The spatial resolved plasma diagnostics is a powerful tool for the characterization of technical plasma processes. The langmuir probe concept is the most used plasma probe concept for the last few decades in research and industrial development, which is discussed below.

1 Introduction

The Langmuir Probe is an electrostatic probe. It uses a tungsten wire, which is immersed into the plasma and charged with a voltage sweep. The resulting current is measured and the \( VI \)-characteristic is analysed (see figure 2). From the \( VI \)-characteristic electron density \( n_e \), electron temperature \( T_e \), plasma potential \( V_{pl} \) and floating potential \( V_{fl} \) can be derived. \( V_{fl} \) is assigned to the point of inflection of the \( VI \)-characteristic, while \( V_{pl} \) is the intersection point with the voltage axis for net current \( I_{probe} = 0 \) A, where the electron current is equal to the ion current. For the determination of \( n_e \) and \( T_e \), there are multiple methods available [1–3]. The applied methods for \( n_e \) and \( T_e \) evaluation are discussed in the following section.

2 Langmuir probe measurements

The LP is an established diagnostic tool and well documented [1–4]. For the plasma characterization of plasmas the (Langmuir) Automatic Probe System 3 - APS3 - is used, which was developed at the institute of electrical engineering and plasma technology at the Ruhr-University Bochum [4]. It operates with a sampling rate of 50 kHz to perform fast voltage sweeps and is equipped with a so-called floating probe for the compensation of low frequency shifts of the plasma potential. The rf-signal from the generator and its first five harmonics are blocked using notch filter. The probe tip is made of tungsten wire for thermal stability with diameter \( d = 50 \mu m \) and length \( l = 5 \text{ mm} \).

Figure 2: Concept of Langmuir probe measurements. A voltage sweep is performed and the \( VI \)-characteristic is analysed. Here, the shape of the characteristic is needed for derivation of plasma parameters.
For the interpretation of $VI$-characteristics, the cold ion approximation is adopted and a polynomial function is fitted to the ion saturation branch. This grants access to the electron retarding current $I_e^*$. It is employed according to Druyvesteyn [2], to calculate the electron energy distribution function $f_{E,e}(E)$ (EEDF) with the second derivative of the electron retarding current, given as:

$$f_{E,e}(E = -eV_p) = \sqrt{-8m_e e(V_p - V_{pl})} \frac{d^2 I_e^*}{dV_p^2}$$

for $V_p \leq 0$ V.

It has to be considered, that the potential shown in figure 3 is defined with respect to ground with

$$V_p = V - V_{pl}.$$  

Hence, $V_p = 0$ V means $V = V_{pl}$. Furthermore, $A_p$ denotes the area of the probe tip, $e$ the elementary charge and $V_p$ the probe potential. $d^2 I_e^*/dV_p^2$ is extracted from the $VI$-characteristic, which is smoothed with the Hanning-Blackman FFT filter.

![Figure 3: VI-characteristic measured with the APS3 system. The horizontal dotted line indicates I=0 A. The intersection with the first vertical dotted line shows the floating potential, the second vertical line denotes the plasma potential at the point of inflection of the VI-characteristic.](image)

With $f_{E,e}(E) \sim d^2 I_e^*/dV_p^2$, the second derivative of the electron retarding current, the gradient of the logarithmized EEDF can be used to compute $T_e$ as follows.

$$\ln \left( \frac{d^2 I_e^*}{dV_p^2} \right) = \frac{e}{k_B T_e} V_p + \ln(\text{const}) = mx + b$$

The electron temperature is derived by

$$T_e = \frac{e}{k_B} \left( \frac{d \ln(I_e^*(V_p))}{dV_p} \right)^{-1} = \frac{e}{k_B} \left( \frac{d \ln(f_{E,e}(E))}{dV_p} \right)^{-1}.$$  

With $T_e$ known, the electron density is calculated with the current at the plasma potential $I_e(V_p = V_{pl})$.

$$n_e = \frac{1}{eA_p} \sqrt{k_B T_e} \int_{-e(V_p=0)}^{-e(V_p=V_{pl})} f_{E,e}(E) dE,$$

while the electron temperature is calculated from

$$T_e = \left( \frac{-e(V_p=V_{Pl}-V_{pl})}{\int_{-e(V_p=0)}^{-e(V_p=V_{pl})} f_{E,e}(E = -eV_p) \cdot E \cdot dE} \right) / n_e.$$  

This method is more stable than the first approach, but it is unsensitive to falsified measurement data, which could be caused by deposition on the probe surface [5]. A successful measurement means, that both methods are in good agreement.

References