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Impurity Emission Characteristics of Long Pulse Discharges in Large Helical Device

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Abstract

Line spectra from intrinsic impurity ions have been monitored during the three kinds of long-pulse discharges (ICH, ECH, NBI). Constant emission from the iron impurity shows no preferential accumulation of iron ion during the long-pulse operations. Stable Doppler ion temperature has been also measured from Fe XX, C V and C III spectra.

Keywords:

impurities, ion temperature, steady state, helical, LHD

1. Introduction

One of the principal aims of Large Helical Device (LHD) with superconducting coils is to develop physics and technology for steady state operation using the divertor [1-3]. Long-pulse discharge for the steady-state operation was demonstrated using three kinds of heating (ECH, ICRF and NBI). In steady state operation, impurity accumulation could have serious consequences at the improved confinement of H-mode plasmas. In this paper we report the time evolution of the radiation and Doppler ion temperature from intrinsic impurities in LHD during the long-pulse discharge. Especially, the line emission from highly-ionized iron ion at the core was studied concerned with the impurity accumulation. For most of shots in the long-pulse discharge, the major plasma bulk parameters including impurity concentrations are almost constant. However there is a case of an oscillation in the plasma parameters which is known as the "breathing" plasma [4]. The out-of-phase

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oscillation in emission intensities between light impurities and iron ion is discussed.

2. Spectrometers for Impurity Emission Measurements

Two spectrometers were used for spectroscopic diagnostics in long-pulse discharges. One is a Schwob-Fraenkel type 2 m grazing incidence spectrometer equipped with two multichannel detectors [5]. The total wavelength coverage of the instrument is 0.5–34 nm when equipped with a 600 g/mm grating, and 2–150 nm using a 133 g/mm grating. And the other is a 1-m UV, visible spectrometer, equipped with 1000 nm blazed grating and multichannel detector. The measurement of the 4–5th order spectra in UV region enables us to measure the Doppler ion temperature with high wavelength resolution (FWHM of 0.01 nm). C III (229.68 nm), C V (227.09 nm) and Fe XX (266.51 nm) spectra were measured to monitor the ion temperature. Two spectrometers are located on the horizontal port in LHD, and observe a horizontally elongated plasma section.

3. Long-Pulse Experiments

3.1 ICRF heating

Long-pulse discharges by Ion Cyclotron Range of Frequency (ICRF) heated plasma were carried out using a pair of loop antennas with applied frequency of f = 38 MHz. Relatively high influx rate of iron ion was observed during the ICRF heating. Figure 1 shows the time evolutions of highly ionized iron emissions for a pulse duration of 15 sec. Emission line intensities are kept constant.

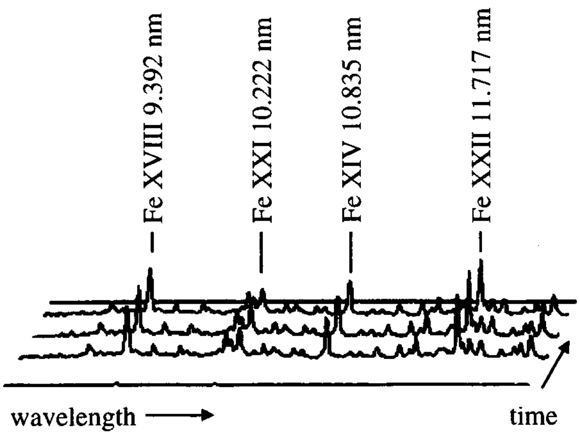

Fig. 1 Time resolved display of spectra for 15 sec discharge in the 8–12 nm range with 600 g/mm grating. Exposure time for one frame is 5 sec. (#17161)

Figure 2 shows the time evolution of Fe XX line intensity at 266.51 nm and derived ion temperature from Fe XX line profile in 68 sec injection (B_t = 2.75 T and R_{ax} = 3.60 m and the input power 0.9–1.1 MW). Various plasma parameters in 68 sec injection are almost constant with following, stored energy W_p = 100 – 130 kJ, electron temperature $T_e(0)$ = 2 keV, radiation power P_{rad} = 200 kW. The electron line-average density is also almost constant of $\overline{n_e}$ = 0.9 – 1.0 × 10^{19} m^{-3}. Ion temperature from Fe XX line profile is almost constant of about 2.0 keV for 68 sec. Line spectra from light impurities are also observed in other shots. Ion temperature from C III and C V spectra are about 80 eV and 500 eV, respectively and are constant until the end of the discharge.

