Droplet Striations Formed in a 900-MHz Microwave Argon Atmospheric-Pressure Plasma Jet

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***Abstract*—Unique striations were observed in the formation of 900-MHz microwave argon atmospheric-pressure plasma jet in air. The striated patterns are easily observed even with the naked eyes at a flow rate of above 3 slm and an input power of below 3 W. Moreover, the striated patterns, which were associated with shortening in the plasma jet length, are obtained by adding less than 1 vol.% of O_2 gas to Ar.**

***Index Terms*—Droplet striation patterns, intensified charge-coupled device (ICCD) image, microwave argon atmospheric-pressure plasma jet.**

IN THIS paper, we present unique striated patterns (similar to water drops) which were observed in the formation of 900-MHz microwave argon atmospheric-pressure plasma jet in air. The plasma jet system is a quarter-wavelength coaxial resonator with one open end and one short end. More details about the experimental setup and the principles of operation were reported previously [1], [2]. In previous works, striated patterns were observed under certain power and gas flow conditions [3], [4]. The unique shape of striated patterns is observed not only with the variation of applied power and gas flow but also with the addition of O_2 to Ar in microwave case. Moreover, O radical spatial distribution, which is an important agent in biomedical field, also followed the striated patterns.

A plasma jet visualized photograph, which is captured by a digital single-lens reflex camera (Samsung VLUU ES70), is shown in Fig. 1(a). Because of high intensity of optical emission from the plasma plume, striated patterns are not observed in this photograph. Therefore, the PI-MAX2 intensified charge-coupled device (ICCD) from Princeton Instrument is used to visualize the striated pattern formation clearly. In addition, the spatial resolution of O radical is observed with a bandpass filter, which is centered at 777.1 nm, placed in front of the ICCD. The images in Figs. 1 and 2 are not normalized. Fig. 1(b) shows a clear example of the 900-MHZ microwave Ar plasma jet striated patterns using an ICCD camera. The striations were clearly observed at the end of the plasma plume at 3 W of input power and 3 slm of argon gas flow rate. Many cases of striated plasma patterns and plasma-bullet-resembling ellipsoidal plasma discharge were reported [3], [4]. Striation patterns can be related to the reduction of plasma intensity caused by strong mixing of the air at the end of the plasma plume. An experiment of directly mixing an O_2 to the plasma carrier gas is also conducted.

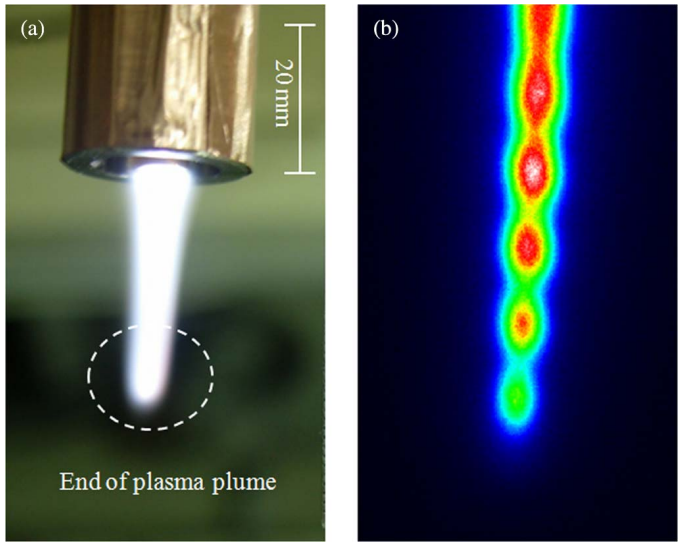

Fig. 1. 900-MHz microwave-induced plasma device. (a) Real plasma photograph with 3 W of effective power and 3 slm of argon gas flow rate. (b) ICCD image of end of plasma plume with the same condition.

The striations are also observed on the whole plasma plume by mixing a small percentage of O_2 to the Ar gas. A MYKRONS FC2805 mass flow controller and a DFC4000 digital gas flow controller were used to control the percentage of O_2 gas up to 1 vol.%. ICCD images with the addition of O_2 gas (0.5 vol.% to 0.9 vol.%) are shown in Fig. 2. The upper row of the images [from (a) to (e)] are the visible images, which were captured without the use of the bandpass filter, while the lower row of images [from (f) to (j)] are obtained for O radical spatial distribution with the use of the bandpass filter. In both cases, the plasma plume has a dimply shape from 0.6% of O_2 flow rate and no dimply shape until 0.6%, and the striated patterns are observed obviously with the increasing flow rate of O_2. The striated patterns became predominant and looked like water drops with the addition of 0.9 vol.% of O_2 to Ar flow rate of 3 L/min at 4-W input power.

Manuscript received November 29, 2010; revised February 21, 2011; accepted March 6, 2011. This work was supported in part by the Korea Science and Engineering Foundation under Grant R01-2007-000-10730-0, funded by the Korea government (Ministry of Science and Technology), and in part by the Korea Ministry of Education through its Brain Korea 21 Program.

