§23. Modeling of Velocity Distribution Function at Debye Sheath Entrance

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In simulation studies of impurity transport, the physical sputtering yield is calculated by the binary collision model with the aid of a Monte Carlo technique. Although they are widely used in recent simulation codes, e.g. ERO[1)] and IMPGYRO[2)], an empirical model of the physical sputtering yield is also employed in these codes. The yield, $Y(E, \theta)$, can be expressed as a function of incident energy, E, and angle, θ, where the angle is measured from the surface normal by using the Bohdansky[3)] and Yamamura[4)] models. A shallow impact enhances the yield especially for high-energy projectiles. This result implies that the angular distribution of incident atoms can radically change the mean sputtering yield. Therefore 1D PIC (particle-in-cell) simulation with a boundary of sheath entrance is widely employed to solve the sheath layer and obtain kinetic information of the incident particles at the wall boundary. The simultion, however, requires velocity distribution function at the sheath entrance, which is determined from the upstream SOL plasma.

Maxwellian distribution, which is frequently emplyed, is also not suitable for SOL plasma with weak collisionality. Although self consistent kinetic models of the distribution function have been developped, they are not sufficient to describe the SOL plasma because of their strict modeling of plasma source. On the other hand, a fluid equation has flexibilities in source distribution and geometrical configuration, and thus the fluid is widely used for SOL models. From a practical point of view, we employ a fluid solution for the SOL and obtain the kinetic information at the sheath entrance.

A simple SOL model used in ERO is as follows. Coordinate x of the 1D system is taken along a magnetic field line and the perpendicular transport is modeled only by the plasma source due to the diffusion. Electron and ion temperatures, T_e and T_i, are constant. A uniform source with constant temperature, T_i, is assumed. Plasma profiles are assumed to be symmetric at $x = 0$. From these assumptions, balance equations of flux and pressure give a simple solution of the electrostatic potential,

$$\frac{e\phi(x)}{T_e} = \ln \frac{1 + \sqrt{1 - x^2/L^2}}{2}, \qquad (1)$$

where the length L is a half of the connection length. The velocity at $x = 0$ is chosen to be zero and the Bohm criterion is used at $x = L$.

In order to obtain the ion distribution function at the sheath entrance, $x = L$, we assume collisionless parallel dynamics for the ion. The distribution function in the region, $-L < x < L$, can be determined from the Vlasov equation in steady state,

$$\frac{d}{dt} f(x, v) = v\frac{\partial f}{\partial x} - \frac{q}{m}\frac{d\phi}{dx}\frac{\partial f}{\partial v} = S(x, v), \qquad (2)$$

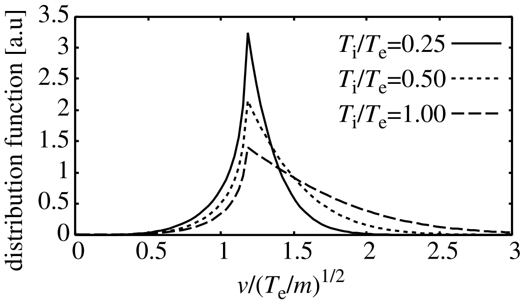

Fig. 1: Distribution functions at the sheath entrance for three different source ion temperature.

where the ion charge and source are denoted by q and S, respectively. Although the distribution function, $f(x, v)$, and the potential $\phi(x)$ are coupled in the Poisson's equation, we use the solution of the fluid equation, Eq. 1, as the potential. Integration of the Vlasov equation along the characteristic curve, i.e. $mv^2/2 + q\phi = \text{const.}$, gives the distribution function. A formal solution is expressed as $f(L, v) = \int S(x', v')/v' dx'$ or $f(L, v) = \int S(x', v')/[-(q/m)d\phi/dx]dv'$, where the characteristic curve is given by $mv'^2/2 + q\phi(x') = mv^2/2 + q\phi(L)$ and the potential at $x = 0$ is taken to be by zero, i.e. $\phi(0) = 0$. We note that the second expression of the integral is necessary when the plasma source, $S(x, v)$, includes a delta function like Tonks-Langmuir model. Since the potential profile given by Eq. 1 is a monotonically decreasing function of x, we obtain an explicit form of the integral,

$$f(L, v) = \int_{x_0}^{L} \{S(x', v') + S(x', -v')\} / v' dx', \qquad (3)$$

where the reflection position of ion with negative velocity, x_0, and the velocity at $x = x'$, v', are given by $x_0 = 0$ for $mv^2/2 + \phi(L) \leq 0$, $\phi(x_0) = mv^2/2 + \phi(L)$ otherwise, and $v'(x') = \sqrt{v^2 - (2q/m)[\phi(x') - \phi(L)]}$. Numerically obtained distribution functions are shown in Fig. 1 for three different source ion temperatures, $T_i/T_e = 1/4$, $1/2$ and 1. The high temperature source leads to broad distribution but the plasma temperature is less than that of the source because of the acceleration in the collisional presheath. The shape of the distribution is quite similar to the kinetic solution by Emmert[5)]. The velocity at the peak is, however, higher than in Emmert model because the potential drop is larger, $\simeq 0.7T_e/e$, than that of Emmert model, $\simeq 0.4T_e/e$.

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