# Emissive Probes in Complex Plasmas

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Emissive probes are of widespread use in various plasmas for a direct determination of plasma potential and electric fields, since the floating potential of a strongly emissive probe is close to the plasma potential. Recently such probes were also applied for edge electric fields measurements in toroidal fusion experiments [4,6]. In many plasmas additional energetic electron populations are present, frequently truncated at the high energy tail due to production and/or acceleration mechanisms. We have therefore investigated the usefulness of emissive probes in complex plasmas. Here we present fundamental measurements in magnetized as well as non-magnetized DC discharge plasmas in Ljubljana and Innsbruck, respectively.

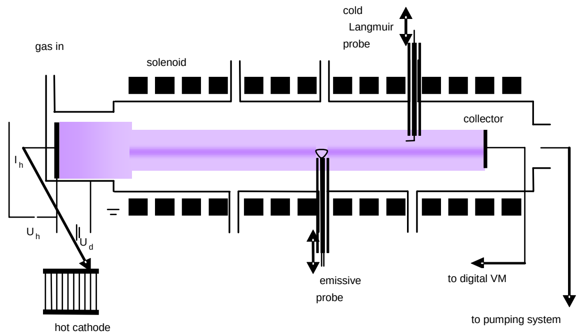


Fig.1 Ljubljana Linear Magnetized Plasma Device - LMPD

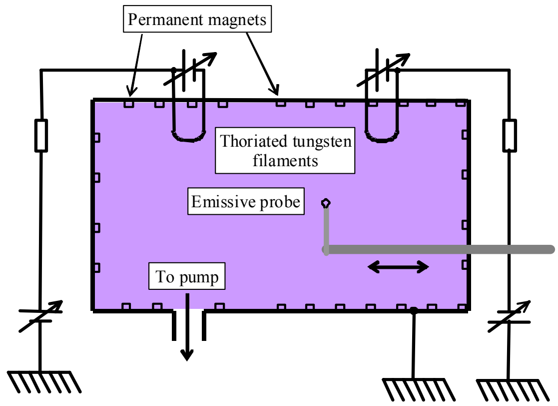


Fig.2 Innsbruck Double Plasma (DP -) Machine

Several methods for the plasma potential determination were used, i.e. the inflection-point method, the differential method and the floating potential method in hydrogen, argon and helium plasma gases at low and high working pressures. Plasmas with very different densities, electron temperatures and even with two electron populations with higher and lower temperature are obtained. Special attention is devoted to the dependence of the floating potential on the heating current of the probe. The saturated value of the floating potential for high heating currents is currently believed to be a good measure of the plasma potential, but the influence of the space charge of emitted electrons and of a magnetic field on the saturation value still needs investigation.

In both machines plasma is created by low pressure discharge using tungsten or thoriated tungsten filaments as hot cathodes with hydrogen, helium and argon as working gases. The plasma density is typically $10^{16}$ $m^{-3}$, the electron temperature about 3 eV, the background gas pressure is around $10^{-2}$ to $10^{-1}$ Pa.

In the LMPD the homogeneous magnetic field is in the range of 10 mT. In the DP-machine the plasma is unmagnetized, save at the edges where permanent magnets improve the confinement of the plasma.

In both machines the emissive probes consist of loops of 0,2 mm thoriated tungsten wire with a loop length of around 5 mm, mounted on an alumina double bore ceramic tube of 3 mm diameter.

In spite of being almost the only diagnostic tool for a direct determination of the plasma potential with good spatial and temporal resolution also in unmagnetized plasmas, emissive probes are still not fully understood. Main problems are:

(i) Frequently it is claimed that emissive probes strongly perturb the plasma and might even cause additional fluctuations. Therefore especially measurements of temporal variations of $\Phi_{pl}$ might be falsified.

(ii) Supposedly the floating potential of even a strongly emissive probe $V_{fl,em}$ will remain below the true value of $\Phi_{pl}$ by a value on the order of $T_e$ [[1] – [6]].

Here we present results which shed more light on the complexity of the plasma and sheath conditions around an emissive probe and show that under special conditions emissive probes can be used for fast and yet reliable measurements of the plasma potential.

The floating potential of an emissive probe is given by: $V_{fl} = \Phi_{pl} - \ln\left(\frac{I_{es}}{I_{is} + I_{em}}\right)T_e^* = \Phi_{pl} - \alpha_{em}T_e^*$.

Thus for $I_{es} = I_{em} + I_{is}$ we obtain $\Phi_{pl} = V_{fl,em}$ (1).

Probe behaviour in the magnetized $H_2$-plasma of the LMPD for increasing probe heating current $I_h$is shown in Fig 3. The yellow rectangle indicates the range where strong emission from the probe into the plasma takes place. The red squares show the floating potential of the probe $V_{fl,em}$. Values start at the cold probe floating potential $V_{fl,c}$= -27,33 V. For $I_h \cong 3{,}7$ V,

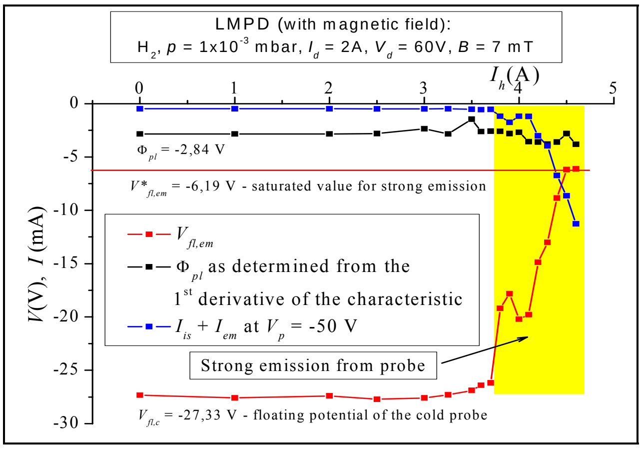


Fig.3. Probe behaviour in the magnetized $H_2$-plasma of the LMPD for increasing probe heating current *Ih*.

