# Propagation Properties of Laser-induced Streamer Corona in Atmospheric Air under Positive DC Voltages*

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In a DC glow corona discharge for the rod-plane and wire-plane gap arrangement in atmospheric air, when this ion drift space is irradiated by a pulsed-laser, streamer corona is induced with high probability. The occurrence of the streamer corona and it's propagation process were observed by a high-speed camera in detail. From above results, we observed that the electron-burst, which is produced from photoionization by laser irradiation, drifts to glow corona area and the streamer corona is induced. We developed also the method to generate a long curtain-shape streamer corona for a wire-plane system, which may be applied as a non-thermal plasma reactor for the control of air pollution.

***Key Words***: Nonuniform Field Gap, Room air, YAG Laser, Streamer Corona, Propagation Properties

## 1. Introduction

DC breakdown characteristic under inhomogeneous field gap in room air is depended on electrode geometry, humidity, floating particle, etc., which play an important role in complicated corona mode, especially, with the occurrence of the glow-corona, a significant increment in sparkover voltage is caused due to the corona stabilized phenomenon by space charges. In order to investigate the transition process from glow corona to sparkover, it is essential to understand the effect of space charge field and the occurrence mechanism of breakdown streamer[(1)]. However, a high-intensity laser beam can produce optical breakdown plasmas or optical ionization plasmas in air or other gases[(2)]. The gaseous breakdown induced by the plasmas, has been used in the development of low-jitter and high -speed spark gaps[(3)] or laser-triggered lightning[(4)], and other numerous studies which have been reported[(5)]. On the other hand, in pulse corona discharge under positive streamers, a various plasma chemical reaction application, for example, the formation of $O_3$[(6)] and the removal of NOx and SOx, is investigated[(7)(8)].

To produce many long positive streamers, instead of the pulsed power technology which short pulse voltage with high frequency is used[(9)(10)], much more simpler method without electromagnetic noise induced from a short electrical pulse, is now under development at our laboratory. For positive streamer corona converted from positive DC glow corona, pulsed-laser triggering method was used[(11)(12)]. The induced streamer corona by laser irradiation has the characteristic of very high occurring probability and small variation of time lag. In order to realize the industrial application (such as air pollution control), a large volume streamer discharge is important and will be easily produced by a pulsed laser irradiation.

In this study, in order to practical use of the ionized plasma in the area of high field near the front of laser-induced streamer, we investigated the laser control performance of a streamer corona for various electrode arrangements and laser irradiation conditions. For the investigation of laser-induced streamer corona propagating process in rod-plane and wire-plane gaps, an optical observation was conducted.

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## 2. Experimental Setup and Method

DC corona discharge generator with positive polarity, electric signal measurement and discharge luminous observation apparatuses, laser irradiating system and it's input-output detector are shown in figure 1. Electrode arrangement have two kinds of rod-plane and wire-plane systems. The gap length is set to 2cm. This experiment is being done under the condition of atmospheric air, such as pressure is 755〜760 Torr, temperature is 25〜27℃ and relative humidity is 45〜70%.

The electrode arrangement of rod-plane is consisted of a brass rod anode with a hemispherical tip of $\phi$=0.1cm or $\phi$=0.3cm in diameter and a brass disc cathode $\phi$=12cm in diameter. And the wire-plane arrangement is consisted with a copper wire anode of $\phi$=0.15cm in diameter with the length of 8cm and a copper plane of square 18×18$cm^2$. DC voltage Va was applied to the high field electrode. The observed corona current waveforms are shown in figure 2. Here, in the case of wire-plane gap, corona is indicated by linear current density (current per unit length of wire) and is observed by the divided plane electrode method.

Pulse laser is two kinds of YAG laser: Model: MiniLase II-10Hz (output: 5mJ, pulse width: 4〜6ns, beam diameter: 2.25mm), which is called small output laser, and Tempest 10T-10Hz (output: 50mJ, pulse width: 3〜5ns, beam diameter: 5mm), which is called large output laser. They are all in third harmonic wave length: 355nm. Laser light is focused

