Monitoring of the relationship between $\text{H}_\alpha$ and $\text{D}_\alpha$ emission as a detection method for water microleaks into ITER

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Abstract. The validation of spectroscopic method for water microleakage detection in ITER plasma chamber by IO Vis/IR diagnostic system is presented. The method is based on evaluation of the intensity ratio between $\text{H}_\alpha$ and $\text{D}_\alpha$ spectroscopic lines. These lines are shifted by about 0.2 nm (656.28 and 656.10 nm). They have rather large intensity in low pressure discharges (glow, RF, microwave, for instance) and correspond to the middle range 600-700 nm with maximum of the IO Vis/IR sensitivity.

1. Introduction
Utilization of an emitted light from water molecules and their fragments exited in some plasma discharges is the most perspective method for operative detection and localization of water cooling system microleakages in ITER plasma vessel. The spectroscopic method usually is based on controlling intensity level of the spectral lines corresponded to exited fragments of the water molecule. Previous investigations [1, 2] have shown that $\text{OH}^+$ hydroxyl band (in vicinity of 310 nm wavelength) is a preferred candidate for stationary diagnostics. The limit of sensitivity is estimated as $3 \times 10^{-5}$ Pa m$^2$s$^{-1}$. However, the spectroscopic microleak detection using hydroxyl radiation is possible at the first stages of ITER operation, because of the fast degradation of the optic elements for UV range under neutron radiation. Also proposed wavelength is strongly attenuated as it passes through the IO Vis/IR diagnostic systems optics as they are designed presently [3].

Proposed method is based on evaluation of the intensity ratio between $\text{H}_\alpha$ and $\text{D}_\alpha$ spectroscopic lines. These lines are shifted by about 0.2 nm (656.28 and 656.10 nm). They have rather large intensity in low pressure discharges (glow, RF, microwave, for instance) and correspond to the middle range 600-700 nm (the maximum of Vis/IR sensitivity). Experiments on validation of the method were carried out at PR-2 facility. In normal conditions the discharge in He will stimulate desorption of deuterium and background protium (in ITER it must be at the level below 0.6 %) from the wall tiles. So, if the water vapors would ingress into rather hot and dense discharge He plasma, $\text{H}_2\text{O}$ molecules would excite and dissociate. Discharge parameters have been optimized on maximum of $\text{H}_\alpha$ radiation (as a fragment of $\text{H}_2\text{O}$ dissociation). Thus, the enhanced radiation of $\text{H}_\alpha$ relative to $\text{D}_\alpha$ would point on the leakage vicinity. This method can be considered as an alternative to previously developed method based on the detection of hydroxyl radiation in UV range.

2. Experimental setup
PR-2 beam plasma facility in MEPhl [4] can operate in different discharge modes in broad range of plasma parameter. Plasma with electron densities $10^{14}$-$10^{19}$ m$^{-3}$ is routinely obtained with density

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gradient up to $10^{21} \text{ m}^{-3}$. PR-2 is equipped by a number of the plasma diagnostics. The local plasma parameters are controlled by single Langmuir probe, the ion mass-spectrum in plasma column – by the stationary magnetic mass-spectrometer (MS) [5] using own magnetic field of the plasma device, the residual gas composition – by the standard quadruple mass analyzer QMA EXTOR XT100M. Stationary optical emission spectroscopy system is based on MDR-206 spectrometer [1] mounted in front of the quartz window equipped by the collimator narrowing a light flux from the plasma and the cylindrical lens with focal length 15 cm used as light concentrator. Scheme of spectroscopic measurements is shown on figure 1.

![Diagram](image1.png)

**Figure 1.** Scheme of spectroscopic measurement of $H_\alpha/D_\alpha$ radiation from a beam-plasma in PR-2.

The technical parameters of MDR-206 allow us to divide $H_\alpha$ and $D_\alpha$ lines with sufficiently high sensitivity. Figure 2 shows the example of spectra for electron beam driven discharge in deuterium with different admixtures of protium.

![Diagram](image2.png)

**Figure 2.** Enhancement of $H_\alpha$ line intensity with growing of $H_2$ admixture to $D_2$ (according to settings of mass flow controllers).

Water vapor injection into vacuum vessel was carried out by calibrated thermochemical water source based on Ca(OH)$_2$ thermal destruction [1, 2, 6]. It has fine-tuning of a water vapor flow in the
range from $10^{12}$ molecules/s to $10^{22}$ molecules/s by a heater temperature. Low limit of the range is caused by pressure of a saturated vapor of a calcium hydroxide ($10^{-5}$ Pa).

