§20. Wall Potential Drop at a Plasma-Facing Wall for a Two-Temperature Electron Distribution

Tomita, Y., Kawamura, G.,
Ueno, M., Ohno, N. (Nagoya Univ.),
Huang, Z.H., Pan, Y.D., Yan, L.W. (Southwestern Institute of Physics)

Detailed analysis of a wall potential drop at a plasma-facing wall (PFW) is studied for a two-temperature electron distribution (TTED). In this study the electrostatic potential ϕ is assumed to decrease monotonically from the sheath entrance, where $\phi = 0$, to the plasma-facing wall. The electron and ion velocity distribution functions at the sheath entrance are Maxwellian and shifted Maxwellian distributions, respectively. The shifted ion speed is assumed to be the ion sound speed at the sheath entrance, which is expressed by using the effective electron temperature $T_{e,eff}$:

$$c_{s,TTED} = \sqrt{(Z_i T_{e,eff} + \gamma_i T_i) / m_i} \ , \qquad (1)$$

where m_i, Z_i and γ_i are the mass, atomic number and the ratio of specific heats of the ions, respectively. The effective electron temperature is defined as:

$$\frac{n_{se}}{T_{e,eff}} = \frac{n_{ec}}{T_{ec}} + \frac{n_{eh}}{T_{eh}} \ , \qquad (2)$$

where n_{ec}, n_{eh} and n_{se} are the cold-, hot-electron density and the total density at the sheath entrance, respectively, and T_{ec} and T_{eh} are the temperatures of the cold and hot electron components, respectively. Under this model the floating wall potential drop $|\phi_w|$ ($\phi_w < 0$) is determined by the condition of equal current density of plasma electrons and ions to the PFW:

$$\begin{aligned} &\frac{2n_{ec}}{1+\mathrm{erf}\sqrt{-e\phi_w / T_{ec}}} \sqrt{T_{ec}} e^{e\phi_w / T_{ec}} \\ &+ \frac{2n_{eh}}{1+\mathrm{erf}\sqrt{-e\phi_w / T_{eh}}} \sqrt{T_{eh}} e^{e\phi_w / T_{eh}} \\ &= n_{se}\{\sqrt{2\pi m_e Z_i T_{e,eff} / m_i} \\ &+ \frac{2\sqrt{m_e T_i / m_i}\, \exp[-(Z_i T_{e,eff} + \gamma_i T_i)]}{1+\mathrm{erf}\sqrt{(Z_i T_{e,eff} + \gamma_i T_i)/2T_i}}\} \end{aligned} \qquad (3)$$

In this study the model is applied to a hydrogen plasma and $\gamma_i = 1.0$.

In order to study the effects of the TTED on the wall potential drop, we consider the ion temperature T_i to be negligibly small. The density and the temperature of the hot electron component give a higher electron current to the PFW. Therefore, $e|\phi_w|$ becomes larger to limit the electron current density, while the ion current density does not change. In the case of a much deeper potential drop, the electron current due to the cold component becomes much smaller and the floating potential is determined by the electron current due to the hot component [the 2nd term on LHS of Eq. (3)], and the ion current; the effect of truncation of the hot-electron velocity distribution is also negligibly small. In this case the potential drop $\phi_{w,1}$ becomes:

$$\frac{e\phi_{w,1}}{T_{ec}} = \frac{T_{eh}}{T_{ec}} \ln\left(\frac{n_{se}}{n_{eh}} \sqrt{\frac{T_{ec}}{T_{eh}}} \sqrt{\frac{2\pi Z_i m_e}{m_i} \frac{n_{se}}{n_{ec} + n_{eh} T_{eh} / T_{ec}}}\right) . \qquad (4)$$

In the case of a lower electron temperature of the hot electron component, e.g. $T_{eh}/T_{ec} = 3.0$, the potential drop is as low as around 5. This means the approximation of $\phi_{w,1}$ is not applicable, where the effect of the cold component is neglected. On the other hand, for a higher electron temperature of the hot electron component, e.g. $T_{eh}/T_{ec} = 20.0$, the potential drop is as high as about 50, where ϕ_w is in good agreement with the approximate form $\phi_{w,1}$.

In the case of finite ion temperature, the ion current density increases and $|\phi_w|$ decreases to balance the electron current density. Therefore, $|\phi_w|$ is determined by the competition of between the hot electron component and the finite ion temperature. These effects are shown in Fig.1 by the relation between the hot electron component and the finite ion temperature, where on the boundary line $|\phi_w|$ is equal to that without either of them $|\phi_{w0}|$.

$$|\phi_{w0}| \equiv |\phi_w(n_{eh} = 0, T_i = 0)| = \left| \frac{T_e}{2e} \ln\left(\frac{2\pi Z_i m_e}{m_i}\right) \right| . \qquad (5)$$

For the hydrogen plasma $e|\phi_{w0}| / T_{ec}$ is 2.839. In the case that the ion temperature is higher than the boundary value, the wall potential drop $|\phi_w|$ is smaller than $|\phi_{w0}|$, because the effect of ion temperature is stronger than that of the hot electron component. On the other hand, in the case the hot component, n_{eh}/n_{se} or T_{eh}/T_{ec}, is higher than the boundary value, the wall potential drop is larger than $|\phi_{w0}|$. For example, for $n_{eh} / n_{se} = 0.03$, $T_{eh} / T_{ec} = 5.0$ and $T_i = 0$, the normalized potential drop increases to 3.727. An ion component with a temperature $T_i / T_{ec} = 0.628$ decreases this value to $e|\phi_{w0}| / T_{ec} = 2.839$. In the case of a higher hot electron component, $n_{eh} / n_{se} = 0.1$ and $T_{eh} / T_{ec} = 10.0$, the boundary ion temperature is as high as 11.12.

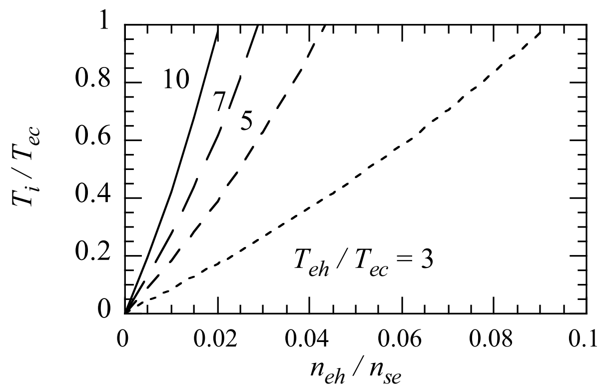

Fig.1 The relations between the hot electron component and the finite ion temperature, where the $|\phi_w|$ is equal to that without either of them $e|\phi_{w0}| / T_{ec}$.