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Influence of Discharge Geometry on Power Dissipation and Sheath Impedances in Silane Discharges

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The influence of the interelectrode distance on the power consumed in rf silane glow discharges, for two different electrode sizes and at two different silane pressures is reported. The effect of the increasing grounded surface area in contact with the discharge is analysed by using a simplified calculation of the rf and grounded sheath impedances. At all cases the power consumed in the discharge increases with interelectrode distance and is higher for higher pressures, for a constant excitation voltage. The sheath impedances are always higher for lower pressures except for the case of the ground sheath when using the large electrode set.

KEYWORDS: glow discharge, power, plasma potential, sheath impedance, geometry

1. Introduction

The measurement of the exact amount of power consumed in rf discharges arrises as an important technological issue in the last few years. This is because, there is no way of performing reliable parametric analysis without effectively knowing if and how the amount of power dissipated in the discharge is influenced by the variation of macroscopic parameters such as the excitation voltage, the gas pressure and the discharge geometry. This last parameter is of greater importance since it is correlated with the optimum design of the system. Recent results of this group,[1] have shown that a method using voltage and current measurements, can be effectively applied for an accurate determination of the power and impedance in silane plasmas, for the examination of the effect of different discharge parameters or in conjunction with other diagnostic techniques, as for example mass spectrometry,[2] for the investigation of gas phase kinetics. The results presented in this work concern the effects of the interelectrode distance, for two different electrode sets, on the power consumed in a silane discharge.

2. Experimental

The experimental setup, shown in Fig. 1, consists of a 160 mm in diameter and 210 mm long parallel-plate discharge chamber, with 55 mm or 95.5 mm in diameter interchangable electrodes. The electrodes are cylindrically symmetric, and their distance can be continuously varied from 0 to 70 mm. One of the electrodes each time is powered by an ENI ACG-3 13.56 MHz rf generator isolated with an L-type matching network, while the other electrode as well as the chamber walls are grounded. Pressure and flow rate are independently adjusted by

