Spatial density variation in the corona of a laser plasma at fluxes 10^{14}–10^{15} W/cm^2

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Different procedures are used to investigate the dynamics of the spreading of a laser plasma during the course of a heating pulse. The formation of a perturbation on the profile of the electron density is observed.

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In the problem of laser-controlled thermonuclear fusion,[1] an important task is to reveal the singularities of the interaction of high-power laser radiation with the plasma corona, and their influence on the plasma parameters. One of the investigation methods is measurement of the space-time profile of the electron density of the plasma within the duration of the heating pulse.[2,3] In earlier studies (for example[2,3]) it was possible to trace the spatial dependence of the plasma dependence of the plasma density up to values $N_e \sim 2$

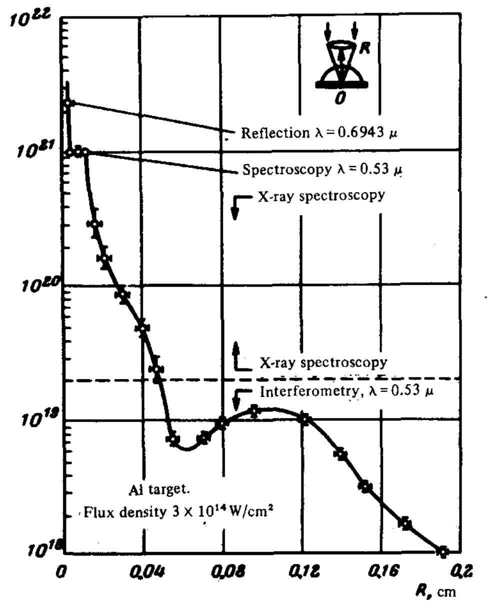

FIG. 1. Profile of electron density of a laser plasma at the second nanosecond.

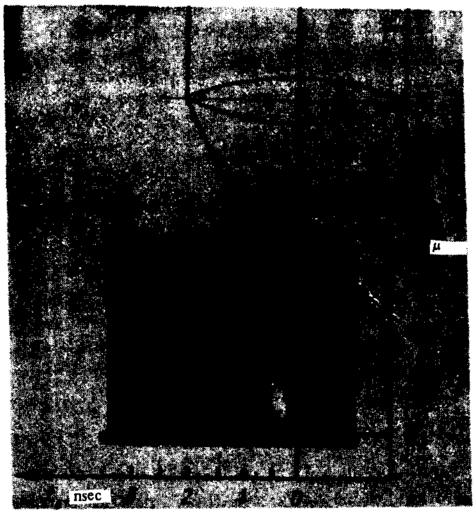

FIG. 2. Slit scanning of the laser-plasma emission region at the second harmonic frequency (in a direction perpendicular to the light beam).

$\times 10^{19}$ cm^{-3}. However, by virtue of the imperfection of the procedure used to interpret the interference patterns, the measured density profile of the plasma decreased monotonically with increasing distance from the target surface. The procedure for the determination of the density on the basis of x-ray spectral measurements is still in the development stage, and demonstrates only the feasibility in principle of performing measurements in the range of values $N_e > 10^{19}$ cm^{-3}.[4]

In the present investigation, using a specially developed comprehensive procedure, we were able to trace the evolution of the density profile in the range of values from 10^{18} to 2.4×10^{21} cm^{-3}. This has enabled us to discern the fine spatial structure of the plasma corona and to observe the appearance of a perturbation on the density profile.

The radiation from a high-power nine-channel laser setup[5] was focused on the surface of a bulky aluminum target placed in vacuum. The laser energy in this series of experiments was 200 J at a duration 2 nsec and a flux density (averaged over the focal spot) $\sim 5\times10^{14}$ W/cm^2 (the flux density at the maximum could exceed the average value by one order of magnitude).

