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Direct plasma potential measurements by a novel probe

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1. Introduction

Up to now, emissive probes [1] and heavy ion beam probes [2] were used for the determination of the plasma potential in tokamaks. However, the use of these techniques is hampered by technical problems and peculiarities in the interpretation of the data. In practice single Langmuir probes are used to measure the floating potential V_{fl}, and the plasma potential Φ is deduced from the simple formula:

$$\Phi = V_{fl} + T_e \ln(R) \qquad (1)$$

where T_e is the electron temperature in eV. The quantity $R = I_{sat}^{-}/I_{sat}^{+}$ represents the ratio of the electron and ion saturation currents, respectively. In a hydrogen plasma the theoretical value of $\ln(R)$ is about 3.

The plasma potential derived from Eq. (1) is correct only if T_e and R are known. The electron temperature can be estimated from the *I-V* characteristics of a Langmuir probe, but R can not be obtained experimentally. The basic idea of the direct plasma potential measurement, which is proposed in this contribution, is to adjust R to be equal to one. If this is achieved, the floating potential of the probe V_{fl} is equal to the plasma potential Φ (Eq. (1). In a strong magnetic field, a novel probe, called "ball-pen" probe, offers the possibility to reduce the electron saturation current to the same magnitude as that of the ion saturation current. This is realised by a shield, which screens off an adjustable part of the electron current from the probe collector due to the much smaller gyroradius of the electrons. A similar probe was developed by Katsumata and Okazaki [3,4], but in their case the purpose was to screen off the electrons completely.

2. The "ball-pen" probe

The probe head, inserted perpendicular to the magnetic field, is shown in Fig. 1. The probe consists of a conically shaped collector, which is shielded by an isolating tube of boron ni-

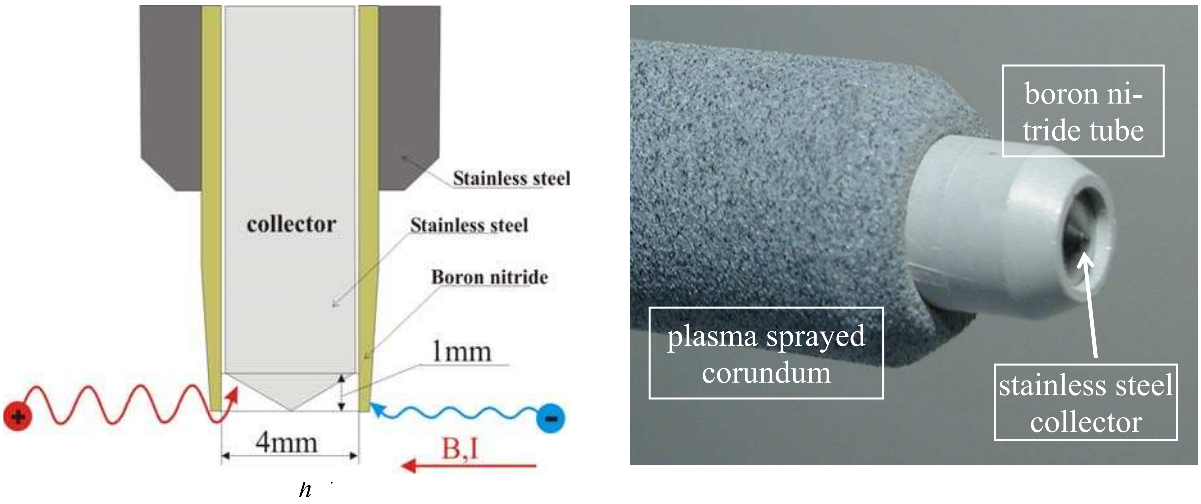


Fig. 1. Schematic and photograph of the ball-pen probe.

