TEMPERATURE OF IMPURITY IONS IN A RF HEATED PLASMA OF THE U-3M TORSATRON AS MEASURED BY MEANS OF THE DOPPLER SPECTROMETRY

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1. INTRODUCTION

The spectroscopic methods of measurements of ion temperature, T_i, are routinely used in magnetic fusion experiments. However some strong requirements must be satisfied as for the quality of spectroscopic equipment and reproducibility of plasma parameters when spectral line profile is obtained shot by shot. Besides, the radial location of ions of the given ionization state in the plasma volume should be known. The correctness of T_i measurement results has to be controlled by comparing them with temperature T_i of the main plasma ion component (H^+, D^+) by calculation of energy balance for impurity ions. Important is also the requirement to estimate the role of other possible mechanisms of broadening of the impurity ion line profiles.

The goal of this paper is to determine the plasma ion temperature using data on profiles of spectral lines of intrinsic impurity, i.e., carbon ions (lines CV 227.1 nm and CIII 229.6 nm) in the plasma confinement volume of U-3M torsatron and to compare these results with data of T_i measurements based on the energy distribution of charge exchange atoms (CXA) obtained by neutral particle analyzer (NPA).

2. EXPERIMENTAL CONDITIONS AND RESULTS

The experiments were carried out on the fusion device Uragan-3M (U-3M) which is a l=3, 9 magnetic field period torsatron with major radius 100 cm and mean plasma radius 12.5 cm. The hydrogen plasma was produced and maintained during ~50 ms by RF fields in the frequency range $\omega \le \omega_{ci}$ corresponding to a multimode Alfven resonance regime. The spectroscopical measurements were provided for the following conditions: toroidal magnetic field 0.7T, $P_{RF} \le 240$kW, mean plasma density $\sim 1\cdot 10^{18}\, m^{-3}$.

Fig.1 shows the relative positions of diagnostic ports

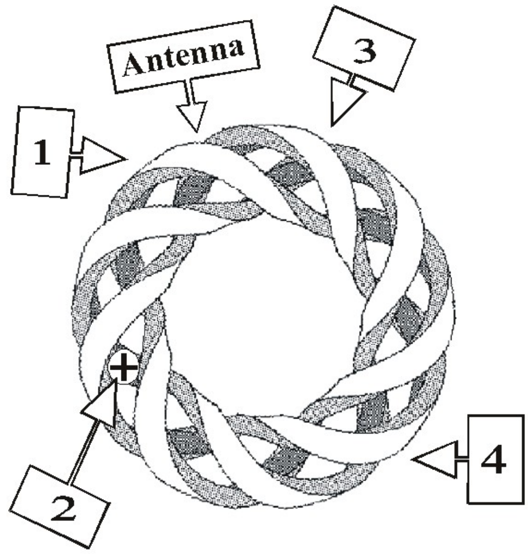

Fig.1 Disposition of diagnostic channels.

relating the present work: 1. NPA_{II} – for measuring CXA fluxes, i.e., the H^+ ion energy distribution along the toroidal direction with the line of sight passing near the RF antenna; 2. $NPA_{\perp}$ for measuring the CXA flux in vertical direction was positioned at ~90° from the RF antenna along the toroidal direction; 3. Spectroscopy for measuring the chord distributions of different spectral lines in vertical direction of the cross section (DD), where plasma column is symmetrical relatively the central plane of U–3M;
4. Spectroscopy along the toroidal direction of the plasma confinement volume.

For spectroscopy measurement of ion temperature the C^{4+} and C^{2+} ions were used. The potentials of excitation of these ions differ very strongly each other what gives chance to obtain some data on the T_i radial distribution. During these experiments, the spectral range chosen for spectral measurements, was practically free of other spectral lines.

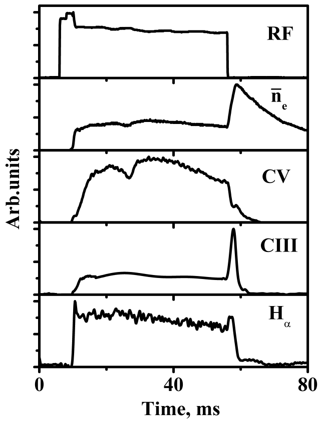

Fig.2. Time behaviors of RF power supplied to antenna and integrated along lines of sight: the plasma density n_e and spectral line intensities of indicated lines.

