CHARACTERIZATION OF A PLASMA JET PRODUCED BY A VACUUM DISCHARGE FOR DIAMOND DEPOSITION

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Abstract

In this paper the results of the measurements to determine the best conditions for diamond synthesis, in an arcjet apparatus, PJET, that has been developed at LAP/INPE are discussed. The arcjet can be operated at a maximum of 3kW of electric power with argon, hydrogen and methane as working gases at a total pressure of about 100 Torr. The plasma density and electron temperature were measured by a double electrostatic probe scanning along the axis of the plasma jet for different power and gas fluxes. The cathode and substrate temperature were also measured using a pyrometer and a thermocouple, respectively. The highest values obtained at PJET were: $T_e \sim 0.5$eV, $n_e \sim 10^{18}m^{-3}$, cathode temperature $\sim 800°$C and substrate temperature $\sim$1000°C.

1. Introduction

Intensive research has been developed all around the world concerning the synthesis of diamond films from the vapor phase. Particularly, several schemes have been studied using the "Chemical Vapor Deposition" (CVD), to grow diamond in a relatively low temperature substrate (600 – 1000° C) and at low pressure environment (< 1 atm).[1,2]

The diamond synthesis using CVD technique, is basically characterized by a gas phase, usually composed of hydrocarbon with molecular hydrogen. This gas phase must be activated, for some process, in order to beginning the chemical reaction for diamond synthesis.

The use of a plasma jet, produced by a low pressure arc discharge, as the active medium for diamond synthesis was first reported by Kurihara et al in 1988.[3] The main advantage of this scheme is reaching very high deposition rate. Deposition rate as high as 900 μm/h has already been reported.[2]

A low power arc jet device has been developed at LAP/INPE in order to investigate the physics of the process. The results presented in this paper (plasma density and electron, cathode and substrate temperatures) determine the best conditions for diamond synthesis.

2. Experiment

A schematic diagram of the plasma jet experiment is shown in figure 1. Basically, the system comprises a stainless steel vacuum vessel and an arc chamber. The arc chamber is composed of two axial electrodes. The inner one is the cathode, a copper rod with diameter of 18mm ended by a molybdenum conical tip. The other one is the anode, a cylindrical copper case with an orifice with diameter of 4mm (nozzle). The distance between anode and cathode is 0.3mm and it can be continuously adjusted. Both electrodes are water cooled and electrically insulated by a nylon flange protected by a ceramic jacket. A DC power supply (1500V × 20A) is connected to the electrodes. Gas can be fed by three independent access. The pressure in the vessel is kept constant at about 50mbar

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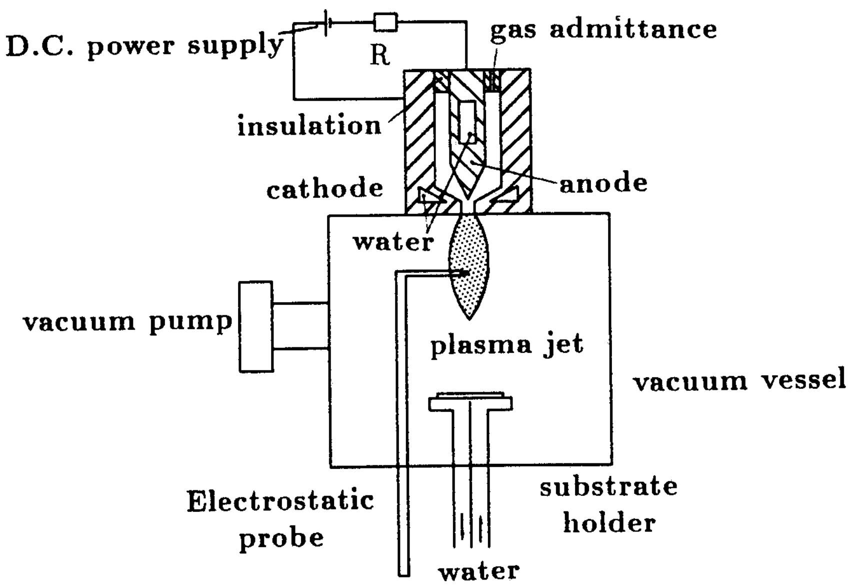