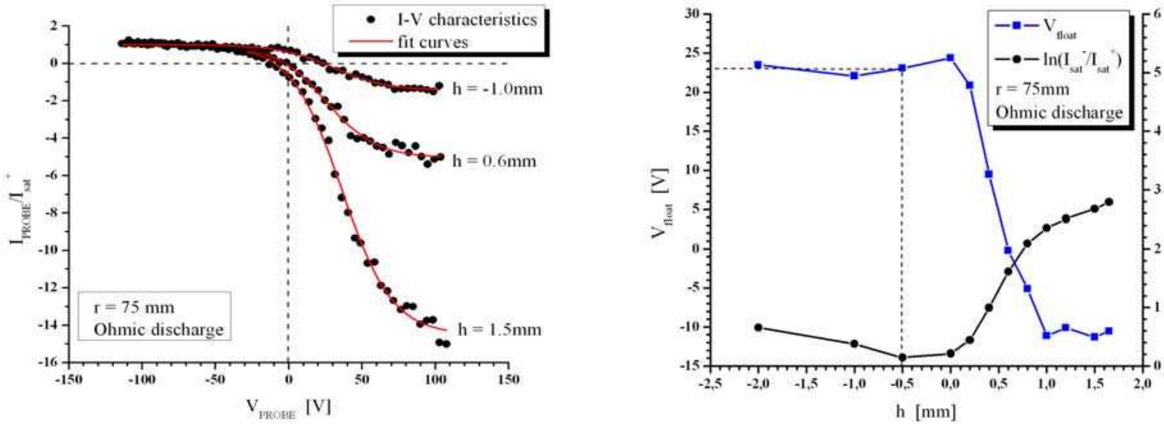
tride. The collector is movable inside the tube on a shot-to-shot basis. The parameter h indicates the distance of the collector tip from the opening plane of the boron nitride tube. When the collector is hidden inside the tube (i.e., for $h < 0$), as shown in Fig. 1, in principle only ions with sufficiently large Larmor radii can reach the collector, whereas the collecting area for electrons is negligible ($R << 1$). When the collector is shifted towards the plasma ($h > 0$), the electron current as well as R increase. For a certain value of h, the electron and ion currents are expected to be balanced (i.e., $R = 1$), in which case $V_{fl} = \Phi$.

Tests of the ball-pen probe have been performed at the CASTOR tokamak (major/minor radius 40 cm/8.5 cm, $B_T = 1.3$ T, $I_P = 10$ kA). At the plasma edge, the electron and ion temperature are in the range of 10 eV. The corresponding Larmor radii are $\rho_i \cong 0.5$ mm and $\rho_e \cong 0.01$ mm. The edge plasma density is $n \cong 10^{18}$ m^{-3}. The probe was inserted into the edge plasma and biased by a sweeping voltage ($f = 1$ kHz, ±100 V). Examples of I-V characteristics are plotted in Fig. 2a for three positions h.

The probe current is normalized to the ion saturation current I_{sat}^{+}. The parameters T_e, I_{sat}^{+} and V_{fl} are obtained by fitting the ion branch of the I-V characteristic ($V_p \leq V_{fl}$). The value of R is given by the saturation of the electron branch of the I-V characteristic (Fig. 2a). We see that R and V_{fl} strongly depend on the collector position h. The magnitudes of I_{sat}^{-} and I_{sat}^{+} are almost balanced, when the collector is 1 mm inside the shielding tube ($h = -1$ mm).

Fig. 2b shows the floating potential V_{fl} and the ratio R as a function of the collector position h. It is evident that ln(R) is always positive for any value of h. This indicates that electrons are present even in the shadow of the shielding tube, and I_{sat}^{-} is always higher than

I^{+}_{sat}. This is in contrast to the simple model based on the electron and ion gyromotion along the magnetic field lines. The reason for this discrepancy might lie in an $E\times B$ drift of the particles into the shielding tube. Nevertheless, ln(R) attains a minimum (viz. ln(R) = 0.1), when the tip of the collector is slightly inside the tube (h = –0.5 mm). In this situation the probe potential is close to the plasma potential.



(a) (b)

Fig. 2. (a) I-V characteristics for various collector positions. h is negative when the collector is inside the shielding tube; (b) floating potential V_{fl} *and* ln(R) *with respect to h. The radial position of the probe head is at 75 mm.*

Fig. 2b shows that the value of the probe potential significantly decreases when the collector is more and more exposed to the plasma. When the collector is fully outside the shielding tube ($h \cong 1.5$ mm), the probe operates as a conventional single Langmuir probe and measures the floating potential V^{0}_{fl}. The probe potential is approximately constant and equal to the plasma potential Φ even when the collector is completely hidden inside the tube ($h <$ –0.5 mm). The reason for this behaviour is not yet clear. However, it has practical relevance for direct measurements of Φ since in this way the collector could be protected from high energy flux of the plasma particles.

