Paschen Curves and Film Growth Rates
in Low Pressure Capacitively Coupled Magnetron Plasma Polymerization

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Abstract:
This work deals with a 15 kHz plasma polymerization of methane enhanced by a magnetic field. It is observed that the maximum of the film growth rate as well as the minimum breakdown voltage - measured independently - occur at the same pressure. This is verified at four inter-electrode distances. This result can be used to determine the pressure at which the maximum growth rate occurs at a given inter-electrode distance. A phenomenological explanation is proposed.

Keywords: Paschen curve; magnetron; plasma polymerization; methane

1. Introduction

This work deals with a magnetron enhanced 15 kHz discharge. We observed a relation between the Paschen curves and the deposition rate. The purpose of this work is to present the results obtained with methane and discuss some possible explanations qualitatively.

2. The setup

The reactor and the magnetic field lines are schematically represented in Fig. 1.

Fig. 2 shows a picture of the magnetron configuration. The magnetic field is created with eight permanent magnet bars placed in a steel body with the south oriented to the center of the structure and the north towards the outside. The resulting field is concentric with a value of 41 mT at a distance of 5 mm away from its top surface in the direction of the opposite structure, i.e. where the electrode sits.

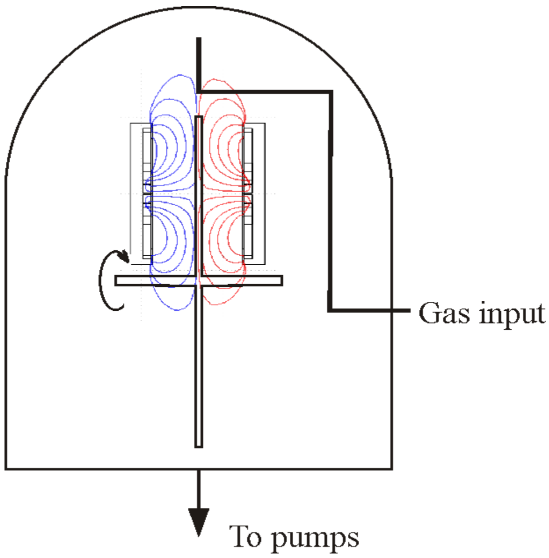

Figure 1. Bell jar reactor made of Pyrex glass of 42.5 cm diameter at the base for a total volume of about 115L with a stainless steel bottom. The blue and red lines represent the simulated magnetic field lines. The substrates are fixed on the rotating wheel

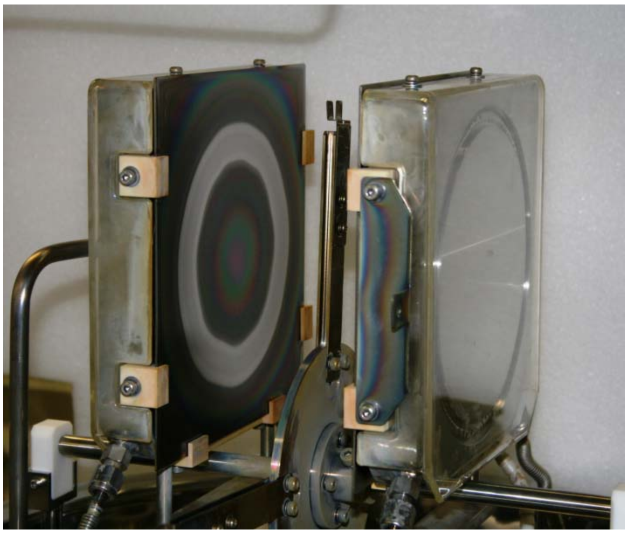

Figure 2. Picture of the magnetron electrode configuration in the reactor

For the deposition, the electrodes are connected to a ground free symmetric power supply system (Kyoto Denkiki AF-400S) set at 15 kHz. The process is current controlled; all discharges are carried out at a constant gas flow rate (5 sccm) and current (50 mA), hence at constant I/FM [1]. The substrates are fixed on a rotating wheel in the middle of the inter-electrode volume.

For the measurement of the Paschen curves, a DC power source (Heinzinger, UMP 50-3500) was used without any series resistor. The gas flow rate is not changed.

3. Growth rate

The profile of the growth rate as function of the pressure with the inter-electrode distance as parameter is shown in Fig. 3 and has been described in [1]. The 15 kHz discharge works like two DC discharges with cathode and anode swapping sides every half-cycle. Because the discharge is current controlled, the voltage varies according to the gas conditions.

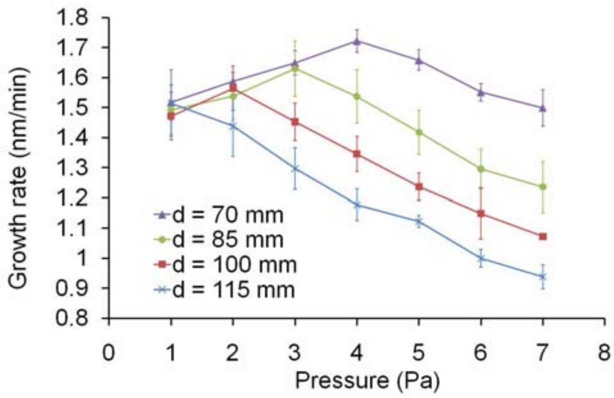

Figure 3. Film growth rate in a glow discharge of pure methane at a constant flow rate and at different inter-electrode distances, activated at 15 kHz.