Figure 1. Schematic diagram of the plasma jet experiment.

and the pressure at the admittance orifice of the arc chamber is $\sim$ 350−400mbar. At these conditions a voltage of about $\sim$100V is enough to obtain the breakdown of the gas, establishing the arc discharge. The ionized gas between the electrodes expands through the nozzle generating the plasma jet inside the vacuum vessel. The highest arc current attained at PJET is about 8A with a voltage of 350V.

3. Results and Discussions

3.1. Plasma Parameters

An electrostatic double probe[1,5] was used to measure the electron temperature (T_e) and density (n_e) of the plasma jet. The power of the arc discharge is low (<3kW), allowing the insertion of the probe inside the plasma. The probe tip is a tungsten wire (diameter: 0.5mm and length: 1.8mm). Figure (2a) shows the circuit used to polarize and measure the signals of the double probe. Figure (2b) shows the probe characteristic curve, measured at 12mm from the nozzle.

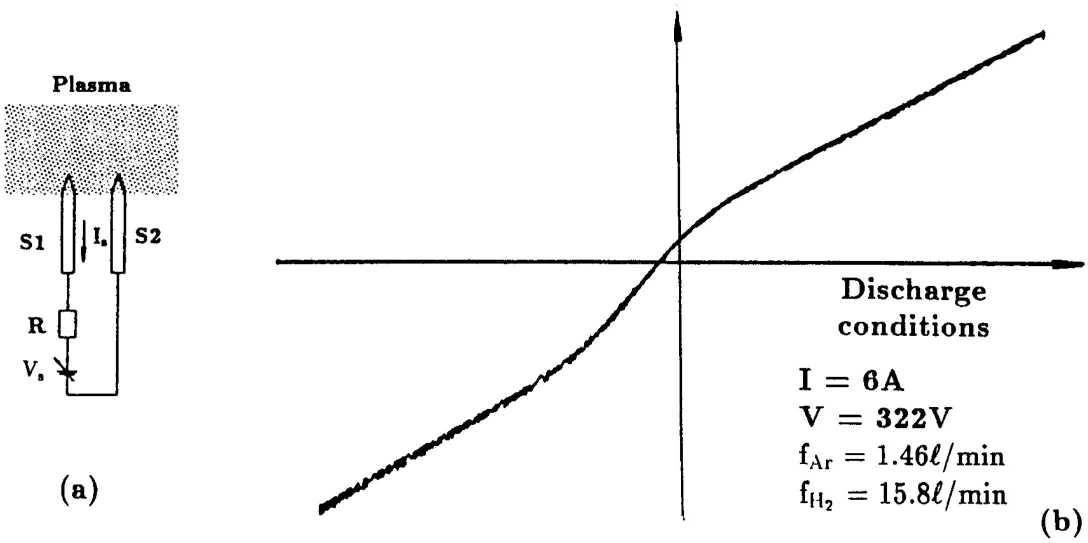


Figure 2. (a) Schematic diagram of the double probe circuit, (b) characteristic curve for axial position x = 12mm.

Figure 3 shows the electron temperature and density of the plasma jet as a function of arc current taken at different argon and hydrogen fluxes and at 12mm from the nozzle. Figure 4 shows the electron temperature and density of the plasma jet as a function of the distance from the nozzle taken at different arc currents an gas fluxes. It can be observed that both T_e and n_e increase for higher arc currents and decrease as the distance from the nozzle increases. The values of T_e in the range of 0.07 – 0.47eV and the values of n_e in the range of 10^{16} – $10^{18}m^{-3}$ are quite reasonable and are in agreement with other measurements.[6] Typical error bars are shown in the figures.

