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ON THE PROBLEM OF CORRECTNESS IN THE STARK SPECTROSCOPY OF HIGH-DENSITY PLASMA STREAMS

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This work is devoted to investigations of probable errors of the spectral methods for electron density measurements. The theoretical calculation of the optical plasma thickness τ for the hydrogen H_β line was performed for the different values of the electron density and temperature. It was demonstrated that impact of the optical thickness on the electron density measurements is negligible small in our conditions.

Introduction

As far as the parameters of plasma streams (first of all plasma energy density and pulse length) generated by powerful quasi-stationary plasma accelerators (QSPA)[1] are more or less comparable to the parameters of plasma flowing to the divertors plates of the ITER tokamak, such QSPA can be used for modelling situation that can be occurred on the first wall or divertor plates during current disruption conditions. The main experimental work content on the problem of the plasma-target interaction was carried out using the optical interferometry technique for the plasma density measurements. This method and some experimental results are offered in [2,3]. There are some difficulties with processing of interferograms and its interpretation in our conditions. Particularly, large values of the electron density gradient and absence of axial symmetry (non-regular structure of shielding layer) doesn't give possibility for adequate interpretation of some experimental data. The absolute necessity of giving more precise determination of the electron density distributions has reached. In that way we turn to spectroscopy technique.

For the analysis of plasma parameters the optical-spectroscopy technique has found wide use in the investigation of the physical processes occurring in the quasi-steady-plasma accelerator (QSPA) - Kh-50, as well as in the imitation experiments on the problem of plasma-target interaction. The output plasma parameters of QSPA as well as the target plasma parameters were determined [1,2]. The main characteristics of plasma streams are the electron density n $>10^{16}$ cm^{-3}, velocity (2...4)*10^7 cm/s, pulse duration >100 μs. The working gas is hydrogen. The target is the carbon disk (130mm, 50mm, 200mm diameter). The determination of the plasma electron density was based on the well-known technique of the Stark H_β line broadening. It was developed for optically thin plasma layers, when the optical thickness $\tau=\chi_0 l<<1$ (χ_0 is the absorption coefficient, l is the length of a luminous column). In our experiments [3] the plasma density reached 10^{17} cm^{-3}, (at plasma diameter~5-10cm) the electron temperature was ~1-3 eV. With these parameters it was necessary to argue the reason of applying the technique for optically thin plasma layers. Therefore, the thorough analysis of radiation absorption influence with taking into account the value of optical thickness $\tau=\chi_0 l$ in the every concrete case was required.

The main aim of the present work was the substantiation of this method in our experimental conditions having mind the possible errors constrained with high values of the optical thickness. Other sources of probable measurement errors are discussed also. Besides, the density was defined by comparison of Hβ line wings obtained in experiments with those calculated on the base of asymptotic approximation from the quasi-statistical theory [4].

Theoretical analysis

The theoretical calculation of the optical plasma thickness -τ for the hydrogen Hβ line was performed with the use of well-known formula [5]

$$\chi_0=2r_0(\lambda^2/\Delta\lambda_L)f_{ik}N^*$$

Where $r_0 = 2.8*10^{-13}$ is the classical electron radius, N* is the absorber atom concentration, f_{ik} is the oscillator force in absorption, λ is the wave length, $\Delta\lambda_L$ is the half-width of the line (having a Lorenz profile, as a best approximation of Stark contour), l is the geometrical thickness of plasma. From the Boltcman`s equations we find $N^*=N_2$ - the concentration of excited hydrogen atoms at a level with the main quantum number n=2 (lower level of H_β). In the case of local thermodynamic equilibrium:

$$N_2=(g_2/g_1)\, N_1\exp(-\Delta E/T)$$

Where g_2, g_1 are the statistical weights of the excited and basic levels, N_1 is the concentration of neutral hydrogen on basic level, ΔE is the energy excitation. From the other side we may applied Sacha`s equations for the determination of the neutral hydrogen depending on known electron density and concentration.

$$N_e^2=N_1(2g_i/g_1)3*10^{21}T^{3/2}\exp(-E_h/T)$$

Where g_i=1-statistical weight of ion, T-the electron temperature (eV), N_e-the electron density (cm^{-3}), E_h=13.6eV-ionization potential for hydrogen. We set there $N_e=N_i$ - ion density for purely hydrogen plasma and neglect the contribution of high-excited levels in statistical sum. Using foregoing formulas we get finally follows equation for the optical thickness of hydrogen line H_β:

$$\tau=2*10^{-36}N_e^2T^{-3/2}\exp(3.4/T)l/\Delta\lambda$$

For the hydrogen line H_β, we used follows atomic parameters - λ= 486.1 nm f_{ik} = 0.119, and $\Delta\lambda \sim N_e^{2/3}$ (corresponding Stark-broadening from the Griem theory).

Fig.1 represented the calculated dependencies of the optical thickness of the plasma being studied (l=20 cm) for the hydrogen line H_β on the temperature T at the given plasma densities within $N_e=10^{15}$-$10^{17}cm^{-3}$.

