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Comparison on heat flux deposition between carbon and tungsten wall – Investigations on energy recycling

H. Bufferand [a,*], J. Bucalossi [a], G. Ciraolo [a], N. Fedorczak [a], P. Genesio [b], Ph. Ghendrih [a], J. Gunn [a], Y. Marandet [b], C. Martin [b], N. Mellet [b], E. Serre [c], P. Tamain [a]

[a] CEA, IRFM, 13108 St Paul-Lez-Durance, France
[b] PIIM, CNRS, Aix-Marseille Université, 13397 Marseille, France
[c] M2P2, CNRS, Aix-Marseille Université, 13451 Marseille, France

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ABSTRACT

The influence of the plasma facing components material on the scrape-off layer plasma is investigated. In particular, the energy recycling is found to be more pronounced for tungsten wall compared with carbon wall. Edge plasma simulations performed with the transport code SOLEDGE2D-EIRENE show that this enhanced energy recycling in the tungsten case leads to an increase of the scrape-off layer temperature. Moreover, the energy recycling depends on the ion angle of incidence with the wall. A PIC code has been used to model the ion acceleration in the magnetic pre-sheath and determine the later angle of incidence. These simulations show that ions mostly impact the wall with rather shallow incident angles leading to a further increase of the energy recycling.

1. Introduction

In the perspective of designing plasma facing components for nuclear fusion reactors, an important effort is made to understand and properly simulate the properties of different materials interacting with hot plasma. Two main materials are used in high heat load divertors: CFCs and high Z metals such as tungsten which is the material retained for ITER divertor. We investigate with the transport code SOLEDGE2D-EIRENE [1] the difference in plasma properties that stem from the choice of wall materials.

Properly estimating wall material properties when interacting with the plasma is still an open subject. In particular, quantitative estimation of the "energy reflection coefficient" R_E characterizing the amount of the incident ion energy that will be transfered to the reflected neutral is still subject to large uncertainties. These numbers can be provided by Monte-Carlo quantum mechanical treatment of ion-atom collisions in the solid (e.g. TRIM/SRIM [2]). TRIM provides R_E as a function of the incident ion's energy and of the angle of incidence of the latter ion with the wall surface (see Fig. 1). This angle of incidence is determined by the acceleration in the sheath.

In the tungsten case, the high mass of the wall atoms tends to increase the energy reflection coefficient with respect to the carbon case [3].

In this contribution, one investigates the influence of energy recycling on the edge plasma. Two parameters are taken into considerations: the wall material and the angle of incidence. In the first section, a comparison between carbon and tungsten wall is presented. Secondly, a PIC code is introduced to describe the acceleration in the magnetic pre-sheath. In particular, tables for the ion angle of incidence with the wall are generated. These results show that ions mostly impact the wall with shallow angles, assuming smooth surfaces. The consequence of these grazing incidence trajectories on the energy recycling is discussed.

2. Material properties impact on the scrape-off layer

To study the influence of material reflection properties on the edge plasma, Soledge2D-EIRENE simulations have been performed in the double-null WEST tokamak geometry considering first a wall in carbon and then a wall in tungsten. The simulation parameters only differ from the wall material. In both cases, one considers a plasma of pure deuterium. The simulations parameters (see [1]) are gathered in Table 1.

In this section we consider model #1 where the electric field in the sheath is assumed to be strong enough to bend the ion trajectory so that ions impact the wall with an average velocity almost

* Corresponding author.
E-mail address: hugo.bufferand@cea.fr (H. Bufferand).

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normal to the material surface [4]. More precisely, ions are described by a Maxwellian distribution of temperature $T_{i_{wall}}$ and shifted with a velocity $\vec{u}_{i_{wall}} = c_s\vec{n}$ where c_s is the sound speed and $\vec{n}$ is the normal vector with the wall. The average angle of incidence for such a distribution is $\alpha \approx 70^\circ$.

Simulation results show an increase of the temperature in the tungsten SOL with respect to the carbon case (Fig. 2). This effect is explained by the more intense energy recycling in the tungsten case. More precisely, a larger fraction of the incident ion flux is reflected as hot deuterium atoms which further deposit their energy on the ion channel when they ionize.

Fig. 3 shows the energy fluxes on the divertor targets. The deposit of energy on the wall is quite similar for the two materials. A small reduction of the peak heat load as well as a slight broadening of the heat flux channel is observed in the tungsten case. Once again, this phenomenon is coherent with the more intense energy recycling where hot deuterium atoms generated near the strike points take the energy away from the separatrix to deposit it deeper in the SOL and in the private flux region. More precisely, looking at the different contributions to the net heat flux on the wall, even if the net heat fluxes are roughly the same for both cases, the plasma energy flux impacting the wall is somewhat higher in the tungsten case. This higher plasma flux is compensated by a more significant reflected energy flux.

