Observation of laser-driven compression of gas-filled microspheres

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Results are presented of experimental investigations of the interaction of radiation from the nine-channel "Kal'mar" installation with spherical SiO_2 shells filled with deutrium. Pinpoint cameras were used to record a thousand-fold compression of the target.

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In contrast to experiments on compression of shell targets at flux densities $q \sim 10^{15}$–10^{16} W/cm^2 and pulse durations $\sim 10^{-10}$ sec,[1,2] in the present study, just as previously,[3] the pulse

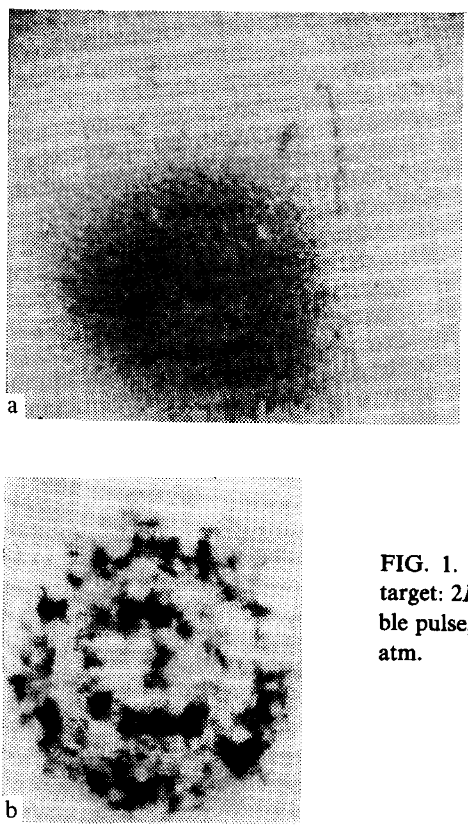

FIG. 1. Pinpoint photographs of laser plasma: a) SiO_2 target: $2R = 140$ μm, $\Delta R \approx 2.2$ μm; $p_{D_2} \approx 35$ atm. b) double pulse; SiO_2 target: $2R = 80$ μm, $\Delta R \approx 1.5$ μm, $p_{D_2} = 0$ atm.

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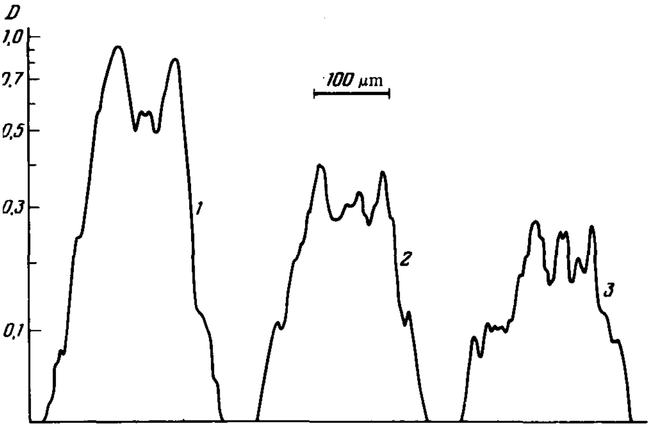


FIG. 2. Density patterns of central sections of the pinpoint photographs, corresponding to Be filters of thickness 200 (1), 300 (2), and 400 μm (3). SiO_2 target: $2R=98$ μm, $\Delta R \approx 1.4$ μm, $p_{D_2}=0$ atm.

duration ($\tau \sim 1$ nsec) was comparable with the shell compression time. As shown in[4], this compression regime leads to large final gas densities.

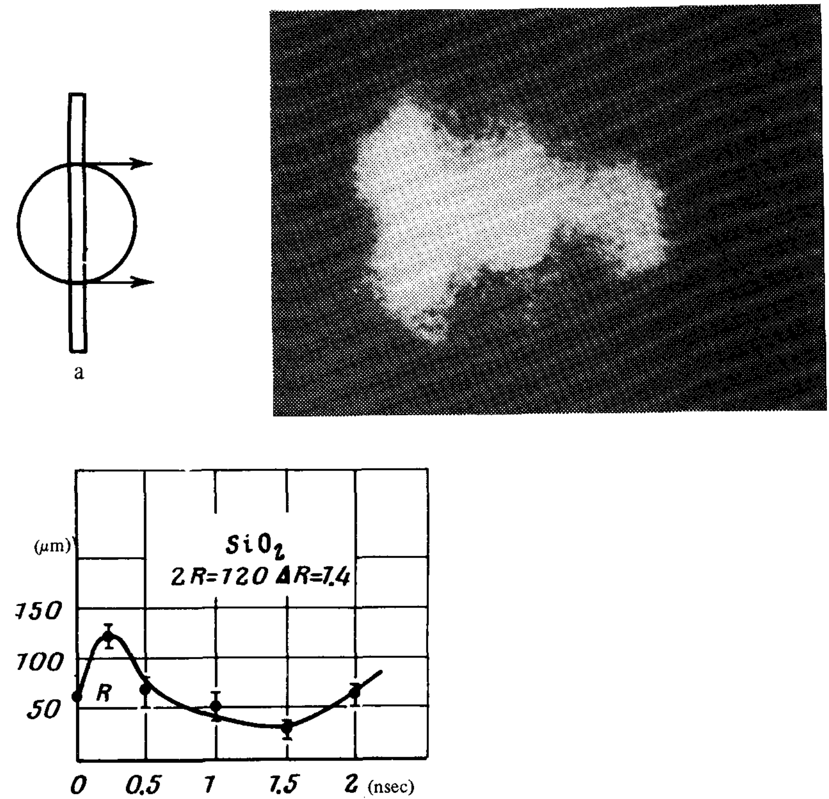
Radiation of the "Kal'mar" laser setup was focused from nine sides on an SiO_2 glass shell target ($2R\sim 70$–100 μm). With the light beams having a diameter ~ 150 μm in the region of the target and an energy $E_{\text{inc}} \sim 60$–100 J, the flux density was $q \sim 10^{14}$ W/cm².[5] The laser pulse had a duration ~ 1 nsec at half-intensity at a leading-front duration ~ 0.5 nsec.

