DC Pulsed Atmospheric Pressure Plasma Jet Image Information

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**Abstract**—This paper presents optical imaging and optical emission spectroscopy (OES) data of an atmospheric-pressure plasma jet. It is shown how the visual information and OES information of the air discharge are related as the blown arc extends from the nozzle (2–4 mm) with a molecular nitrogen rotational temperature on the order of 1700 K and the flowing afterglow beyond this region is dominated by the cooler (300-K) NO–O chemiluminescent reaction that produces NO$_2$ species.

**Index Terms**—Atmospheric-pressure plasmas, optical emission, plasma applications, plasma temperature.

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**I. APPJ SYSTEM**

The APPJ OpenAir system uses dry compressed air as the working gas with an inlet pressure between 100 000 and 300 000 Pa and a flow rate between 37.5 and 76.6 L/min. The APPJ is driven by a unipolar square-wave pulsewidth modulation (PWM) power circuit switch. This circuit provides an immediate amount of electrical power between fully on and fully off at a drive switching frequency between 17 and 25 kHz [1].

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**II. OES MEASUREMENTS**

The spectrum by a low-resolution spectrometer for the OES survey as a function of fixed axial position (0, 5, 10, and 15 mm) within the discharge afterglow is shown in Fig. 1. The OES intensity at 777 nm is greatly reduced, and the NO$\gamma$ bands (λ = 236–258 nm), the second positive system of molecular N$_2$ (C$^1\Pi_u^+$ − B$^3\Pi_g^+$), and at λ = 391 nm, the ν = 0 → 0 band of the first positive nitrogen ions N$_2^+$ (B$^2\Sigma_u^+^0$ − X$^2\Sigma_g^+$) is observed. At longer wavelengths, the atomic-H-Balmer-$\alpha$ line at λ = 656 nm, nitrogen, and the continuum intensity at 800 nm are also present. Moving away from the anode nozzle along the discharge axis, the optical emission undergoes an abrupt change in emission content at 5 mm, under the processing conditions used. Here, the excited NO$_2$ molecule (λ = 405–800 nm) continuum is formed with the second positive system of molecular N$_2$; atomic oxygen is greatly reduced, and the NO$\gamma$ bands are still maintained. Continuing along the discharge axis line to 10 mm, the NO$_2$ continuum has decreased in intensity, and the NO$\gamma$ bands are no longer present. At 15 mm, the NO$_2$ continuum intensity at 550 nm has decayed by one-half of that obtained at 5 mm.
Using the procedure from [1] and [2], the rotational temperature is found to be in the range of 1709 ± 100 K at 25 kHz to 1761 ± 100 K at 19 kHz. These OES measurements demonstrate that, as the air is pushed through the arc region, nitrous oxide (NO) is formed, which then undergoes partial oxidation to the excited NO$_2$ state within the flowing afterglow. This process is represented by the NO–O chemiluminescent reaction

$$\text{NO} + \text{O} \rightarrow \text{NO}_2 + h\nu.$$ 

In conclusion, the air APPJ discharge was found to have two distinct plasma regions: the blown arc and the flowing afterglow region, where the flowing afterglow can be subdivided into near afterglow and far afterglow (see Fig. 2). Photodiode measurements reveal that the arc region has a time-modulated polychromatic light emission that follows the PCT (effective duty cycle) of the applied power from the power supply.

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REFERENCES
