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On measurement of ion temperature at the center of high density plasmas of JT-60SA
JT-60SAの高密度プラズマ中心部でのイオン温度測定について

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Because of significant decay of neutral beam, the C VI emission intensity becomes so low that estimated uncertainties of the ion temperature and Doppler shift do not satisfy the requirements in the JT-60SA research plan. To satisfy the requirements, it is necessary to increase the law signal by a factor of 5 for the uncertainty of the ion temperature and by a factor of 20 for that of the Doppler shift. This can be accomplished by increasing the number of bundled optical fibers, or long exposure of a detector although the spatial and/or time resolution decreases.

1. Introduction

Ion temperature is one of the fundamental quantities to determine the fusion reaction rate. In fusion experimental devices, in order to measure the ion temperature, beam-aided charge exchange recombination spectroscopy (CXRS) [1] has been often applied. With this measurement technique, local ion temperatures along neutral beam can be measured. However, the measurement is limited to the location where sufficient neutrals are supplied from the neutral beam. Hence it is difficult to measure the ion temperature at the center of high density plasmas due to significant decay of the neutral beam. This is the case in JT-60SA. Uncertainty of the ion temperature depends on the signal-to-noise ratio of the measured spectrum. In order to evaluate the signal-to-noise ratio, it is necessary to consider the sensitivity of the whole measurement system, which consists of optics, a spectrometer and a detector, in addition to evaluation of the emission intensity from the plasma. This evaluation gives essential information for design of the measurement system.

2. Simulation

2.1. *Target plasma and neutral beam*

The electron and ion temperature, and electron density profile for the present analysis are shown in Fig. 1. The plasma effective charge is assumed to be 2.2. These parameters are based on Scenario 2 of JT-60SA. A deuterium neutral beam with an injection power of 1.7 MW is injected from the edge (the normalized minor radius, ρ = 1) toward the center (ρ = 0). The ratio of the beam component with an energy of 85 keV, 42.5 keV and 28 keV is assumed to be 65 : 20 : 15 [2]. The beam deposition, density and emission intensity of C VI (n= 7-8) are calculated one-dimensionally along the beam axis with 50 cells.

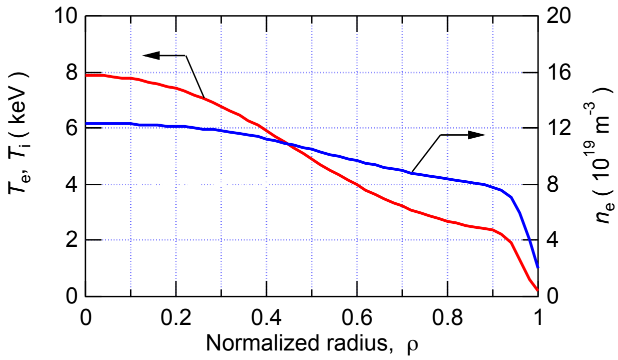

Fig.1. Electron (T_e) and ion (T_i) temperature ($T_e = T_i$) and electron density (n_e) profile.

2-2. *Analysis model*

The deposition of the neutral beam n_{dep} at a cell i is calculated with a beam stopping cross-section σ_{ST} [3] as follows:

$$n_{dep}(i) = n_{NB}(i)\,\sigma_{ST}\,v_{NB}\,n_e(i)\,dt \quad (m^{-3}),$$

where n_{NB} is a beam density, v_{NB} a beam velocity, dt a time to penetrate a cell i. Some of beam deuterium atom is excited by a collision with electron and deuteron in the plasma. The population of excited level at a principal quantum number of 2 is calculated with a collisional-radiative model in the case of electron collision [4] and with a coronal model in the case of deuteron collision. Then, the charge exchange reaction of the ground and the excited beam deuterium with thermal C^{6+} produces excited C^{5+} at n=8, resulting in C VI (n=7-8) emission, which intensity is calculated with emission rate coefficients from ADAS [5].

