Measurement of the spatial profile of the electron density in a magnesium laser plasma by determining the Stark broadening in the x-ray region of the spectrum

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We investigated the Stark broadening of the $1s$–$5p$(λ = 6576 Å) line of the hydrogen-like ion MgXII in the x-ray emission spectrum of a laser plasma. The energy of the heating laser pulse was $E = 25$ J, the duration was $\tau = 10^{-10}$ sec, and $\lambda = 1.06$ μ. From the magnitude of the Stark broadening we constructed the dependence of the electron density N_e of the plasma on the distance to the target. The maximum value of N_e, measured near the target, was 3.1–10^{21} cm^{-3}. The spatial resolution of the laser flare was 25 μ.

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The investigation of the Stark broadening of multiply charged ion lines in the x-ray region of the spectrum is of considerable interest as a spectroscopic method of diagnostics of dense and superdense laser plasma.[1]

In the visible region of the spectrum, measurement of the Stark broadening is one of the most direct methods of measuring the electron density of the plasma. Observation of a Stark broadening of lines of multiply charged ions is as a rule difficult, since it is usually masked by the large Doppler broadening. There are only several reports of measurements of the Stark broadening in far ultraviolet region of the spectrum, for example, the studies of Aglitskiĭ, Boĭko, *et al.*[2], who investigated the 3—4 transition line of the hydrogenlike carbon ion ($\lambda = 520.6$ Å), and the study of Malvezzi *et al.*[3] devoted to the broadening lines of the Lyman series of hydrogenlike beryllium ($\lambda = 60$—76 Å).

We report here the results of an experiment in which we were able to measure the Stark broadening of the $1s$—$5p$ line of the hydrogenlike ion MgXII ($\lambda = 6.576$ Å). This had made it possible to carry out the investigation of the distribution of the electron density in the laser plasma as a function of the distance to the target.

The plasma was heated with a neodymium-glass laser ($\lambda = 1.06$ μ) with pulse energy 25 J and pulse duration 10^{-10} sec. The driving generator, operating in the mode-locking regime, emitted a train of pulses. An electro-optical shutter was used to separate from this train a single pulse, which was further amplified. To amplify the radiation of the driving generator we used one of the channels of the laser setup described in[4]. The laser radiation was focused on the target by a three-component lens with $f = 60$ mm. The flux density at the target was $\sim 5 \times 10^{15}$ W/cm^2, and the radiation contrast was $\sim 10^4$.

A target in the form of a disk of 30 mm diameter was placed in the vacuum chamber, in which a vacuum not worse than 10^{-3} Torr was maintained.

For the spectral expansion of the x rays from the plasma, we used a Johann-scheme focusing spectrograph with a bent mica crystal. The spectrograph is described in[5]. The line was investigated in the third order of the spectrum. The dispersion of the spectrograph for $\lambda = 6.576$ Å was 5.46×10^{-3} Å/mm (1.565 eV/mm) at an apparatus-function width $\delta\lambda \approx 3 \times 10^{-4}$ Å ($\delta E \approx 0.1$ eV).

The x-ray source, namely the laser flare, was located inside the spectrograph. The line of sight from the target to the spectrograph made an angle of 15° with the surface of the target. To obtain the spatial distribution of the glow of the flare, a slit was placed between the laser flare and the mica crystal[5] and was parallel to the dispersion, thus ensuring a spatial resolution of the details of the flare. The spectra were registered with the special UF-VR x-ray film, which has a sensitivity close to 10^7 quanta per cm^2.[6] To convert the film density into relative radiation intensities, we used the characteristic curves obtained in[6]. The large aperture of the spectrograph and the large sensitivity of the UF-VR film have made it possible to register the x-ray spectrum in a single laser flash, and the high resolution precluded any influence of the recording apparatus on the contour of the investigated line.

We investigated the Stark broadening of the 1*s*—5*p* line of MgXII for two target configurations. In one case the laser radiation was focused on a flat surface (spatial resolution 25 μ), and the other into a pit of diameter and depth 0.1 mm (spatial resolution 50 μ). Figure 1 shows plots of the experimental width

