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Multichord Photoemission Monitoring System in UV-Visible Range of a Reversed Field Pinch Machine TPE-RX

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Abstract

Population distribution of carbon ions (C^{4+}) in a poloidal cross section of a reversed field pinch machine TPE-RX was derived from chord-averaged emission intensities. Thirteen vertical ports of the poloidal section were used to observe photoemission. The peak of the distribution appeared at $|r/a| = 0.9$ where a (= 450mm) was minor radius of the plasma. The C^{4+} ions were almost absent around core region.

Keywords:

RFP plasma, poloidal distribution, emission, carbon, impurity, Abel inversion, C^{4+}, TPE-RX, tomography

1. Introduction

The dominant ionization stage of a certain impurity in a small volume of plasma depends primary on the electron temperature (T_e) around the volume. Electron density (n_e) also contributes the equilibrium. Therefore, the continuous observation of the emission intensity from various ions can be a technique to monitor the change of T_e and n_e. The temporal resolution of light detection in visible and UV region is quit high, and therefore, the photoemission monitoring has an advantage to detect the sudden change of T_e compared with, for example, the Thomson scattering method.

The wavelength range of our monochromators is from 200 to 800nm. In this range, the promising spectral line of a likely species, which has high ionization potential, is the $2s^3S^0(J = 1) - 2p^3P^0(J = 0, 1, 2)$ transition (227.1nm) of C^{4+} ion (I_p = 392.1eV). Therefore, we have first tried to derive the population distribution of C^{4+} ion in a poloidal cross section for a typical discharge of a reversed field pinch machine TPE-RX [1]. The result can be used as a standard for the future various experiments.

2. Experimental Method and Results

A multichord photoemission monitoring system for TPE-RX was constructed. Thirteen vertical ports were designed for the tomography of photoemission in a poloidal section. The cross section of the vacuum vessel is shown in Fig. 1 [2]. Two monochromators (Optometrics DMC1-02, f = 74mm) were connected to those ports using glass fibers. The number of monochromators was insufficient at the present, and the connecting ports were changed shot by shot. The wavelength was set at 227.1nm. The wavelength resolution of the monochromator was up to 1 nm in FWHM. The temporal resolution of the measurement was limited to be 10 kHz by a preamplifier. The signal was recorded by CAMAC data acquisition system whose sampling frequency was set at 100kHz.

The discharge shots were repeated with a flat-top plasma current of 270kA. The reproducibility of the

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time evolution of photoemission was enough to obtain higher reliability by averaging. Twenty shots were repeated for each port. (Two monochromators were simultaneously connected to different ports, and therefore, the data for totally 130 shots were analyzed.) An example of the time evolution of the recorded data for port S2U10 is shown in Fig. 2 together with those of plasma current (I_p) and toroidal magnetic field at plasma surface (B_{tw_in}).

The first peak from 1 to 3 ms was assigned to the $5s^4P^0$-$3p^4D$ transition of C^+ ions (227.0 nm). The emission of the $2s^3S^0(J = 1) - 2p^3P^0(J = 0, 1, 2)$ transition of C^{4+} ions gradually increased from t = 7ms and continued to the end of the shot. Several spikes were apparent after t = 10 ms in all shots. Those spikes may be due to iron emission produced by plasma wall interactions. The number of spikes decreased after the reversal toroidal field was applied for t > 20ms.

Observed radiation intensity at the flat-top phase of t = 25–35ms was accumulated, and the derived values are plotted in Fig. 3. Each point in Fig. 3 was the averaged values over twenty shots. The intensity at the limiter surface (r = ±45cm) was assumed to be zero.

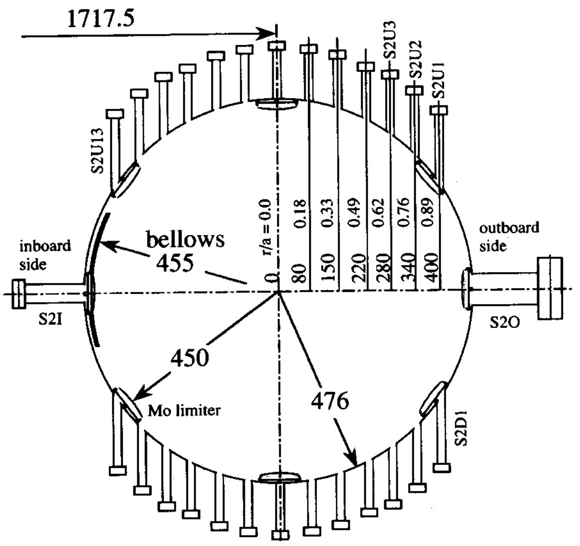

Fig. 1 The poloidal cross section of the vacuum vessel of TPE-RX for the tomography experiment of light emission. The molybdenum limiters were attached between the root of the ports and bellows parts of the torus. The plasma diameter was limited by the limiters up to 450mm. The inner diameters of the bellows and simple pipe parts were 455mm and 476mm, respectively.