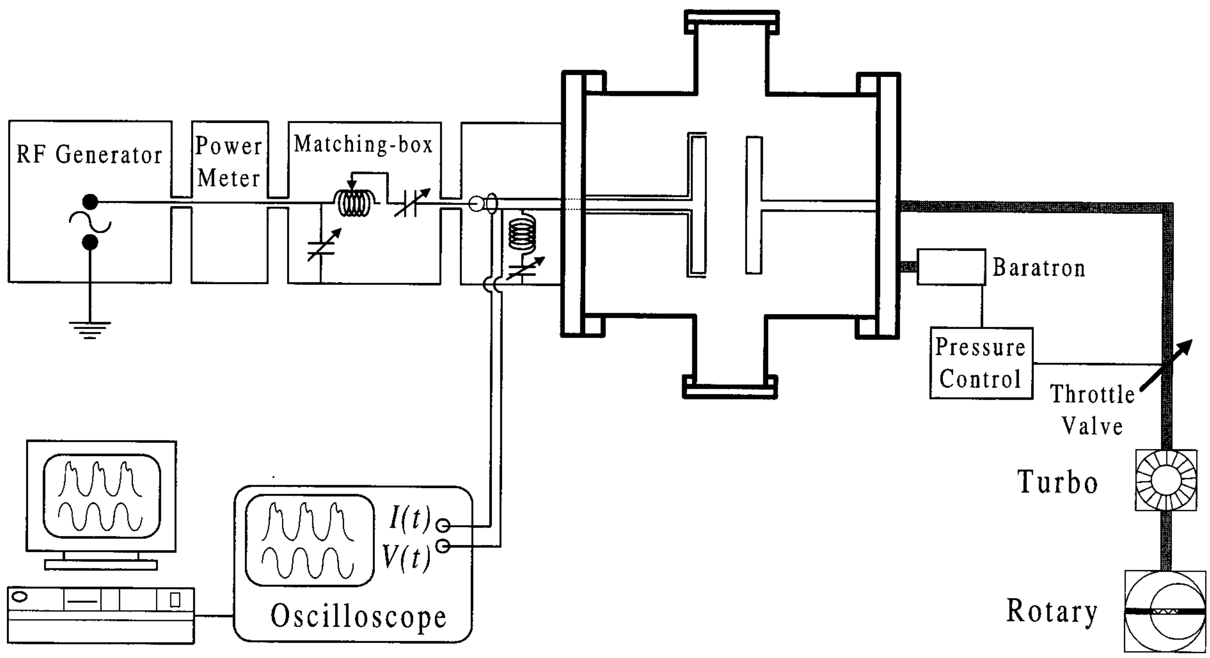

Fig. 1. Schematic diagram of the plasma chamber and the electrical connections used for the power and the impedance measurements.

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a downstream throttle valve controller and an upstream mass flow controller respectively.

The excitation voltage and the discharge current signals are measured on the power electrode lead using a high impedance 1:100 attenuation voltage probe and a 0.1 Ω transfer impedance rf current probe. The measured voltage and current waveforms are transformed to the equivalent ones at the surface of the powered electrode using a proper characterization of the stray impedance of the cell.[1] Namely, the measured voltage and current waveforms, $V(t)$ and $I(t)$, differ from the equivalent waveforms at the surface of the powered electrode, $V_e(t)$ and $I_e(t)$. More specifically, the measured voltage, $V(t)$, is different from $V_e(t)$, due to the voltage drop along the power lead feedthrough caused by the inductance between the measurement point and the electrode, while some of the measured current, $I(t)$, is not drawn by the plasma, but by the parasitic capacitance between the electrode and its ground shield. The electrode voltage and current thus determined are used for the electrical characterization of the discharge and for the calculation of the dissipated power. The probes are corrected for propagation delays while an external shunt circuit, consisting of a coil and an air variable capacitor, is used for increasing accuracy. Resistive losses in the shunt circuit and the cell's elements are also taken into account.[1,3] Figure 2 shows an example of the measured (dotted) and calculated (solid) voltage and current waveforms, illustrating that the effects of cell parasitics and of propagation delays in the probes are significant. The waveforms correspond to the 55 mm in diameter electrode set, 65 mm interelectrode distance, and a silane plasma of 13.3 Pa pressure and 100 V peak-to-peak driving voltage. All the measurements were performed in particle free conditions, as controlled by a laser light scattering technique.[2]