In the density range 10^{18}–3×10^{19} cm^{-3}, the investigation was carried out with high-speed interferometry using an image converter in the slit-scanning regime for the registration. The interference patterns were reduced with a computer by a specially developed approximation procedure. A perturbation of the electron-density profile was observed at the end of the laser pulse, with the perturbation moving towards lower densities. The nonmonotonic character of the density profile during the second nanosecond is illustrated in Fig. 1.

The electron-density profile in the range 10^{19}–10^{21} cm^{-3} was investigated by measuring the continuous x radiation (~3–10 keV) with a spatial resolution 20 μ (multichannel pinpoint camera) and with a time resolution ~1 nsec. To determine the density profile from the luminosity diagrams by an independent method, we measured the distribution of the electron temperature T_e over the volume of the plasma. In the direction along the laser beam, T_e decreases from 1 keV (at a distance 100 μ) to 0.2 keV (~400 μ). The density profiles, taking into account the fact that the main contribution to the x rays is made by recombination to the ground level, was determined from the known temperature and luminosity. It should be noted that the use of an x-ray spectral procedure in the region near critical density $N_e \sim N_{e\,\mathrm{cr}}$ calls for a simultaneous investigation of the spatial distribution and the spectral composition of the radiation from the plasma, since the possible anisotropy of the x radiation and of the "temperature" with respect to the polarization vector of the heating radiation[6] can greatly lower the accuracy with which the temperature and plasma-density profiles are measured.

To determine the dynamics of the motion of the critical point ($N_{e\,\mathrm{cr}} = 10^{21}$ cm^{-3}) an image converter with slit scanning was used to observe the space-time evolution of the plasma radiation region at the second-harmonic wavelength. According to theoretical premises, the second harmonic is generated in the plasma zone with $N_e \approx N_{e\,\mathrm{cr}}$ as a result of coalescence ($l + t \to t$) of the electron oscillation (l) with the transverse optical wave (t), or else the coalescence of two Langmuir oscillations ($l + l \to t$), regardless of the mechanism whereby the Langmuir waves are produced.[7] Thus, region of plasma emission at the second-harmonic frequency can apparently be identified with the region where $N_e \approx N_{e\,\mathrm{cr}}$. Figure 2 shows a streak photograph of the emission region at the wavelength of the second harmonic. We see that at the initial instant of time the emission region moves with velocity $\sim 5\times10^{7}$ cm/sec, and slows down towards the end of the laser pulse. It is interesting to note that the emission region expands to 100 μ in the direction of the heating-beam axis towards the end of the

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laser pulse. This suggests that there exists a plateau on the density profile, with a width ~100 μ with $N_{e\,\mathrm{cr}}$. Favoring the existence of such a plateau is also the result of[8], where the gradient of the electron density, equal to $dN_e/dx \sim 10^{25}$ cm^{-4} was determined by measuring the reflection of the ruby laser emission from a point with $N_e \sim 2.4\times10^{21}$ cm^{-3}. The presence of so large a gradient (the maximum value of the gradient is ~10^{24} cm^{-4} in the region $N_e < 10^{21}$ cm^{-3}) is evidence of a break on the density profile at $N_e \approx N_{e\,\mathrm{cr}}$. Another possible cause of the broadening of the second-harmonic radiation band may be oscillations of the point of the profile with $N_e \approx N_{e\,\mathrm{cr}}$ along the laser beam, with a period smaller than the temporal resolution of the streak camera (i.e., less than 10^{-10} sec).

One of the possible explanations of the behavior of the electron-density profile (Fig. 1) is the abrupt increase of the light pressure $P_L \approx q/c$ in the region with $N_e \approx N_{e\,\mathrm{cr}}$. This pressure amounts to $P_L \sim 10^5$ atm at $q \sim 10^{15}$ W/cm^2, and is comparable with the thermal pressure even without allowance for the abrupt increase in the longitudinal component of the electric field, which appears in the case of oblique incidence of polarized light on a plasma with a large density gradient.[9] Owing to the redistribution of the intensity, an opto-hydrodynamic "impact" may be produced, due to the increase of the concentration of the electromagnetic field, and can lead to the appearance of a perturbation on the density profile.

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