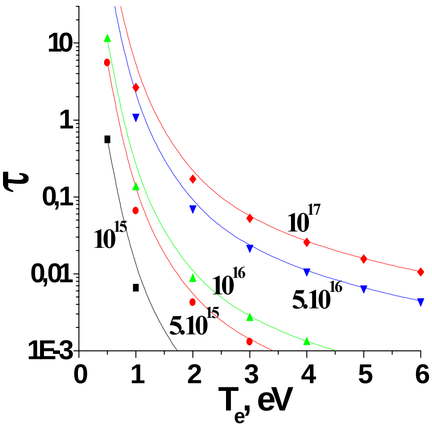

Fig.1. Optical thickness for Hβ

Analysis of the curves obtained allows one to conclude that the plasma optical thickness decreases sharply with increasing T for the plasma densities $N_e=10^{15}$-$10^{17}cm^{-3}$, and at temperatures T~2-3eV, observed in our experiments, plasma is optically transparent and τ<<1. We must point that these calculations are performed for purely hydrogen plasma, therefore the value (is maximum at goal electron density. One can see that the value of optical thickness, may be measured upper (τ>1), when the electron temperature is lower than 1eV. These conditions may occur at the shielding layer near the target. Therefore it is need the experimental work on this problem.

Experimental results and discussion

The fact that the plasma is transparent is evidenced experimentally while studying the standard source luminosity absorption during the passage through the plasma (Fig.2).

The light from the spectral radiation source of light ISI -1 (1) placed in the lens focus (5) (f =20 cm) passed through the plasma bulk (7) and came to the slit of the monochromator MDR-23 (8), separating the area 486.1 nm, which was recorded with the photomultiplier FEU-39 with the oscillograph (5) . The level of ISI-1 radiation (charge in the capillary from textolite of 1mm diameter and 5 mm length) placed in the lens focus, made it possible to carry out investigation at considerable spaces (up to 5 m) from the source in

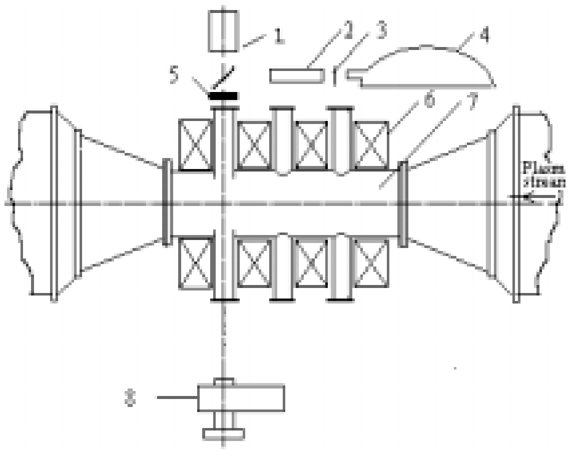

Fig.2. Optical scheme

parallel rays. The influence of the own plasma radiation on the measurement results was almost excluded.

In Fig.3 given are the oscillograms of signals from FEU-39: radiation of the standard source ISI-1 (QSPA not operating), ISI-1 radiation that passed through the plasma bulk, i.e. the set-up and source were operating simultaneously.

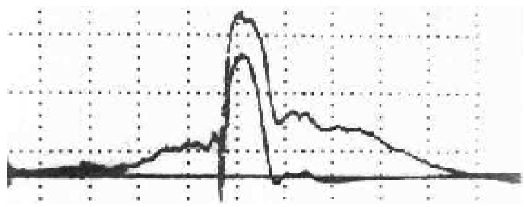

Fig.3. Signals from FEU-39, 50μs/div

Examination of oscillogram and confirms the fact that the plasma is optically thin and the absorption does not take place. Thus we have the possibility to neglect the errors connected with optical thickness of our plasma.

MDR-23 comprising an electron-optical converter - EOC (time resolution ~2μs), provided with a camera attachment. The hydrogen H_β line was recorded using a monochromator. Peculiarities of this variant of registration were offers earlier [1].

We have continued the experiments on studying the space-time density distribution of the near-surface plasma layer formed as a result of plasma stream action onto the material barrier (target) with the use of VFU-1 having the diffraction grating. Recording with VFU-1 (4 in Fig.2), in spite of the lower sensitivity and time resolution (~10μs), has the advantage that allows one to observe immediately the time dependence of the H_β line width per pulse. The plasma density can be defined from the Stark H_β line broadening after taking into account and excluding the instrumental and Doppler broadening. Comparison between experimental and theoretical Stark contours was carried out for part of our plot. It was demonstrated its good coincidence. At that electron density values for lines wings were found slightly higher than for half-width method (30%-40%). These values must correspond to maximum values on chord, and show heterogeneity of plasma.

Fig.4 shows the electron plasma density N_e as a function of the distance from the target surface L at the point of time when the power density is reaching maximum value.

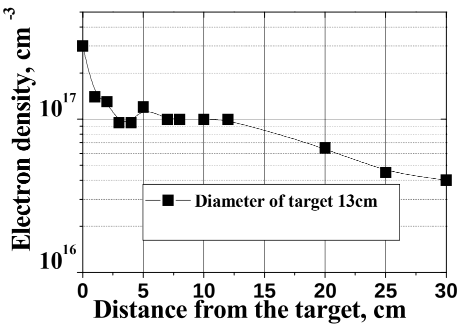

Fig.4. The electron density distribution

The plot is obtained from the time distributions for different values of the distance from the target. These distributions for some distances are shown in fig.5. The values of the N_e density determined over the Hβ line VFU-1 or EOC are in good agreement

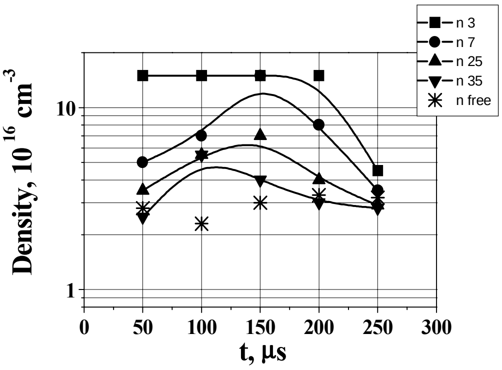

Fig.5. Time dependence of N_e

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