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Radial Argon K_α Profile Measured with Pulse Height Analyzer in LHD

MUTO Sadatsugu, MORITA Shigeru and LHD Experimental Group

National Institute for Fusion Science, Toki 509-5292, Japan

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Abstract

The first measurement of time-resolved radial profiles of argon K_α lines has been successfully done in Large Helical Device, using an assembly equipped with conventional semi-conductor detectors and pulse-height analyzers. The fixed argon discharges enabled the radial scanning of the assembly. Results obtained here indicate that a transport study on impurity also becomes possible with the pulse-height analyzers as well as the measurement of electron-temperature profile.

Keywords:

argon, titanium, chromium, iron, K_α line, radial profile, Large Helical Device

1. Introduction

Measurement of x-ray spectrum is important to obtain significant information from a core plasma such as the electron temperature, heavy impurity concentration, an impurity transport, and the non-thermal electron density. Especially, regarding to the impurity transport, the measurement of a space- and a time- resolved spectra are essentially requested. In order to obtain such spectra in x-ray region, a few diagnostics have been constructed until now. In JET tokamak a diffusion coefficient was evaluated combining with an impurity injection [1].

The x-ray signals detected from high-temperature plasmas are always integrated along the line-of-sight. An Abel inversion of the detected signal is necessary in order to obtain the radial emission profile. The Abel inversion strongly depends on the plasma shape and the line-of-sight of the diagnostics. In order to eliminate the large error after Abel inversion, the soft-x-ray diagnostic system installed in Large Helical Device (LHD; R_{ax} = 3.6 m, a = 0.64 m, B = 2.9 T) was set at the vertically-elongated plasma cross-section and measured perpendicularly to the magnetic axis from just below the plasma.

In this paper the measurement on the time-resolved argon K_α profiles in LHD is presented. Furthermore, inverted emission profile of argon is also reported with K_α profiles of intrinsic heavy metallic impurities.

2. Experimental procedure

The first measurement of time-resolved Ar profiles in LHD was done using an assembly equipped with Si(Li) semi-conductor detectors and a movable slit which can scan the sight line of the detectors along the major radial direction of LHD. The position of the movable slit is monitored by an encoder. The x-ray signal detected with the assembly was converted into the line-integrated radial profile using the encoder signal [2]. The evaluations of electron-temperature profile up to 10 keV and metallic impurities are available, since the detector covers a broad energy range from 1 keV to 30 keV. A fast pulse-height analyzer (PHA) is also adopted for digitizing of the amplified signal voltage. The maximum counting rate of 64 $\times$ 4 kcps was achieved per one detector in which four Si (Li) elements are mounted. Consequently, the intensity of the line spectrum has been estimated with a time resolution of 2 msec as the maximum performance. The time- and space- resolutions are not simultaneously obtained at present. In order to obtain many radial points needed for better radial profile, several fixed discharges were carried out.

The continuum intensity becomes too high below an x-ray energy of 4 keV. In order to avoid the signal saturation of the PHA, 1 mm-thick beryllium is normally inserted as a filter. The use of the filter, however, also reduced the Ar K_α intensity, because the x-ray attenuation rate at Ar K_α energy was larger than 10^2.

In LHD Ar discharges have been carried out for a specific purpose of high-performance discharges with higher central ion temperature. In addition, a small

Corresponding author's e-mail: mutos@nifs.ac.jp

amount of Ar gas is routinely puffed at the beginning of discharges to measure ion temperature from ArXVII Doppler broadening. Then, the argon becomes a regular element for in LHD discharges. The Ar discharges were produced and heated by three tangentially injected neutral beams (NBI). The line intensity of Ar K_α x-ray lines was remarkably enhanced compared with K_α lines from intrinsic heavy impurities in H_2 and He discharges. Therefore, the measurement of Ar K_α profile was clearly improved with decreasing a static error.

