Flame and Trident Plasma Emissions of Single Rectangular-Shaped Atmospheric Pressure Plasma Jet

Choon-Sang Park, Do Yeob Kim, Yang-Suk Ko, Hal-Bon Gu, Heung-Sik Tae, and Sung-O Kim

***Abstract*— A single atmospheric pressure plasma jet device using a rectangular tube has been proposed for generating the intense glow plasmas. Two plasma regimes were found to exist in the same plasma structure under changes of gas flow rate and applied voltage conditions: the flame plasma regime and the trident plasma regime. When the gas flow rate and applied voltage were at low values, the flame glow plasma was produced, whereas the trident glow plasma was produced when the gas flow rate and applied voltage were at high values. Under identical electrical driving and gas conditions in each plasma regimes, the optical intensity of the trident plasma regime was approximately two times larger than the flame plasma regime. This highly energetic trident plasma jet is useful in developing novel applications requiring strong atmospheric pressure discharge processes by using very simplified structures, easy fabrication, potable and light weight, wide area, patterning generation, and low manufacturing and maintenance cost compared with the vacuum plasmas.**

***Index Terms*— Atmospheric pressure plasma jet (APPJ), cold plasma jet, flame plasma regime, intense glow plasmas, rectangular tube, trident plasma regime.**

I. Introduction

A COLD atmospheric pressure plasma jet (APPJ) device is one of the easiest plasma sources from which could be created nonthermal atmospheric pressure plasmas. Their easy fabrication, simple structure, low temperature emission, and high chemical reactivity make them particularly useful in novel thin film, etching, surface treatment, nanomaterial, semiconductor, and military applications [1]. However, APPJs are based on weakly ionized discharges, and the intensities of these plasmas are relatively low when compared with those of low-pressure plasmas generated by vacuum chambers. Several tough structures have developed to mitigate the problems involved in generating high-intensity plasmas, and they are most difficult to create [2], [3]. Accordingly, we have developed a single rectangular and switchable atmospheric pressure plasma jet device which can generate the intense flame and trident plasmas by controlling parameters in the same device.

Fig. 1 shows the flame glow plasma and trident glow plasma plumes created at the APPJ in a single rectangular tube structure that ensures a widely treated plasma area. As shown in the two right figures of Fig. 1, the plasma plumes were split into three groups that subsequently formed a trident shape. This is the first reported occurrence of this phenomenon single-tube APPJs. The photograph was taken using a digital single-lens reflex camera with macro lens (Canon EOS Rebel T1i camera with Tamron SP AF 90-mm F2.8 Di Macro 1:1 lens). The rectangular tube has an inner diameter of 2 mm $\times$ 6 mm and a wall thickness of 0.7 mm. The copper tape, used as a powered electrode, is wrapped around single rectangular tube 7 mm from the end of the tube. High-purity helium (He) gas (UHP grade, 99.997% purity) was used as the discharge gas into the plasma jet. As shown in Fig. 1, when the sinusoidal voltage waveform was applied to the powered electrode, the plasma plume produced different appearances, because of the changes in the gas flow rate and applied voltage. First, at the He gas flow rate of 6.2 slm (standard liter per minute), the peak voltage of 5.5 kV (V_{pp} of 11 kV), and the frequency of 36.0 kHz, the plasma plume with flame shape from the single rectangular tube jet device was produced. The resultant plasma plume had a long length of approximately 25 mm. Second, at the He gas flow rate of 7.5 slm, the peak voltage of 8.8 kV (V_{pp} of 17.6 kV), and the frequency of 32.0 kHz, the intense plasma plume with trident shape from the single rectangulartube jet device was produced. The plasma plumes of the trident plasma regime were split into three groups. The center plume was observed to be more enhanced while in trident plasma regime. Thus, the intense plasma can be produced using the trident regime. Though the resulting plasma plume had a length of approximately 20 mm, the plasma plumes in the ambient position were quite wide.

A photosensor amplifier (Hamamatsu C6386) was used to observe plasma emissions, and the wavelength-unresolved optical emission waveform from the photosensor amplifier was plotted on the oscilloscope. All optical emissions from the plasma regimes were measured at 10 mm with 45° angle away from the end of the tube. As shown in Fig. 2, the optical intensity of the trident plasma plume from the single plasma jet

