Method of pulsed DC bias for negative-ion production study on surfaces of insulating materials in low pressure H2 plasmas

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We present a study of negative ion surface production in hydrogen and deuterium low-pressure plasmas. A sample facing a mass spectrometer is negatively DC biased with respect to the plasma potential. Upon the positive ion bombardment some negative ions are formed on the surface and are accelerated towards the mass spectrometer where they are detected according to their energy. In the present contribution, a DC pulsed bias technique is introduced to enable the study of negative ion surface production on insulating samples.

1. Introduction

Negative-ions (NI) production mechanisms in low-pressure plasmas is of interest for many plasma applications such as microelectronics, space propulsion, magnetically confined fusion… In the latter intense hydrogen negative-ion beams are extracted from a low-pressure hydrogen plasma source and accelerated to high energy. They are then neutralized and injected inside the fusion plasma where they deposit their energy and contribute to the plasma heating. Next generation fusion devices requires high intensity (40 A) negative-ion beams which pushes towards the development of efficient negative-ion sources. Volume production of negative-ions by dissociative attachment of electrons on molecules is not efficient enough and these sources rely on surface production. In the present study we investigate surface production of negative ions on diamond materials.

2. Experimental set-up and results

2.1. Experimental set-up

A sample is introduced in a low-pressure (2 Pa) hydrogen plasma and negatively biased (using DC bias) with respect to the plasma potential. The negative- ions formed on the surface upon positive ion bombardment are accelerated by the sheath in front of the sample and then self-extracted towards a mass spectrometer facing the sample at a distance of 4 cm. Negative ions are detected according to their energy and mass, and Negative-Ion Energy Distribution Function (NIEDF) is measured. This experimental method proved to be efficient for the study of negative ions production on different materials. In particular we have shown that boron doped diamond is producing high yield of negative-ions [1] compared to metals such as stainless steel or molybdenum. In order to extent this method to insulating materials that cannot be DC biased we developed a pulsed DC bias method and applied it to the study of non-doped diamond samples.

When an insulating sample is DC biased it acts as a capacitor. The DC bias initially appears on the sample surface. Positive ions are therefore attracted towards the sample and the capacitor is charged by the positive ion saturation current. The rate of change of the surface bias is given by the ratio of the ion saturation current over the sample capacitance ($dV/dt = I_i/C$). For a few µm thick diamond layer the capacitance of a 1 cm^2 sample is on the order of 1 nF. The ion saturation current is below 100 µA/cm2 in our experiment giving a surface bias rate of change on the order of 0.1 V/µs. As the time resolution of the mass spectrometer is 2 µs, measurements can be performed on diamond samples at an almost constant surface bias. We show that with this method it is possible to measure energy distribution functions of negative ions created on insulating materials.

2.2. Result

NIEDF measurements are synchronized with the pulsed DC bias. The surface bias rate of change is determined experimentally based on the energy of the negative ions detected. The sample current is measured by a microamperemeter. A model is developed to better understand the charge of the sample by the positive ions during the pulse ON phase, and the unload of the sample by electrons in the pulse OFF phase. The model is compared to the time resolved measurements of sample bias and current.

The effect of pulse frequency and pulse duty cycle on the negative-ion surface production is studied. It is shown that a low duty cycle (10 %) at a frequency around 1 kHz allows for efficient negative-ion production and detection. Surprisingly, negative-ion surface production on boron-doped diamond is much higher in pulsed mode than in continuous mode. Production on non-doped diamond is as high as the one on boron doped diamond. This effect is attributed to a less defective diamond surface in pulsed mode.

3. References

[1] Kumar et al Journal of Physics D: Applied Physics 44, nº 37 372002