Observation of the emission of neutral atoms during laser compression of microballoons

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Time-of-flight mass spectrometry of atoms has been used for the first time to study the effect of the conditions under which the laser beams of a multibeam installation are focused on a shell target. The experiments were carried out at the Vulcan laser installation in the Rutherford Appleton Laboratory in Great Britain.

1. In experiments on laser heating and compression of shell targets, neutral atoms of the microballoon material appear during the expansion of the dense plasma which is produced. Two emission stages can be distinguished. The first lasts until the end of the laser pulse. A recombination of the ions to a neutral state in the expanding plasma corona is improbable and could occur only in the slow tail of the velocity distribution (at velocities below 4×10^7 cm/s). The second stage begins at the time of collapse. The typical expansion velocities and the charge composition of the particle flux depend on the parameters of the compressed target in this case. As the density increases and the temperature decreases, the relative number of ions which recombine into atoms increases.[1] It follows that there is a possibility for developing a particle method for diagnostics of a compressed microballoon.

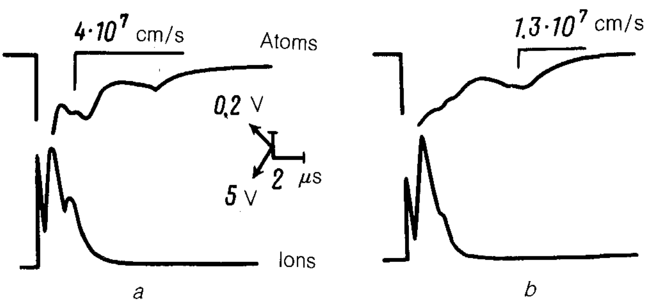

FIG. 1. Oscilloscope traces of the current drawn by the ion collector ($R_H = 50\ \Omega$) and by the neutral-particle detector ($R_H = 1\ k\Omega$). *a*—Nonuniform bombardment; *b*—uniform bombardment (phase plates in laser beams).

2. The experiments were carried out at the Vulcan laser installation: 12 beams, a laser light wavelength of 0.53 μm, and an energy of 800 J in a pulse 0.6 ns long. High-aspect-ratio shell targets 500–700 μm in diameter with a wall thickness of 0.75–1.3 μm, filled with a deuterium–tritium mixture to a pressure of 2–3 atm, were used. These targets were developed at the Lebedev Physics Institute, Moscow.[2]

A ring ion collector was positioned in a drift tube 90 cm from the target; an electron multiplier was positioned behind this collector, 110 cm from the target. An electrostatic ion deflector (with a potential difference up to 3 kV) was placed between the collector and the electron multiplier to remove ions from the atomic beam. Figure 1 shows oscilloscope traces of the currents drawn by the collector and the multiplier.

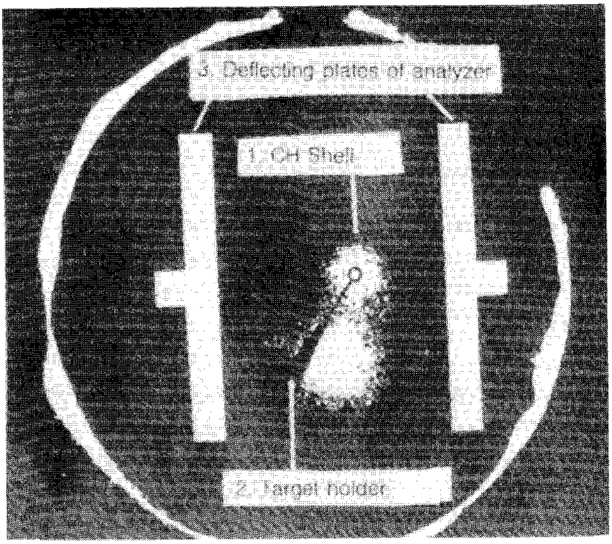

FIG. 2. Particle pinhole photograph of a source of neutral particles recorded during the bombardment of a polystyrene (CH) microballoon.

A characteristic feature of nonuniform bombardment is the double structure of the ion signal. The first ion peak (Fig. 1a) corresponds to a velocity of 8.2×10^7 cm/s.) This peak is made up of ions which have been emitted by "hot" zones on the target surface. The second ion peak has a velocity of 3.8×10^7 cm/s and characterizes the "cold" region of the microballoon. Note that there are some slow ions (with velocities to 1.5×10^7 cm/s) during nonuniform bombardment of the target.

Figure 2 shows a particle pinhole photograph of a shell with an initial diameter of 266 μm and a thickness of 9.2 μm. The multichannel detector[3] was strobed at a rate