3.2 ECH

In the electron cyclotron heating (ECH) the injection pulse duration was extended up to 120 sec in 2nd cycle experiment. The time evolution of the spectral lines in 8–19 nm region is shown in Fig. 3. Because of the low injection power of 50 kW, only low ionized iron spectra were observed with a constant level of intensity.

Figure 4 shows the line-average electron density evolution in the beginning part of ECH long pulse

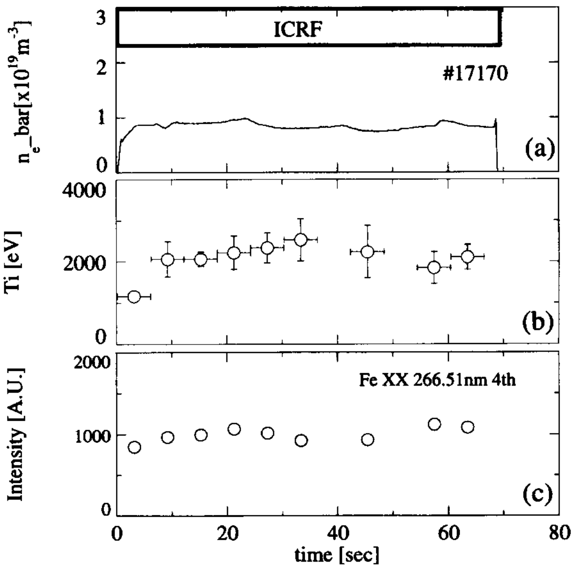

Fig. 2 (a) Time evolution of line-average electron density n_e, (b) Time evolution of Doppler ion temperature T_i from Fe XX, (c) Time evolution of line intensity of Fe XX spectrum in long-pulse ICH discharge.

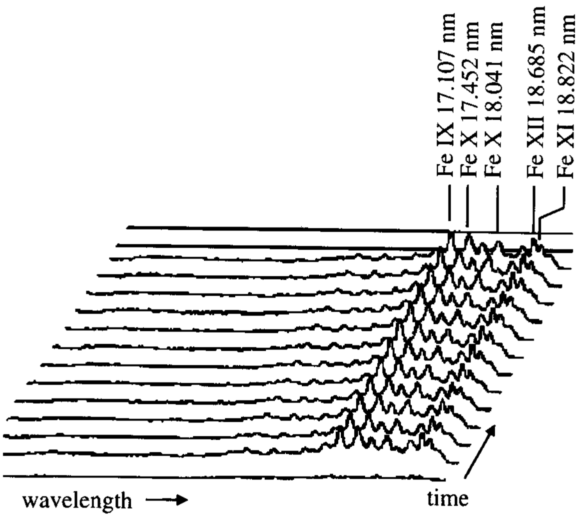

Fig. 3 Time-resolved display of spectra for 120 sec discharge in the 8–19 nm range with 133 g/mm grating. Exposure time for one frame is 10 sec. (#7132)

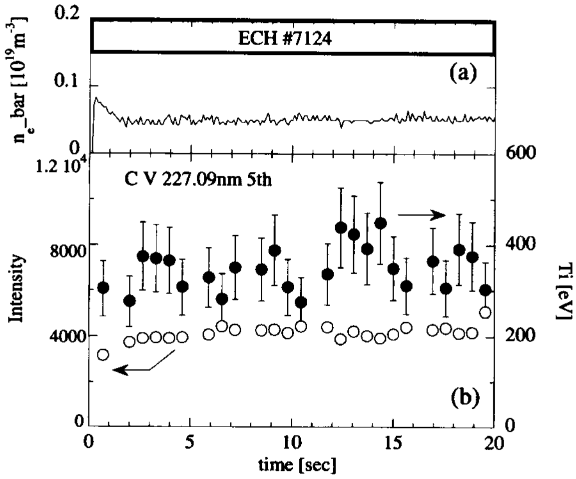

Fig. 4 (a) Time evolution of n_e, (b) Time evolution of T_i and line intensity on long-pulse ECH discharge.

