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Spatial distribution of atomic and ion hydrogen flux and its effect on hydrogen recycling in long duration confined and non-confined plasmas

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ABSTRACT

In order to understand the atomic hydrogen distribution in different kinds of plasma and its influence on the recycling, two kinds of plasmas were used: non-confined annular electron cyclotron resonance (ECR) and confined long duration plasmas. The permeation probes are used to measure directly the atomic hydrogen flux at several poloidal positions. The permeation through metals due to the ion and atom component of the hydrogen flux to the wall is indistinguishable. To estimate the contribution of the ions directly, Langmuir probes were used. The Γ_{inc} profile behind the plasma facing components (PFCs) is almost constant, $\sim 2\times10^{18}$ H/s/m^2.

1. Introduction

The retention and recycling of the hydrogen isotopes in the first wall materials of the fusion devices is an unresolved and important problem. Several approaches have been used to study hydrogen retention in-situ in the fusion devices and in the laboratory facilities. From the laboratory studies [1,2] it has been reported that the irradiation of the materials by the low-energy hydrogen atoms and ions leads to a significant hydrogen retention. Detection of the low-energy hydrogen atomic fluxes in tokamaks is a difficult task. Membrane probes could be used to resolve this problem. Several attempts with the membrane probes have been done in different tokamaks in the past twenty years [3–7]. The measurement of the neutral flux far from the walls has been done in TEXTOR and the raw signals of the permeation probes have been compared with the plasma core density and gas fuelling [3–4]. In QUEST a work was done for the past few years to develop the membrane probe system able to measure incident hydrogen flux in-situ in real time. Different types of the membranes (Ni, F82H, PdCu) were tested [5–7] and finally, the PdCu membrane was selected for the probe system. PdCu has faster response time, wider permeation regime, and higher sensitivity independent of the incident hydrogen flux. An array of the five membrane probes has been installed inside the QUEST vessel.

The poloidal distribution of the incident flux consisting of both protons and atomic hydrogen can be measured directly with the permeation probe (PP). This results are compared with the direct ion flux, measured with a Langmuir probe array (LPA) or the neutral hydrogen flux, estimated by a hydrogen Balmer line intensity (H_α). By solving a problem of the diffusion of the hydrogen atoms in metal, the permeated flux is converted to the incident flux (Γ_{inc}), and the total fluence (Φ; time integrated flux during the discharge period) is compared with the amount of the retained hydrogen. The latter is derived by global gas balance based on a difference between the external pumping and fueling amounts. This technique has been commonly carried out in the graphite and metal devices [8–10] and the amount of the retained hydrogen is determined as the difference between the injected and

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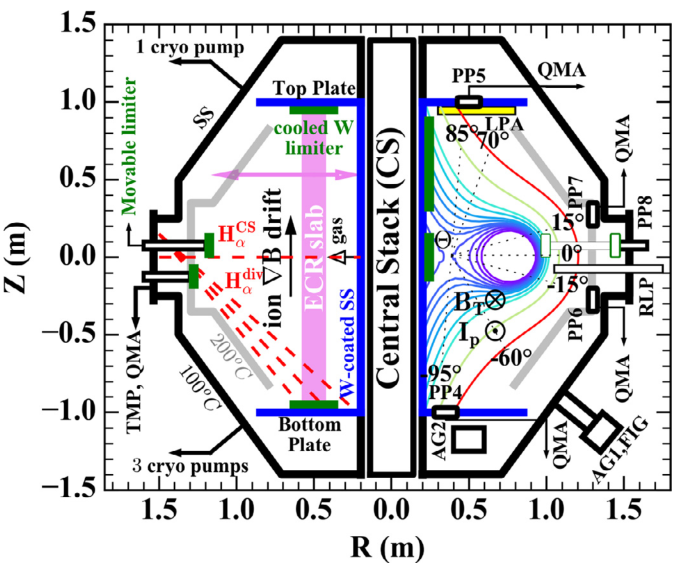

Fig. 1. QUEST vertical section schematic view. The angles, indicated in the right site correspond to poloidal position of the PPs and borders of the H_α and LP. The poloidal flux surfaces are shown for SSTO1,2. In the left side red dashed lines indicate line of sight of the hydrogen light spectroscopy. A wide magenta line (ECR slab) indicates the annular ECR plasma resonance position for ECR1-3.

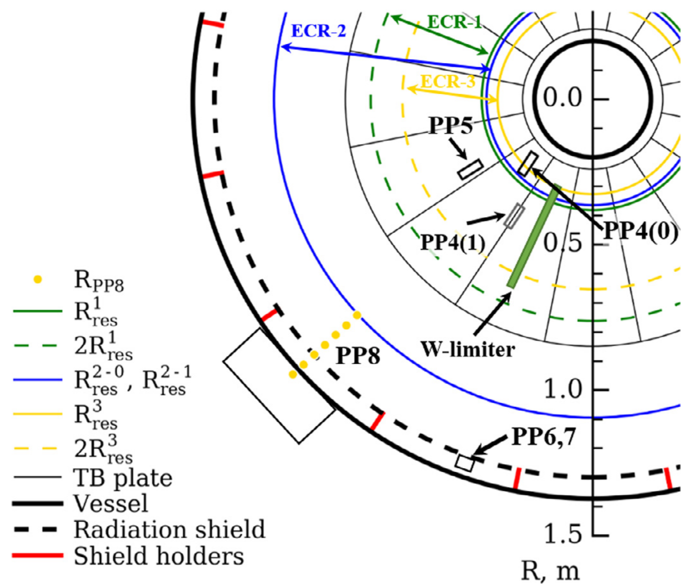

Fig. 2. QUEST horizontal section schematic view. Positions of PPs are shown. PP4(0) – position of PP4 in SSTO-2, PP4(1) – in all other cases. R_{res} – resonance positions in ECR 1-3. Rpp8 – positions of PP8 in Fig.3.