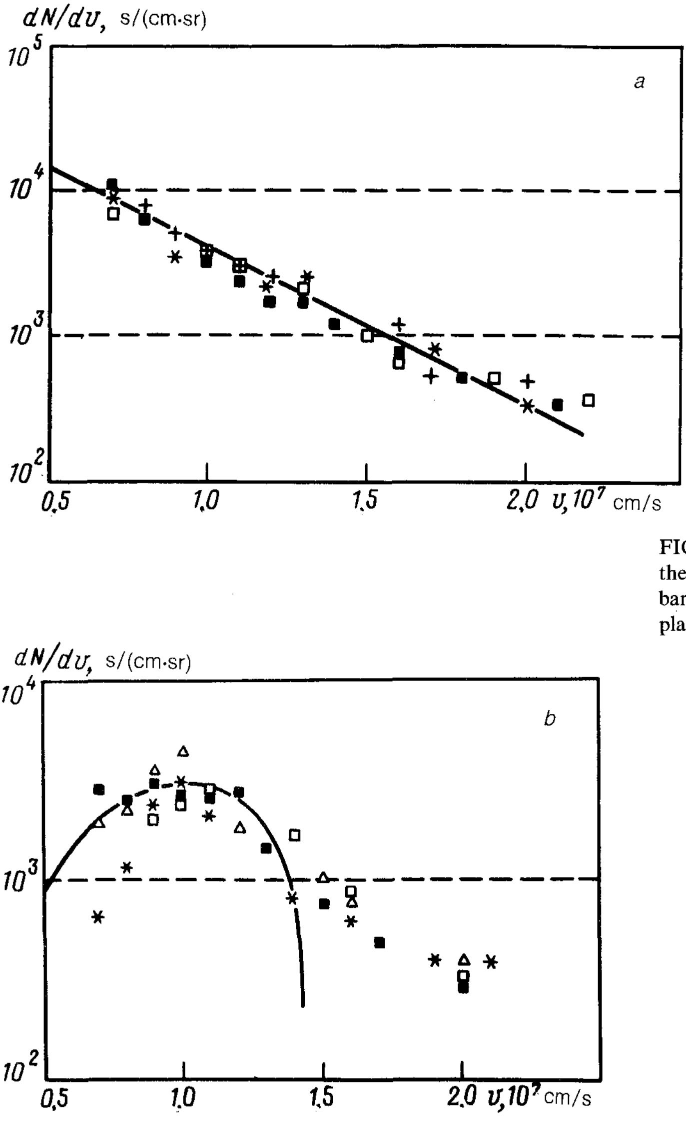

FIG. 3. Velocity distributions of the atoms. *a*—Nonuniform bombardment; *b*—focusing with phase plates.

corresponding to a velocity of $(1.3–1.8)\times 10^7$ cm/s. It can be seen from Fig. 2 that the region from which the slow atoms which are detected are emitted consists of not only the target but also its holder (a glass capillary). An emission of atoms from the holder can arise because of a heating of the holder by heat from the target (including radiant heat) and also because the holder may be struck by the laser light, expecially since the target was small, and the laser energy was high ($E_l = 748$ J).

The velocity distribution of the atoms can be calculated from $dN/dv = LI_{se}/(ke\gamma_{se}v^2\Omega)$, where I_{se} is the current from the electron multiplier, with a gain k and a secondary-electron emission yield γ_{se}, L is the distance from the target, and Ω is the solid angle. Figure 3a demonstrates the similarity of the atomic velocity distributions in experiments with approximately the same parameters of the laser pulse and the target. In all of the shots shown here, the neutron yield was greater than 10^9 [it varied over the range $(1.5–3)\times 10^9$]. The experimental data can be approximated satisfactorily by a function $dN/dv = N_0\exp(-v/v_0)$ with $N_0 = 5\times 10^4$ s/(cm·sr) and $v_0 = 0.4\times 10^7$ cm/s.

Under the assumption that the atoms with velocities of $(1–2)\times 10^7$ cm/s are material of the compressed shell (with a mass $m_{\rm res} \sim 0.1m_0$), we can estimate the relative number of atoms: $\alpha \sim 10^{-4}–10^{-5}$. In other words, the ions do not recombine to a neutral state in the course of the expansion, because of the high temperature (above 100 eV) and the relatively low density (less than 1 g/cm^3) at the time of collapse.

Figure 3b shows atomic velocity distributions in experiments with uniform bombardment, in which the shell collapse velocity decreases (according to x-ray streak pinhole photographs), and the neutron yield decreases significantly, to $(0.2–1.5)\times 10^8$. The peaks on all the curves in Fig. 3b are near a velocity $v = 1\times 10^7$ cm/s, which is close to the measured collapse velocity. An approximating curve was found from the model of the adiabatic expansion of a gaseous sphere:[4]

$$\frac{dN}{dv} = N_0\left(\frac{v}{v_m}\right)^2\left[1-\left(\frac{v}{v_m}\right)^2\right]^{3/2},$$

where $N_0 = 10^4$ s/(cm·sr) and $v_m = 1.5\times 10^7$ cm/s.

In summary, this study has shown that the atomic velocity distributions during the laser compression of high-aspect-ratio microballoons can be utilized for diagnostics of the state of the compressed shell. This diagnostic technique has more extensive possibilities in experiments on the compression of relatively thick microballoons.

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[1] Yu. A. Zakharenkov *et al.*, Fiz. Plazmy **14**, 623 (1988) [Sov. J. Plasma Phys. **14**, 367 (1988)].

[2] N. G. Borisenko *et al.*, Kvant. Elektron. (Moscow) **16**, 1895 (1989) [Sov. J. Quantum Electron. **19**, 1221 (1989)].

[3] A. A. Erokhin *et al.*, Fiz. Plazmy **15**(9), 1076 (1989) [Sov. J. Plasma Phys. **15**, 624 (1989)].

[4] Ya. B. Zel'dovich and Yu. P. Raĭzer, *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*, Academic, New York, 1966).

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