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PLASMA ETCHING OF DLC FILMS USING A CONSTRICTED HOLLOW CATHODE

F.M. Freitas[1,*]; H.S. Maciel [1]; G. Petraconi Filho[1]; K. Grigorov[2]; M. Massi[1]
[1] *Instituto Tecnológico de Aeronáutica, 12228-900, São José dos Campos, SP, Brazil*
[2] *Institute of Electronic, 72, Blvd. "Tzarigradsko Chaussee", 1784 Sofia, Bulgaria*

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ABSTRACT

Thin films are etched in a recently developed modality of high vacuum reactor. Diamond-like Carbon films manufactured by sputtering technique are used to the plasma etch studies. A constricted hollow cathode (CHC) is used as Argon plasma source. To reach etching characteristics adequate to the microelectronic processes, extensive experiments are carried out to estimate the influence of several control parameters. Bias voltage technique is employed for energetic ion extraction from the produced plasma jet. Helmholtz coil applies an axial magnetic field for improved plasma confinement. The effect of varying bias voltage, magnetic field intensity and plasma power on etch rate has been studied. The bias voltage determines the sputtering yield through the acceleration of Ar ions extracted from the CHC originated plasma jet. The applied magnetic field drives the ion flux to the substrate. Ion flux adjust is also attained by plasma power selection. The results show that the processes in high vacuum with the presence of moderate magnetic fields offer some potential advantages of this technique in comparison to the standard plasma etching processes.

1. INTRODUCTION

Diamond-like carbon (DLC) films have been subject of intensive studies in the last quarter century as a result of its significant mechanical, optical, electrical, chemical and tribological properties [1,2]. On this context, etching processes are important to achieve reliable materials [3]. With this purpose, the use of reactive ion etching (RIE) systems is widely spread [4], in spite of the consequent undesirable production of micro-masking on the film.

To present an alternative to the current systems, we use a new plasma reactor that rely on the production of a stream of plasma (plasma jet) of low intensity. A similar geometry was already employed in a multi-plasma system for film deposition [5]. In this work, we investigate the use of the plasma jet for etching processes.

The influence of the axial magnetic field, the substrate bias voltage and the plasma power on the etch characteristics of the film were studied.

2. EXPERIMENTAL

DLC thin films was deposited, on a (100) oriented silicon wafer, by 150 W dc magnetron sputtering of a graphite target, with the discharge produced in an Ar atmosphere at a working pressure of 5 mTorr. The target substrate distance was kept at 6 cm. After the deposition process, the wafer was cleaved into small 1 by 1 inch square samples. The samples were used to determine the etch rate of DLC films by an Ar jet plasma. This proccedure was carried out by professor Marcos Massi on a different device described further on refference [4].

In order to produce a step between the etched and non-etched regions, parts of the samples were covered with a mechanical mask during the etching process. The resulting step was measured by an Alpha-Step 500 profilometer, and their respective values used to compute the etching rates.

Fig. 1 shows a schematic view of the experimental set-up. The etching system consists of two chambers working at different pressures (at least 1-2 orders of magnitude), connected by a narrow channel (1 mm diameter). The source chamber corresponds to a cylindrical cavity of 1 cm diameter, with a constriction on one extremity and a one-quarter inch orifice for gas admittance on the other. Within this volume an Ar hollow cathode discharge (HCD) was produced. The processing chamber, represented by a 20 cm diameter, 40 cm long, Pyrex cylinder, enclosed by aluminum flanges on the extremities, was evacuated by a combination of rotary and turbo-molecular pumps to achieve a residual pressure of 10^{-6} Torr.

The gas was fed directly into the processing chamber through the source chamber, at a flow rate of 100 sccm and a fixed pressure of 5.4 mTorr. The pressure difference between the source chamber and the processing chamber promoted a plasma flow towards the latter one, where an expanding plasma jet was produced. The HCD was operated in direct current (DC) mode with fixed voltage and current of 350 V and 100 mA, respectively.

At a distance of 5 cm from the source chamber, a substrate holder was positioned, which was biased with a negative polarization V_p (0-200 V) in order to extract and accelerate ions towards the substrate. In addition, a Helmholtz coil was placed outside the vacuum recipient for the purpose of providing a magnetic confinement of the plasma flux and to strengthen the ion bombardment effect.

