DESIGN OF A SIMPLIFIED ION-FLUX PROBE FOR PLASMAS FREE OF INSULATING DEPOSITS

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ABSTRACT

In plasma processing, it is particle fluxes arriving at and leaving surfaces which determine the details of the plasma-surface interaction. Among the various methods that have been proposed for ion flux measurements in plasma processing environments, a novel one was proposed by Braithwaite et al. [1]. This technique uses a planar probe and is tolerant of insulating deposits, it is non-perturbing, it has the potential for absolute flux determination, it is applicable whatever the means of plasma excitation and it is considerably easier to implement than any of the other methods. Based on this previously presented concept, a simplified cost-effective system is hereby presented for use in plasmas free of insulating deposits only.

1. INTRODUCTION

Braithwaite et al. [1] proposed a planar surface probe for determining the ion flux. This probe has a variable capacitor connected in series (C_s), which when is driven by a radio frequency (RF) voltage works similarly to the biased electrode of a CCP reactor (with C_s playing the role of the blocking capacitor). Thus, C_s is charged to a negative potential, i.e. it develops a self-bias. When the RF driving voltage is removed (or chopped to give RF bursts), the C_s is discharged up to the floating potential of the plasma. Assuming negligible leakage currents in the circuitry and a self-bias high enough to repel energetic electrons, the only possible way of discharging C_s is the current due to the constant flux of ions arriving on the probe.

Although an RF-driven probe may be suitable for depositing plasmas as well, the quite complex circuit demanded for producing the RF bursts could possibly be avoided for measurements in less complicated plasma environments. Thus, an alternative biasing method is herein attempted. The biasing circuit consists of a chopper providing negative DC pulses on a variable capacitor C, with adjustable amplitude, frequency, and duty cycle. This chopped negative voltage is applied to the probe as shown in Fig. 1 and plays the same role with the self-bias described above. If the negative voltage is set to an appropriate level to repel most of the energetic electrons, the almost linear part of the C-discharge waveform is related to the positive ion current. The latter provides the ion flux value (see section 4).

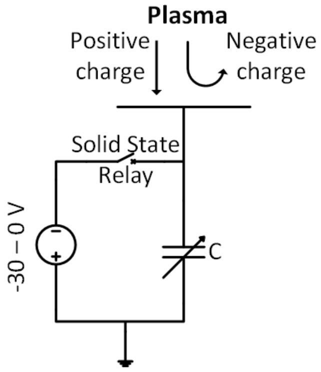

Fig. 1 Conceptual view of the DC-driven probe

The design of the probe and biasing circuit, the integrated interface for recording the C-discharge waveform on an oscilloscope, and the developed software for data processing, are herein presented. Finally, the system as a whole unit is tested in an electrode-less high-frequency (13.56 MHz) discharge and its reliability is proven.

2. PROBE DESIGN

The general draw of the probe body is shown in Fig. 2. It is practically the one proposed in [1], but some technical improvements have been introduced. Briefly, the head of the probe is a planar circular surface (disk-electrode 7 mm in diam., see piece e. in Fig. 2) guarded by a ring-shaped electrode (20.5 mm/8.5 mm, see piece d. in Fig. 2). Thus, a space of 0.75 mm is formed between their peripheries. The head is attached on a completely shielded housing (b. in Fig. 2). The latter brings a high vacuum CF16 electrical feedthrough (a. in Fig. 2) for biasing both the disk-electrode and the guard ring, and it is easily adapted on any KF25 flange (c. in Fig. 2) of a reactor. As it will be shown in the next section 3, special attention must be paid to maintain the potential on the disk-electrode as close as possible to that of the ring-electrode during the C discharge, preventing thus any edge effect efficiently. For this purpose, an identical bias circuit is connected on the ring-electrode (see Fig. 3).