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Digital Object Identifier 10.1109/TPS.2011.2128343

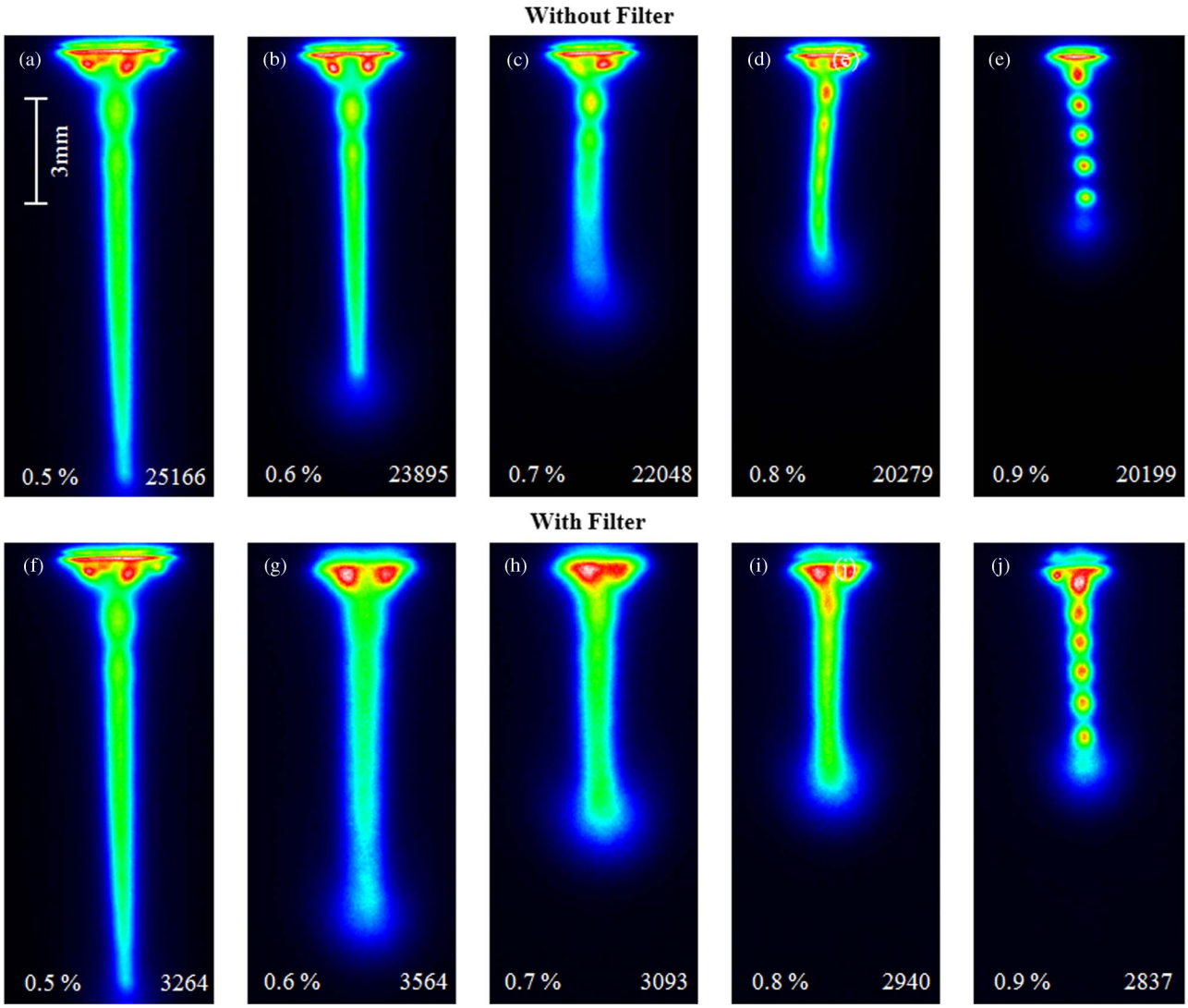

Fig. 2. ICCD image of microwave plasma plume with a variation of O_2 mixture (0.5 vol.% to 0.9 vol.%) with 4 W and 3 slm of argon gas flow. (a)–(e) Without filter. (f)–(j) With filter. Maximum intensity is presented at the right side of each image.

In conclusion, water-drop-like plasma striation patterns have been observed through the 900-MHZ microwave argon plasma jet. This striation patterns is obtained at the end of plasma plume by increasing the Ar flow rate at constant input power (3 W) or decreasing the input power at constant flow rate (3 slm). Moreover, the striation patterns are achieved by adding a small percentage of O_2 to the Ar gas. The addition of O_2 was also combined by a decrease in the plasma jet length. A previous work reported that striation patterns are related to ionization process and electron kinetics in plasma plume [4]. Thus, its unique water-drop-like striations could be associated with the high frequency (900 MHz) of applied power and high energetic electron energy [5] compared with another frequency. However, the detailed reasons behind these droplike striations are still an open point for future research.

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