2 \simeq 97\ \mu m$.

The energy balance was studied with a system of various types of calorimeters[6] in a vacuum chamber. The energy deposition was found to be slightly higher (by a factor of about 1.5) than in the case of a simple polystyrene shell[7]: The loss due to refraction of the laser beam in the plasma corona was reduced, and the fraction of radiant energy transmitted through the target was reduced to zero. The explanation for this result evidently lies in the presence of the target holder.

Figure 1c shows a typical x-ray pinhole photograph of the plasma of the two-shell target. We can clearly see two concentric bright regions corresponding to the emission of the outer and inner shells. There is an extremely obvious increase in the emission of the outer shell in the equatorial part of the target, corresponding to the position of the film support. This increased emission indicates a significant increase in the absorption in this region, in agreement with the calorimetric measurements of the energy balance. The emission from the inner shell in experiments with targets of this design is nevertheless quite uniform, indicating that the energy distribution over the surface of the inner shell is more uniform than that on the outer shell. In a few of the experiments the pinhole photographs revealed a third inner ring, evidence of a compression of the second shell. The volume compression of the second shell was relatively low, $\delta \lesssim 150$, apparently because of both the asymmetric design of the target and the rather low quality of the manually assembled targets.

Spatially resolved measurements of the plasma electron temperature were taken with multichannel pinhole cameras with various filters which passed photons with $h\nu \gtrsim 1$ keV; these measurements revealed $T_e \simeq 500$ eV for the outer shell (as in the case of simple polystyrene shells) and $T_e \simeq 300$ keV for the inner shell. The x-ray emission continuum at $h\nu \gtrsim 10$ keV corresponds well to experiments with simple polystyrene targets in terms of both shape and the number of x rays.

Measurements with a Thomson mass spectrometer[8,9] showed that the expanding plasma contains ions of hydrogen (H^+) and carbon (C^+–C^{+6}), which are constituents of the outer shell. The velocity of these ions reaches $v_{\max} \simeq 10^8$ cm/s. The energy distributions found for these ions from the mass spectra can be used to determine the mass removed from the outer shell and to determine the kinetic energy of the outer shell at the time of the collision with the inner shell.

In certain shots with an outer shell not thicker than 2 μm we observed ions of silicon and oxygen with a charge up to $z = 6$ and a velocity reaching $v_{\max} \simeq 8 \times 10^7$ cm/s. The distributions of the silicon and oxygen ions have two peaks, at ~ 10 keV and ~ 50–70 keV. The mass spectra were calibrated through the use of the data from the ion collectors and from an electrostatic analyzer. It turned out that the average charge of the ions of the inner shell was roughly half that in the experiments with single-shell glass targets over the entire velocity range, $v \sim (3$–$8) \times 10^7$ cm/s. The plasma electron temperature inferred from the positions of the peaks in the mass distribution if $T_e \simeq 0.5$–0.6 keV for the carbon ions and $T_e \simeq 0.3$ keV for the silicon and oxygen ions, in good agreement with the x-ray measurments.

We studied the dynamics of the compression of the two-shell targets by monitoring the motion over space and time of the plasma region emitting at the second harmonic of the laser frequency; the second harmonic is generated in the region with the critical density,[10] $n_c \simeq 10^{21}$ cm^{-3}. Figure 2 shows the results found from a typical experiment for a target with $R_1 \simeq 129$ μm, $\Delta_1 \simeq 1.7$ μm, $R_2 \simeq 53.5$ μm, and $\Delta_2 \simeq 1.2$ μm. From the path traced out by the critical surface it can be assumed that the outer shell reaches the inner at $t^*_1 \simeq 0.8$ and that the average velocity of the outer shell is $\bar{u}_1 = (R_1 - R_2)/t^*_1 \simeq 9 \times 10^6$ cm/s. According to data on the mass evaporation rate found from the mass-spectrometric measurements of hydrocarbon ions, by the time (t^*_1) at which the shells collide the mass of the outer shell has decreased by half ($m^*_1 \simeq 200$ ng) but is still roughly twice the mass of the second shell ($m_2 \simeq 108$ ng). The kinetic energy of the outer shell moving toward the center of the target is estimated to be $E^*_{1\,\mathrm{kin}} \simeq 1$ J or about 5% of the laser energy absorbed by the time t^*_1. These experiments thus show that it is possible to compress an inner shell in a collisional

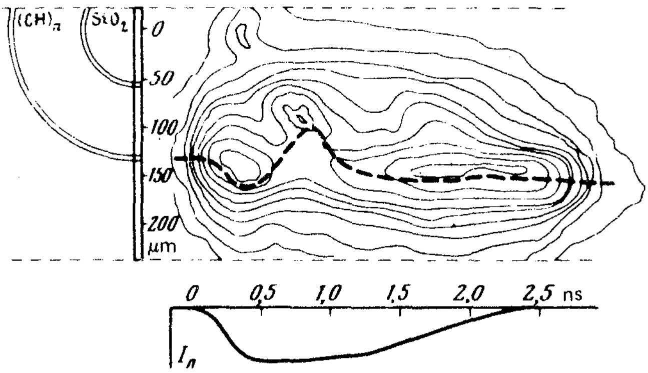

FIG. 2. Densitometer contour map of a time sweep of the emission from the target plasma at the second harmonic frequency, $2\omega_0$. Dashed curve—reconstructed trajectory of the n_c region; bottom—shape of the laser pulse.

interaction with a laser-bombarded outer shell.

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