In Fig.2 the waveforms are shown for RF power supplied to antenna and integrated along the line of sight: the plasma density n_e and spectral line intensities of carbon and hydrogen lines. The chord distributions of intensities of these lines in the D-D cross-section are presented in Fig. 3.

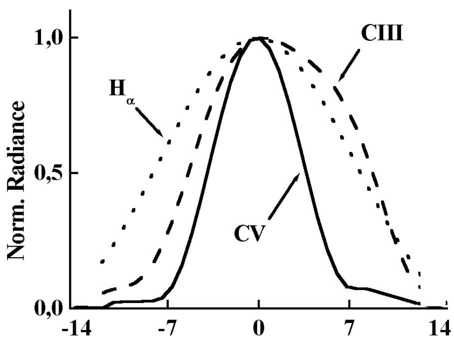

Fig. 3. Chord distributions of intensities of lines in the D-D cross-section.

The technique of obtaining the radial distribution of line intensities from measured chord distribution is minutely described in [5]. It is seen that the chord profile of CV radiation was limited by size 14-15 cm, CIII radiation – 24-25 cm and H_α radiation – 26-27 cm. The intensities of indicated lines of carbon ions in a poloidal cross section were not enough for measuring the line profiles if one takes into account the requirements on the widths of entrance and exit slits of the spectrometer in use. Therefore for line profile measurements we used the port for the tangent plasma observation. With this, the center of the observation line was antipode to the position of the RF antenna center (Fig.1) and according to geometry of measurements, the volume of observation was 5-6 cm in diameter. For the spectrometer MDR-23 with grating 1200 lines per mm the inverse linear dispersion was 1.3 nm/mm in the first order, but to work with better resolution we used the 3rd order of the spectrum. The total number of points on the line contour was ~30 (obtained shot by shot). The instrumental contour was measured by means of Hg lamp (line 253.6 nm) operating in a cold regime and its halfwidth was ≈ 0.015 nm what corresponds to the "instrumental temperature" ~8 eV (for carbon). The contribution of Zeeman and Stark effects into broadening of indicated carbon lines may not be taken into account, [1,2].

The probable Doppler width of spectral line contours were estimated with taking into account the previously obtained NPA data, [3,4].

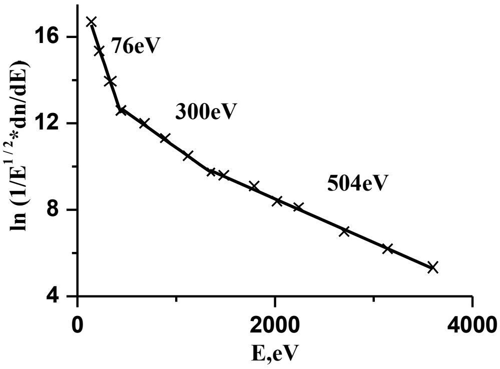

Fig.4. Energy distribution of H^+ ions obtained by NPA_{II}.

In Fig.4 the energy distribution of H^+ ions obtained by NPA_{II} are presented (note, that results of $NPA_{\perp}$ measurement are very much similar). These data indicate that there are three groups of H^+ ions in the confined plasma with "temperatures" equal to: $T_1 \cong 70$eV, $T_2 \cong 300$eV

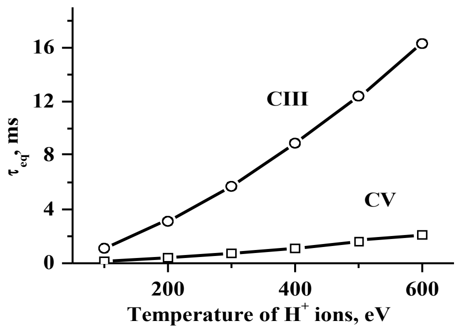

Fig. 5. Equipartition time for C^{4+} and C^{2+} ions in the background H^+ plasma.