3. Discussion

We have tried curve fittings to the experimental data by using various fitting functions, and the result using $I(r) = e^{A(r-B)} + e^{C(r-D)} + E$ is also shown in Fig. 3, where A, B, C, D and E are the fitting parameters. This function was selected because we thought the

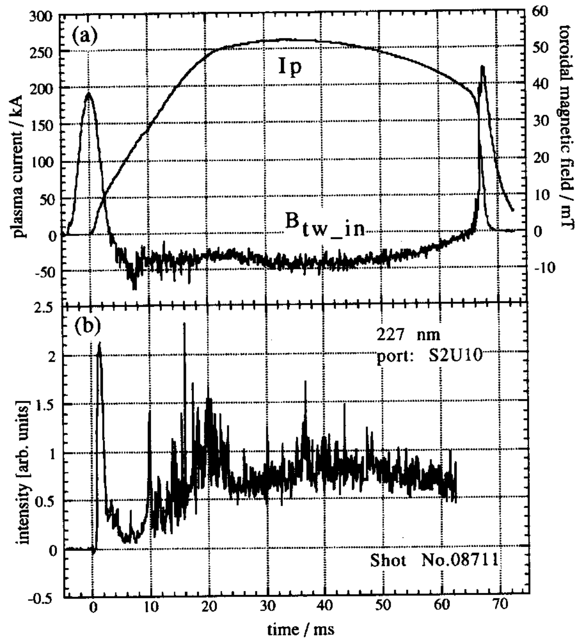

Fig. 2 Time evolutions of (a)plasma current, toroidal magnetic field at the plasma surface (B_{tw_in}) and (b)photoemission at 227nm for shot #08711. The monochromator was connected to port S2U10. The emission signal was interrupted because of insufficient record length of memory.

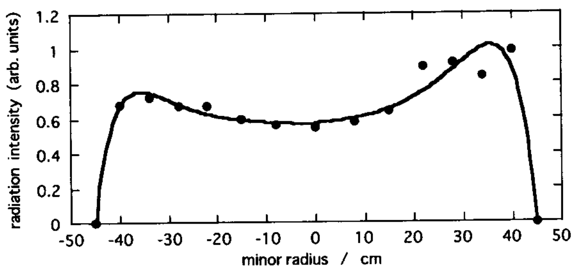

Fig. 3 Chord-averaged emission intensity at 227nm. The signal was accumulated over 25–35ms. Each point was averaged value of data for twenty shots. The fitted functions for the data were also shown. The fitting was carried out for the outboard and inboard sides separately with $I(r) = I(r) = e^{A(r-B)} + e^{C(r-D)} + E$ where A, B, C, D and E were the fitting parameters.

distribution have to be smooth with minor radius. The data for the outboard and inboard sides were fitted separately. The resulting distribution of C^{4+} ions via the Abel inversion of the fitted function is shown in Fig. 4. As seen in the figure, the peak of the C^{4+} distribution appeared at $|r/a| > 0.9$, and C^{4+} ions were almost absent in the core region $-0.5 < r/a < 0.5$. Consequently, a hollow distribution is apparent. The outmost ports are located at $|r/a| = 0.89$ (S2U1 and S2U13), and therefore, the reliability of the derived peak position of the C^{4+} distribution is doubtful. We think that the peak position is located at least outer than the second ports ($|r/a| = 0.76$).

The result suggests that the electron temperature and electron density at $|r/a| = 0.9$, i.e. only 5cm apart from limiter surface, are high enough to ionize C^{3+} into C^{4+} despite the ionization potential is as high as 65eV. Furthermore, the excitation energy of the upper level of the observed C^{4+} transition is 308eV. Therefore the presence of electrons with translational energy higher than 300eV is evident. The C^{4+} ions are almost fully ionized into C^{5+} around $|r/a| < 0.5$. In RFX, The peak position of $r/a \sim 0.8$ was derived from a one-dimensional impurity diffusion model [3]. Our observed distribution is close to the RFX situation. We are planning to apply the simulation calculation to TPE-RX.

From the Doppler broadening of the C^{4+} line, ion temperature (T_i) of 50–100eV was observed. When the

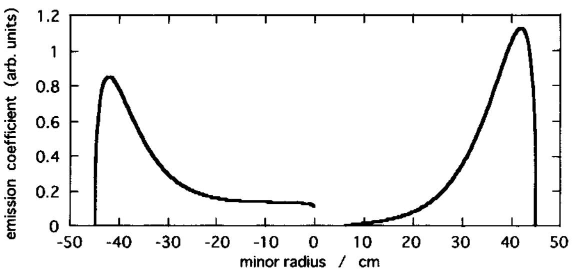

Fig. 4 Calculated C^{4+} population distribution for 25–35ms by the Abel inversion of the fitted functions shown in Fig. 3.

parabolic dependence [4] of ion temperature (T_i) is assumed, $T_i(r = 0) = 300$–500eV is derived from $T_i(r/a = 0.9) = 50$–100eV. This result is well coincide with the $T_i(r = 0) < 700$eV calculated by the relation $T_i/T_e \sim 0.7$ [5] using $T_e < 1$keV (X-ray analysis with a SiLi detector [1,6]).

The significantly higher intensity at the outboard side was found in Fig. 3, and we do not have any explanation for this unbalance at the present. The similar result was observed in the RFX machine in Italy.

4. Conclusions

The population distribution of C^{4+} ions for the discharge with a 270kA flat-top current was derived from chord-averaged radiation intensity of C^{4+} line at 227nm. The peak of the distribution appeared around $|r/a| = 0.9$ where outermost ports were connected. This result indicates that (1) the electron temperature and density at $|r/a| = 0.9$, i.e. 5cm apart from plasma boundary, reaches to almost fully ionize from C^{3+} to C^{4+} ions ($I_p = 65$eV) and (2) those at $|r/a| = 0.5$ are enough to ionize from C^{4+} to C^{5+} ions ($I_p = 392$eV).

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