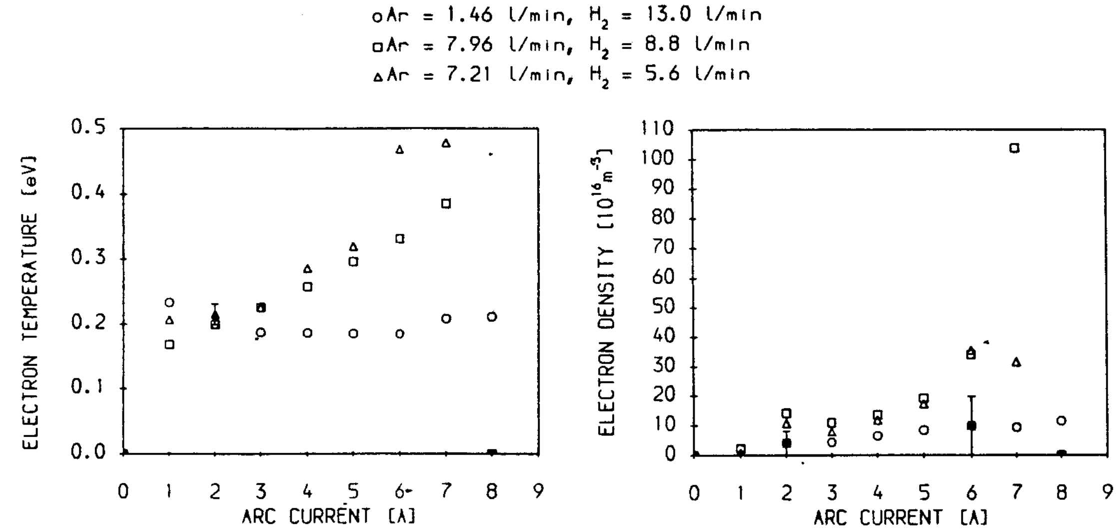


Figure 3. Dependence of the electron temperature and density on the arc current measured at x = 12mm.

