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Evaluation of Dependence of Current Decay Time on Electron Temperature Measured by He I Line Intensity Ratios in JT-60U Tokamak

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1. Introduction

Disruption is one of the most crucial issues for next generation tokamaks such as ITER. In order to estimate the electromagnetic force acting on in-vessel components during disruption, precise prediction of plasma current decay time is important. In general, so called, L/R model is used to estimate the decay time[1]. In this model, the decay time is proportional to $T_e^{3/2}$, where T_e is electron temperature. Since huge intermittent heat load damages the probes during disruption, we have measured T_e during disruption in JT60-U tokamak based on He I line intensity ratios. Dependence of He I line intensity ratios on T_e and electron density n_e was analyzed by a collisional radiative (CR) model. The measurements of T_e and n_e based on the CR model using the line intensity ratios have been applied in some plasma devices[2,3,4]. This diagnostic has an advantage in the fusion rectors because He is intrinsic species in fusion burning plasmas. In order to measure three He I lines at the same time, a spectrometer equipped with three bandpass interference filters was employed to make it possible to measure the time evolution of T_e with a sufficient time resolution. We have adapted this diagnostic to measure T_e in the disruptive discharge of the JT-60U, to obtain the dependence of the plasma current decay time on T_e.

2. Experimental Setup

Figure 1 shows diagnostic system. Visible light emission from inner and outer divertor region of JT-60U are transmitted through optical filter to the spectrometer. The light is collimated with a lens to be divided to three beams by using beam splitters (1:3), (1:2) and

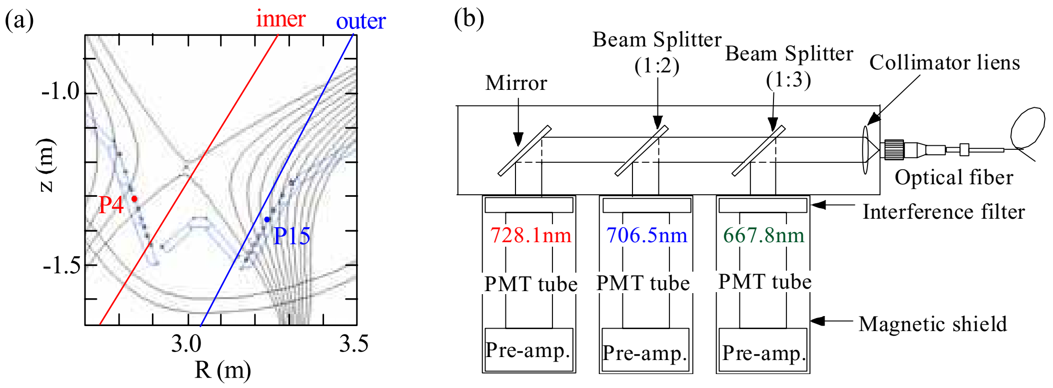

Fig. 1 (a) Cross-sectional view of the divertor and the line of sight for the measurement. (b) Schematic view of spectrometer.

mirror. Wavelength of each beam is selected with bandpass interference filters which have the center wavelengths of the transmission bands of 667.8 ($2^1P – 3^1D$), 706.5 ($2^3P – 3^3S$) and 728.1 nm ($2^1P – 3^1S$) respectively, and the full width at half-maximum of about 5 nm. The emission intensities of each wavelength are detected by three photomultiplier tubes[5]. It is one of the features that the spectrometer has the high time resolution.

In order to determine n_e and T_e from the intensity ratios of *I*(667.8 nm) / *I*(728.1 nm) and *I*(728.1 nm) / *I*(706.5 nm), the measured values are compared with the ratios calculated by the CR model[3]. In this paper, we neglected the recombining component and the effect of radiation trapping[4] in the CR calculation.

