Second-harmonic generation and measurement of the compression velocity of high-aspect-ratio shell targets

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Compression velocities up to 300 km/s of high-aspect-ratio shell targets ($A_s > 100$) are inferred from the generation of the second harmonic of the laser frequency in the DEL'FIN-1 device.

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The compression velocity of a shell target is one of the most important target characteristics, determining whether the material being compressed can reach fusion temperatures. In this letter we report the use of diagnostic methods for studying the dynamics of the critical-density region[1,2] ($n_c \simeq 10^{21}$ cm^{-3}) to study the compression of high-aspect-ratio targets ($A_s = R_0/\Delta_0 > 100$, where R_0 is the shell radius, Δ_0 is the

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shell thickness, and A_s is the aspect ratio) in the DEL'FIN-1 laser apparatus.[3] Targets of this sort have attracted interest because they present the possibility of attaining high compression velocities, $u > 2\times 10^7$ cm/s, and hydrodynamic transfer ratios up to 20%, by virtue of the evaporation of a substantial part of the shell by the time of the collapse.[4]

The six beams of the DEL'FIN-1, with a total energy up to 1 kJ, provide a power density $q_0 \lesssim 5\times 10^{13}$ W/cm^2 at the target surface at a pulse length $\tau_L \simeq 2.3$ ns. The energy absorption coefficient is $\sim 50\%$. Glass shells with $A_s \simeq 100$–300 ($R_0 \simeq 170$–280 μm, $\Delta_0 \simeq 0.7$–2.4 μm) and also polystyrene shells with a low $A_s < 30$ were used in the present experiments. A 10× image of the target was projected by an objective onto the slit of an ISP-51 spectrograph. The spectral resolution was 2 Å, and the spatial resolution 20 μm (at the object).

The pump beam had a spectral width (at half-intensity level) $\delta\lambda_0 \simeq 100$ Å and a maximum at $\lambda_0 \simeq 10\,598$ Å. The spectral width of the harmonic generated in the plasma, $2\omega_0$ (ω_0 is the laser frequency), was $\delta\lambda_2 \simeq 50$ Å, and its maximum was shifted (with respect to $\lambda_0/2 \simeq 5299$ Å) by an amount $\Delta\lambda_2 \simeq 5$–12 Å in the long-wavelength direction (Fig. 1). Only in certain shots did we detect an additional broad component (a pedestal with $\delta\lambda_2 \simeq 150$ Å), slightly more intense than the continuum, in addition to the main component of the harmonic. The fraction of the laser energy converted into the $2\omega_0$ harmonic was 10^{-7}–10^{-8}.

The single-component structure of the $2\omega_0$ spectrum and its small width ($\delta\lambda_2 \simeq \delta\lambda_0/2$) indicate that the harmonic is produced during a coalescence of the pump beam with plasma waves which arise near n_c in the course of a linear conversion of the incident beam.[5] The low intensity of the pedestal indicates that parametric processes are negligible in the harmonic generation.[5]

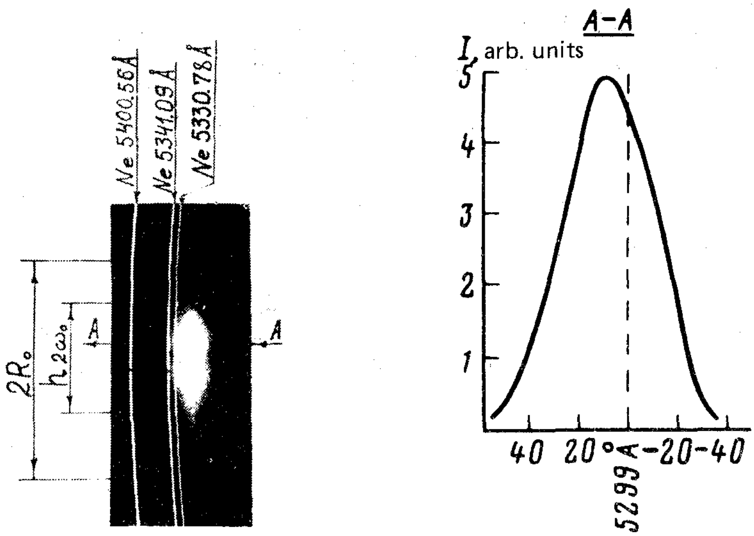

FIG. 1. Typical spectrogram of the $2\omega_0$ harmonic and a densitometer trace of this spectrogram for a glass shell.

