Radial Profile of K_α line energy shift from Metallic Impurities measured with X-Ray Pulse Height Analyzer in LHD

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Radial profiles of metallic impurity have been successfully obtained in Large Helical Device, using an assembly equipped with conventional semiconductor detectors and soft x-ray pulse-height analyzers. Long pulse discharges have enabled the radial scanning of the assembly to measure the radial profiles of K_α lines of metallic impurities. The assembly of soft x-ray pulse-height analyzer makes it possible to obtain the concentrations of the impurities in connection with a cord calculation.

Keywords: Pulse Height Analyzer, Iron, chromium, titanium, Large Helical Device.

1. Introduction

Measurement of x-ray energy spectrum is important to investigate fundamental properties of magnetically confined high temperature plasma, since the spectrum reflects information on electron temperature, impurity, and non thermal electron. [1] Recently, it is intended to rise up the spectral, special and temporal resolution in the x-ray diagnostics to obtain significant information such as the shift of magnetic axis, electron temperature profile, and especially impurity transport. [2] However, in an x-ray region it is fundamentally difficult to get simultaneously the energy and another resolution mentioned above. Recent technology has not yield any applications which can fully resolve the problem.

An assembly of pulse height analyzer (PHA) has been constructed in Large Helical Device (LHD). The assembly is equipped with a utility called a radial scanning system which modulates and identifies the sight line of PHA along the major radius direction of LHD. The scanning range of the system fully covers the plasma in the major radial direction. With the system the radial profile of x-ray spectrum is obtained. Accordingly, Abel inversion of x-ray spectrum is available, although signals obtained with an x-ray detector are line integrated along the sight line of the detector,

It is the most important advantage of the PHA that the energy resolution is enough to distinguish each K_α line of impurity and the absolute number of photons can be obtained. Especially, K_α lines of impurities heavier than argon have been observed in LHD. [2]

The radial profiles of K_α lines emitted from metallic impurities such as titanium, chromium, and iron have been successfully observed with the assembly. The energy shift of K_α line is also observed. In addition to the experiment the intensity profile of K_α line emitted from respective charge state of metallic impurity is calculated as a function of electron temperature and density profiles. As a result absolute density has been estimated in comparison with the experimental results and the calculation.

In this article experimental results in LHD are presented on the radial profiles of K_α line observed with the assembly. Furthermore, the analysis on the density of the respective charge state is also reported.

2. Assembly for x-ray measurement

The profiles of K_α lines have been carried out in LHD using the assembly. The performance of the assembly has been reported with observed K_α lines of metallic impurities and continuum in a reference [3]. It must be mentioned here that the energy resolution of the PHA is 160 eV at 3.2 keV and the maximum counting rate is 10 kcps in the present experiment. The sight line of the detector is modulated along the major radial direction of LHD in a few hundred milliseconds. Next scanning starts in a time interval of a few seconds. Then, scanning is available approximately four times in ten seconds. It is also the advantage of the assembly to permits adjustable acceptance of the sight line and scanning time. As a result, the spatial resolution is approximately 20 millimeters on the central cord.

The observed x-ray spectrum must be inverted to a local emissivity profile. The x-ray intensity obtained with the assembly is line integrated. The calculation process of the inversion is qualitatively reported with the arrangement of the assembly. [2]

3. Experimental results

Examples of x-ray spectra obtained in the present experiment are shown in Fig.1. Taking into account the transmission rate of a beryllium filter with a thickness of

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1 mm, the spectrum has to be modified. Then, the real intensity is stronger in the energy range below 4.0 keV. The spectra consist of emissions from two different origins. One is the continuum emission from electrons as bremssstrahlung. The other is the K_α lines emitted from metallic impurities. The radiation loss due to metallic impurities is comparable with that of the continuum in the energy range above 4.0 keV as is shown in the figure. Accordingly, the intensity of the K_α lines must be estimated by subtracting the continuum. The intensities of the spectra are strongly dependent on the electron temperature. Particularly, it is available to estimate the electron temperature from the continuum. In addition to the continuum it is also confirmed that K_α line emitted from iron at a radius of ρ = 0.5 shifts toward lower energy side than that of ρ = 0.2. This fact is one of significant results in order to obtain the density profile of respective charge state of metallic impurity, since lower charge state of ion emits lower energy photon.