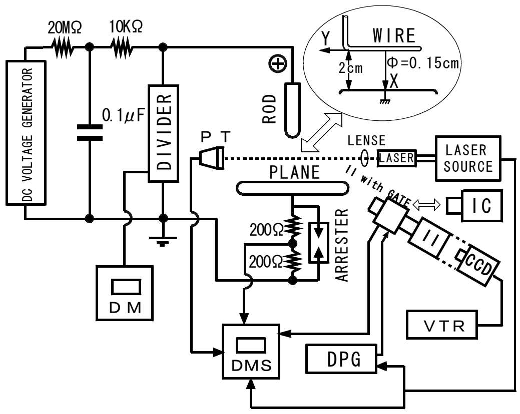



**Fig.1** Schematic diagram of experimental setup.

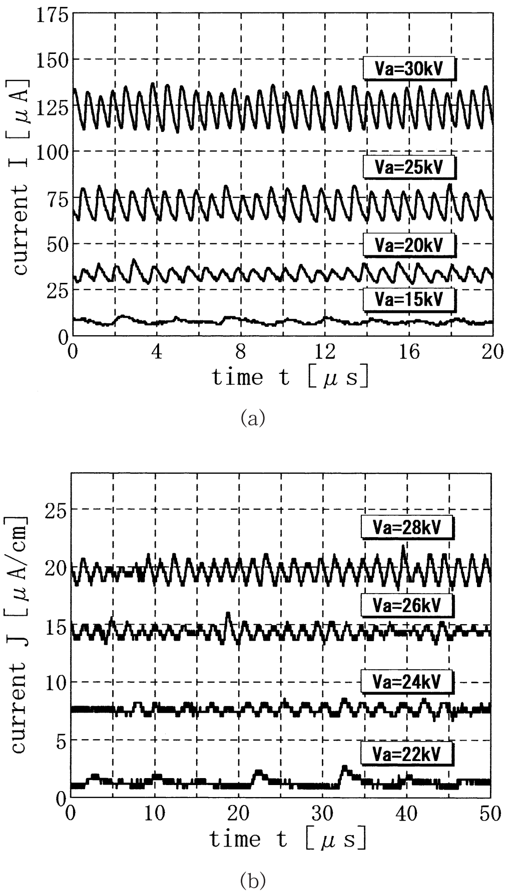



**Fig.2** (a) Current waveform of glow corona discharges for rod-plane gap ($\phi$=0.3cm, d=2cm) and (b) current waveform with the value of current per unit length of the wire for short wire-plane gap ($\phi$=0.15cm, d=2cm).

by a quartz convex lens which the focusing length is 8cm or 50cm, and irradiated to the ion drift space of DC glow corona discharge. The time from laser irradiation to the induction of streamer corona is defined by streamer time lag td (see in figure 3(a)).

The luminous of the induced streamer corona, was observed by two kinds of high-speed camera. The image intensifier (with gate circuit) CCD observation system is set in one frame mode (shutter mode). And the exposure time can be set above 100ns. The image converter camera (TRW, ID3S 20) is also mainly used in streak mode. The exposure time of discharge photograph is indicated by the time ts after streamer corona occurrence (ts=0).

## 3. Results and Discussion

### 3.1 Mechanism of Laser-Induced Streamer Corona for Rod-Plane Gaps

The discharge current (a) and luminous process in streak (b) and shutter mode (c) for the induced streamer are shown in figure 3. From figure 3(a), the inception of laser irradiation and streamer corona can be specified. From figures 3 (b) and (c), it can be seen that streamer corona is consisted by primary streamer ps, which develops to the cathode at a speed of about $3.3\times10^{7}$cm/s[13], and secondary streamer ss, which increases rapidly in its speed and luminous intensity when the primary streamer arrives to the cathode. With increasing in the applied voltage, secondary streamer extends gradually to the cathode, at last it reaches the cathode. When the secondary streamer reaches the cathode, the occurring probability of sparkover increases extremely. For laser-induced breakdown, these sparkover voltages are less than those without a pulse laser.

Under the condition of glow corona discharge, streamer corona from glow corona luminous area is induced from the electron burst produced by the laser irradiation, as shown in figure 4. From these observed results, it is confirmed that, under the condition of glow corona discharge, the streamer corona can be induced not only from the tip of rod electrode but also the column of rod. However, the electron burst drifts along the electric line of force, when it reach outer of glow corona luminous area, the streamer corona can not be induced by the laser irradiation. This reason can be explained that there exist larger instabilities in glow corona volume induced by the electron burst.