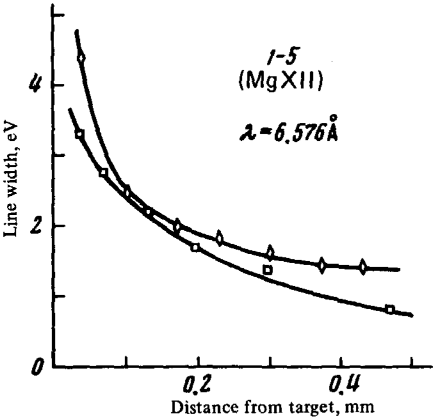

FIG. 1. Experimental values (in electron volts) of the width of the 1*s*—5*p* line ($\lambda = 6.576$ Å, MgXII) against the distance *r* to the target (mm); ◇—flat target, □—laser radiation focused into a pit (diameter and depth ≈ 0.1 mm).

against the distance to the target for these cases. We estimated the various factors influencing the broadening of the 1*s*—5*p* line of MgXII, namely the quasistatic broadening by the ions, the contribution due to the electron impact, the Debye screening, and the Doppler effect.[7] Estimates have shown that broadening by the electrons does not make an appreciable contribution, and the main factors are the broadening by the ions (with Debye screening playing a major role) and by the Dopper effect. The magnitude of the Doppler broadening was determined by us by measuring the widths of the resonance and intercombination lines of helium-like ion MgXI, and was eliminated from the experimental width when determining the Stark broadening.

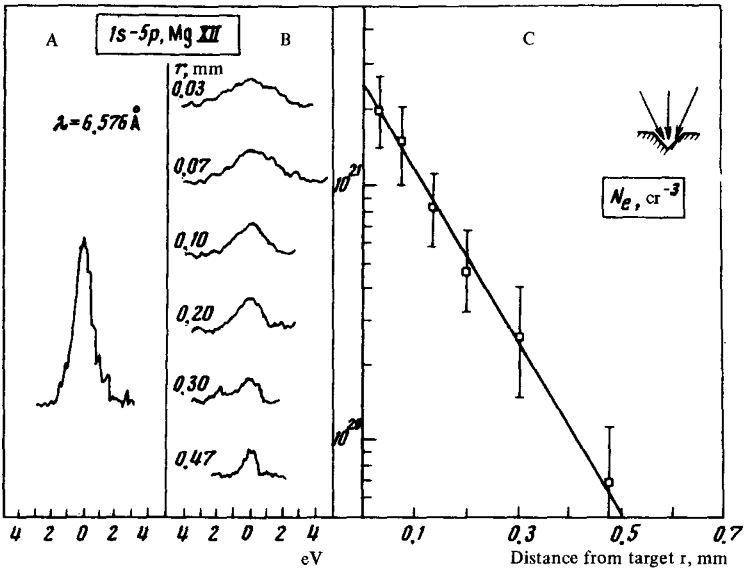

FIG. 2. Laser radiation focused in a pit of the target. (A)—contour of the 1*s*—5*p* line (MgXII) without spatial resolution. (B)—contour of the 1*s*—5*p* line at various distances *r* (mm) from the target. (C)—spatial profile of the electron density $N_e(r)$ (cm^{-3}), determined from the Stark broadening of the 1*s*—5*p* line.

When account is taken of the Debye screening ([7,8]), the usual Holtsmark formula for the width is replaced for the particular case under consideration by the approximate formula

$$\Delta E \approx 0.76\,(N_e/10^{20})^{0.6}\,T_e^{0.21}\quad, \tag{1}$$

where ΔE in eV is the Stark broadening of the 1*s*—5*p* line, and T_e in keV is the electron temperature of the plasma. The approximations used in the derivation (1) are valid when the values of the Ecker parameter δ[7,8] lie in the range $0.2 \leq \delta \leq 12$ (δ is the number of ions inside the Debye sphere). For our conditions, the values of δ did not range outside these limits.

Formula (1) served as the basis for the determination of the electron density from the Stark broadening of the 1s—5p line. Data on the local electron temperature T_e were obtained from the relative intensities of the 1s—2s [H] resonance line of the MgXII ion and its dielectron satellite $1s2p^1P_1—2p^{21}D_2$.[6,9,10] $T_e = 0.2$ keV near the target and $T_e = 0.6$ keV at a distance 0.3 mm.

In the case of a flat target, the maximum value of the electron density measured near the target was $N_e = 3\times10^{21}$ cm^{-3}, while for a target with a pit we obtained $N_e = 2.0\times10^{21}$ cm^{-1}. With increasing distance from the target, no substantial difference between the values of n_e is observed for these two cases. The plot of $N_e(r)$ for a target with a pit is shown in Fig. 2(C). The same figure 2(B) shows the variation of the contour of 1s—5p line MgXII with increasing distance of the target, and also the contour of this line, obtained without spatial resolution (2(A)).

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