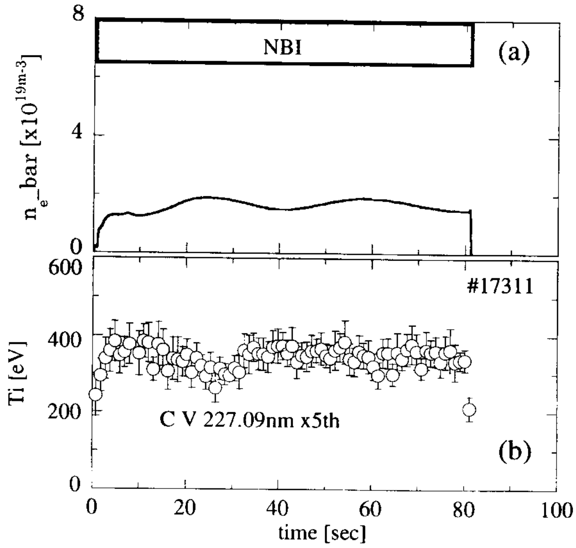

Fig. 5 (a) Time evolution of n_e, (b) Time evolution of T_i from C V on long-pulse NBI discharge.

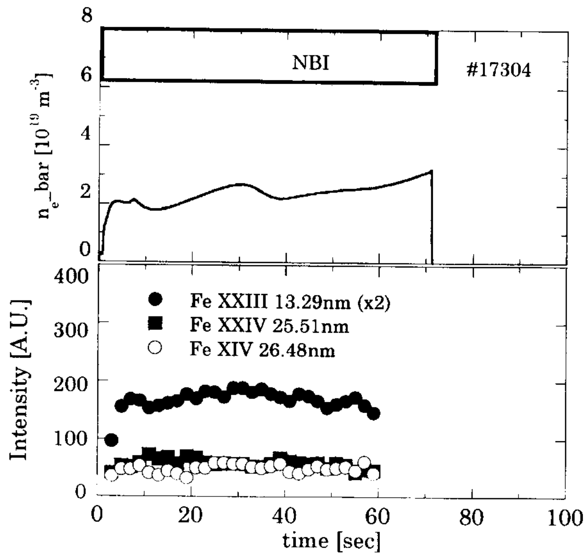

Fig. 6 (a) Time evolution of n_e, (b) Time evolution of line intensity from highly-ionized iron at the core or the middle on long-pulse NBI discharge.

discharge (B_t = 1.5 T, R_{ax} = 3.75 m, P_{ECH} = 50 kW). Electron density of 5×10^{17} m^{-3} was kept constant until the end of discharge. Though the electron density was low, the spectral line from C^{4+} ion which has an ionization potential of 392 eV was observed with sufficient intensity to enable us to measure the Doppler ion temperature. Derived ion temperature is about 350 eV and kept constant. Since this C^{4+} ion has the highest ionized potential among observed spectra in ECH discharge, this ion temperature is thought to reflect the central ion temperature.