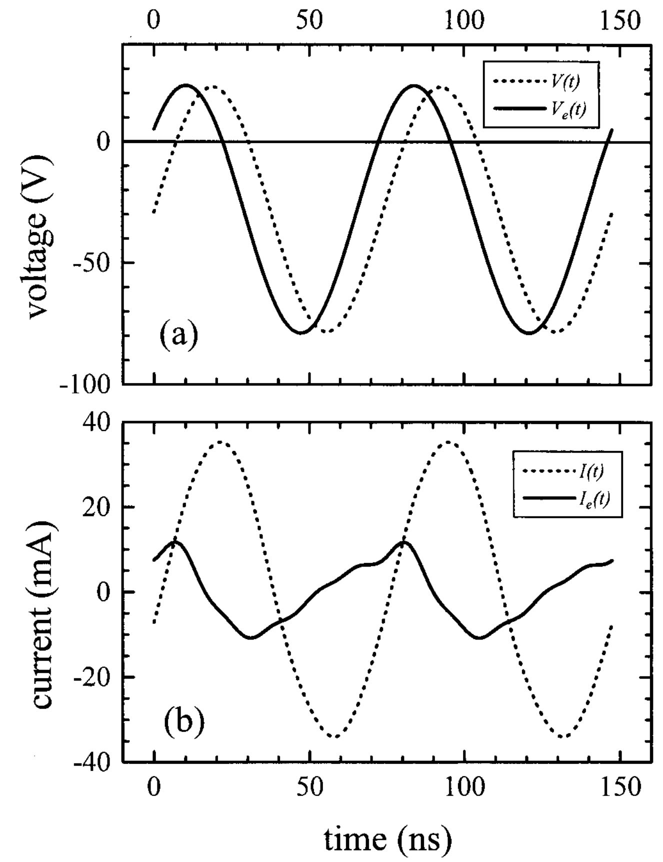

Fig. 2. Voltage (a) and current (b) waveforms for a silane discharge at 13.3 Pa and 100 V peak-to-peak driving voltage. The measured voltage and current waveforms, $V(t)$ and $I(t)$ are given by the dotted curves. The solid curves are the waveforms $V_e(t)$ and $I_e(t)$ obtained after the correction for the time delays of the probes and the parasitic impedance of the cell.

3. Results and Discussion

The dependence of the dissipated power on the interelectrode distance is presented in Fig. 3. More specifically, the power is measured for interelectrode distances ranging from 21 to 33 mm, for pressures of 6.7 and 13.3 Pa and for constant peak-to-peak driving voltage, V_{pp}, 87 V, using the 95.5 mm in diameter electrode set, in conditions that have been used in the past for the deposition of device quality a-Si:H.[5] The total dissipated power is divided by the area of the rf electrode surface to give the power density in mW per cm^2. It is observed that the dissipated power is higher for the 13.3 Pa pressure than that of the 6.7 Pa, for all interelectrode distances and has a clear tendency to increase at greater distances for both pressures. At higher pressures there is an increase of the number of electron molecule collisions, the discharge becomes more resistive and more effective in decomposing silane.[2] On the other hand previous work of this group indicates that the production of radicals, which is related to the density of high energy electrons, decreases with increasing interelectrode distance.[4] This appears to be contradictory to the observed increase of the power dissipated in the discharge under the same conditions and points out that this increase can only be due to the higher current flow towards the increasing grounded surface. As a consequence this results to a more negative rf electrode self bias potential, V_{dc}, and a decrease of the plasma potential and the amount of elec-

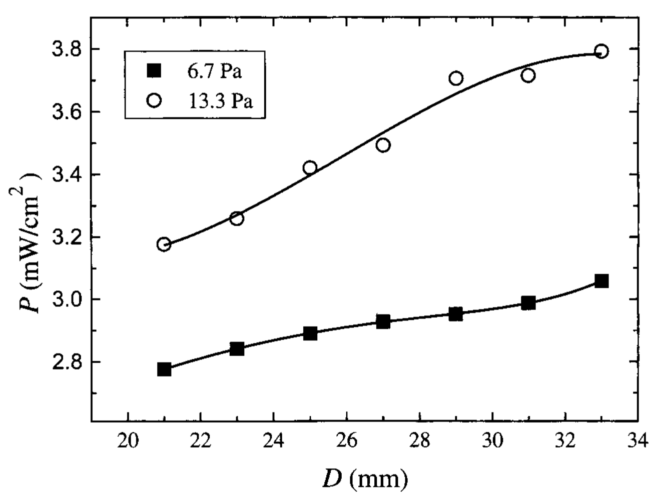

Fig. 3. The dissipated power, P, in mW/cm^2 in silane glow discharges as a function of the interelectrode distance, D, for 6.7 and 13.3 Pa pressure. The 95.5 mm in diameter electrode configuration is used and a constant, 87 V, peak-to-peak voltage is applied.

trons participating in stochastic or wave riding collisions which is the primary electron heating mechanism under these conditions. Thus, the amount of electrons capable of dissociating silane decreases and this is in agreement to the observed decrease of the total emission and laser induced fluorescence intensity, observed in ref. 4.