In order to analyze the radial profile of Ar K_α lines, the integration equation derived from the arrangement of the assembly is taken into account;

$$F(\rho) = 2\int_0^\infty \mathrm{d}x f\left(\sqrt{\rho^2 + x^2}\right), \tag{1}$$

where $f(\rho)$ is a radial distribution of impurity lines. The impurity K_α profile observed with the assembly is expressed by $F(\rho)$ in Eq. (1). Of course, it is assumed that the x-ray intensity from impurities is constant along a magnetic surface. If $F(\rho)$ is a gaussian, $f(\rho)$ is easily derived as expressed by Eqs. (2) and (3),

$$f(\rho) = \frac{1}{\sqrt{\pi}\sigma} F(\rho), \tag{2}$$

$$\because \; F(\rho) \equiv e^{-(\rho/\sigma)^2}, \tag{3}$$

where the normalized plasma radius and the width of the Gaussian profile are denoted by ρ and σ, respectively.

3. Results and discussions

In H_2 and He discharges of LHD an x-ray spectrum was obtained with the assembly at center code as is shown in Fig. 1. The K_α emissions from titanium, chromium, and iron appear at 4.7 keV, 5.6 keV, and 6.6 keV, respectively. The continuum x-rays originally increase when the x-ray energies decrease. However, the observed intensity begins to decrease below 4.5 keV. This is simply explained by the reduction of the transmission rate in the used beryllium filter. The signals below 2.0 keV are discriminated because of the signal noise from a preamplifier of the detector.

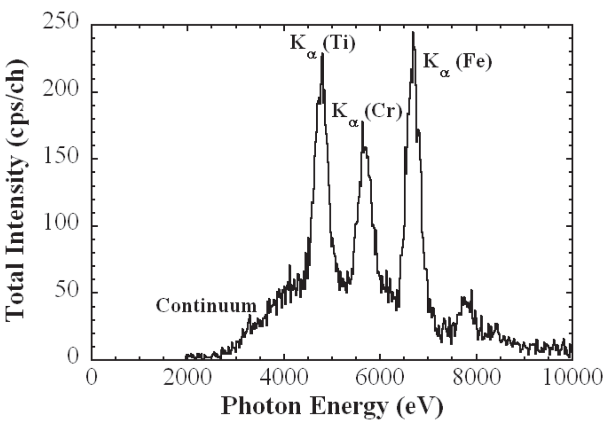

Fig. 1 Typical spectrum obtained from H_2 and He discharges in LHD. Spectrum was measured with the PHA assembly. Lines denoted with K_α (Ti), K_α (Cr) and K_α (Fe) indicate the K_α lines of titanium, chromium, and iron, respectively.

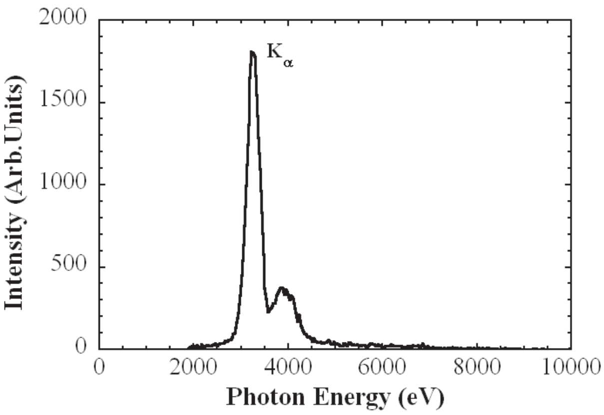

Fig. 2 Typical spectrum from Ar discharges in LHD.

In the case of Ar discharges an x-ray spectrum was obtained as is shown in Fig. 2. The Ar K_α line appears at 3.2 keV. Taking into account the transmission rate of the Be filter, the real Ar K_α emissions are 2 orders stronger than those of metallic K_α lines as mentioned above. In Fig. 2 the intensity of continuum is negligible in compared with Ar line, while the continuum intensity is comparable to the metallic impurity case (also see Fig. 1). Accordingly, the radiation loss in Ar discharges is dominated by the Ar line emissions in an x-ray region higher than 3 keV. This situation is quite different from the case of H_2 and He discharges.

Figure 3 shows typical profiles of metallic K_α lines obtained with the assembly in a single shot. The electron temperature profile measured from the continuum is also indicated. In the case of H_2 and He discharges, long pulse discharges become available [3]. In these discharges, the electron temperature, density, and the intensity of impurity lines were constant at least over 8 sec. In order to obtain the profile the movable slit was continuously scanned at a constant velocity.