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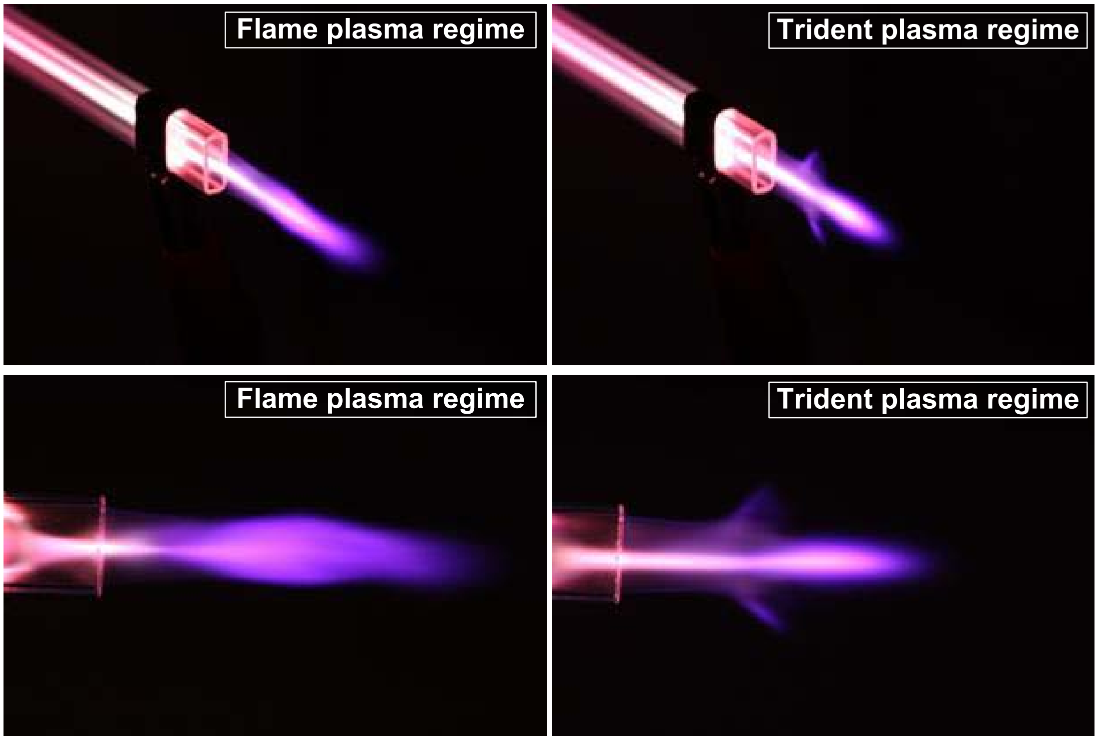

Fig. 1. Flame glow plasma and trident glow plasma plumes of the APPJ with single rectangular shape.

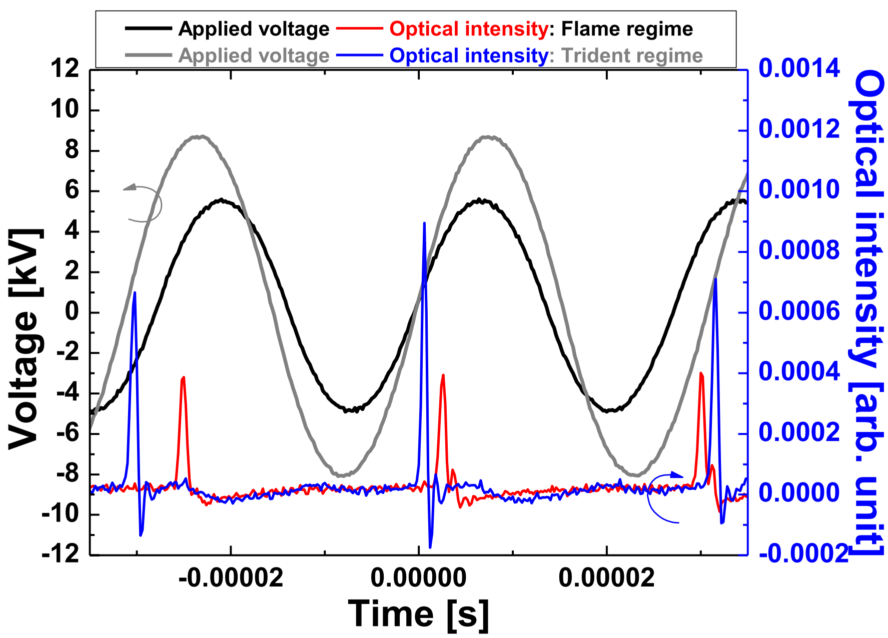

Fig. 2. Comparison of applied voltage and optical intensity of flame and trident plasma plumes from the APPJ in single rectangular tube structure.

was two times larger than the flame plasma plume, indicating the effectiveness of this method in producing plasmas of great intensity and width.

These results imply that properly ordered intense trident plasma jet may be of use in novel applications that require strong and wide plasma discharge processes with very simple structures, which are easily fabricated, are potable and light weight, can generate patterns, and cost very little to manufacture and maintain.

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