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Emission Rates of CH/CD and C_2 Spectral Bands for Hydrocarbon-Loss-Events Measured in JT-60U Divertor Plasmas

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Introduction

Chemical erosion is one of the key processes to limit the operation of nuclear fusion devices such as ITER, because the erosion determines the lifetime of the carbon divertor tiles and co-deposition of tritium with the hydrocarbons, generated by the chemical erosion, determines the tritium inventory in the devices. Hence, for quantitative estimation for the lifetime and the inventory, the chemical sputtering yields are required and have been measured in tokamaks with carbon divertor plates. For estimating the sputtered hydrocarbon flux, spectroscopic measurements have been widely used. Because the emission rates of the CH spectral band include significant uncertainty, the chemical sputtering yields, even the CH_4 yields (the simplest case), are different from one another by a factor of 2 [1]. The CH_4 flux is expressed as follows,

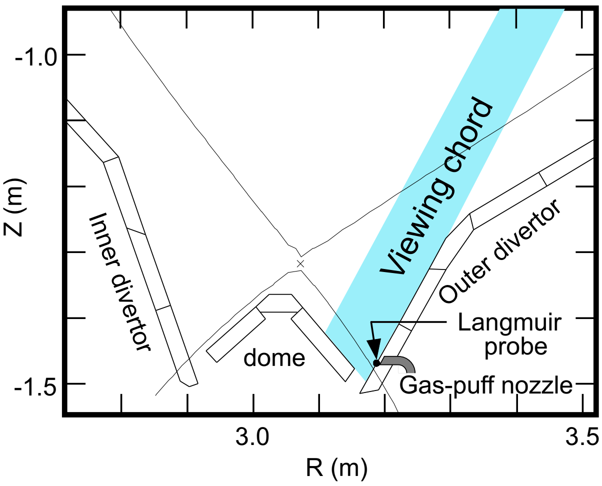

Figure 1: *Cross-sectional view around the divertor. Viewing chord for the spectroscopic measurement, location of the gas-puff nozzle, and the magnetic configuration are shown. Another viewing chord and a Langmuir probe are positioned on different poloidal cross-sections.*

$$\Gamma_{CH_4} = \left(I^{CH}_{CH_4} - \sum_n I^{CH}_{C_2H_n} \right) = \left(I^{CH}_{CH_4} - \sum_n B_{C_2H_n} \cdot I^{C_2}_{C_2H_n} \right) \cdot LEP^{CH}_{CH_4} \quad (1)$$

Because contribution of the CH emission originating from heavier hydrocarbons such as C_2H_6 is significant [2], the contribution should be removed as shown in eq. (1). However, these extension has not been done except for [2]. Here $LEP^{CH}_{CH_4}$ stands for '*CH_4 Loss-Events / CH Photon*', which is defined as a reciprocal of the number of CH photons emitted until one CH_4 is lost, and $B_{C_2H_n}$ is a branching ratio of CH to C_2 emission originating from C_2H_n. If $LEP^{CH}_{CH_4}$ and $B_{C_2H_n}$ are known, Γ_{CH_4} can be estimated from measured intensities of CH and C_2 spectral band. However, $LEP^{CH}_{CH_4}$ and $B_{C_2H_n}$ depend on the transport during the break-up chain from CH_4 to CH, which is influenced by the divertor geometry. Hence, $LEP^{CH}_{CH_4}$ and $B_{C_2H_n}$ are not identical amongst devices but are required to be determined in each device. In this work, to determine LEP and B in JT-60U, CH_4, CD_4 and C_2H_6 were injected into spectroscopic observation volume around the outer strike point.

Experimental

As shown in Fig.1, a gas-puff nozzle has been installed at the outer divertor plate. From this gas-puff nozzle, CH_4, CD_4 and C_2H_6 were injected to the outer divertor plasma at a known rate. Along a viewing chord in front of the gas-puff nozzle (diameter : 110 mm on the plane of the gas-puff nozzle, hereafter, VC_g) observed were CH/CD ($A^2\Delta - X^2\Pi$) or C_2 ($A^3\Pi - X^3\Pi$) spectral band. Along the other viewing chord, toroidally apart from the gas-puff nozzle by $\sim$ 150 mm (hereafter, VC_b) observed were CH/CD or C_2 spectral band originating from intrinsic hydrocarbons. The electron temperature and density were measured by a Langmuir probe, which is positioned on a different poloidal cross-section from the gas-puff nozzle.