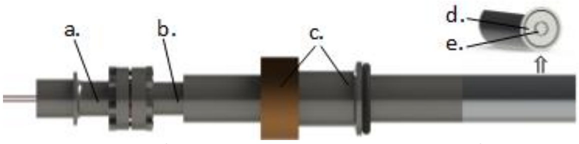

Fig. 2 Overview of the entire probe a. CF16 electrical feedthrough, b. probe body, c. KF25 oring gland for quick connection, d. guard ring and e. disk-electrode

3. ELECTRONIC CIRCUITS

The overview of the circuit implemented is depicted in Fig. 3, where two components may be distinguished: the biasing circuit and the dual buffer circuit (probe/oscilloscope interface) for transferring both electrode waveforms to an oscilloscope without the need of any commercial high impedance voltage probes. Two identical units of variable capacitors used for producing the discharge waveform on each electrode due to the ion current are shown as well.

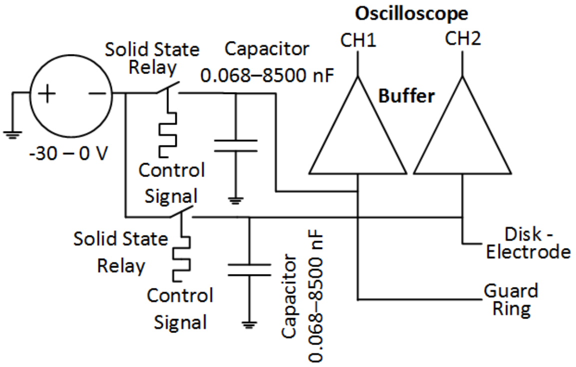

Fig. 3 The circuit for both electrode biasing and discharge waveform recording

3.1 BIASING CIRCUIT

The biasing circuit is a simple switching circuit that chops an adjustable negative dc voltage. This is realized with two solid state relays (SSRs), for driving the disk- and guard-electrode independently. The SSRs are controlled by external TTL pulses of adjustable frequency and duty cycle. In the schematic of the two-channel chopper shown in Fig. 4, the components for protecting the SSRs from excessive current and voltage overshoots are depicted as well.

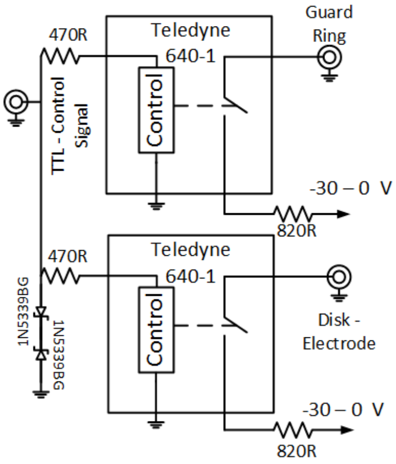

Fig.4 The two-channel chopper

3.2 PROBE/OSCILLOSCOPE INTERFACE

The reliable operation of the system is strongly depended on the ability to record simultaneously the discharge waveforms of both capacitors due to the ion current only, i.e. any leakage current must be negligible. Therefore, a high impedance buffer is connected between each electrode and the 1 MΩ input of an oscilloscope. This dual 300 kHz buffer is analyzed in Fig. 5 and it is physically attached on the CF16 electrical feedthrough of Fig. 2 in a continuous shielding. The input impedance of the buffer is 36.3 MΩ and the output one is 50 Ω. The leakage current through the 33:3.3 MΩ voltage divider is compensated numerically in the software developed for the ion current evaluation.

The second prerequisite for reliable operation of the system is the matching of the discharge waveforms of both capacitors on the oscilloscope, since this matching ensures minimization of the edge effects. This condition is fulfilled by varying in-situ both capacitances of Fig. 3; various high precision fixed capacitors connected to 12-DIP switches provide high flexibility for this purpose (0.068-8500 nF) [2]. These variable capacitors are enclosed in shielded boxes and BNC-connected to the buffer, as in Fig. 5.