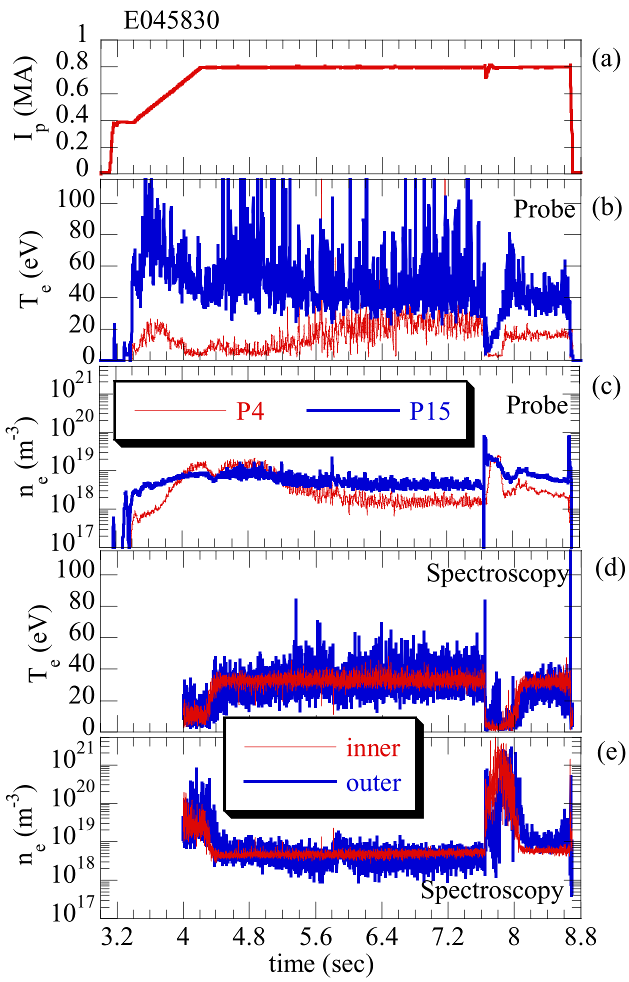

Fig. 2 Temporal evolution of (a) plasma current I_p, (b) electron temperature and (c) density measured by Langmuir probes, (d) electron temperature and (e) density obtained by the comparison of measured and calculated ratios at the inner and outer divertor region. The measurement positions of probes and sight lines of spectroscopic methods are shown in Fig 1 (a).

3. Experimental result

Figure 2 shows the waveform of disruptive discharge in JT-60U. It is found that the minor collapse is happened during t = 7.6 ~ 7.7 s and disruption is occurred during t = 8.6 ~ 8.7 s.

From the measurements by Langmuir probes(P4, P15) located on divertor plates shown in Fig. 1(a), sudden drop of T_e and increase of n_e are observed at the minor collapse. The same behaviours are also reproduced in the time evolution of T_e and n_e with the spectroscopic method, although n_e is larger than that by the probe measurement at the minor collapse. This indicates that the temporal evolution of T_e and n_e with the spectroscopic method is available.

Figure 3 shows the waveform around the current quench. Just after the thermal quench start time t_{TQ}, the emission intensities of H_α and He I increase rapidly. It is necessary to note that a part of the emission intensity of λ = 728.1 nm is saturated at inner divertor region. As shown in Fig. 3(g), T_e after the thermal quench drops to be around 10 eV. Normalized current decay time τ_{exp}/S as a function of T_e is plotted in Fig. 4 (a), where τ_{exp} is defined the time-width which gives 60 % of the whole plasma current around the time having maximum $-dI_p/dt$ value[6], as shown in Fig. 3 (b). Squares, triangles and crosses in Fig. 4(a) show calculated $\tau_{L/R}/S$ based on L/R model as a function of T_e at different inductance L and effective charge Z_{eff}. Experimental data are very scattered and all data cannot be reproduced by the simple L/R model with various parameters. In the simple L/R model, τ increases with T_e, however there is