2-3. *Synthesis of spectrum*

The C VI emission is collected with lenses, transmitted through optical fibers into a spectrometer, and detected with a CCD camera. The sensitivity of the optical system is assumed to be the same as that of the optical system used in JT-60U. With this sensitivity, the C VI emission is converted to the number of photo-electrons N_{PH} in each CCD pixel. The noise for the photo-electrons expressed as $\sigma_{PH} = N_{PH}^{0.5}$ is added. Then, the number of photo-electrons is multiplied by a factor of 200 (this is a simulation of a gain function such as EM gain), and converted to digital counts by dividing with a analog-to-digital ratio of 8.7. Finally the spectrum of C VI (n=7-8) is synthesized from the counts and the width determined from the ion temperature at the center of the plasma (8 keV).

The synthesized spectrum is fitted with a Gaussian function in order to evaluate uncertainties of ion temperature and Doppler shift.

3. Results

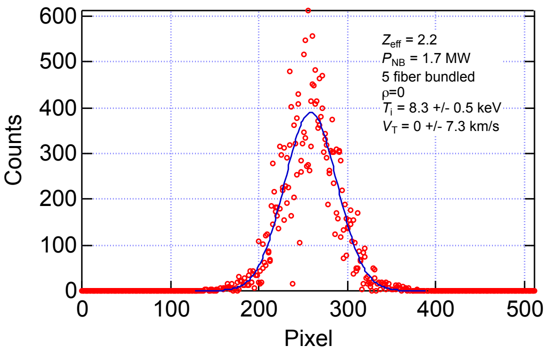

Fig.2. Predicted C VI (n=7-8) spectrum and a curve fitted with a Gaussian function as a function of pixel number of CCD. The number of bundled optical fiber is assumed to be 5.

Figure 2 shows the spectrum synthesized with the present model. The evaluated uncertainty of the ion temperature (0.5 keV) is satisfied with the requirement, 10% of the ion temperature, *i.e.*, 0.8 keV, according the JT-60SA research plan [6]. However the uncertainty of the Doppler shift is larger than the requirement, 5 km/s.

In order to reduce the uncertainty of the Doppler shift, it is necessary to improve a signal-to-noise ratio by increasing collected number of photons. Here this is investigated by increasing the number of bundled optical fibers. Figure 3 shows the uncertainties of the ion temperature and the Doppler shift as a function of the number of bundled optical fibers. The uncertainty of the Doppler shift decreases with increasing number of optical fibers. The requirement of the uncertainty of 5 km/s is satisfied in the case that 20 fibers are bundled.

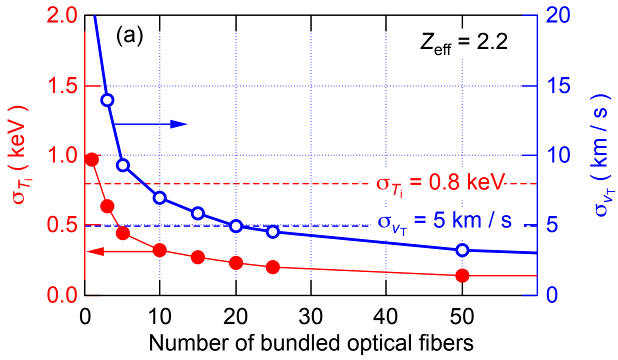

Fig.3. Estimated uncertainties of the ion temperature σ_{T_i} and the Doppler shift σv_T as a function of bundled optical fibers.

4. Discussion

To improve the signal-to-noise ratio, long exposure of the CCD camera is an alternative way. However, long exposure time results in poor time resolution while increasing the number of bundled optical fiber results in poor spatial resolution. Hence the best solution, which satisfies the requirements of the time and the spatial resolution, should be determined. This depends on an experimental purpose.

Other factors that cause uncertainties, for instance, background emission of C VI (n=7-8) and bremsstrahlung emission, will be considered in future analysis. Because both of the above factors decrease the signal-to-noise ratio, further increase of the number of bundled optical fiber is required to meet the requirements for the uncertainties.

5. Conclusions

The requirement of uncertainty of the ion temperature from the JT-60SA research plan can be satisfied if 5 optical fibers are bundled. However, a bundle of 20 optical fibers is needed to meet the requirement of uncertainty of the Doppler shift.

References

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