A pulsed DC bias technique to study the negative-ion production on insulating surfaces in hydrogen plasmas

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1. Introduction

Negative-ion production on surfaces in contact with plasmas is usually a mechanism of minor importance. However, in certain circumstances this mechanism can be very efficient. When low work-function metals such as cesium are in contact with plasma, a huge surface production of negative-ions by conversion of positive ions or atoms is observed. This effect is the basis of the most intense H-/D- negative-ion sources developed for fusion or particle accelerator applications. However, cesium is a pollutant and the development of a cesium-free intense H-/D- negative-ion source is highly valuable. One of the promising alternatives for the high rate negative-ion production is the use of diamond layers in hydrogen plasmas.

2. Experiment

A sample is placed inside the plasma chamber facing a mass spectrometer (MS, Hiden EQP300). Measurements are performed at 2.0 Pa hydrogen gas pressure with an injected RF power of 20 W in the capacitive coupling mode. The sample is DC biased negatively with respect to the plasma potential. Negative ions formed on the sample surface upon positive ion bombardment are accelerated by the sheath towards the plasma, cross it and reach the mass spectrometer where they are detected according to their energy. The shape of the measured negative-ion energy distribution function (NIEDF) is essential to understand the mechanism of the negative-ion surface production [1].

The DC bias applied to the sample surface is of primary importance since it provides the self-extraction of the negative-ions. This raises the question of testing insulator materials which cannot be DC biased. RF bias could be used, but it would lead to broadening of the NIEDF, which would require a much more complicated analysis of the NIEDF shapes. In order to address this issue, a pulsed DC bias solution has been developed to study insulators as negative-ion enhancer materials. A similar method have been used by Samara et al [2] to measure the ion saturation current, or by Kudlacek et al [3] in order to control the ion energy in industrial plasma processes dealing with insulator materials.

At the start of the DC pulse, a full negative bias appears on the surface of the insulator sample. Positive-ions are collected by the sample and the surface bias V_s decreases at a rate determined by the ion saturation current I_i and the capacitance C formed by the sample: $\frac{dV_s}{dt} = \frac{I_i}{C}$. When the DC pulse is over, the sample surface loaded by positive ions immediately acquires a positive V_s potential. The sample starts to collect electrons, which leads to a perturbation of the plasma potential. The sample charge is slowly unloaded afterwards. The next DC bias must occur after complete discharging of the surface to ensure that the full applied DC bias is actually present on the sample surface.

3. Results

NIEDFs were measured using 10 µs acquisition window set at different delay times with respect to the beginning of a long DC pulse of 300 µs (pulse frequency 1 kHz), for an insulated diamond layer a few µm thick. The onset energy of the NIEDF measured by the mass spectrometer is an indication of the sample surface bias V_s (the mass spectrometer entrance is grounded). dV_s/dt was estimated to be about 70 V/ms in this particular case. Under the low plasma density conditions used, the surface bias decrease rate is relatively slow and allows for a time-resolved measurement of the NIEDF at the beginning of the pulse, with an almost constant bias (a 5 µs acquisition window leads to a negligible decrease of 0.35 V during the measurement). Therefore, all the techniques developed to analyze NIEDF shapes with conducting materials [1] can be applied for insulators. The surface discharging and the perturbation of the plasma potential after the DC pulse were studied by using the time-resolved measurement of the positive-ion distribution functions. Several attempts were made to limit this perturbation, which allowed to use the highest possible pulse frequency in order to lower acquisition time. The ion flux to the surface was estimated from dV_s/dt. The pulsed bias method was successfully applied for the NIEDF measurement on various insulators.

References

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