3. Experimental results

First experiments were carried out without water vapor injection. The relative intensity $\frac{H_\alpha}{D_\alpha}$ in the emission spectrum of deuterium plasma was studied for different hydrogen gas flow. Relative gas puff was set in range from 1 % to 9 % by calibrated mass-flow controllers. Figure 3 shows the change between $H_\alpha$ and $D_\alpha$ with smooth change in $D_2$ and $H_2$ composition in the gas puff. It is seen that line intensity is approximately proportional to relation between $D_2$ and $H_2$ flows. Some deviations can be explained by a higher mobility of $H_2$ and HD molecules.

![Figure 3](image3.png)

**Figure 3.** $H_\alpha/D_\alpha$ change with low $H_2$ admixtures to $D_2$ into the electron beam driven discharge at PR-2.

QMA shows an increase of $H_2$ and HD generated in plasma. The change of the H-components in residual gas was negligible compared with absolute value of the main molecular deuterium peak. Evaluation of the QMA spectrum is shown on Fig. 4. The molecular ions which are generated in the gage and have not neutral forms are shown in brackets.

![Figure 4](image4.png)

**Figure 4.** QMA signals with protium concentration change in $H_2/D_2$ mixture.

Small additive of hydrogen leads to increase of heteronuclear ions in ion mass-spectrum of the plasma column. Figure 5 shows the redistribution of the ion composition during the experiment.
Signals from MS with protium concentration change in H$_2$/D$_2$ mixture.

The H$_a$/D$_a$ method can be easily applied for cleaning discharges. It can't be applied during ITER campaign with protium discharges. In powerful deuterium working discharges the broadening of the main D$_a$ line would mask the appearance of H$_a$. The experiment with water vapor injection simulates cleaning regimes of a discharge in He without strong magnetic field (B < 0.1 T) and as a consequence without a noticeable Zeeman effect. Zeeman broadening would split H$_a$/D$_a$ lines into triplets. As an example the calculated shape of the D$_a$ line for divertor JET conditions (2.8 T) is presented [7]. It shows that the right satellite of H$_a$ can be resolved from the D$_a$ one.

PR-2 works predominantly with protium. So, in He discharges the protium desorption background prevails, the presence of protium in the D$_3$ balloon also limits its minimal quantity in the vacuum chamber. We used the deuterium addition into He puff for the H$_a$/D$_a$ intensity ratio change during water injection. The most close and brightest He line is the one with 667.8 nm wave length. The rise of H$_a$/D$_a$ ratio above the background level with water source ampoule heating is clearly seen (fig.6). The raise of H$_2$O concentration in the vessel is calculated via vacuum gage signal readings with taking into account of component sensitivities. The reaching of equilibrium value for concentrations of water vapor in the chamber and of excited hydrogen atoms H$^+$ in plasma are determined by rather complicated kinetics. The gain of H$_a$ intensity is more rapid in the beginning of water ingress.

**Figure 5.** Signals from MS with protium concentration change in H$_2$/D$_2$ mixture.

**Figure 6.** Enhancement of H$_a$/D$_a$ ratio with water ingress into He (with 7% D$_2$) discharge.
The change of the plasma ion composition with vapor ingress rise is shown in fig. 7. The most noticeable growth for H\(_+\) correlates with enhancement of H\(_\alpha\) radiation. It is also seen that the water source of excited and ionized protium is less effective relative to gas D\(_2\) admixture (7\%) to He discharge. So, discharge parameters can be optimized on further increase of H\(_\alpha\) radiation.

![Figure 7. Plasma ion composition change with vapor ingress.](image)

It must be mentioned that measurements have been made for a global water vapor pressure raise. Its raise above 1\% can be registered by H\(_\alpha\)/D\(_\alpha\) method for He discharge in PR-2. This level corresponds to the ingress of about 10\(^{16}\) water molecules per second.

4. Conclusion
The spectroscopic method for water microleakage detection in ITER plasma chamber by IO Vis/IR diagnostic system based on relationship between intensities of H\(_\alpha\) and D\(_\alpha\) lines was validated. The sensitivity of the method was about 10\(^{16}\) molecules/second of the water vapor inflow. It must be mentioned that measurements have been made for a global water vapor pressure raise. The method's sensitivity can be improved for localized water plume observation. So, with further enhancement of the monochromator resolution and detector photosensitivity, the detectable water ingress level can be decreased by at least an order to correspond the requirements for the sensitivity of the water leakage detection system in ITER. The H\(_\alpha\)/D\(_\alpha\) method can be easily applied for He cleaning discharges, but not during ITER campaign with protium discharges.

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