3. Impact of the particle angle of incidence

3.1. Tables for sheath properties from PIC simulations

In the Soledge2D-Eirene simulations, the wall reflection properties are computed with the TRIM code. TRIM follows impacting plasma ions in their many collisions with the material atoms. A key parameter for these simulations is the angle of incidence of the ions with the wall surface. The reflection coefficients computed by TRIM strongly depend on this parameter, see Fig. 1. This impact angle depends of the kinetic properties of the sheath. In the following, we present a systematic way to determine this average angle

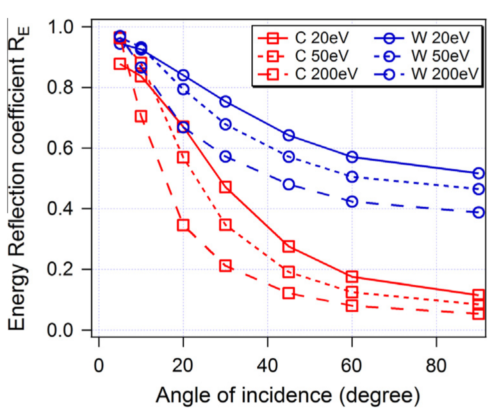

Fig. 1. Energy reflection coefficients computed by the TRIM code for deuterium ions impacting on a carbon surface (red squares) and a tungsten surface (blue circles) as a function of the angle of incidence α ($\alpha = 90^\circ$ corresponds to a normal incidence with the surface). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

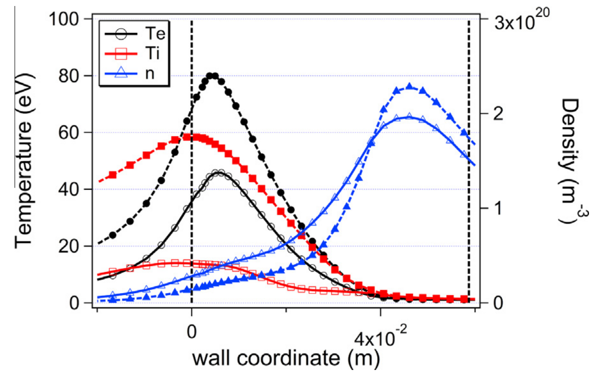

Fig. 2. Soledge2D-Eirene results in the WEST configuration with a carbon wall (open symbols) and a tungsten wall (full symbols) on the target plate at inner strike point position. Results obtained with sheath model #1.

of incidence using tables generated with a PIC code [5,6] consistently describing the sheath.

The PIC code is based on [7]. The geometry of the simulation domain is described in Fig. 4 where the z axis coincides with the parallel-to-B direction, the y axis points in the perpendicular-to-$\vec{B}$ direction and lies in a plane perpendicular to the wall surface, the x axis pointing in the $\vec{E} \times \vec{B}$ direction parallel to the wall surface, the sheath electric field being considered normal to the wall surface. α_B denotes the angle of the magnetic field with the wall surface. The PIC code solves the three components of the equation of motion,

$$m\frac{du_x}{dt} = qBu_y \quad (1)$$

$$m\frac{du_y}{dt} = -qBu_x + qE\cos\alpha_B \quad (2)$$

$$m\frac{du_z}{dt} = qE\sin\alpha_B \quad (3)$$

where the electric field $\vec{E}$ is self-consistently computed by Poisson's equation,

$$\Delta\phi = \frac{d^2\phi}{ds^2} = -\frac{e}{\varepsilon_0}(n_i - n_e) \quad (4)$$

n_i and n_e being the local ion and electron densities, s denoting the coordinate perpendicular to the wall surface.

At $s = s_W$, the wall is considered perfectly absorbing and the wall potential is set to $\phi_W = 0.5\ln[(2\pi m_e/m_i)(1 + T_i/T_e)]$. On the other side, at $s = 0$, charged particles are launched according to the distribution by Chung and Hutchinson [8], the potential is set to $\phi = 0$. The simulation domain size s_W is set to be much greater than the particle Larmor radius.

In addition to the geometrical parameter α_B, the normalization of the equations shows that three nondimensional parameters gorvern the solution: the mass ratio $\mu = m_i/m_e$, the temperature ratio $\tau = T_i/T_e$ and the "sheath magnetization" $\zeta = r_L/\lambda_D$ where r_L and λ_D denote the Larmor radius and the Debye length respectively. For a given set of the latter parameters, the PIC code gives access to the particle and energy distribution of particles on the wall as a function of their angle of incidence, see Fig. 5. By averaging these

Table 1
Soledge2D-Eirene parameters.

Parameter	D	ν	χ_e	χ_i	Power	n_{OMP}
Value	0.6 $m^2\,s^{-1}$	0.2 $m^2\,s^{-1}$	2 $m^2\,s^{-1}$	2 $m^2\,s^{-1}$	8 MW	$3\cdot10^{19}\ m^{-3}$

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