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Probe measurement under the influence of secondary electron emission
プラズマの二次電子放出を考慮したプローブ測定

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For a plasma with an electron tempertature, being high enough with influence of secondary electron emission by electron impact to an electrode, the electron temperaure can be estimated from a slope of the logarithmic plot of the probe V-I characteristics. However, an electon density needs to be estimated using a correction factor depending on the electron temperature.

1. Introduction

To improve probe measurements of tokamak boundary plasmas with energetic electrons, we need to consider secondary electron emission by electron impact. Then, the effective coefficient of secondary electron emission depending on an electron temperature has been derived from an empirical formula of secondary electron emission for a plasma with a Maxwellian electron velocity distribution. The validity of the effective coefficient was experimentally investigated using probes with electrodes made of tungsten and molybdenum electrodes.

2. Coefficient of secondary electron emission

The coefficient of secondary electron emission is a function of the energy of primary electron, E_p, and might be given by an empirical formula of the coefficient as follows: [1]

$$\delta = (2.72)^2 \delta_\mathrm{m} \frac{E_\mathrm{p}}{E_\mathrm{m}} \exp\left(-2\sqrt{\frac{E_\mathrm{p}}{E_\mathrm{m}}}\right) . \qquad (1)$$

Here, δ_m is the maximum yield and E_m is the primary energy with the maximum yield; δ_m and E_m depend on a material. Table I gives their values for tungsten (W) and molybdenum (Mo) for probe electrodes.

Table I. Values of δ_m and E_m for tungsten (W) and molybdenum (Mo).

	δ_m	E_m (eV)
W	1.35	650
Mo	1.25	375

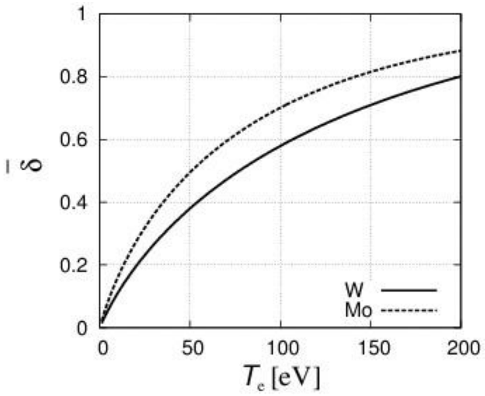

Fig.1 Dependence of $\bar{\delta}$ with T_e. Solid curve indicates for tungsten (W) and broken curve indicates for molybdenum (Mo).

For a Maxwellian electron velocity distribution with an temperature, T_e, the effective value of secondary electron emission coefficient, $\bar{\delta}$, can be defined by

$$\bar{\delta} = \frac{\int_{v_0}^{\infty} \delta(E_\mathrm{p}) v \exp(-m_\mathrm{e} v^2 / 2k_\mathrm{B} T_\mathrm{e}) dv}{\int_{v_0}^{\infty} v \exp(-m_\mathrm{e} v^2 / 2k_\mathrm{B} T_\mathrm{e}) dv}$$

$$= (2.72)^2 \delta_\mathrm{m} \frac{k_\mathrm{B} T_\mathrm{e}}{E_\mathrm{m}} \int_0^{\infty} \xi e^{\left[-\xi - 2\sqrt{\left(\frac{k_\mathrm{B} T_\mathrm{e}}{E_\mathrm{m}}\right)\xi}\right]} d\xi. \qquad (2)$$

Here, m_e is an electron mass, k_B is the Boltzmann constant, $\frac{1}{2} m_\mathrm{e} v_0^2 = e(V_\mathrm{s} - V_\mathrm{b})$ and

$E_p = \frac{1}{2} m_e (v^2 - v_0^2)$ with an elementary charge e, a space potential V_s and a bias potential applied to a probe electrode V_b. It is easily seen that $\bar{\delta}$ doesn't depend on $V_s - V_b$ but T_e [2]. Figure 1 shows $\bar{\delta}$ of tungsten and molybdenum, as functions of T_e. It might be worth to mention that there is the condition of $\bar{\delta} \le 0.81$ for the existence of a monotonic sheath [3].