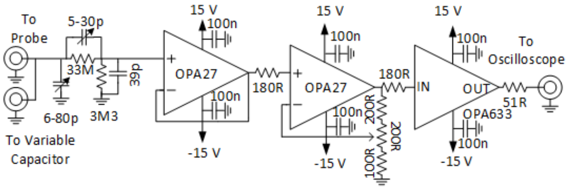

Fig. 5 1/2 of the dual buffer

4. DATA PROCESSING

The ion flux is calculated from the discharge waveform of the capacitor C, which follows the formula [1]

$$du_C/dt = eA[\Gamma_i - \Gamma_e(u_C)]/C \qquad (1)$$

In equation (1), Γ_i and Γ_e stand for the ion and electron fluxes, respectively, A is the disk-electrode area, C is the capacitor value after matching (Fig. 6b), and t=0 corresponds to the moment of the DC chopping. If $u_C(0^+)=V_{DC}$ (pulse DC amplitude) is set negative enough for $\Gamma_e(V_{DC})$ to be considered negligible, the ion flux can be determined from the quantity $du_C/dt|_{t=0+}$ of the recorded discharge waveform on the oscilloscope. The capacitance C is measured in-situ with a bridge for taking into account any stray capacitance. Equation (1) is treated in MatLab^{TM}, providing the ion flux Γ_i. Additionally to Γ_i, the floating potential V_f and the effective temperature kT of the "tail" electrons are calculated, if a Maxwellian distribution is assumed for this population (see second term in equation 2).

The software developed in this work processes the data as follows:

1. it detects the point t=0^+ from the negative slope of the TTL trigger signal (Fig. 6a)
2. it accepts the inputs C and $u_C(t)$
3. it smooths the waveform $u_C(t)$ by applying a Savitzky-Golay (SG) filter and calculates the discharge current i_C=$C\, du_C/dt$ from the smoothed waveform. At this step, the leakage current mentioned in section 3.2 is compensated, i.e. the term $u_C(t)$/36.3 MΩ is added to i_C.
4. the curve $u_C - i_C$ is well approached (fitted) by

$$i_C = I_0\{1 - m(u_C - V_f) - \exp[e(u_C - V_f)/kT]\} \quad (2)$$

5. it represents graphically the smoothing results as in Fig. 6c and the fitting results as in Fig. 6d for confirmation of the processing. For details on the plasma setup used for this test, see section 5.
6. it provides the quantities I_0, V_f, and kT from the fitting in step 4, and finally calculates the ion flux $\Gamma_i = I_0/eA$.

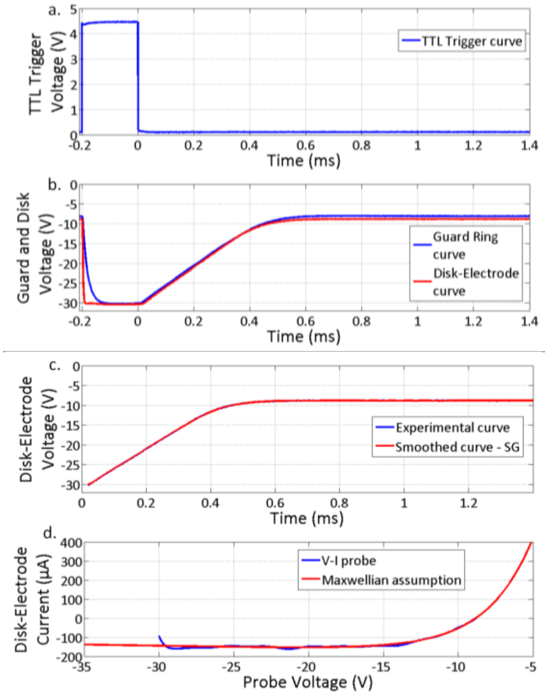

Fig. 6 Indicative software output after data processing a. the TTL trigger signal b. the matched waveforms of the capacitor discharges c. smoothing of the experimental results d. fitting of the results (test plasma at 50 mTorr and 30 W)

5. PROBE TEST

Tests of the above system are carried out in an electrode-less high-frequency (13.56 MHz) discharge generated in a quartz cylinder reactor (Ø60 mm x 380 mm) around which a coil is wrapped. The probe is mounted on one of the two edge metallic flanges of the reactor. The gas fed is Ar (99.999%) and parametric tests are conducted for variable pressure (10-200 mTorr) and RF power (10-50 W). Ion species identification in the plasma is realized by means of UV-visible optical emission spectroscopy (OES), focusing in the vicinity of the ion flux probe with an optical fiber (Oriel 77556). The spectrometer is a Newport MS260i (¼ focal length) one equipped with a 600 lines/mm grating (blazed at 400 nm, 250-1300 nm) and a CCD camera (78105 Oriel Linespec™, 200-1100 nm). The collected light is efficiently focused on the grating by an optical matcher installed on the entrance slit of the spectrograph (Newport 77529).