pumped out amounts of hydrogen atoms. In the case of the all-metal plasma-facing components the release of the hydrogen occurs mostly in the form of the H_2 and H_2O molecules. The former is a second order surface reaction with the recombination process. The later relates to another nonlinear processes between hydrogen and oxygen containing molecules on the surface [11]. It is also expected that atomic hydrogen irradiation of the walls will lead to the changes in the metal oxides due to formation or dissociation of the water molecules on the surfaces. In [11] it was clearly shown that efficiency of the water formation induced by the atomic hydrogen irradiation is comparable with water formation during plasma irradiation. Oxygen presence in the working gas can lead to both increase or decrease of hydrogen retention in stainless steel depending on its concentration in gas and hence on the surface. It is desirable to understand influence of the oxygen concentration in the discharges on the hydrogen retention in differently conditioned PFCs. For this purpose, water partial pressure and OII emission was analyzed in different kinds of plasma.

In the present work after a brief description of the experimental set-up in the Section 2, the poloidal distribution of the irradiation fluxes is shown in the Section 3.1, radial distribution and a role of the atomic hydrogen is shown in the Section 3.2 and gas balance results are shown in the Section 3.3. The temporal behavior of the global gas balance is discussed in the Section 4, and finally conclusion is given in the Section 5.

2. Experimental set-up

Experiments were performed in the spherical tokamak QUEST [12,13]. Details of the set-up were previously described in [7,14]. The cross sectional view of the QUEST vessel is shown schematically in Fig. 1. Two kinds of plasmas are examined in this paper: a steady electron-cyclotron resonance (ECR) slab annular plasma [15] and a steady state high poloidal beta plasma in an inboard poloidal field null (IPN) configuration [16,17]. The slab plasmas are produced by electron-cyclotron waves (ECW) at 2.45 GHz ($<$ 10 kW) or 8.2 GHz ($\sim$ 20 kW) without the poloidal field. A vertically elongated slab plasma is formed near the cyclotron resonance position and diffuses towards the side wall. The plasma-wall interaction (PWI) regions are mainly restricted on the top/bottom (TB) plates. IPN plasma has been achieved by 8.2 GHz (60 kW) with the highly curved poloidal filed. A horizontally oblate plasma with the inboard poloidal field null and a natural divertor configuration is formed. The magnetic surfaces are schematically shown in Fig. 1. All poloidal coil currents are kept constant including the current start-up phase. The IPN configuration is formed immediately after ECWs injection and is sustained for a whole discharge duration. The main PWI regions are limited on the divertor rings on the upper and lower part of the centre stack (CS) and on the most inner parts of TB plates, where the scrape off layer (SOL) plasma terminates. The several hot spots and melting parts on the CS cover plates have been observed as a consequence of the severe interaction.

Measurement of the particle fluxes was done with PPs, distributed poloidally from $\theta = -95°$ to 85° (see Fig. 1), where the poloidal angle $\theta = 0$ corresponds to the mid plane, and the origin is at the major radius R = 0.4 m. The LPA, installed at the top plate, was used to analyze the detailed distribution of the Γ_{ion}, estimated from the ion saturation current, at $65° < \theta < 95°$. The locations of the PPs (4,5,6,7), LPA, reciprocating Langmuir probe (RLP) [18], reciprocating permeation probe (RPP; 8) and lines of sight for Hα spectrometry are shown in Fig. 1. The RLP and RPP are located at the same port, and are used to study the radial dependence of the irradiation fluxes along the major radius in the plasma region and beyond the radiation shield to the end of the port.

The positions of PPs in respect to the ECW resonance are shown in Fig. 2. A detailed description of the PPs structure and measuring process is presented in [14]. The diffusion parameters of the PdCu membrane were investigated in [19]. The detection area is 1.2×10^{-3} m^2 for PP4-7 and 7.5×10^{-3} m^2 for PP8, respectively. The radial positions of PP4 and 5 are (0.285–0.345) m and (0.450 – 0.520) m, respectively. In SSTO-2 (Table 1) the radial length of PP4 was the same as of the PP5.

The chamber wall (thick black lines), made of the stainless steel (SS) and tungsten coated SS (blue lines) are the main PFCs. The vessel temperature is always kept at $\sim$ 100 °C. The upper and lower oblique plates ("hot wall" ; tungsten coated SS, gray lines) and vertical plates (radiation shield; SS, vertical gray lines) are in-