Figure 5 shows the luminous photograph of laser induced streamer corona under the condition of

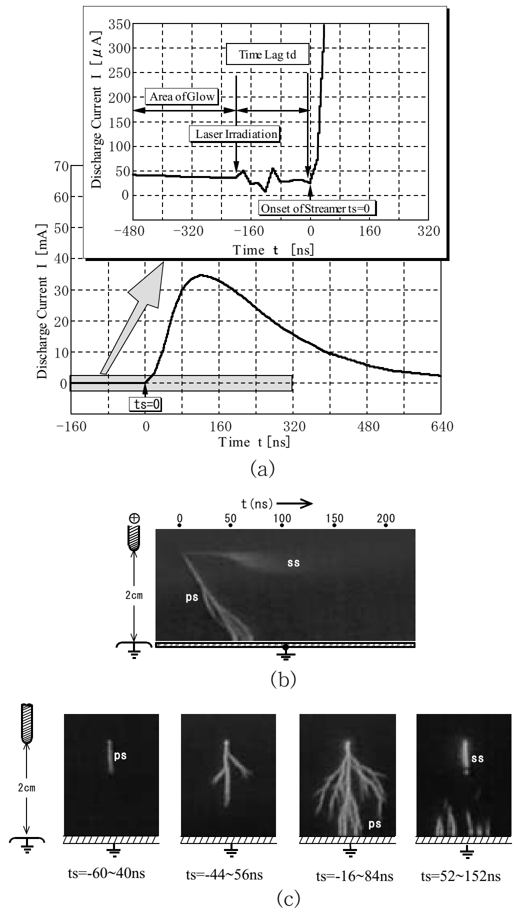



**Fig.3** The current waveform and the luminous process of streamer corona for a rod-plane gap, (a) discharge current, (b) streak photograph and (c) shutter photograph. ($\phi$=0.3cm, Va=20kV, irradiated point: Z=1.0cm, R=0.0cm)

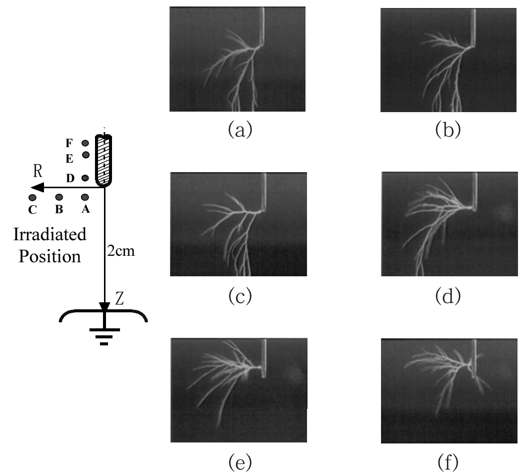
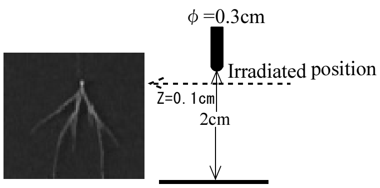



**Fig.4** Relationship between laser irradiating position and streamer trajectory, irradiated position: (a) Z=0.1cm, R=0.2cm, (b) Z=0.1cm, R=0.5cm, (c) Z=0.1cm, R=0.8cm, (d) Z=−0.1cm, R=0.2cm, (e) Z=−0.3cm, R=0.2cm, (f) Z=−0.4cm, R=0.2cm. ($\phi$=0.1cm, Va=17.5kV)

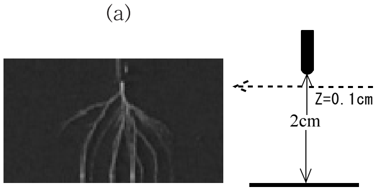
large output laser. For this discharge gap arrangement, the measured corona onset voltage Vc is 12.4kV. From figure 5 (a), under the irradiating condition of large output laser, it can be observed that the streamer corona can be induced below corona onset voltage. The reason is that the number of primary electron produced by laser photo-ionization increase. Furthermore, with the increment in applied voltage, it is found that the streamer corona can be induced over a wider space and guided partly along the laser beam (see in figure 5 (c)).

### 3.2 Mechanism of Laser-Induced Streamer Corona for Short Wire-Plane Gaps

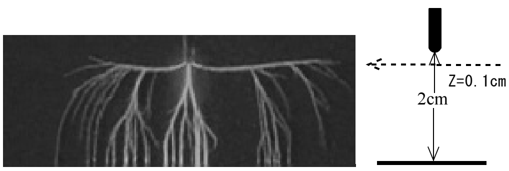
For short wire-plane gaps, under the condition of glow corona discharge at the applied voltage of Va=24kV, small output laser is irradiated crossly to the spot Z=0.5cm under the center of wire electrode for the gap length of d=2cm, the discharge current of the induced curtain-shape streamer corona is shown in figure 6 (a), and it's luminous photograph is shown in figure 6 (b).




