MASS SPECTROMETRY OF NEGATIVE IONS
FROM PLASMAS

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ABSTRACT

The extraction of negative ions from a plasma by an anodic orifice probe is investigated. The extraction mechanism depends on the potential distribution in front of the probe. By an evaluation of the energy distributions of negative and positive ions the proposed extraction mechanism is confirmed, the energy of the negative ions is attributed to the acceleration in a double sheath.

1. INTRODUCTION

In a plasma contacting a wall or an insulated probe a sheath of positive space charge and a quasineutral presheath develops. Here the positive ions are accelerated towards the probe whereas electrons and negative ions are repelled. This effect of trapping of negative ions hinders their extraction into a mass spectrometer through an orifice probe. For an effective negative ion extraction the trapping field has to be removed e.g. by following methods

- increase of the Debye length by plasma expansion,
- decrease of electron temperature in the afterglow (1,2),
- change of potential distribution by an anodic orifice probe (3-6).

The anodic orifice probe can be embedded in the wall or can intrude into the plasma at the top of a supporting structure.

This paper deals with the extraction by an anodic orifice probe at the wall. Corresponding spectra of negative ions have been found to depend sensitively on the extraction parameters (6). The measured spectra remain to be correlated to the situation in the plasma bulk. The extraction mechanism is determined by the potential distribution in front of the orifice probe. In this paper the extraction mechanism and the potential distribution are investigated with the help of energy distributions of different positive and negative ion species. Positive and negative ions in an argon buffer are produced by an Ar/H$_2$-
discharge contacting a previously etched pyrex tube.

2. CONTACT PLASMA/ORIFICE PROBE

For the current transport to an anode in a glow discharge or to an anodic orifice probe three different modes exist listed in the order of increasing current density

- a non-luminous contact with a sheath of positive space charge, i.e. with a negative anode fall;
- the anode glow with a sheath of negative space charge, i.e. with a positive anode fall;
- the anode spot formed by a secondary plasma.

An example of the potential distribution in front of the anodic orifice probe measured recently (7) is shown in Fig.1. The top of the distribution including the maximum contains the secondary plasma which contacts the probe via a sheath of positive space charge and the main plasma via a double sheath. For the top of the distribution and for the sheath the ambipolar transport of charge carriers is responsible; the voltages scale with the temperature of the low energy component of the electrons in the secondary plasma. Within the double sheath electrons are accelerated producing the secondary plasma. The extension of the double sheath is of the order of the mean free path of the electrons. The voltage drop across the double sheath is determined by Langmuir's U^2/2-law for bipolar space charge limited current.

![Fig.1. Potential distribution, plasma potential U_0 versus distance x from the orifice probe, in argon.](image)

Negative ions from the main plasma are accelerated in the double sheath, overcome the retarding field in front of the electrode, and enter the mass spectrometer with energies corresponding to the voltage difference between probe and plasma of the order of some 10 V. Their energy distribution is determined by the process of production and by the collisions during the passage to the orifice probe. Negative ions which are produced in the secondary plasma with low energies cannot reach the orifice probe.

Only positive ions from the secondary plasma are extracted. The extraction situation is similar to that of positive ions
from the main plasma with a floating probe. The energy distribution of the positive ions from the secondary plasma is expected to possess a shift due to the acceleration in the collisionless sheath, and a temperature due to the production process and the collisions during the passage to the orifice probe. In an experimentally investigated secondary plasma positive ions with no detectable acceleration in the sheath and with temperatures of about 0.2 eV/k have been found (8). The corresponding potential distribution is expected to be changed according to the smaller energies. In this paper the described model of a contact plasma/anodic orifice probe will be checked by the evaluation of the energy distributions of extracted positive and negative ions.

3. EXPERIMENTAL

Positive and negative ions from a positive column of a glow discharge are investigated by a mass spectrometer allowing energy analysis. The experimental set-up is described in Refs. 9, 10. A plasma is produced in argon with an admixture of 4.5% hydrogen. As found recently (10) hydrogen removes fluorine and oxygen from the previously etched pyrex wall. The ions O, OH, F, and ArH⁺, OH⁺, H₂⁺ are analysed. The identity of the negative ions is checked by parallel measurements with deuterium. The discharge parameters

- current: 30 mA, total pressure: 6.7·10⁻² mbar,

guarantee a collisionless sheath and allow comparison with parallel investigations (7) of the double sheath.

4. RESULTS AND DISCUSSION

Figs. 2, 3, 4 show the measured integrated energy distributions for different working points of the orifice probe, characterized by the probe current Ip, and for different ionic species.

The negative ion distributions possess a linear, i.e. Maxwellian high energy part. This part is shifted with the probe voltage (see Fig.5) and can be attributed to ions which have been accelerated between main plasma and probe without collisions. The observed temperature is independent of the type of the ions and of the working point. Polarization interaction of the ions with the neutral atoms and practically equal masses may be responsible for the independence of temperature on the type of species. The left part of the distributions represents ions which have suffered collisions if a possible contribution of the secondary plasma is neglected because of energetical reasons.

The energy distributions of the positive ions from the main plasma (Ip=0 mA) show a Maxwellian part, followed by a flat region in accordance to former measurements (11). The energy distribution of positive ions from the secondary plasma (Ip=9 mA) possess two linear parts corresponding to two
Figs. 2, 3. Integrated energy distributions, negative ion current I- at the mass spectrometer versus retarding voltage $U_{\text{ret}}$, for different orifice probe currents $I_p$ and different ionic species.

components of different temperatures (see Fig. 6). Similar low energy components have already been described (8) and can be attributed to ions which have gained their temperature during the transport in the presheath of the secondary plasma. The high temperature component may have gained its energies by a special production mechanism. As in Ref. 8 no additional acceleration of the low temperature component in the sheath is detected. This means that only a reduced sheath can exist. The occurrence of ions of "negative energies" may be explained by differences in work function and penetration of the extraction field through the orifice. An influence of probe current supports the last hypothesis. There exists further experimental
evidence on field penetration: the energy distribution of the low temperature component shows a hysteresis with a change of $I_p$; the appearance of the high temperature component depends on the extraction field.

Fig. 4. Integrated energy distributions, $ArH^+$ current $I_+$ at the mass spectrometer versus retarding voltage $U_{ret}$, for different orifice probe currents $I_p$.

Fig. 5. Voltage-current characteristic of the orifice probe, $U_p$ versus $I_p$, and characteristics of the retarding voltage $U_{ret}=U_{ret}(I_-=10^{-15}A)$ versus probe current $I_p$, for different negative ionic species, describing the shift of the measured energy distributions with changing probe current.

Fig. 6. Temperatures of $ArH^+$ ions for different probe currents, derived from the linear part of the measured energy distributions (see broken lines in Fig. 4).
5. CONCLUSIONS

Negative ions can be extracted from a plasma by an anodic orifice probe. In front of the orifice probe a secondary plasma is built up which is separated from the main plasma by a double sheath. The negative ions are accelerated in the double sheath and reach the orifice probe with energies of some 10 eV.

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REFERENCES


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