3. Experiment

An argon plasma was filled in a pyrex glass tube with a diameter of 100 mm and a length of 800 mm, where a structure similar to a double plasma device was constructed. By decreasing a wall potential of a driver side against a wall potential of a target side, a plasma with two Maxwellian electron velocity distributions, the temperatures of which are T_{ec} (≈ 2 eV) and T_{eh} (10-40 eV), respectively, was produced in the target side. In such the plasma with two electron components, the electron current of a probe electrode, I_e, is composed by two parts as follows:

$$\begin{aligned} I_e / S &= I_{ec} / S + I_{eh} / S \\ &= \left[1 - \bar{\delta}(T_{ec})\right] n_{ec} \sqrt{\frac{k_B T_{ec}}{2\pi m_e}} \exp\left(\frac{eV_b}{k_B T_{ec}}\right) \\ &\quad + \left[1 - \bar{\delta}(T_{eh})\right] n_{eh} \sqrt{\frac{k_B T_{eh}}{2\pi m_e}} \exp\left(\frac{eV_b}{k_B T_{eh}}\right), \end{aligned} \tag{3}$$

where S is the area of the surface of the probe electrode; and n_{ec} and n_{eh} are densities of the components with T_{ec} and that with T_{eh}, respectively. Note that $\bar{\delta}(T_{ec})$ represents $\bar{\delta}$ for T_{ec} and that $\bar{\delta}(T_{eh})$ represents $\bar{\delta}$ for T_{eh}. Accordingly, both T_{ec} and T_{eh} are determined from the usual logarithmic plot of the electron current. Using the logarithmic plot of I_e with higher voltages of V_b, T_{eh} is determined since the contribution of the component with T_{ec} to I_e is small. Then, using the logarithmic plot of the remaining electron current after the component with T_{eh} is subtracted from I_e, T_{ec} is determined. On the other hand, the usual treatment gives densities of the two components, n_{ec}' and n_{eh}', which are smaller than true densities we want to obtain, n_{ec} and n_{eh}, respectively, due to the effect of secondary electron emission. Specifically, $n_{ec}' = [1 - \bar{\delta}(T_{ec})] n_{ec}$ and $n_{eh}' = [1 - \bar{\delta}(T_{eh})] n_{eh}$. Then, we define two ratios of the density of the component with T_{eh} to that of the component with T_{ec}, i.e., $f_n = n_{eh} / n_{ec}$ and $f_n' = n_{eh}' / n_{ec}'$. Between the two ratios, we have the relation of

$$f_n = \frac{1 - \bar{\delta}(T_{ec})}{1 - \bar{\delta}(T_{eh})} f_n'. \tag{4}$$

Probe measurements were made with consideration that different values of f_n' might be obtained but almost the same value of f_n would be obtained using probes with electrodes made of different materials. Since we used probes with electrodes made of tungsten and molybdenum, we can compare $f_{n\text{-W}}$ with $f_{n\text{-Mo}}$ and $f_{n\text{-W}}'$ with $f_{n\text{-Mo}}'$. The results are shown in Fig. 2, where $f_{n\text{-Mo}} / f_{n\text{-W}}$ and $f_{n\text{-Mo}}' / f_{n\text{-W}}'$ are plotted as functions of T_{eh} by closed circles and open circles, respectively. Consequently, we find the validity of using $\bar{\delta}$ from the facts that $f_{n\text{-Mo}} / f_{n\text{-W}} \approx 1$ and $f_{n\text{-Mo}}' / f_{n\text{-W}}' \approx [1 - \bar{\delta}_{Mo}(T_{eh})] / [1 - \bar{\delta}_W(T_{eh})]$, because of $T_{eh} >> T_{ec}$, where the subscript of $\bar{\delta}$ indicates the material (W or Mo) of an electrode.

References

[1] E. W. Thomas: Nuclear Fusion Special issue(1984) p. 94.

[2] G. Fuchs and B. Schlarbaum: Journal of Nuclear Materials **145-147** (1987) p.268.

[3] G. D. Hobbs and J. A. Wesson: Plasma Physics **9** (1967) p.85.

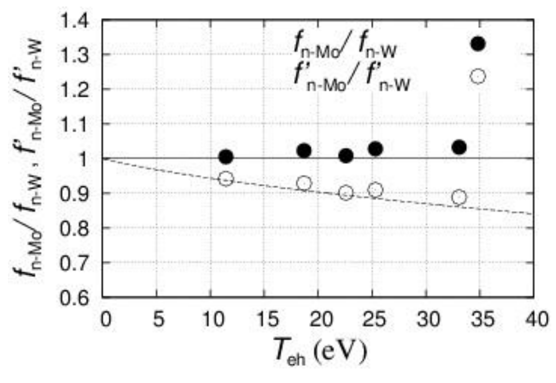

Fig.2 $f_{n\text{-Mo}} / f_{n\text{-W}}$ and $f_{n\text{-Mo}}' / f_{n\text{-W}}'$ are plotted as functions of T_{eh} by closed circles and open circles, respectively. Solid line represents $f_{n\text{-mo}} / f_{n\text{-W}} = 1$ and Broken curve represents $f_{n\text{-mo}}' / f_{n\text{-W}}' = [1 - \bar{\delta}_{Mo}(T_{eh})] / [1 - \bar{\delta}_W(T_{eh})]$.