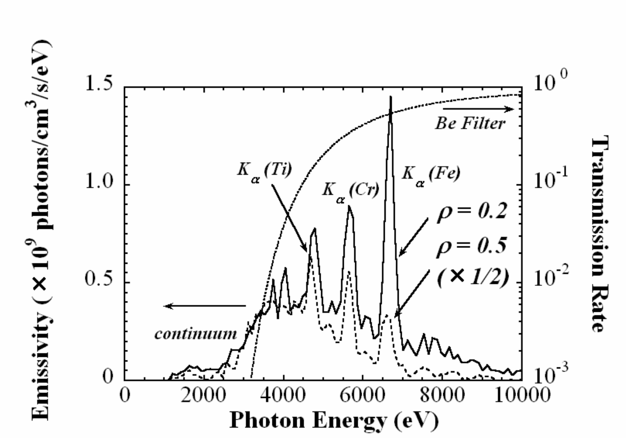

Fig.1 Typical x-ray energy spectra inverted from the radial profile of the spectrum which has been observed with the assembly in a single discharge. Solid and broken lines represent the spectra locally emitted from the radius of ρ = 0.2 and ρ = 0.5, respectively. The measurement has been carried out in hydrogen and helium discharges heated by NBI. K_α emissions from titanium, chromium and iron appear at 4.7 keV, 5.6 keV and 6.6 keV, respectively. The dotted line represents the transmission rate of the beryllium filter. The sign of 'ρ' represents the normalized radius of the LHD plasma.

Figure 2 shows typical profiles observed with the assembly. The radial profile of electron temperature estimated from continuum is also indicated. At present the flat top duration of the discharge is approximately 8 sec. Especially, the electron temperature, density, and the intensity of x-ray have been maintained to be constant during the accumulation time of the PHA. Consequently, the intensities of K_α lines reflect only the amount of the impurities.

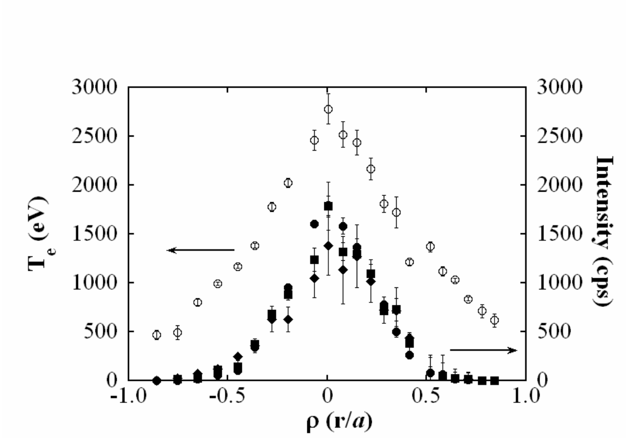

Fig.2 Typical radial profiles of K_α line emitted from metallic impurities of titanium, chromium, and iron, respectively. The intensities are line integrated along the sight line of the detector. Filled circles, filled rectangular, and filled diamond represent the line intensity of iron, chromium, and titanium, respectively. Solid lines are fitting functions for the observed profiles. Each function is a single Gaussian. Open circles with error bars represent electron temperature estimated from continuum. The accumulation time of x-ray for each point is 240 milliseconds.

4. Results of analysis and discussions

Figure 3 shows the intensity of the iron K_α lines emitted from two different positions in LHD plasma. In the figure results from a cord calculation is also indicated as vertical lines. The energy of line is depending on charge state as is indicated in the figure. Accordingly, the K_α line spectrum reflects the amount of respective charge state. In addition it is shown in the figure that the emission is mainly contributed from helium, lithium, beryllium, and boron like ions. In the present experiment the electron temperature is approximately 2 keV at the plasma center. Then, it is suggested from the calculation and the experimental results that there is much lower contribution from hydrogen like ion than helium like ion. In the calculation the diffusion coefficient is assumed to be 0.2 m^2/s. This assumption is consistent with the result from an argon transport experiment in LHD. [2]

It is obtained with the assembly that the intensity of the K_α line shifts toward lower energy side as the normalized minor radius increases as is shown in Fig.3. This fact qualitatively reflects that K_α lines from lower charge states increase at higher radius, since the electron temperature decreases. The shift is able to be qualitatively explained using Fig.4. In the figure the most intense line is emitted from lithium like ion in the region within ρ = 0.6. However, the intensity of lower charge state than lithium like ion rapidly increase in the region higher than ρ = 0.5. On the contrary, helium like ion decreases.

Consequently, it is qualitatively consistent with the experimental result shown in Fig.3 that the cord calculation predicts the spectrum to shift toward lower energy side.