Figure 2 shows waveforms of a CD_4 injection experiment to determine $LEP^{CD}_{CD_4}$. At 25 s, CD_4 was injected, and its flux became almost constant in 1 s. The CD photon flux measured along the viewing chord, VC_g, shows a waveform similar to the CD_4 flux while the CD photon flux measured along the other viewing chord, VC_b, is not affected by the CD_4 injection. Hence, the net CD photon flux originating from the injected CD_4 can be estimated by subtraction of the CD photon fluxes measured along these two viewing chords. On the assumption that all the injected CD_4 molecules were lost by the molecular processes such as dissociation in the spectroscopic observation volume, the $LEP^{CD}_{CD_4}$ is inferred as a ratio of the injected CD_4 flux to the measured CD photon flux. This assumption is valid in the case the electron density is higher than $5\times10^{18}\mathrm{m}^{-3}$ and the present experiments were performed in this

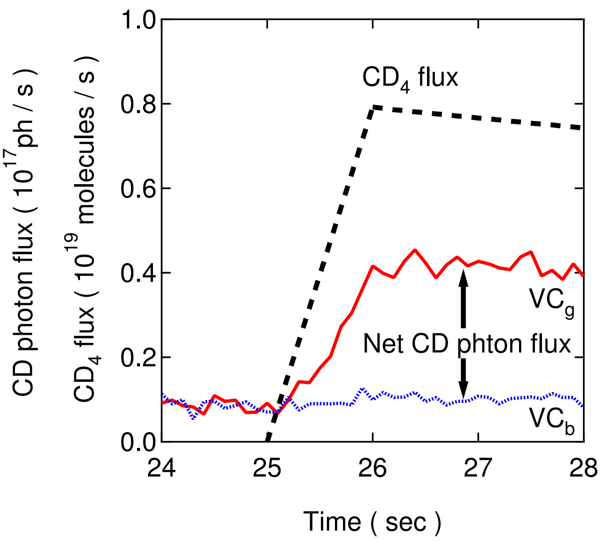

Figure 2: *Waveforms of CD_4 flux, and photon fluxes of the CD spectral band. The CD photon flux shown by the solid curve was measured along the viewing chord in front of the gas-puff nozzle (VC_g), and the CD photon flux shown by the dotted curve along the other viewing chord (VC_b). During the measurement, the electron temperature was 70 eV.*

condition. Similar experiments were performed by injecting CH_4 to determine $LEP^{CH}_{CH_4}$, and C_2H_6 to determine $LEP^{CH}_{C_2H_6}$, $LEP^{C_2}_{C_2H_6}$ and $B_{C_2H_6}$.

Results

Figure 3 shows the measured $LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$ as a function of electron temperature on the assumption that the electron temperature is not affected significantly by the CH_4 or the CD_4 injection. An isotope effect between $LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$ was not pronounced : $LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$ agree within the errors at 30 eV - 50 eV. The dependence of $LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$ on the electron temperature is weak : both $LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$ are almost constant around 200 between 30 eV and 60 eV. Similar dependence was observed in the data taken in JET [3] and AUG [4, 5]. On the contrary, the data taken in PISCES-A [6] and TEXTOR [7] increase with increasing electron temperature. The calculated $LEP^{CH}_{CH_4}$ by a model [8], which considers dissociation, ionization, charge exchange, also indicates an increasing trend with electron temperature. The data at electron temperatures below 30 eV would enable more precise comparison.