* fernando004@yahoo.com.br

3. RESULTS AND DISCUSSION

Fig. 2 shows the DLC film etch rate as a function of the dc bias voltage for a fixed Ar flow of 100 sccm, pressure of 5.4 mTorr and power of 35 W. The increase of the bias voltage produces a corresponding rise in the etch rate. This is expected because the dc bias voltage creates a potential difference above the substrate, which is responsible for the acceleration of Ar ions. Those energetic ions promote etch of the DLC film by means of a physical sputtering.

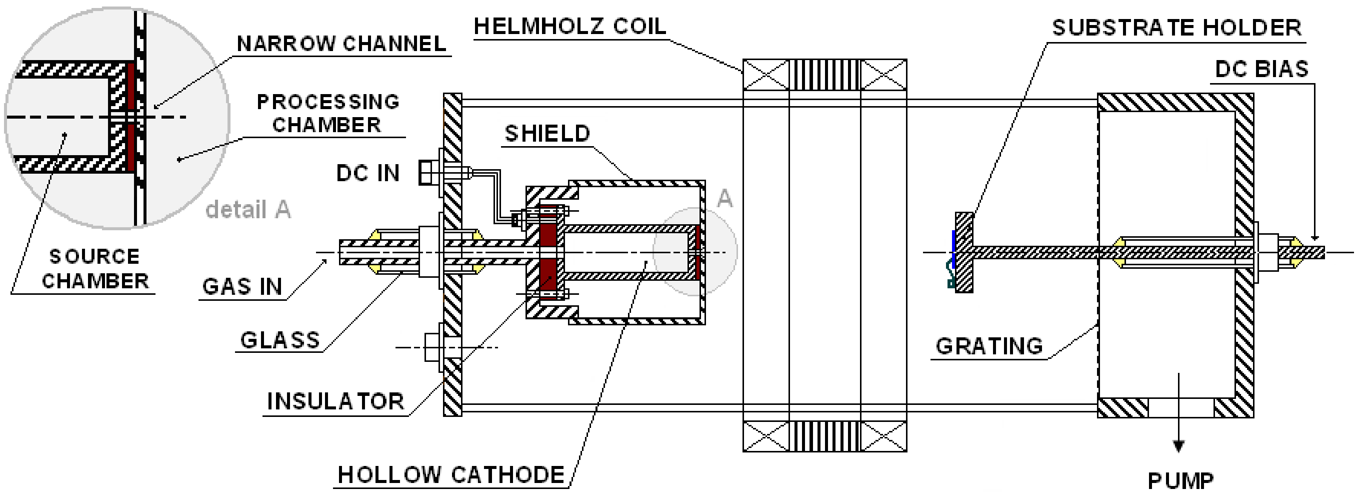

Figure 1 – Schematic view of the plasma jet reactor, whith constriction detail on the left upper corner.

Moreover one can recognize the presence of a threshold energy above which the etch rate became noticeable. This minimum energy lies between the 50–100 V range, and finds it explanation in the necessity of the sputtered atoms to surpass the surface binding energy potential in other to leave the material.

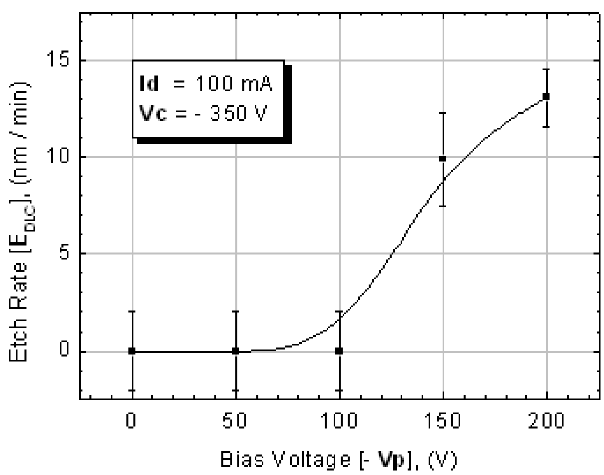

Figure 2 – DLC etch rate E_{DLC} as a function of substrate bias voltage Vp for a fixed discharge current and voltage, Id and Vc.