In order to further analyse this phenomenon it is necessary to examine the voltage and current distribution in the discharge. The rectification process of the rf electric field occurring in electrode sheaths results in the rise of a potential barrier where positive ions are accelerated towards the electrodes while plasma electrons are repelled to the plasma. The plasma-sheath boundary formed in this way oscillates under the effect of the rf field. The successive contraction and expansion of the sheath is accompanied by the movement of plasma electrons incoming from the plasma to the boundary and receding to the plasma. Assuming that in the instant of the rf cycle when the sheath has its smaller width the voltage drop across it becomes zero, the fundamental component of the bulk plasma potential, V_{pl}, becomes:[3,5)]

$$V_{pl} = \frac{1}{2}(V_{el} + V_{dc}) \qquad (1)$$

where V_{el} is the fundamental component of the electrode voltage, $V_e(t)$, and V_{dc} is the dc electrode potential which is built up due to the rectification process of the sheath in order to null the net dc current to the electrode during one rf cycle. The fundamental component of the powered electrode sheath voltage, V_{ps}, is determined by the difference:

$$V_{ps} = V_{el} - V_{pl}. \qquad (2)$$

In nonelectronegative gases, like argon, the high capacitive impedance permits the application of the above assumptions without considerable error. In this case the voltage drop across the glow region, where the electron density is relatively high, is considered to be negligible compared to the voltage drop across the sheaths. Indeed, in refs. 6 and 7 the V_{dc} and the V_{ps} is recorded in an asymmetrically driven argon glow discharge. The experimentally determined values of V_{ps} give a powered electrode sheath voltage analogous to the electrode voltage. The use of eqs. (1) and (2) for the determination of the powered electrode sheath voltage gives the same analogy between the two voltages.

Silane is an electronegative gas at high pressure where electron attachment in the bulk plasma induces the buildup of a rf electric field between the sheaths. This is evident from the increase of the resistive part of the discharge impedance at high pressures.[8)] This increase can be associated with an increase of the amplitude of the plasma electric field and is usually accompanied by the presence of particulates whose dimensions range typically from nanometers to tens of microns and behave as microscopic probes. Their charge is negative and they act as an electron sink.[9)] The influence of attaching gases on the electrical characteristics of rf parallel-plate discharges has been investigated by other workers.[10,11)] For low pressure silane discharges however, and in the absence of particulates in the gas phase, electron attachment does not prevail and the bulk plasma impedance is much smaller than the impedance of the sheaths, as indicated by the high capacitive impedance of these discharges.[2)]

Therefore, by applying the same methodology as in argon discharges,[3)] two separate regions of the glow discharge are electrically characterized in a simple way. Namely, the region between the bulk plasma and the powered electrode, with fundamental impedance Z_{ps}, and voltage $V_{ps}(t)$, is called the powered electrode sheath, while the region between the bulk plasma and the ground electrode and the grounded chamber walls, with fundamental impedance Z_{gs}, and voltage $V_{gs}(t)$, is called the ground sheath. The powered electrode sheath impedance, Z_{ps}, is given by the ratio:

$$Z_{ps} = \frac{V_{ps}}{I_{el}} \qquad (3)$$

and the impedance of the ground sheath, Z_{gs}, is given by the ratio:

$$Z_{gs} = \frac{V_{gs}}{I_{el}} \qquad (4)$$

where $V_{gs} = V_{pl}$ is the fundamental component of the ground sheath voltage $V_{gs}(t)$, and I_{el} is the fundamental component of the electrode current $I_e(t)$. The impedances of the powered and ground sheath, Z_{ps} and Z_{gs}, as a function of the interelectrode distance, D, are shown in Fig. 4. Z_{ps} is greater for the 6.7 Pa pressure than the 13.3 Pa for all interelectrode distances, while the opposite is true for the ground sheath impedance, Z_{gs}. There is a clear tendency of Z_{gs} to decrease for