The shift of the spectral maximum of the $2\omega_0$ harmonic generated in the linear conversion results from the Doppler effect accompanying the motion of the n_c region.[1,5] This circumstance underlies the diagnostic method of determining the velocity of this region, $u_c(t)$, from the magnitude of the shift[1,5] $\Delta\lambda_2(t)$: $u_c(t) = c^{\Delta\lambda_2(t)}/\lambda$. With only the time-integrated measurements of the harmonic spectrum furnished by these experiments it is possible to obtain information on the velocity u_c at the times corresponding to the maximum harmonic intensity. Figure 2 shows the velocity u_c determined in this fashion vs the quantity $(q_a/10^{13})^{0.44}(A_s/\rho_0)^{1/2}$ (q_a is the power density of the incident beam, in watts per square centimeter, and ρ_0 is the density of the target material, in grams per cubic centimeter) for the polystyrene and the high-aspect-ratio glass shells. This particular combination of parameters was chosen in accordance with the "experimental" scaling $\bar{u} = 1.2\times 10^6\,(q_a/10^{13})^{0.44}(A_s/\rho_0)^{1/2}$ for the average shell compression velocity. This expression, found in Ref. 4, gives a satisfactory description of essentially all measurements of the compression time $t^* - R_0/\bar{u}$ which have been carried out in the various laboratories. A straight line can be drawn through the experimental points, which lie in the range $(1.2\text{–}3.2)\times 10^7$ cm/s, as can be seen from Fig. 2. This line corresponds to a proportionality with a factor $K_D \simeq 2.2\times 10^6$, which is 1.8 times the corresponding factor according to the scaling law. By way of comparison we note that a line drawn through the points obtained by the same method for low-aspect-ratio shells ($A_s < 30$) in the KAL'MAR device yields a proportionality factor $K_K \simeq 10^6$, slightly lower than that found from the scaling law (Fig. 2a).

This discrepancy between the new experimental data and the scaling law stems from differences in the dynamics of the compression in these two series of experiments. For the low-aspect-ratio shells, the acceleration is typically low, so that by the time the $2\omega_0$ harmonic reaches its maximum intensity the shell is moving at a velocity less than its average velocity over the entire compression process. Further evidence for this

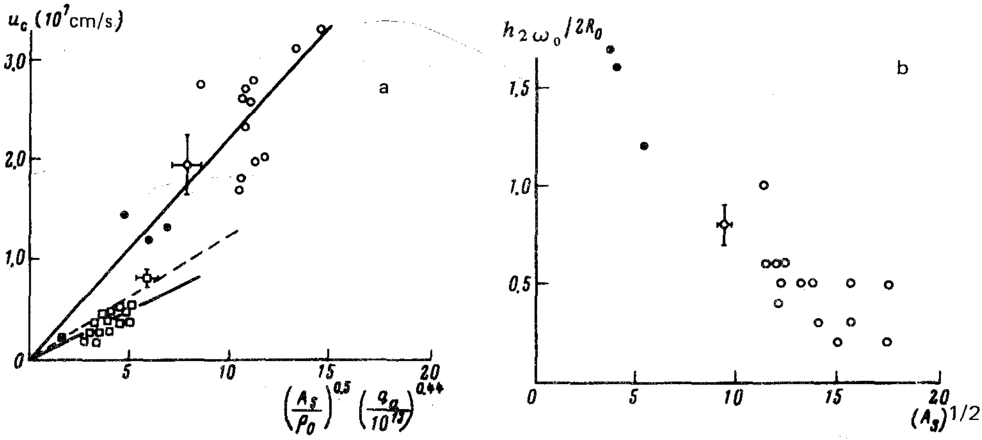

FIG. 2. a—The velocity of the critical-density region, u_c, vs $(q_a/10^{13})^{0.44}(A_s/\rho_0)^{1/2}$, according to measurements in the DEL'FIN-1 (circles) and the KAL'MAR (squares) for shells of glass (open symbols) and polystyrene (filled symbols). The dashed line is the "experimental" scaling[4]; b—the dimension of the region which is emitting at the frequency of the $2\omega_0$ harmonic (the dimension at the 1/100-intensity level) vs $A_s^{1/2}$ (the DEL'FIN-1).