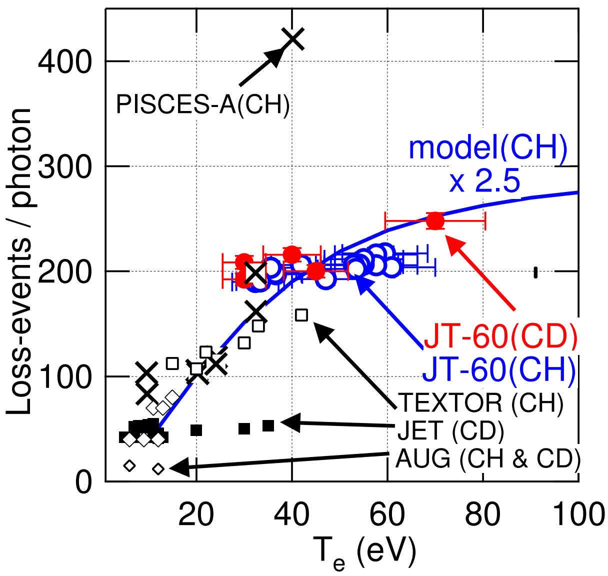

Figure 3: *Loss-Events / Photon ($LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$) as a function of electron temperature (electron density : $0.5-2\times10^{19}m^{-3}$). Data taken in JET [3] (closed squares), AUG [4, 5] (open diamonds), PISCES-A [6] (crosses), TEXTOR [7] (open squares), and data from model calculation [8] (solid curve) are also shown.*

Figure 4 shows the measured $LEP^{CH}_{C_2H_6}$ and $LEP^{C_2}_{C_2H_6}$. Compared to the $LEP^{CH}_{C_2H_6}$, the $LEP^{C_2}_{C_2H_6}$ is substantially larger and depends on the electron temperature more strongly. These two results were also observed in the $LEP^{CH}_{C_2H_4}$ and $LEP^{C_2}_{C_2H_4}$ taken in PISCES-A [6]. The branching ratio of CH to C_2 emission originating from C_2H_6, $B_{C_2H_6}$, is also shown in Fig. 4. At an electron temperature around 15 eV, $B_{C_2H_6}$ taken in JT-60U is larger than $B_{C_2H_4}$ taken in PISCES-A [6]. This result is against expectation that the $B_{C_2H_4}$ is smaller than $B_{C_2H_6}$ because of the smaller number of C-H bonds in C_2H_4 compared to that in C_2H_6. Better comparison would be given when the C_2H_4 injection experiment is performed.

Summary

In order to determine 'Loss-Events / Photon',*LEP*, and a branching ratio of CH to C_2 emission, *B*, in JT-60U, CH_4, CD_4 and C_2H_6 were injected at a know flow rate from the newly installed gas-puff nozzle into spectroscopic observation volume around the outer strike point. The ratio of the gas flow rate to the net increase of CH, CD and C_2 spectral band intensity provided the *LEP* for CH_4, CD_4 and C_2H_6. The $LEP^{CH}_{CH_4}$ and $LEP^{CD}_{CD_4}$ are almost constant around 200 at electron temperatures between 30 eV and 60 eV while the $LEP^{CH}_{C_2H_6}$ and $LEP^{C_2}_{C_2H_6}$ increase with increasing electron temperature. The $B_{C_2H_6}$ also increase with an increase of electron temperature. Similar experiments to determine $LEP^{CH}_{C_2H_4}$, $LEP^{C_2}_{C_2H_4}$ and $B_{C_2H_4}$ are planned. With these data, the sputtering yields of CH_4/CD_4 and C_2H_x/C_2D_x [2] will be modified.

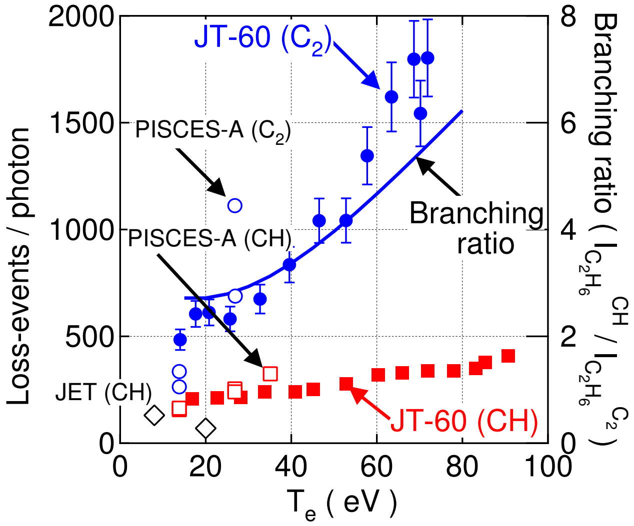

Figure 4: *Loss-Events / Photon ($LEP^{CH}_{C_2H_6}$ and $LEP^{C_2}_{C_2H_6}$) and branching ratio, $B_{C_2H_6}$, as a function of electron temperature. Data taken for C_2H_4 in PISCES-A [6] (open circles for C_2 and open squares for CH) and JET [9] (open diamonds) are also shown.*

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