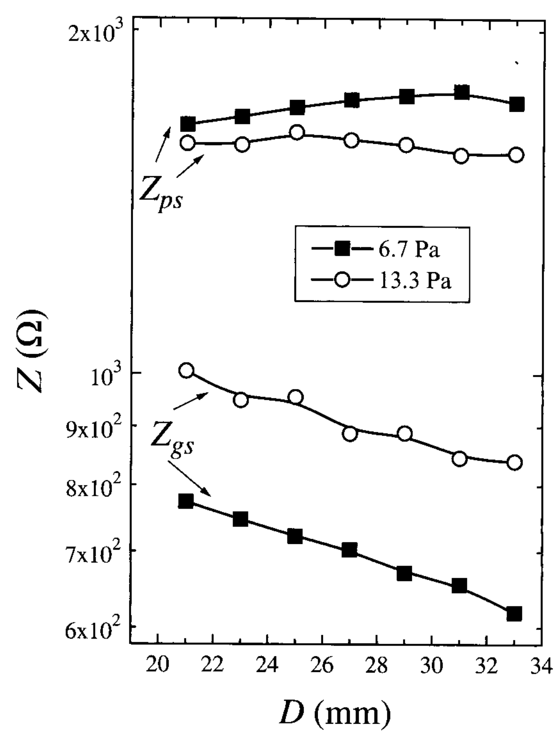

Fig. 4. Magnitudes of the impedances Z_{ps} and Z_{gs} of the two regions of the glow discharge (defined in the text), as a function of the interelectrode distance, D, for silane glow discharges of 6.7 and 13.3 Pa pressures. Configuration and applied voltage as in Fig. 3.

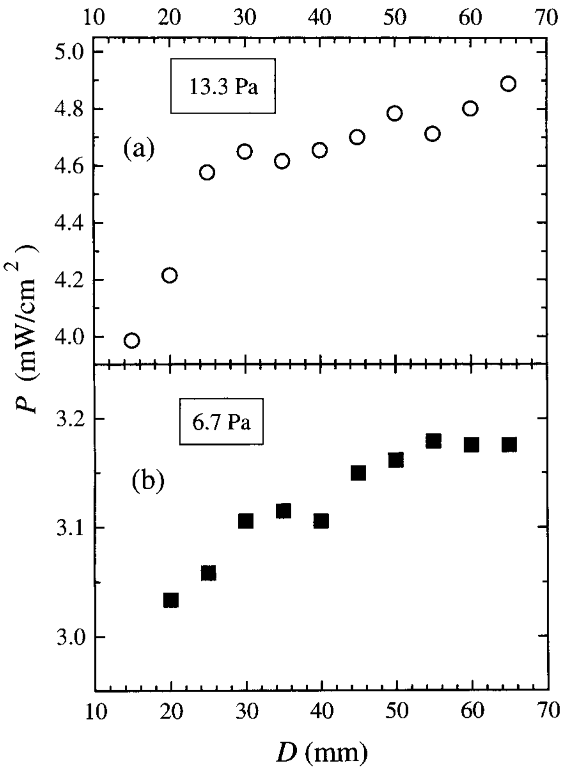

Fig. 5. The dissipated power, P, in mW/cm^2 in silane glow discharges as a function of the interelectrode distance, D, for (a) 13.3 Pa and (b) 6.7 Pa pressure. The 55 mm in diameter electrode configuration is used and a constant, 87 V, peak-to-peak voltage is applied.