3.3 NBI heating

Using a negative-ion-based neutral beam injector (NBI), the long pulse discharge was achieved for 80sec with P_{NBI} ~ 830 kW injection (B_t = 2.75 T, R_{ax} = 3.60 m) on 3rd experimental campaign. As seen in Fig. 5(a) the line-average electron density is almost constant of 2 ×

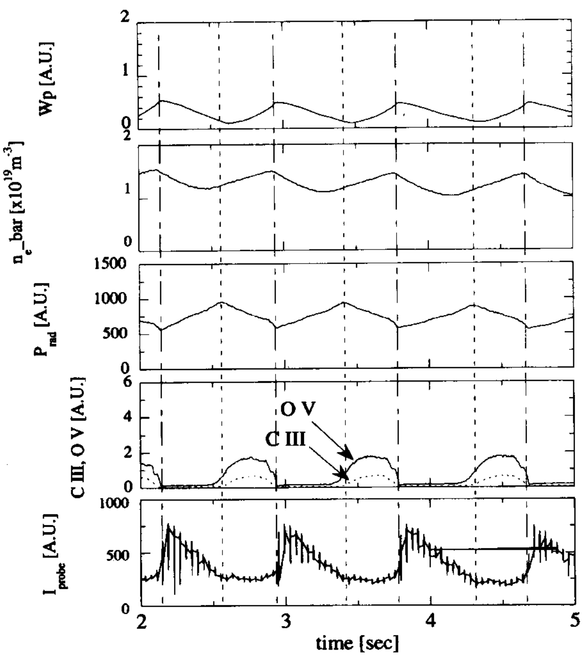

Fig. 7 Time evolution of plasma parameters during the breathing.

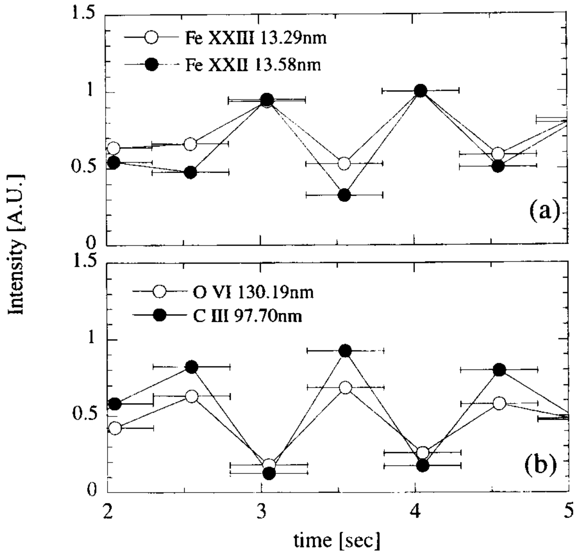

Fig. 8 (a) Time evolution of emission from highly-ionized iron Fe XXIII and Fe XXII at the core, (b) Time evolution of emission from O VI and C III at the edge.

10^{19} m^{-3}. C V line profile was measured to derive the ion temperature at plasma periphery in NBI discharge. Ion temperature from C V line spectrum in Fig. 5(b) was about 350 eV and almost constant after 30 sec. Figure 6(a) shows the time evolution of the line-average electron density in long pulse NBI discharge for 70 sec. The time evolution of radiation was observed for intrinsic impurities, Fe XXIV, Fe XXIII at the core and also Fe XIV at the middle, do not change during the NBI heating, as seen in fig. 6(b).

4. "Breathing" Plasma

During the 2nd experimental cycle, an oscillation in the major plasma bulk parameters was observed during long-pulse NBI operation which is known as the "breathing" plasma. In Fig. 7 we plot the time variation of the parameters W_p, $\bar{n}_e$, P_{rad} and impurity radiation O V and C III. A slow (~1 sec) cycle oscillation in the parameters is seen during NBI heating. The electron density oscillation is nearly out of phase with the radiation oscillation. In Fig. 8 the time evolution of observed spectra, Fe XXIII, Fe XXII at the core plasma and O VI, CIII at edge, are shown with time resolution of 500 msec. The out-of-phase oscillation in emission intensities between light impurities and iron ion is observed.

Summary

Line spectra from iron, oxygen and carbon impurities have been monitored during a long-pulse discharge. In three kinds of long-pulse discharge (ICH, ECH, NBI), emission level from impurity ions has been observed as constant. There is no preferential accumulation of iron either near the center or further outside of the discharge during the long-pulse operations. Ion temperature has been also measured from Fe XX, C V and C III spectra in these discharge. Measured Doppler ion temperature is also stable until the end of the discharge.

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