and $T_3 \cong 500$eV. The estimated relative composition of every this component is: $n_1 \approx 85$-90%, $n_2 \approx 6$-12%, $n_3 \approx 4$-6%. However, for the temperature of impurity ions to correspond to the H^+ ion temperature, the particle life time has to be much longer than the equipartition time. Thus, the life time of H^+ ions, $\tau_p \cong 1.5 \div 2$ ms, found by measuring H_α line intensity, has to be compared with the equipartition time [6] for both, C^{4+} and C^{2+} ions, in a wide energy of H^+ ions, comparable with "temperatures" shown in Fig. 5. From data of this figure one can conclude that the favorable conditions for correct T_i measurements are fulfilled for C^{4+} ion component, and measurements of ion temperature by use of the CIII line can also be correct for $T_i(H^+) \leq 100$eV. The results of measurements of the CV and CIII line contours are shown in Fig.6 (note, that these data are obtained by integration along the line of sight). In Fig. 6a the experimental points are presented together with a Gaussian fitting contour of the same halfwidth as the experimental halfwidth. It is evident that at the wings there is a very big difference of measured points and the fitting curve. However, if the experimental contour is depictured as a sum of two Gaussian profiles with different halfwidth, much better fitting to the experimental profile can be obtained, as Fig. 6b demonstrates.

Such a presentation indicates that in the plasma confinement volume there are two groups of C^{4+} ions with energy distribution corresponding to temperatures ~40 eV and ~300 eV. This result is in good qualitative agreement with measurements by the NPA method. In contrast, contour of the C^{2+} ion line is reasonably depicted by only one Gaussian curve. The halfwidth of this contour corresponds to the temperature value ~30 eV, Fig.6c.

The "temperature" of H atoms found from H_α line width was estimated as ~2ev without accounting other broadening factors. This value is in accordance with typical data for the energy of Franck - Condon H atoms.

3. SUMMARY

1. The spectroscopic data on ion temperature from measurement of CV 227nm line structure showed the existence of double-energy distributions of C^{4+} ions. This is in a quite good agreement with results of NPA data for energy distribution of the main plasma component (H^+ ions).

2. To our regret, the intensity of CIII and CV lines was not enough to provide similar measurements in the D-D cross section and thus to obtain the information on radial distribution of T_i. Such measurements are planned to be provided in the next campaign when plasma parameters n_e, T_e will be sufficient for this.

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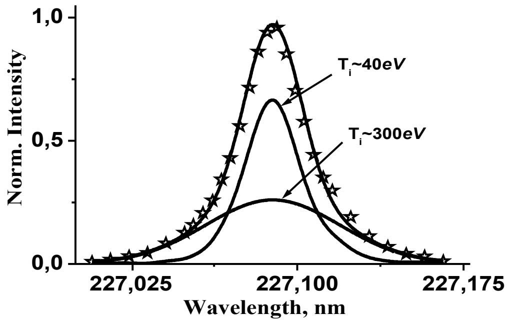

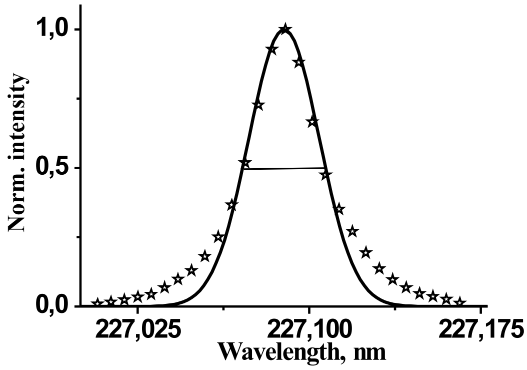

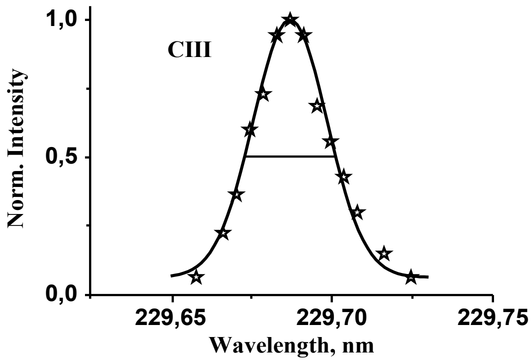

Fig. 6a. Experimental points together with a Gaussian fitting contour.

Fig. 6b Two Gaussian profiles fit with different halfwidth of every component.

Fig.6c. Calculated contour of the C^{2+} ion line and the experimental points.