Fig. 3 demonstrate the influence of an applied magnetic field on the etch rate, respected the same discharge parameters as above. This behavior can be better illustrated in fig. 4, where the same data is represented in a different form where the etch rate is plotted as a function of the axial applied magnetic for three different dc bias voltages, at a power of 35 W.

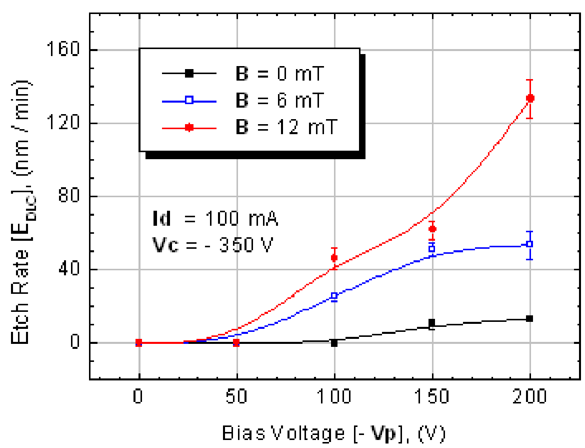

Figure 3 – DLC etch rate E_{DLC} as a function of substrate bias voltage Vp and applied magnetic field B for a fixed discharge current and voltage, Id and Vc.

Fig. 5 shows the etch rate for a higher power of 60 W. Those figures show a significant increase on the etch rate of almost one order in magnitude in the presence of the applied magnetic field. The last two figures are consistent with an increase of etch rate with the augmentation of bias voltage and magnetic field. The former factor was already explained above. The latter can be understood by an increase of plasma density owning to the confinement action of the applied axial magnetic field, on diminishing radial electron diffusion. This corresponds to raise the ion flux to the substrate, what causes the observed behavior.

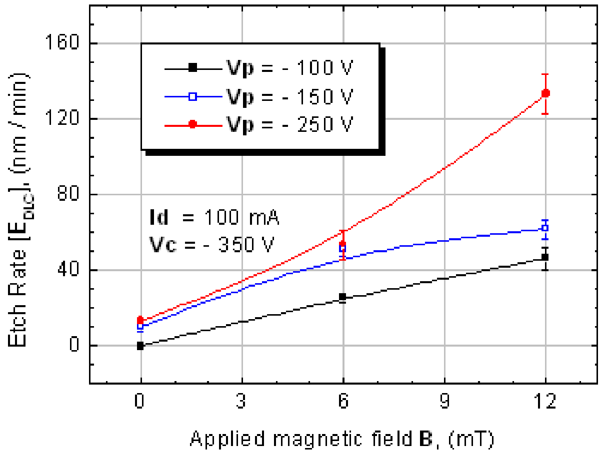

Figure 4 – DLC etch rate E_{DLC} as a function of applied magnetic field B and substrate bias voltage Vp for a fixed discharge current and voltage, Id and Vc (applied power P = 35 W).

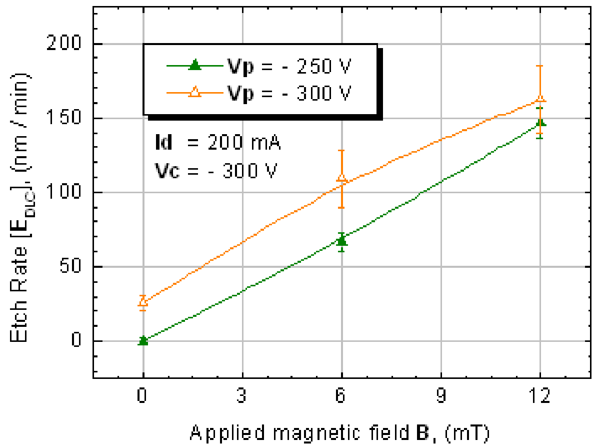

Figure 5 – DLC etch rate E_{DLC} as a function of applied magnetic field B and substrate bias voltage Vp for a fixed discharge current and voltage, Id and Vc (applied power P = 60 W).

4. CONCLUSION

Considering the etch rate as a function of the sputtering yield and the ion flux on the film surface, one can comprehend that the selection of the bias voltage and the applied magnetic field responds for a changes in the sputtering yield and the ion flux, respectively. This behavior makes possible the simultaneous adjustment of two important control parameters in the etching process, providing this particular discharge geometry with a significant advantage over other conventional etching systems.

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