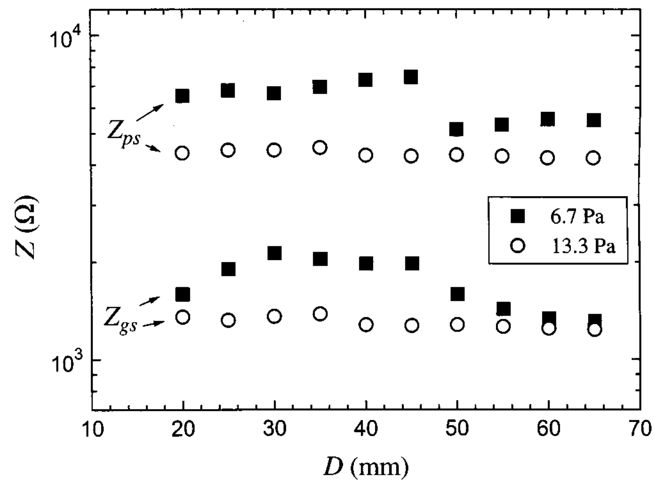

Fig. 6. Magnitudes of the impedances Z_{ps} and Z_{gs} of the two regions of the glow discharge (defined in the text), as a function of the interelectrode distance, D, for silane glow discharges of 6.7 and 13.3 Pa pressures. Configuration and applied voltage as in Fig. 5.

greater distances while Z_{ps} does not change significantly. Therefore as stated before, the increase of the distance, D, increases the current that flows towards the walls decreasing in this way the impedance Z_{gs}.

Within the whole range of the interelectrode distances variation, the magnitude of Z_{gs} is considerably smaller than Z_{ps} and this is because the V_{gs} is much smaller than V_{ps}. As the distance increases however, the powered sheath impedance Z_{ps} increases relative to Z_{gs}, so a relatively larger fraction of the applied voltage is dropped across the powered electrode sheath. Thus, although the distribution of voltage is always asymmetric, this is less pronounced at smaller distances.

The influence of the discharge geometry on the dissipated power is further investigated by modifying the electrodes diameter. The 55 mm in diameter electrode configuration is used and the electrode voltage and current waveforms along with the V_{dc} have been recorded for various interelectrode distances under 87 V peak-to-peak voltage excitation and pressures of 6.7 and 13.3 Pa. Figure 5 presents the dissipated power density as a function of the interelectrode distance for the two pressures. In both pressures the dissipated power increases for greater interelectrode distances and tends to saturation. What is interesting to observe here, in conjunction with Fig. 3, is that the power density is higher (although the total dissipated power is lower) for the smaller electrode configuration for the same excitation voltage. This is due to the higher powered electrode sheath potential associated with the smaller electrodes, which leads to a relatively higher power consumption in the sheath-plasma boundary.

Figure 6 presents the impedances of the powered and ground sheath, Z_{ps} and Z_{gs}, as a function of the interelectrode distance, D, for silane glow discharges of 6.7 and 13.3 Pa and for interelectrode distances of 20 to 70 mm, under a 87 V peak-to-peak voltage excitation. The 55 mm in diameter electrode configuration is used. Both impedances are greater for 6.7 Pa than for 13.3 Pa. In the case of 13.3 Pa, both impedances do not change significantly in the range of the interelectrode distance variation. For the pressure of 6.7 Pa however, the ground sheath impedance increases first and then decreases again as the interelectrode distance increases monotonously, while the powered sheath impedance remains constant for the region of 20 to 45 mm and then drops for the rest interelectrode distances. The ground sheath impedance is greater here for all interelectrode distances in the lower pressure in contradiction with the 95.5 mm electrode configuration of Fig. 4.

Both the power density per unit area of the rf electrode and the discharge impedances do not show any straightforward correlation with either the film quality or the deposition rate, that have been recorded under the same conditions in previous work of this group, although there is a direct influence of the geometric characteristics on both of them.[4,12]

4. Conclusions

The dissipated power increases with the interelectrode distance following mainly the decrease of the ground sheath impedance. There is an enhanced contribution of sheath related fast electrons at small distances that modify the electron energy distribution function in space. A direct consequence of this redistribution of energy consumption is the modification of the high sticking coefficient radicals and the low sticking coefficient ones flux ratio. This affects the deposition rate and the film quality in a complicated manner having no straightforward relation to the power actually consumed. However, the data presented show that even small differences in chamber design can induce significant changes, making the results from similar deposition systems incompatible.

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