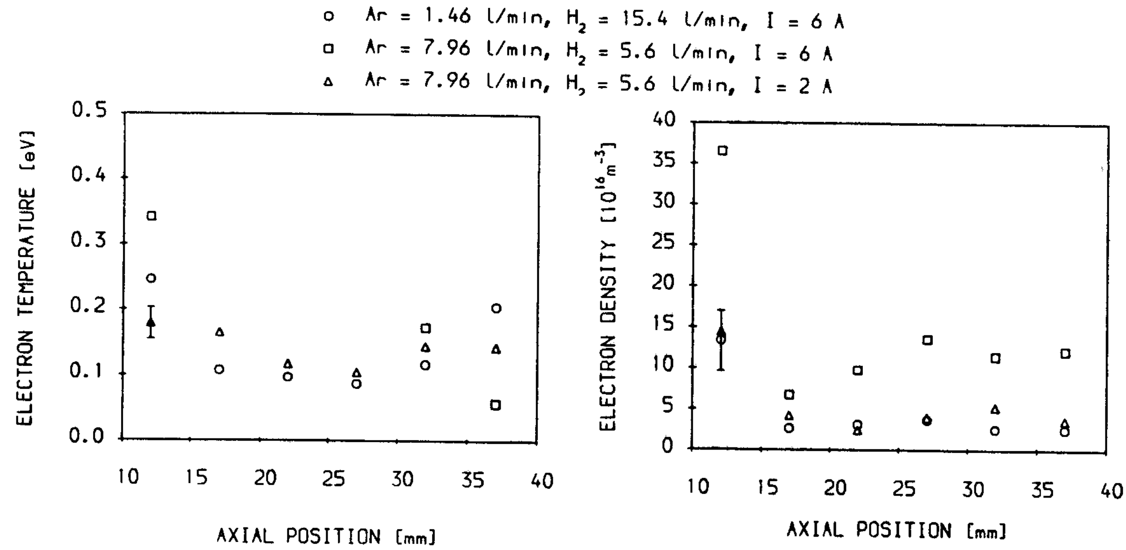
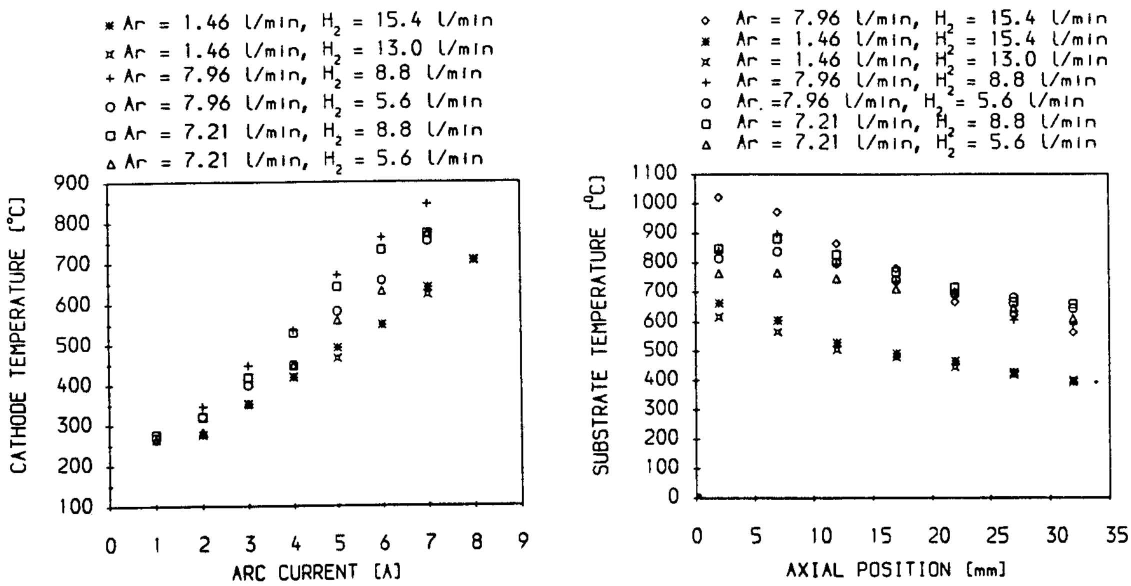


Figure 4. Dependence of the electron temperature and density on the axial distance from the nozzle.

3.2. Substrate and Cathode Temperatures

The cathode temperature, T_c, was measured using a pyrometer. The highest value obtained is 840°C at arc current of 7A with H_2 (8.8ℓ /min) and Ar (7.96ℓ/min). The substrate temperature, T_s, was also measured using a thermocouple, type K (alloy CrNi - "Chromel" and AlNi - "Alumel"). The highest value obtained is 1020°C at arc current of 6A with H_2 (15.4ℓ/min) and Ar (7.96ℓ/min).

Figure (5a) shows the cathode temperature dependence on the arc current and figure (5b) shows the substrate temperature as a function of the axial distance from the nozzle, for an arc current of 6A, both for different gas fluxes. Both temperatures increase for higher arc currents and the total gas fluxes.



(a) (b)

Figure 5. Dependence of the: (a) cathode temperature on the arc current; (b) substrate temperature on the axial distance.

4. Conclusions

The results concerning the electron temperature, plasma density, cathode and substrate temperatures in a low power plasma jet are presented. The axial profiles of T_e and n_e are as expected, as well as, the dependence of T_e and n_e on the arc current. The values of T_e and n_e are in agreement with other measurements. The substrate temperature is a expected, as well as, the dependence of cathode temperature on the arc current. According to these results, it is possible to determine the best position for diamond synthesis at PJET.

5. References

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