Figure 4 shows a typical profile of Ar K_α lines which was plotted at 3.2 keV as shown in Fig. 2. The electron temperature at plasma center was 5.0 keV. The line intensity of Ar K_α was not constant and strongly time-dependent, because a strong Ar gas was puffed at the beginning of the discharges. This situation is quite different from the long pulse H_2 and He discharge cases. Then, the measured line profile could not be obtained in

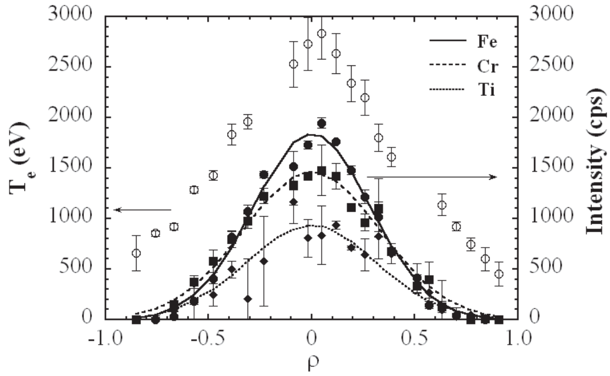

Fig. 3 Typical radial profiles of K_α line emitted from heavy metallic impurities such as titanium (solid diamonds), chromium (solid squares), iron (solid circles) and electron temperature (open circles). K_α profiles were fitted by Gaussian. The data corresponding to each point were obtained with an accumulation time of 240 msec.

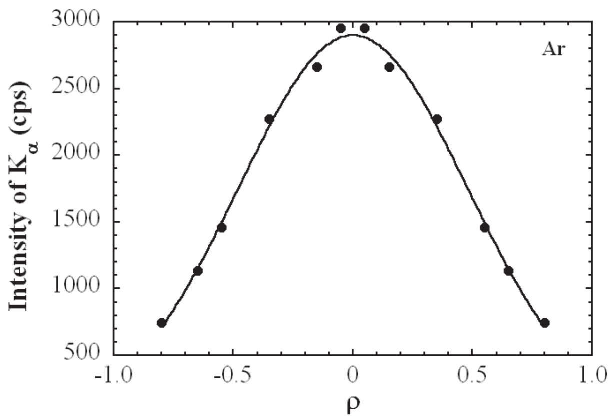

Fig. 4 Typical radial profiles of Ar K_α lines. Solid line indicates a Gaussian fitting. The data are obtained with an accumulation time of 50 msec.

a single shot. Several fixed discharges were necessary to measure the Ar profile. For the purpose the position of the slit was scanned shot by shot. Time- and space-resolved Ar K_α profile was, thus, successfully obtained.

Figure 5 shows the radial emissivity of the K_α lines emitted from Ar, Ti, Cr, and Fe. The radial emissivity of the K_α lines is calculated through the Abel inversion satisfying Eq. (1). The measured K_α profiles of Ti, Cr, Fe, and Ar are fitted by a single gaussian as is shown in Figs. 3 and 4. As expressed by Eqs. (2) and (3), the radial emissivity can be simply obtained using the Gaussian fitting.

The temporal behavior of Ar K_α lines is measured with a time resolution of 25 msec as shown in Fig. 6. The Ar K_α begins to increase after Ar gas puffing at $t = 500$ msec and decays at $t = 700$ mse. Using this behavior the study on impurity transport in core plasma becomes possible.

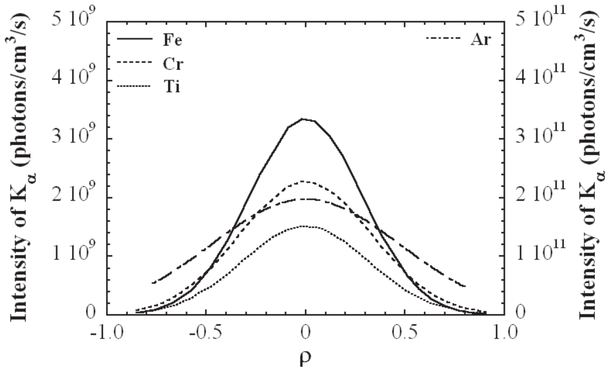

Fig. 5 Typical radial emissivity of K_α line emitted from argon (chain line) and heavy metallic impurities such as titanium (dotted line), chromium (broken line), and iron (solid line). K_α profiles were fitted by Gaussian.

