On the ion energy distribution functions at unbiased walls

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1. Introduction

The energy distribution of ions reaching the surfaces in low-pressure gas discharges are of significant importance for the application of plasmas. Considerable efforts have been devoted to understanding and tailoring the ion energy distribution functions (IEDF) at radio-frequency biased walls. The IEDFs at unbiased walls, on the other hand, have been almost completely neglected, although they are important for understanding such basic and fundamental problems as the ion transport in the plasma bulk and Bohm criterion in multi-component plasmas.

Combining high-sensitivity measurements of the IEDF with plasma-bulk parameters from Langmuir probe diagnostics and the solution of the Boltzmann equation for ions the relation between fundamental ion collisional parameters and the IEDF is revealed. The approach is applied to a series of noble-gas plasmas and excellent agreement is found throughout.

2. Experimental

The measurements are performed in an inductively coupled plasma produced in a chamber with a radius of $R = 25$ cm and a height of 50 cm [1]. The conditions are summarized in Tab. 1. The mass resolved IEDFs are measured with a Balzers Plasma Process Monitor 421 (PPM). The radial distribution of the plasma parameters (effective electron temperature T_e, density n_e, electron energy probability functions (EEPF) and plasma potential V_pl) are obtained by a Langmuir probe.

Tab. 1: *Discharge conditions used in the experiments.*

Gas	He	Ne	Ar	Kr
Pressure (Pa)	1.3	1.3	0.5	0.33
Power (W)	800	600	300	300
λ/R	0.064	0.046	0.074	0.067

3. Theoretical

Except at very low energies, charge-exchange collisions of ions with their parent gas dominate [2]. Then the solution $f(r,v)$ of the cylindrically-symmetric Boltzmann equation with charge-exchange collisions (constant ion free path λ) and a source term $Q(r) = n_\mathrm{e}\nu_\mathrm{iz}$ is

$$f(r,v) = [\Theta(v) - \Theta(v - v_\mathrm{m}(r))] \frac{\mathrm{e}^{-r/\lambda}}{r} g(W). \quad (1)$$

The function g of the total energy W is

$$g = -\frac{m\,\mathrm{e}^{x_0/\lambda}}{\partial eV/\partial x_0}\left[\int_0^{x_0} \frac{y}{\lambda} Q(y)\mathrm{d}y + x_0 Q(x_0)\right], \quad (2)$$

where $x_0 = V^{-1}(W/e)$ is defined by the inverse of the potential profile $V(r)$ and m is the ion mass.

4. Results and discussions

Fig. 1 shows a comparison of the measured IEDF in Ne with the theoretical solution. Two regions can be separated: high-energy ions traversing the bulk and the sheath without collisions (up to the maximal energy in the plasma centre) and lower-energy ions from the sheath.

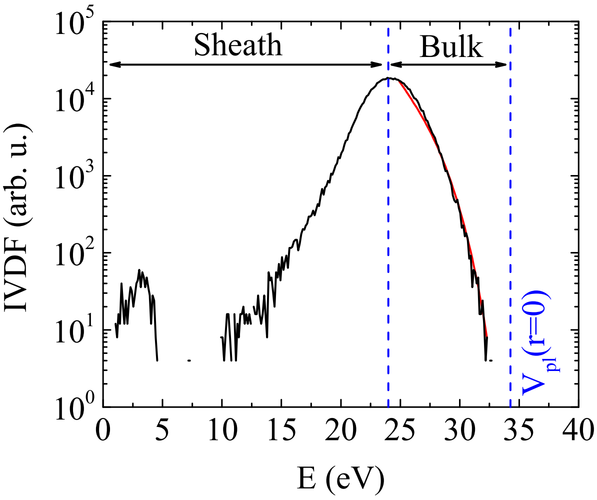

Fig. 1: *IEDF measured in Ne and the solution of the Boltzmann equation using measured plasma parameters.*

The theoretical curve in Fig. 1 is calculated using the solution of the Boltzmann equation where the experimental distribution of the plasma potential and electron density n_e have been used. The free path of the ions has been calculated with values for the cross-section from the literature [3] and the solution has been adjusted for amplitude only. Similarly good agreement is found also for the other noble gases.

References

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