(a)




(b)



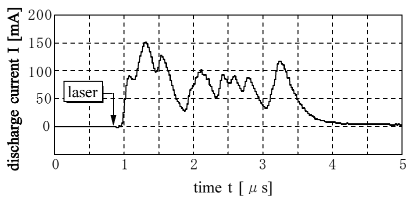

(c)

**Fig.5** Triggering and guiding effect of streamer corona induced by large output laser,
(a) Va=10.5kV<Vc, (b) VLf>Va=15kV>Vc and (c) VLf>Va=23kV>Vc.
(Corona onset voltage: Vc=12.4kV, 50% laser induced sparkover voltage: VLf=24.5kV)

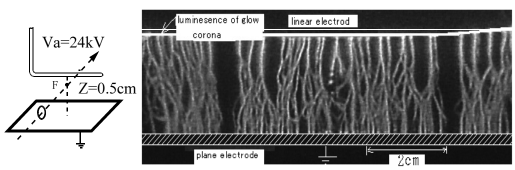
In order to investigate the luminous process of short wire-plane gap discharges, the small output laser irradiated in the parallel and vertical directions to the wire electrode as shown in figure 7, and the induced curtain-shape streamer corona was observed by a high speed camera in shutter mode. In figure 7 (a), when laser was irradiated from parallel direction, near the focus point F, because the electric power density was high of laser beam, many streamer coronas were induced simultaneously at the beginning. In figure 7 (b), when the laser was irradiated from vertical direction, at the focus point, as the electric power density in laser beam was high, then the only streamer corona was induced at the first, and with time passed by, the following streamer corona appeared turning to the two side of wire electrode. The reason is that, because of the occurrence of electron burst from photoionization of the induced streamer corona at the first and the distortion of it's neighboring space charge field, the following streamer corona was induced and the curtain-shape streamer was formed.

### 3.3 Characteristics of Laser-Induced Streamer Corona for Long Wire-Plane Gaps

The arrangements of long wire-plane gap are consisted with a copper wire anode of $\phi$ =0.1cm in diameter, length of wire electrode is about 100cm and a copper plane cathode of square $14\times100cm^2$.




(a)




(b)

**Fig.6** Curtain-shape streamer corona for a short-wire plane gap. (a) discharge current of curtain-shape streamer corona and (b) luminescence of glow corona and curtain-shape streamer.
($\phi$=0.15cm, d=2cm, Va=24.0kV)

The discharge gap length is set to d=5cm. The experimental condition of atmospheric air is also same in previous section.

For long wire-plane gaps, under the irradiation of the large output laser, figure 8 shows the luminous process of curtain-shape streamer corona taken by an high speed camera in shutter mode. Figure 8 (a) shows the picturing method. From figure 8 (b), we can see that, with the irradiation of laser, a large number of streamer were induced simultaneously. When those streamer corona reached near the cathode plane, because of the changing of space charge field, the following streamer corona were also induced from the wire anode and started to propagate in gap space. So the number of streamer increased and the long curtain-shape streamer were formed.

Figure 9 shows the luminescence of curtain-shape streamer corona under different applied voltages. From these photos, it is found that, with increasing of the applied voltage, both the number and the luminous strength of streamer corona increased gradually. Figure 10 shows the relationship between the number of laser induced streamer in centimeter LSCN and the applied voltage Va. From this figure, it can be seen that the