conclusion comes from the measured time evolution of the intensity and spectrum of the $2\omega_0$ harmonic carried out in the KAL'MAR.[1,5] For high-aspect-ratio shells (the DEL'FIN-1), in contrast, the high acceleration has the consequence that the shell can be accelerated to essentially its maximum velocity (exceeding the average compression velocity) and can thus traverse a significant fraction of the initial radius by the time of the maximum in the $2\omega_0$ emission. For low-aspect-ratio shells the method described above therefore gives the velocity of the n_c region in the initial stage of the compression, while for high-aspect-ratio shells it gives the velocity of this region in the final stage, when the n_c region is moving at a velocity near that of the ablation zone. It also follows that for high-aspect-ratio shells we should observe a decrease in the dimension $(h_2\omega_0)$ of the region emitting at the frequency $2\omega_0$ (in the case of time-integrated measurements) with an increase in the velocity u_c, which in turn (Fig. 2a) increases with increasing A_s. This behavior has in fact been observed (Fig. 2b). It turns out that the size of the emitting region decreases from $h_2\omega_0 \simeq 2R_0$ to $h_2\omega_0 \simeq 0.4R_0$ as A_s is increased from 90 to 300. In the case of polystyrene shells $(15 < A_s < 30)$, on the other hand, the dimension $h_2\omega_0$ is in fact greater than the initial dimension of the target. The reason for this result is that in the initial stage of the compression the n_c region is moving outward, away from the target surface, and only later does it begin to move in the opposite direction (because of the motion of the unevaporated shell toward the center).[2] For low-aspect-ratio polystyrene shells, with a low acceleration, the $2\omega_0$ emission maximum corresponds to the initial stage of the compression (but to a time at which the n_c region is moving toward the center of the target, since the harmonic shift on the spectrograms is a red shift). Consequently, the dimensions of the emitting region should be $h_{2\omega_0} > 2R_0$.

The compression velocity inferred from the Doppler shift of the $2\omega_0$ harmonic agrees with data obtained in the same series of experiments from a time sweep of an x-ray image of the plasma. Figure 3 shows the trajectory traced out by the compressing shell $(2R_0 \simeq 482\ \mu m,\ A_s \simeq 195)$ obtained with an x-ray electron-optical image converter.[6] We see that the average shell velocity is $\bar{u} \simeq 140$ km/s, while the velocity in the final stage of the compression is $\bar{u}_{max} \simeq 300$ km/s. The velocity of the n_c region found from the Doppler shift of the $2\omega_0$ harmonic in this experiment is $u_c \simeq 275$ km/s,

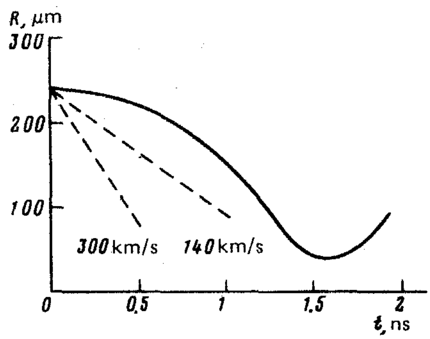

FIG. 3. R—t diagram of the compressing shell found with an x-ray image converter. Dashed lines—Velocities $u \simeq 140$ km/s and $u \simeq 300$ km/s.

approximately the same as the shell velocity at the end of the compression.

In summary, these experiments in the DEL'FIN-1 have yielded record high velocities for experiments on the compression of shell targets in the ablation regime.

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