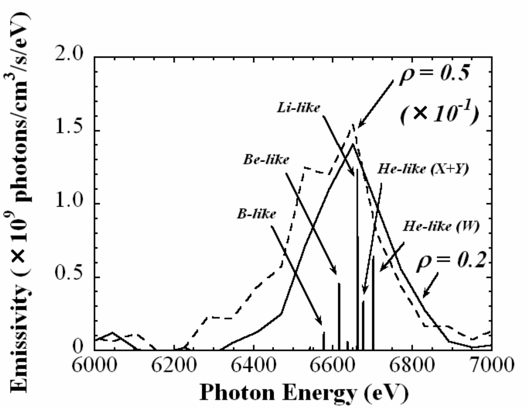

Fig.3 Energy shift of iron K_α line. The spectra are obtained from the inversion process of the experimental result and the subtraction of continuum. The spectra are also modified in consideration with the reduction of the beryllium filter. The solid line and the gray line represent the spectra emitted from the radius of ρ = 0.2 and the radius of ρ = 0.5, respectively. The solid vertical line means the result from the cord calculation.

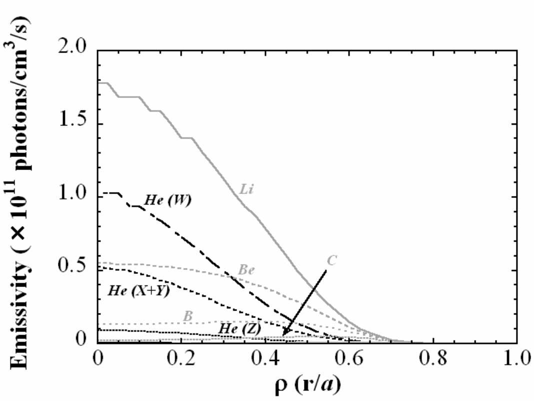

Fig.4 The radial profiles of iron K_α line derived from the cord calculation. Each line represents the emission from respective charge state. The lines emitted from lower charge state than carbon is too low to indicate.

The present experimental result on the energy shift gives rise to important information concerning the density profile of respective charge state of the metallic impurity. It is also the important advantage of the assembly to measure the photon number in addition to the energy resolution. Especially, the assembly makes it possible that the local intensity of the spectrum is obtained from the line integrated spectrum by the inversion process. Accordingly the absolute density profile of respective charge state is able to be quantitatively investigated to fit the spectrum by the cord calculation. Figure 5 shows the observed line spectra fitted by calculated functions in the case of ρ = 0.2. The calculation is consistent with the observed K_α lines emitted from iron, chromium, and titanium.

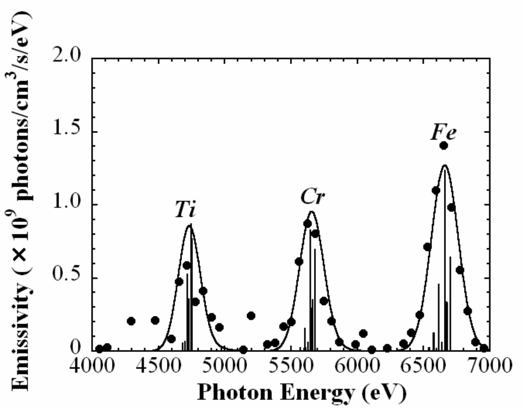

Fig.5 Typical K_α line spectrum obtained from the inversion process and the subtraction of the continuum at the radius of ρ = 0.2. The reduction of the intensity due to the filter is also taken into account. Filled circles and solid line represent the observed spectrum and fitting functions obtained by the cord calculation in consideration with the energy resolution of the PHA. The vertical lines also mean the results of the cord calculation without the energy resolution.

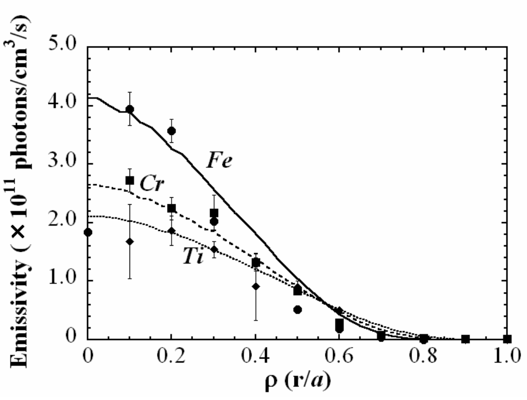

Fig.6 The radial profiles of K_α lines emitted from titanium, chromium, and iron. Filled circles, filled rectangular, and filled diamond represent the line intensity of iron, chromium, and titanium, respectively. Solid line, broken line, and dotted line are fitting functions for the observed profiles of iron, chromium, and titanium, respectively.

