Two-Dimensional Optical Emission Imaging of a Pulsed Supersonic Plasma Jet

Olivier P. Postel and Joachim V. R. Heberlein

***Abstract*—Two-dimensional monochromatic and time resolved imaging of a pulsed supersonic plasma jet is used to qualitatively determine the influence of a secondary discharge on the plasma jet chemistry in a chemical vapor deposition (CVD) reactor. In this reactor, thin films of boron carbide are grown from the thermal dissociation of boron trichloride and methane. We have found in a previous study that a positive bias applied to the substrate increased significantly the growth rate. In this study, we make use of emission spectroscopy imaging to map the possible growth precursors under different bias conditions.**

***Index Terms*—Boron carbide, hard coating, plasma jet CVD, pulsed bias.**

I. Introduction

In previous publications, we have shown that boron carbide could be deposited using supersonic plasma jet chemical vapor deposition (CVD) from the thermal dissociation of boron trichloride and methane [1], [2]. The use of a positive bias has been found to greatly enhance the growth of the films. Also, as seen in Fig. 1, biasing has the effect to increase the plasma jet cross section and its emitted intensity. In the hydrogen, boron trichloride, and methane system, boron chloride (BCl) is believed to be the most stable species [3]. However, the growth rates obtained in this reactor are an order of magnitude higher than one would expect from the growth mechanism based on BCl chemistry.

In this paper, we describe the use of optical emission spectroscopy to image the plasma jet emission of possible growth precursors under different bias conditions.

II. Experimental Setup

The pure argon plasma jet is generated by an arcjet thruster developed by NASA, which is operated at a power between 3 and 4 kW. The plasma is exhausted at supersonic speed into the chamber and impinges after a few tens of microseconds on a substrate. The chamber pressure is kept constant at 266 Pa. The chemical precursors, boron trichloride (BCl_3) and methane (CH_4) are injected into the expansion zone of the supersonic plasma jet and are rapidly dissociated. Details of the overall experimental setup can be found elsewhere [2].

An emission spectroscopy setup (OES) consisting of a set of condensing lenses, two perpendicular slits, a spectrometer, and a photomultiplier tube are used to monitor the plasma emission during deposition. The optical setup can be moved to scan along the plasma jet, thus permitting to resolve spatially the distribution of chemical species in the entire plasma jet.

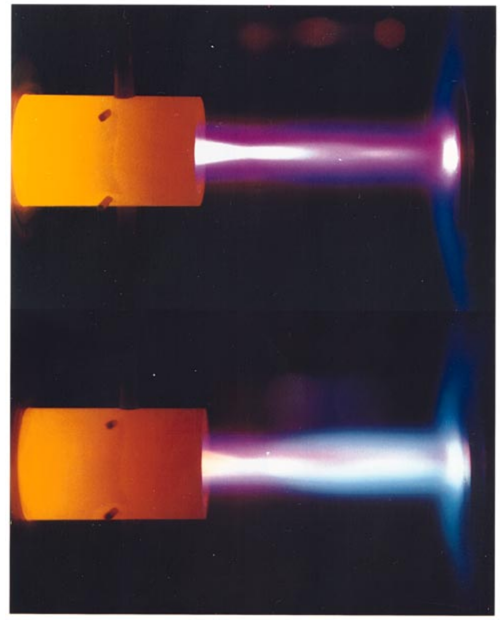

Fig. 1. Photographs of the supersonic plasma jet without bias (high) and with bias (low).

A positive dc or pulsed dc bias can be applied to the substrate using a 1 kW power supply. In this study, the bias magnitude is varied from 0 to 55 V, the duty cycle from 25 to 100%, and the pulse frequency, when applicable, kept at 1 kHz.

III. Discussion

Time resolved two-dimensional (2-D) images of the integrated argon line at 696.5 nm are shown in Fig. 2. The bias conditions are the following, from the bottom to the top: no bias, 15 V dc, 30 V at 50%, 45 V at 25%, and 55 V at 25%. The intensities shown in these images have been Abel inverted and measured while the pulse is on, whenever applicable. From the images, one can clearly see the strong influence of the bias voltage on the argon emission, which means a strong elevation of the electron temperature to excite argon atoms to this particular energy level. When no or little bias is applied, the shock wave nodes in the plasma jet can be clearly seen. The region of hot electrons in the vicinity of the substrate grows larger and becomes more intense with increasing bias voltage.

If one assumes that the effect of the bias on the ionization degree of argon is negligible, then the intensity ratio of atomic boron emission to argon emission gives a good indication on the formation of atomic boron in the complex boron trichloride dissociation process. Fig. 3 shows the time resolved

Manuscript received July 7, 1998. This work was supported by the NASA Lewis Research Center (Ohio) and the National Science Foundation through the Engineering Research Center for Plasma-Aided Manufacturing.

The authors are with the Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN 55455 USA (e-mail: jvrh@me.umn.edu).

Publisher Item Identifier S 0093-3813(99)02422-4.