On the right side of the maximum growth rate:

- at a fixed pressure, the distance that the polymerizable species travel (between where they are created and where they deposit on substrate) is proportional to the inter-electrode distance *d*. Hence, as *d* decreases, the film growth rate *GR* increases;

- the diffusion of the polymerizable species towards the substrate depends on the pressure *p*. Hence, as *p* decreases, *GR* increases.

On the left side of the maximum, the pressure becomes too low and the polymerizable species too scarce. Hence, the growth rate decreases.

4. Paschen curve

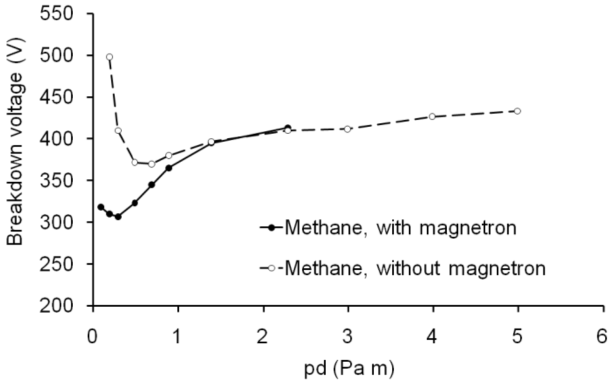

Figure 4. Paschen curves in pure methane for an inter-electrode distance of 100mm with and without magnetic field enhancement

Fig. 4 depicts two Paschen curves in pure methane with and without magnetic field enhancement. It displays in both cases the usual profile [3].

On the right of the minimum, the voltage increases with the pressure and with the inter-electrode distance. It is explained by the decrease of the mean free path of the electrons and the consequent need to increase the applied electric field for the electrons to reach the ionization potential of the gas molecules.

On the left side of the minimum, the increase of the voltage is explained by the number of gas molecule becoming scarce and the consequent decrease of the collision and ionization probability.

5. Growth rates and Paschen curves

Figure 5 displays the measured Paschen curves and growth rate versus the reactor pressure in a methane glow discharge. We notice that the Paschen minima correspond to the maxima of the growth rate. This may be used to quickly determine the pressure at which the maximum deposition rate is reached for a given inter-electrode distance.

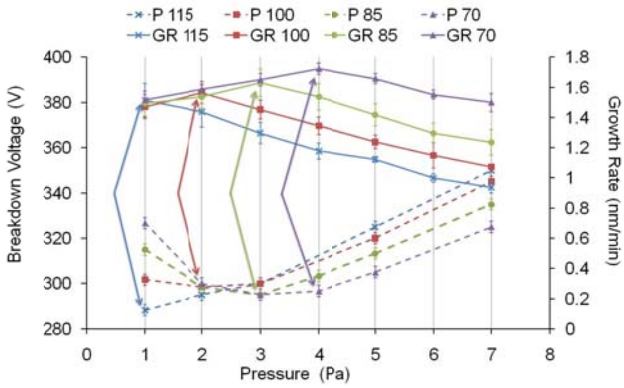

Figure 5. The full lines show the growth rate of film in a methane glow discharge at different inter-electrode distances, activated at 15 kHz. The dashed lines show the Paschen curves. (P stands for Paschen curve; GR for growth rate; the number is the inter-electrode distance in mm)

6. Discussion

The breakdown voltage and the growth rate are both driven by electron collisions with the gas neutrals leading to ionizations, dissociations, etc. and the release of electrons at the cathode surface. In other words, both phenomena depend on the ionization and thus the conductivity of the gas phase. On the left of the Paschen minimum, the gas density becomes too scarce; thus, 1/ the breakdown voltage increases to compensate the lower electron-neutral collision rate, and 2/ the deposition rate decreases because less polymerizable species are created. On the right side of the Paschen minimum, the gas density increases; therefore, 1/ the breakdown voltage increases to compensate the shorter mean free path of electrons, and 2/ the deposition rate decreases because, as the charged particles gain less energy between collisions, collision-based reactions are less efficient. Indeed, the rate of film formation is directly related to the ionization efficiency [2]. Furthermore, as the mean free path of the polymerizable species decreases, the polymerization rate at the substrates (situated in the middle of the inter-electrode volume) decreases [1].

Consequently, it is not unexpected to observe the curves of the breakdown voltage and of the deposition rate to show a minimum, respectively a maximum, under the same gas conditions represented by the pressure *p*.

7. Conclusion

Simple DC breakdown measurement in an existing reactor configuration can help finding the optimum deposition conditions for the film growth conducted in a magnetron enhanced AF plasma polymerization system.

References

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