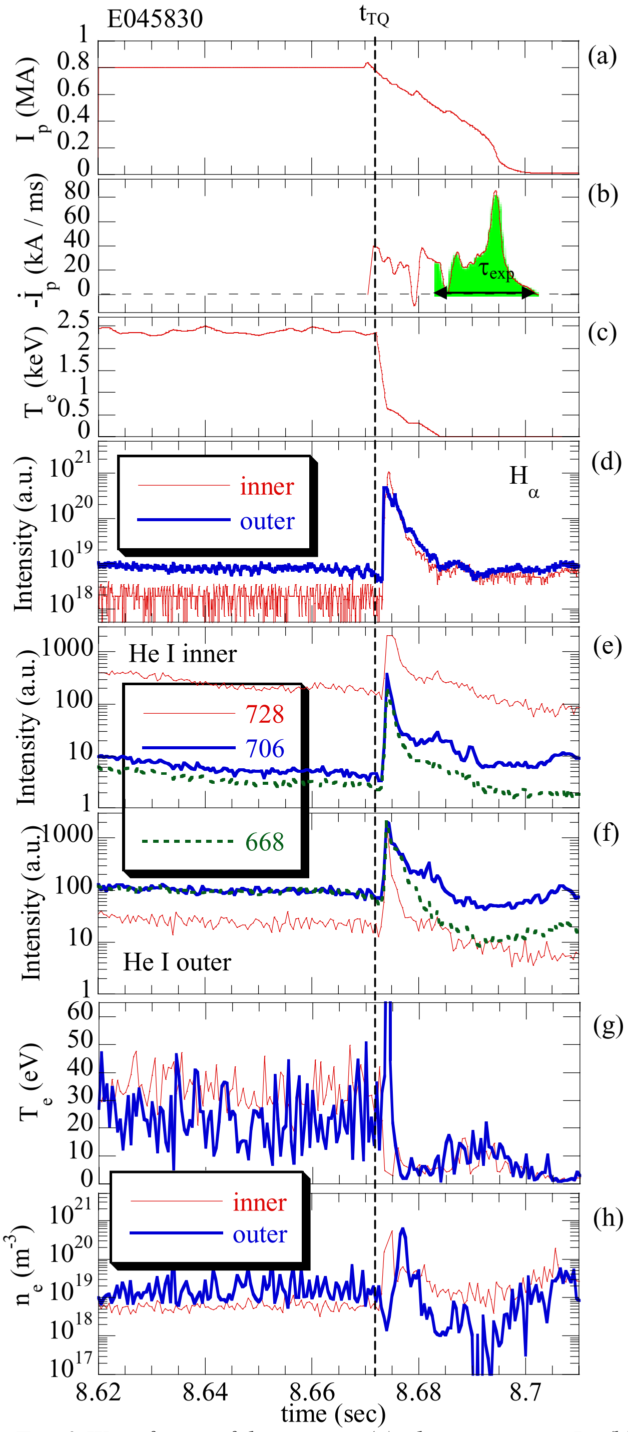

Fig. 3 Waveforms of disruption. (a) plasma current I_p, (b) temporal differentiation of plasma current, (c) electron temperature around center, (d),(e),(f) H_α and He I line intensity, (g), (h) electron temperature and density obtained by the spectroscopic method at the inner and outer divertor region.

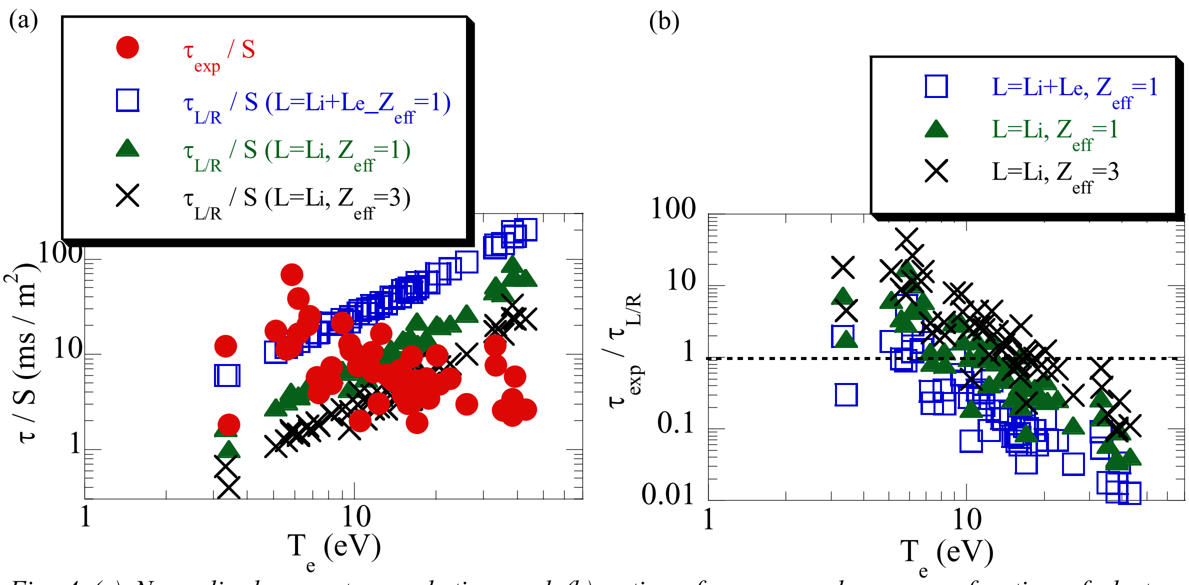

Fig. 4 (a) Normalized current quench time and (b) ratios of $\tau_{proposed}$ and $\tau_{L/R}$ as a function of electron temperature obtained by intensity ratios at inner divertor region. S is the plasma cross-section area just before current quench, τ_{exp} is shown in Fig.3 (b) and $\tau_{L/R}$ means the decay time obtained by measured plasma inductance and resistance calculated from Spitzer formula[7] in each assumption. L_i and L_e are the plasma internal and external inductance just before current quench. The values of T_e are obtained by averaging over the time window of τ_{exp}.

not such a clear dependence of τ_{exp} on T_e. This experimental result indicates that L and Z_{eff} are also important parameters in addition to T_e in order to predict the current decay time based on L/R model. Figure 4(b) shows ratios between τ_{exp} and $\tau_{L/R}$ as a function of T_e. If τ_{exp} obeys L/R model, the ratio should be unity. Especially, calculated $\tau_{L/R}$ is one or two order magnitude larger than τ_{exp} at high T_e region. On the other hand, in Fig. 4(a), minimum values of τ_{exp}/S are likely to be almost constant around 2 ms for various T_e althogh having statistical error due to insufficient number of data points. We can experimentally indicate the relation between T_e and τ_{exp} during disruption at first time. We should reduce the statistacal error by adding more data points and consider the relation between cause of disruption and τ_{exp} in future.

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