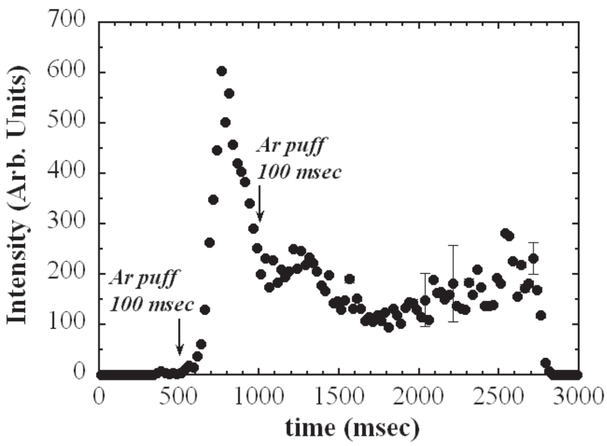

Fig. 6 The time evolution of Ar K_α lines. Ar gas puffing is done at $t = 500$ msec and $t = 1000$ msec.

A diffusion coefficient and a convective velocity of particles are basically a function of radial position of plasmas. The radial flux is derived from a density profile through a transport equation;

$$\frac{\partial}{\partial t} n(\vec{r}, t) = \nabla \cdot \vec{\Gamma}(\vec{r}, t), \tag{4}$$

$$\vec{\Gamma}(\vec{r}, t) = -D(\vec{r}) \nabla n(\vec{r}, t) + \vec{V}(\vec{r}) n(\vec{r}, t), \tag{5}$$

where the vectors $\vec{r}$, $\vec{\Gamma}$, $\vec{V}$, and the scalars $n(r)$, D are radial position, particle flux, convective velocity, density profile, and diffusion coefficient, respectively. From Eq. (4) the diffusion coefficient is obtained as

$$D(\rho) = \frac{D(0)}{2} \left[\left(\frac{\rho}{\sigma} \right)^{-2} \left\{ e^{\left(\frac{\rho}{\sigma} \right)^2} - 1 \right\} + 1 \right], \tag{6}$$

where $D(0)$ is the diffusion coefficient at plasma center. In Eq. (6), the density profile is assumed to be

$$n = n_0 e^{-\left(\frac{\rho}{\sigma} \right)^2} \cdot e^{-\left(\frac{t}{\tau} \right)}, \tag{7}$$

where t, τ, σ and n_0 are time, density decay time, gaussian width and central density, respectively. In addition, the convective velocity is also assumed by

$$V(\rho) = -V_a\rho, \tag{8}$$

$$V_a\tau = -\frac{a}{2}, \tag{9}$$

where a is averaged plasma radius. Thus, the diffusion coefficient and the inward velocity become a simple function of the decay time. Here, the value of the diffusion coefficient at plasma center is given by

$$D(0)\tau = 2\left(\frac{a\sigma}{2}\right)^2. \tag{10}$$

As mentioned above, the time evolution of density distribution is necessary in order to obtain the diffusion coefficient and the convective velocity. A code analysis implies that the width of Ar distribution is approximately 0.47 (= σ) in minor radius. Consequently, the diffusion coefficient at the plasma center is roughly inferred to be 0.2 m^2/s through the Eq. (10). From Eq. (9) the convective velocity at plasma edge is also estimatedto be 1 m/s (inward).

4. Conclusions

In LHD a time evolution of Ar K_α profile has been successfully obtained by several fixed Ar discharges using an assembly equipped with conventional semiconductor detectors. In the present experiment the most important profit of the assembly is conspicuously indicated. Especially, the radial emission profile of K_α emitted from argon, titanium, chromium, and iron are derived.

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