Investigation of magnetic sheath effect on angle of incident ion at graphite wall

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The ion incident angle on an oblique plasma-facing surface can deviate from the magnetic field line, depending on the characteristics of the plasma sheath which is formed between the plasma and the surface. The characteristics of the sheath in an oblique magnetic field is investigated with respect to the magnetic field strength and the angle. A fluid model predicts that, in a weak magnetic field, the sheath structure consists of a presheath and a sheath. In a strong magnetic field, the sheath structure is composed of a collisional presheath, a magnetic presheath, and a sheath. The characteristics of each region and the ion dynamics inside the regions are also revealed. The observed ion incident angle, which is measured by a noble material probe, verifies the fluid model of the oblique magnetic sheath.

1. Background

In the existence of a strong magnetic field (*B*-field), like in a tokamak, it is easy to consider that the ion incident angle on an oblique surface would be comparable to that of the *B*-field line. However, Ahedo [1] suggested a magnetic sheath model that the electric field (*E*-field) inside the plasma-wall transition region (here, we call it the 'transition region') forces the ions to have the ExB drift motion. Thus, the ion motion becomes 3-D, deviated from the *B*-field line. However, no experimental observation that verifies the model has been carried out. Here, we have verified the Ahedo's model by observing the ion incident angle on an oblique plasma-facing surface in magnetic fields. Some ambiguity of the model has also been corrected.

The governing equation set of the model is,

$$\frac{d^2U}{dx^2} = \frac{e(n_e - n_i)}{\varepsilon_0}\ , \quad \ln n_e - \frac{eU}{k_B T_e} = const.\ , \quad n_i V_x = const.$$

$$m_i V_x \frac{d\mathbf{V}}{dx} = e\mathbf{V}\times\mathbf{B} - \left(e\frac{dU}{dx} + \frac{k_B T_i}{n_i}\frac{dn_i}{dx}\right)\hat{\mathbf{x}} - \nu_c m_i \mathbf{V}\,. \quad (1)$$

Here, the *E*-field is assumed to be aligned along the surface normal (-*x* direction) and the magnetic field is lying on the *xz*-plane as $\mathbf{B}=B(\cos\psi, 0, \sin\psi)$ (Fig. 1).

2. Experiments

A noble 'material probe' has been developed to measure the ion incident angle at the probe surface. When immersing a negatively biased graphite probe to a hydrogen plasma, a bundle of nano-tip is formed on the surface (Fig. 1) along the ion incident direction, due to the physical/chemical etching by energetic incident ions. By analysing the inclined angle on SEM images, the ion angle can be measured.

Experiments were carried out in both the weak and strong *B*-field conditions (an ECR source with < 1 kG and the KSTAR far-SOL with ~ 2 T). The angle between the probe (surface normal direction) and the *B*-field was varied in the range of 0º ~ 85º.

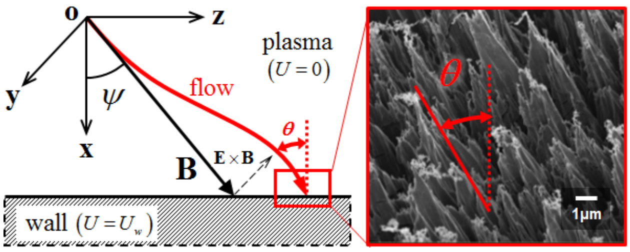

Figure 1. A schematic diagram of the system and the nano-scale tips on the material probe.

3. Results and Discussion

With the parameters of the weak-*B* ECR plasma, the model predicts that the transition region consists of two layers; a presheath and a sheath. In the presheath the ions start to flow along the -*y* direction. The *y*-directional velocity, V_y, is given by,

$$V_y = \frac{\left(V_x^2 - C_s^2\right)}{V_{Ti}^2 - C_s^2}\frac{1}{B\sin\psi}\frac{dU}{dx} + \frac{V_x}{\sin\psi}\frac{\nu_c}{\omega_{ci}}\,. \quad (2)$$

Eq. (2) reveals that the *E*x*B* drift (1st term on RHS) and the collisional property (2nd term on RHS) both affect the ion motion. In the sheath, the ions are accelerated only in the surface normal direction.

With the parameters of KSTAR far-SOL plasma, it is predicted that the transition region consists of three layers; a collisional presheath, a magnetic presheath, and a sheath. Although there is a weak *E*-field inside the collisional presheath, the strong *B*-field confines the ions thus V_y=0 in the region. The ions start to move along the -*y* direction inside the magnetic presheath, and the velocity,

$$V_y = \left(\frac{V_x^2 - C_s^2}{V_{Ti}^2 - C_s^2}\right)\frac{1}{B\sin\psi}\frac{dU}{dx}\,, \quad (3)$$

reveals that only the *E*x*B* drift affects the ion motion. The above effects of the sheath make the ion incident angle much narrower than the *B*-field angle. These prediction is greatly supported by our experiments and the details will be discussed in the conference.

[1] E. Ahedo, *Phys. Plasmas* **4**(12), 4419 (1997).