when emission starts, $V_{fl,em}$ starts increasing towards the saturated value $V^*_{fl,em} \cong$ -6,19 V which is reached for $I_p \cong$ 4,5 A. However, if we determine $\Phi_{pl}$ in the conventional way from the 1st derivative of the cold characteristic, a value of $\Phi_{pl}$ = -2,84 V is obtained. This seems to corroborate the conclusions in Ref. [3] according to which due to space charge effects even a floating emissive probe will stay at a floating potential below the plasma potential. This seems to speak against emissive probes as diagnostic tools for the plasma potential.

According to the formula (1) given above, the difference $\Phi_{pl}$ - $V_{fl,c}$ between the plasma potential and the cold probe floating potential, divided by the factor $\alpha_{em} = \ln(I_{es}/I_{is})$, is the electron temperature *Te*. For a hydrogen plasma $\alpha \cong 2$ [4]. If we take the value for $\Phi pl$ from the 1st derivative of the cold probe characteristic, we obtain $(\Phi_{pl} - V_{fl,c})/\alpha \cong$ 12,25 eV, a value which is by far too high. However, by taking the difference to the saturated value of the emissive probe, i.e. $(V^*_{fl,em} - V_{fl,c})/\alpha$, we obtain a value of $T_e \cong$ 10,57 eV. Also this value is too high for this type of hot cathode discharge plasma where for hydrogen we usually obtain value of $T_e \cong$ 6 eV. As we will see from the comparative measurements in the unmagnetized plasma of the Innsbruck DP-machine, these discrepancies are less pronounced.

Probe behaviour in the unmagnetized $H_2$ plasma of the Innsbruck DP machine for increasing probe heating current $I_h$ is shown in Fig. 4. Expectedly, the behaviour is quantitatively very different from the LMPD (Fig.3). The yellow rectangle indicates the range where strong emission from the probe into the plasma takes place. The red circles show the floating potential of the probe $V_{fl,em}$. Initially we see the cold probe floating potential $V_{fl,c}$ = -3,27 V. For $I_h \cong$ 4,5 V, when emission starts,$V_{fl,em}$ starts increasing towards the "saturated" value $V^*_{fl,em} \cong$ +1,00 V which is reached for $I_p \cong$ 5,5 A. In this case, however, no real saturation is reached but the emissive floating potential further increases. However, here the value of $\Phi_{pl}$ obtained in the conventional way from the 1st derivative of the cold characteristic is very close, i.e., $\Phi_{pl}$ = +0,94 V is obtained.

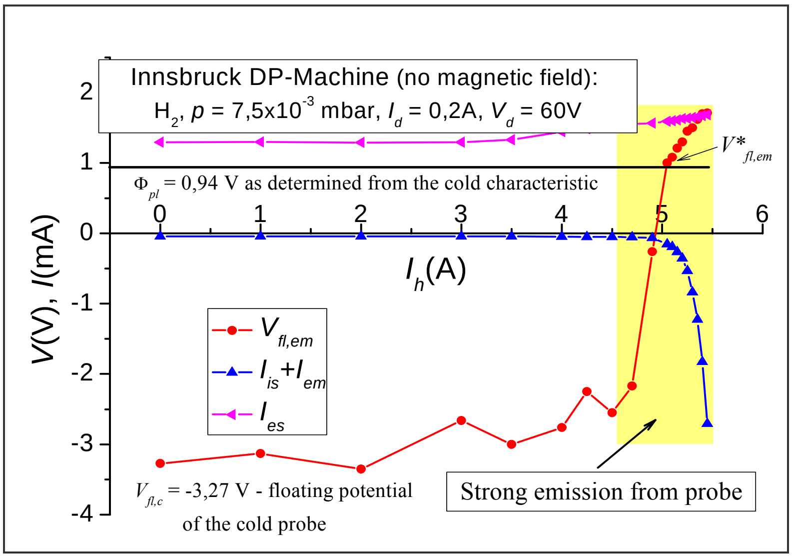


Fig.4 Probe behaviour in the unmagnetized $H_2$-plasma of the Innsbruck DP-machine for increasing probe heating current *Ih*

This does not corroborate the conclusions in Ref. [3] and in this case the emissive probe seems to be a better diagnostic tool for the plasma potential. The question whether this difference behaviour is only due to the magnetic field in the LMPD needs further investigations. In this case, taking the difference between the plasma potential and the cold floating potential $(\Phi_{pl} - V_{fl,c})/\alpha = T_e \cong$ 2,14 eV delivers a reasonable value for the electron temperature. The blue and magenta triangles show the currents on the negative and positive side of the characteristic, respectively, i.,e. in the former case the ion saturation current plus the emission current, $I_{is} + I_{em}$ (which is negative in our definition), in the latter case it is the electron saturation current $I_{es}$. The magnitude of the negative current increases strongly due to the electron emission. The positive current should in principle remain constant, but is also affected by the electron emission. Also this effect has been investigated [5].

Emissive probes can be used to obtain approximate values for the plasma potential, which is particularly easy since we only need to measure their floating potential. However, according to our comparative investigations the magnetic field seems to play a decisive role. Here it seems we get much more reliable results in case of unmagnetized plasma.

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