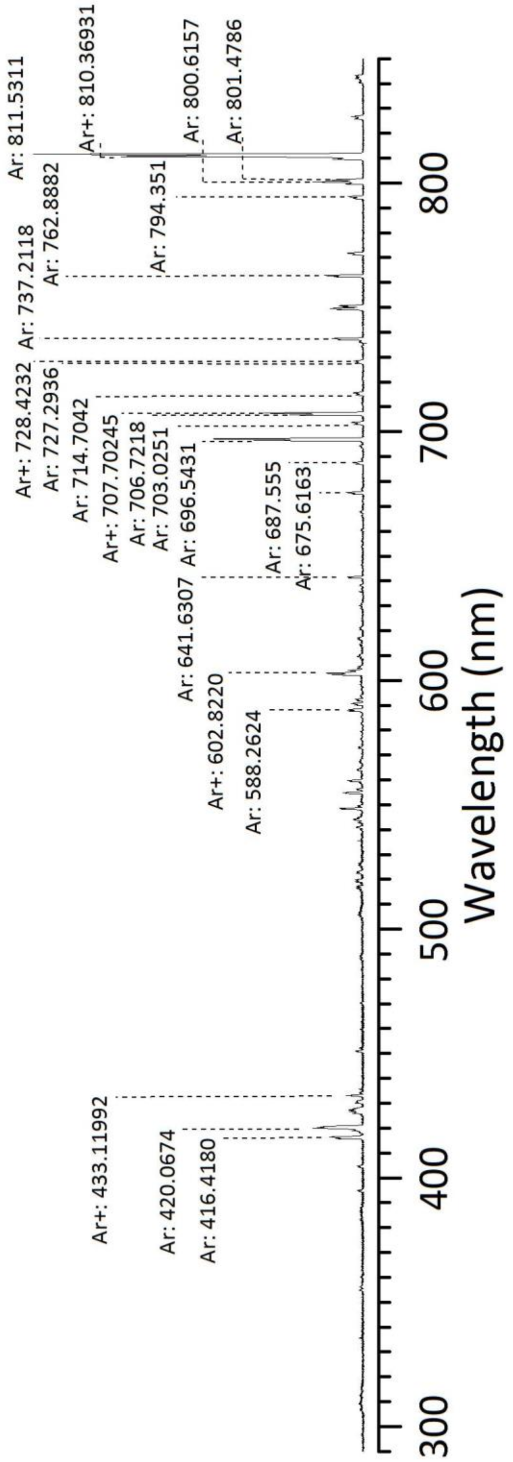

Fig. 8 Wide scan optical emission spectrum of the Ar RF-plasma. The wavelengths on the identified lines correspond to the theoretical values given in [3].

Thus, ion fluxes in the order of magnitude of 10^{15} $cm^{-2}s^{-1}$ are measured, in good agreement with previous published results [1, 4-5]. The calculation of these fluxes is based on the assumption that the ions are single ionized and consequently their charge is assumed to be the elementary one (see equation 1). The wide OES raw scan (the OES relative intensity is not calibrated) in Fig. 8 supports the fact that our plasma is reach in single ionized (excited) ions. Similar spectra have been recorded for all the set of parameters scanned herein (10-200 mTorr and 10-50 W).

6. CONCLUSIONS

In this work, a quite simplified ion flux probe system for measurements on the boundary surfaces in a plasma reactor was designed, fabricated, and tested. Consistent experimental results were obtained in argon radio frequency plasma. This system could be a useful low-cost tool for monitoring plasma-based material processes. Its application is limited to plasmas free of insulating deposits.

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