Figure 1(a) shows a pinpoint photograph of the plasma in its own x radiation ($h\nu \gtrsim 2$ keV). The shell with $2R=140$ μm and $\Delta R \approx 2.2$ μm was filled with deuterium at a pressure ≈ 35 atm. Two concentric glowing rings are clearly seen. The outer ring corresponds to the expanding corona of the target, and the inner ring corresponds to the glass layer adjacent to the compressed D_2 gas located inside the target. The volume compression δ of the gas can thus be determined. As a rule, δ increases with increasing target diameter and amounts to $\approx 10^3$ at $2R \sim 120$–140 μm and $\Delta R \sim 2$–3 μm, as, for example, in the case shown in Fig. 1(a). The density of the compressed deuterium reaches in this case 6–8 g/cm³, and $\rho R \approx 10^{-2}$ g/cm².

The neutron radiation was recorded both by a time-of-flight procedure using three scintillation detectors with multipliers, located at various distances from the plasma, as well as by an integral activation counter. The neutron yield reached 10^3–10^4 neutrons/flash at $2R \lesssim 100$ μm (the overwhelming majority of the experiments with the gas-filled targets were performed for shells with small diameters). The maximum yields, $(3$–$5) \times 10^6$ neutrons, was registered for a shell with $2R=140$ μm and $\Delta R=2.2$ μm.

The low neutron yield did not make it possible to determine with sufficient accuracy the ion temperature of the compressed gas from the time-of-flight measurements. In certain experiments we were able, however, to determine the electron temperature of the compressed region with the aid of the pinpoint photographs.

Figure 2 shows density patterns of the diametral sections of the pinpoint photographs, obtained using beryllium filters of various thicknesses to cover the pinpoint camera. It is seen that with increasing filter thickness (on going to the harder region of the spectrum) the intensity of the



a

b

FIG. 3. a) Streak photograph of plasma emission at the harmonic frequency $2\omega_0$; b) R-t diagram of the motion of the critical density ($N_e = 10^{21}$ cm^{-3}). SiO_2 target: $2\rho = 120$ μm, $\Delta R \approx 1.4$ μm, $p_{D_2} = 30$ atm.

emission of the compressed region decreases much more slowly than that of the corona, i.e., the value of T_e in the compressed region reaches ~ 1.5 keV.

The absorbed energy was measured with two calorimeter systems, one of which recorded the radiation passing through the target and refracted at various angles. In addition, we used a system of calorimeters of the opened type, which recorded in several directions the total energy flux from the target (particles and radiation). The absorbed energy, for example, for the flash of Fig. 1(a) was $E_{\text{abs}} \approx 20$ J.

The average density of the "unevaporated" shell portion collapsing towards the center was measured by two methods. In the first, a specially shaped laser beam was used, with two intensity maxima with an interval ~0.7–0.8 nsec and a minimum $I_{\max}/3$ between them. In this case, the pinpoint photogragh [Fig. 1(b)] contained two outer concentric rings and a central region. Comparing the diameters of the outer rings with the maximum of the laser pulse we could determine the average velocity at which the region with density close to critical, where the plasma luminosity is maximal, moved towards the center. The other method of determining the velocity of the critical-density region consisted of investigating the spatial and temporal behavior of the region where the harmonic $2\omega_0$,[6] shown in the streak photograph of Fig. 3, was generated in the plasma.

t is seen that at the first instant of time the region with the critical density moves away from the arget surface and then turns back as a result of the motion of the shell towards the center. After he compression and the start of the expansion, the critical region again moves away from the enter. We note that both methods yield only the lower bound of the average shell-collapse velocity since the recorded motion is that of the region with the critical density and not the region with the ompressed glass), which amounts to $v_{av} \sim 5 \times 10^6$–$10^7$ cm/sec for the experiments of Figs. 1(b) and).

This value approximately coincides with the data of[7] obtained at $q < 10^{14}$ W/cm^2, and is everal times smaller than at $q \sim 10^{15}$–10^{16} W/cm^2 for short pulses ($\tau \sim 10^{-10}$ sec).[3,8]

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