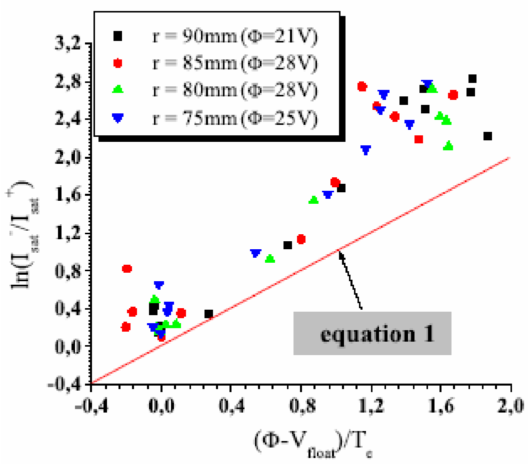
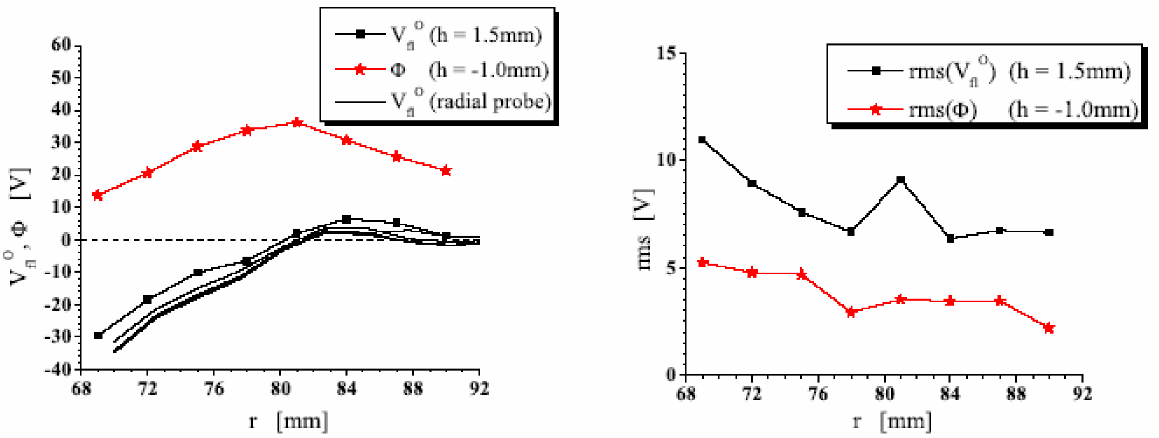


Fig. 3. Experimental relation between the logarithm of R and the difference between plasma (Φ) and floating potential (V_{fl}) *normalized to the electron temperature* T_e.

In Fig. 3 ln(R) is plotted versus the difference of the plasma and the floating potential, normalized to T_e, for several radial positions of the ball-pen probe. The relation between these two quantities appears to be linear. This is in good agreement with Eq. (1), but the linear fit

(y =1.36 x + 0.31) is not exactly confirmed by this simple model. The reason for this discrepancy may lie in the accuracy of the estimation of T_e and R, or in the simplicity of the model, which may be not quite correct for our plasma conditions.



(a) (b)

Fig. 4. (a) Radial profiles of plasma potential (red stars) and floating potential (black squares) measured by the ball-pen probe compared with the floating potential of a radial array of Langmuir probes (black single lines); (b) Radial profiles of rms values of the fluctuations of floating potential (black squares) and plasma potential (red stars).

Fig. 4a shows radial profiles of Φ and V_{fl} in standard ohmic discharges. In this case only the floating potential of the collector is measured. For each radial position of the probe head, the collector is either hidden inside the shielding tube (h = –1 mm) or sufficiently exposed to the plasma (h = 1.5 mm). The figure shows also a comparison with the radial profile of the floating potential measured by a radial array of sixteen Langmuir probes located at a different toroidal position, which is used as a routine diagnostic for the estimation of the electric field at the edge plasma in the CASTOR tokamak. Fig. 4b shows radial profiles of the fluctuations, which here are plotted in rms values. It is evident that the level of the fluctuations of the plasma potential is lower than that of the floating potential by a factor 2.

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