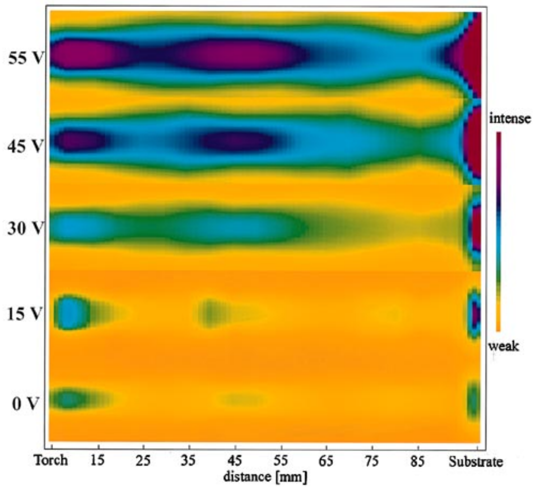

Fig. 2. Images of the argon line emission at 696.5 nm under different bias conditions.

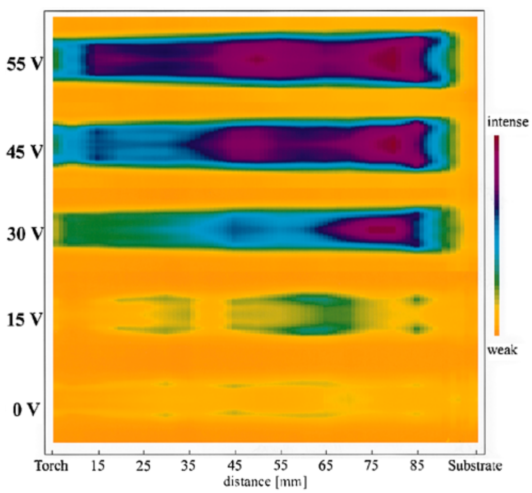

Fig. 3. Images of the ratio of boron line intensity over argon line intensity under different bias conditions.

2-D images of the integrated intensity of the 249.7 nm boron line over argon line emission. One can see that the boron to argon line intensity ratio increases from the torch exit to the substrate, at any bias voltage. Also, the intensity ratio increases considerably when increasing the bias voltage, indicating an increased atomic boron concentration. If indeed more atomic boron is produced, it should be at the expense of boron chloride. Since there is an increased excitation of the argon line at 14.5 eV, there should be an accordingly higher dissociation of the BCl requiring only 5.1 eV.

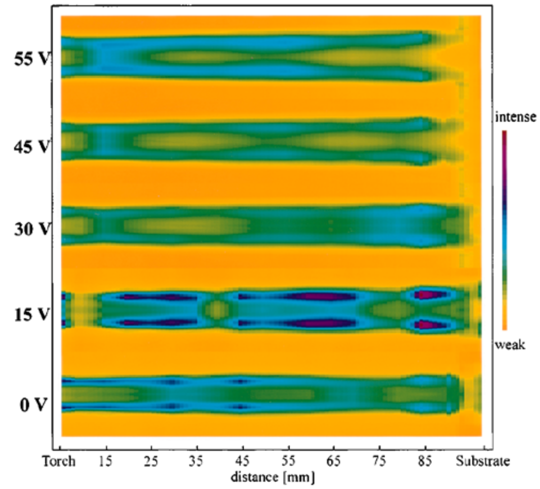

Fig. 4. Images of the ratio of boron chloride band head intensity over argon line intensity under different bias conditions.

Fig. 4 shows the time resolved 2-D images of the line intensity ratio of boron chloride over argon. The BCl intensity is measured at 272.7 nm in the main system $A^1\Pi$–$X^1\Sigma^+$. Here, one can see that the boron chloride over argon line intensity ratio is the highest when no or little (+15 V dc) bias is applied. At higher bias voltages, the intensity ratio seems to decrease in the vicinity of the substrate. Also, from the 2-D pictures, it can be seen that the BCl emission is strong in the fringes and weaker in the center of the jet.

IV. Conclusion

In this study, it has been shown that the positive bias significantly increases the argon emission and that, very likely, atomic boron is produced from the dissociation by electron impact of BCl molecules. Spatially resolved and time resolved 2-D imaging of the plasma turns out to be a useful tool in determining qualitatively the influence of the positive bias on the plasma jet chemistry.

References

[1] O. Postel, N. Otake, and J. Heberlein, "Plasma CVD of boron carbide thin films," in *Proc. 13th Int. Symp. Plasma Chem.*, Beijing, China, 1997, pp. 1088–1093.

[2] O. Postel and J. Heberlein, "Deposition of boron carbide thin film by supersonic plasma jet CVD with secondary discharge," *Surf. Coatings Technol.*, vol. 108–109, pp. 247–252, 1998.

[3] H. B. Schlegel and S. Harris, "Thermochemistry of BH_mCl_m calculated at the G-2 level of theory," *J. Phys. Chem.*, vol. 98, no. 11178, pp. 11178–11180, 1994.