Atomic surface loss coefficient studied by a pulsed fluorescence technique

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The aim of this project is to measure surface loss of atomic species on various materials. In order to get that, materials to be studied are installed on a 4 inches wafer holder in a low-pressure radio-frequency ICP reactor. In the present paper we describe the measurement of the H/D atom loss on the material which are components of the plasma chamber walls, Pyrex and quartz. A pulsed fluorescence technique (PIF) which is based on the time-resolved optical emission spectroscopy was used. The surface loss coefficient on Pyrex is found to be on the order of 10^{-2} under the studied experimental plasma conditions.

1. Introduction

Plasma surface interactions (PSI) are of great interest to researchers because of the wide use of plasma technologies in many industrial processes. Ions and atoms are created during the plasma discharge, whereas during the afterglow these particles are lost in the plasma volume and on the surfaces. The atomic surface loss coefficient (γ) is a key point in PSI studies. It can give information on the species inventory and is also an important input for modelling and theoretical work [1]. The aim of this project is to determine the atomic hydrogen and deuterium (H/D) surface loss coefficient on tungsten sample in a low-pressure radio-frequency inductively coupled plasma (ICP) reactor to address the plasma-wall interaction issues in magnetically confined fusion issues. The atom decay in the afterglow is correlated with the loss on all the surfaces surrounding the plasma. Therefore, one needs to have a low loss background material to make sure atoms are mainly lost on tungsten sample. The present study is focused on the choice of such material for the surrounding walls. Pulsed induced fluorescence technique (PIF), which is a non-intrusive and time-resolved optical emission spectroscopy method, is employed to measure surface loss coefficient.

2. Experimental set-up and results
2.1. Experimental set-up

A 4 inches tungsten sample is introduced horizontally inside an ICP plasma chamber. Pyrex was chosen as a candidate wall material first. It is necessary to measure γ value on Pyrex under different plasma conditions, since there is little literature data available on it. Therefore, a Pyrex tube has been introduced in the plasma chamber. The tube is closed with a Pyrex disc at the bottom and with a quartz window at the top. The H_α line intensity is selected via a monochromator and detected on a photomultiplier. The optical fiber for the line-of-sight measurements of the light intensity is located 0.5 cm above the sample, so that the H_α emission decay is correlated with atom loss on Pyrex. The high density inductively coupled plasma is created by a Dressler 13.56 MHz RF generator. In order to limit both sample and wall heating, pulsed plasma with 1 Hz, 5% duty cycle is employed.

A 26.5 GHz Microwave Interferometer is used to determine time resolved electron density (n_e). A Langmuir probe is installed to obtain the spatial profile of n_e for correcting interferometer measurements and to measure T_e versus time.

2.2. Pulsed induced fluorescence

The PIF signal, H_α line intensity (I_H), is proportional to electron density n_e, to the excitation coefficient which depends on the electron temperature T_e, and to the atomic density:

$$I_H \propto n_e \times k[T_e] \times [H]$$

In this technique, a series of RF pulsed is used to determine the decay of H/D atom surface loss in the afterglow. A long main pulse generates a steady-state plasma, and a secondary shorter probe pulse re-excites the discharge with an adjustable delay with respect to the main pulse. The H_α line intensity at the beginning of the probing pulse is proportional to the remaining atomic density in the afterglow. By varying the delay between the main pulse and the probing pulse, the atomic decay in the afterglow can be obtained, provided that n_e and T_e are constant in the probing pulse for each delay time. The decay is exponential with a time constant τ that is used to calculate surface loss coefficient γ.

2.3. Results

Interferometry measurements show that n_e is varying with time during the probe pulse, and this variation depends on the probe pulse delay. To cancel n_e variation effects, PIF signal is normalized by n_e so

that I_H is proportional to H density and to the excitation coefficient. In order to get rid of the overshoot of T_e at plasma breakdown, a quite long probing pulse is used (5 ms), and the normalized PIF signal is extrapolated at the beginning of the probing pulse [2]. The typical results are shown in Figure 1.
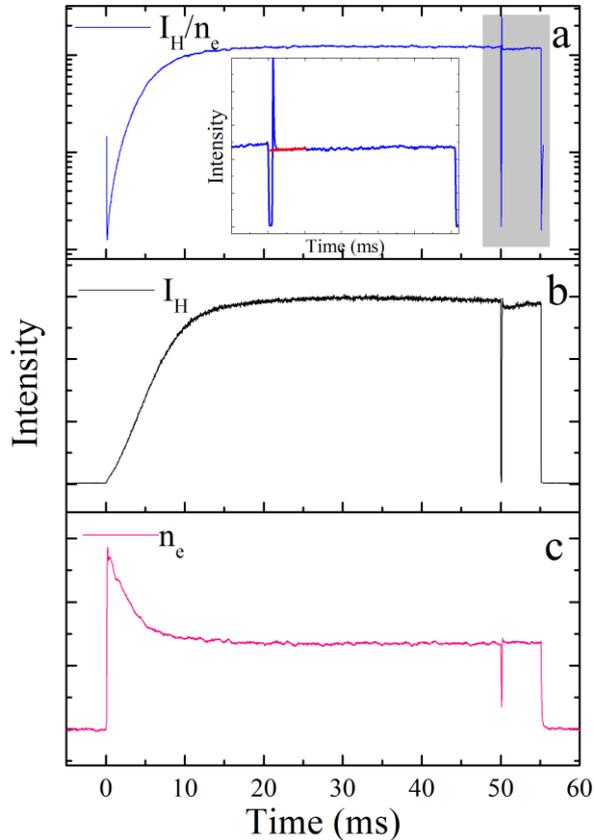

Figure 1. Optical emission signal (b) and time-resolved electron density n_e (c) during the main and probe pulse for delay of 0.1 ms. Figure (a) is H$_\alpha$ line normalized by n_e. The extrapolation of the signal used to obtain I$_0$ (PIF signal) is also shown in red in inserted graph.

A two-stage exponential decay in the plasma afterglow was observed, a fast decay (γ_{fast}) in the early afterglow and a slow decay (γ_{slow}) afterwards. This may correspond to a change of the surface state. Therefore, two different surface los coefficient γ_{fast} and γ_{slow} are determined, and the first one is assimilated to the value of the surface loss during the plasma. The atom surface loss coefficient on Pyrex for H atom (γ_H) and D atom (γ_D) are found to be on the order of 10^{-2} at 5 Pa and 10 Pa, with γ_D being higher than γ_H for both pressures.

The H atom surface loss coefficient on tungsten is expected to be on the order of 10^{-2} [3]. Therefore, under our experimental conditions Pyrex is not a proper choice for the surrounding walls. A lower surface loss coefficient material such as quartz would be preferable for the γ measurements on tungsten.

The detailed information about PIF technique and the results on Pyrex and quartz will be shown in the presentation.

3. References

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