In the case of chromium and titanium the intensity profile of the K_α line is different from that of iron. The intensity of K_α line emitted from higher charge state increases and that from lower charge state decreases as the atomic number decreases. Particularly, the intensity of

K_α line emitted from beryllium like ion is much lower than that from lithium and helium like ion in the case of titanium. The spectrum of titanium consists of only the emission from lithium and helium like ion as is indicated by vertical lines in Fig.5. Although the energy difference of the emission from respective charge state is much smaller than the energy resolution of the PHA, the line width of the observed spectrum becomes gradually wider as the atomic number increases.

Radial profiles of K_α lines are also fitted. Figure 6 shows the observed radial profile of K_α lines and calculated functions. The intensity is obtained from the line spectrum by energy integration. In the case of chromium and titanium, the fitting is consistent within error bars. However, the observed intensity of iron decreases more rapidly than the result on the calculation in the region higher than ρ = 0.3. The assumption of temperature profile in the cord calculation seems to be slightly different from the actual profile. The intensity is sensitively depending on the profile of the electron temperature.

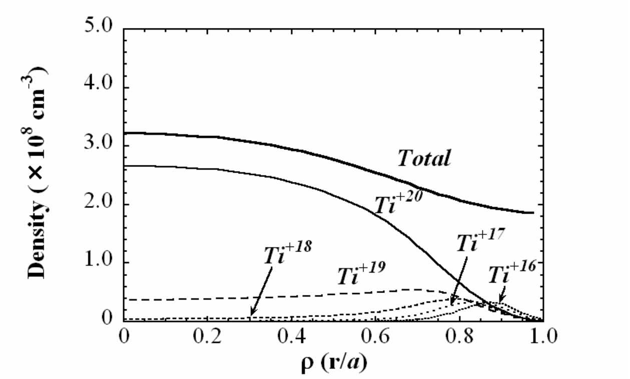

Fig.7 The radial density profile of respective charge state of titanium. Only the charge states mainly contributing to the spectrum are shown.

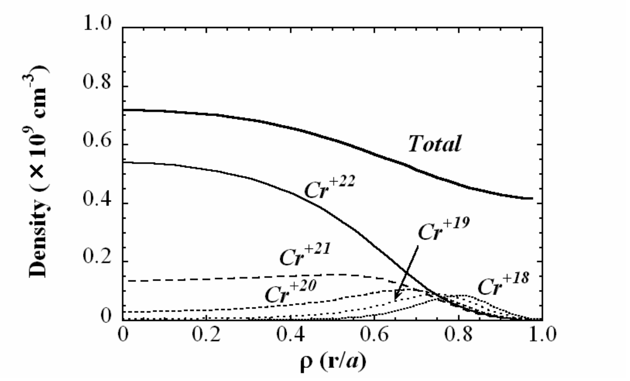

Fig.8 The radial density profile of respective charge state of chromium.

Figure 7 shows the density profile of titanium which is estimated by the fittings of spectrum and intensity profile. In the present experiment the amounts of bear and hydrogen like ion are much lower than helium like ion, although the atomic number of titanium is lowest in the observed impurities. It is commonly shown in Fig.7-9 that the helium like ion is dominant around the plasma center.

The concentrations of titanium, chromium, and iron are estimated to be 9.7×10^{-4} %, 2.1×10^{-3} %, and 5.9×10^{-3} % at the plasma center, while the electron density is 3.6×10^{13} cm^{-3}. Then, the densities of the metallic impurities are much lower than that of the electron. It is due to the difference of the x-ray photo-emission efficiency between the bremssstrahlung and the K_α lines that the intensities are comparable in the range higher than 4.0 keV. The efficiency of the K_α line is approximately four orders higher than that of the electron in x-ray region.

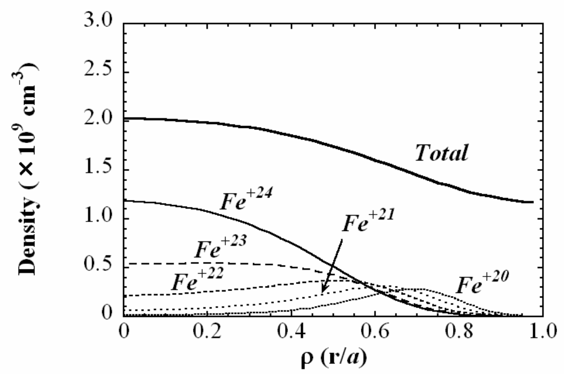

Fig.9 The radial density profile of respective charge state of iron.

5. Summary

Development of an assembly equipped with a radial scanning system attained a remarkable progress on measuring radial profile of x-ray spectrum in connection with conventional utilization of PHA. The line spectra have been successfully observed with good resolution enough to analyze the energy shift of the K_α line. From the analysis the radial density profile of respective charge state is estimated in the case of titanium, chromium, and iron, respectively.

References

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