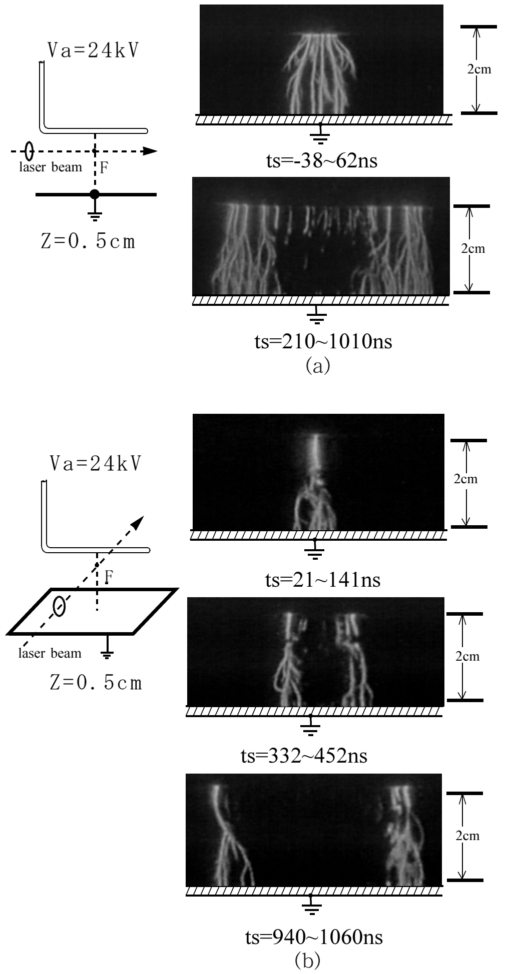



**Fig.7** Luminous process of short curtain-shape streamer corona, (a) laser beam in parallel direction and (b) laser beam in vertical direction.

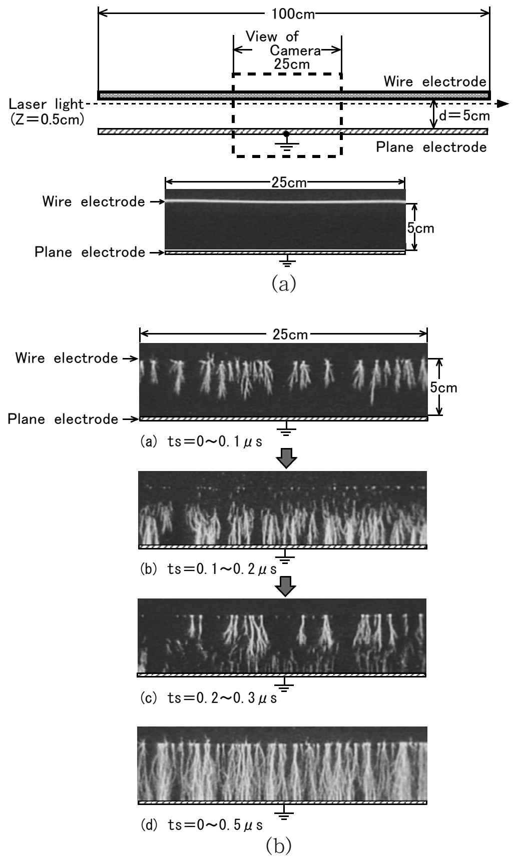



**Fig.8** Luminous process of long curtain-shape streamer corona for a long wire-plane gap. (a) The view of camera and luminescence of glow corona, and (b) Shutter photos of wide curtain-shape streamer corona.
($\phi$=0.1cm, d=5cm, Va=40kV, Vc=19.5kV)

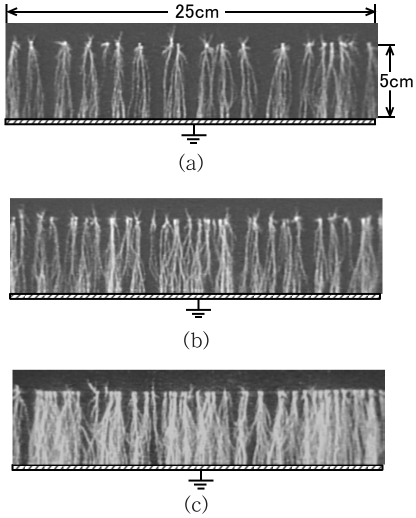



**Fig.9** Shutter photographs of long curtain-shape streamer corona.
(a) Va=32.0kV, ts=0〜2 $\mu$s, (b) Va=36.0kV, ts=0〜2 $\mu$s and (c) Va=40.0kV, ts=0〜3 $\mu$s.

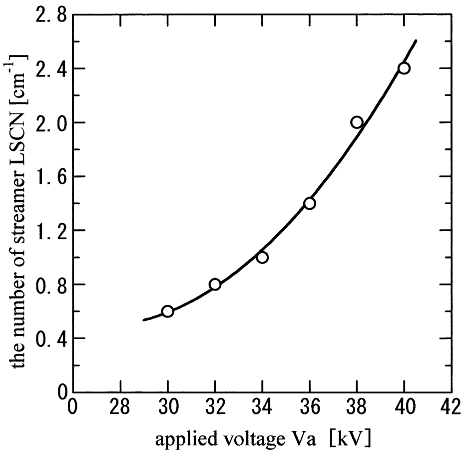



**Fig.10** The number of streamer per unit length as a function of applied voltage.
($\phi$=0.1cm, d=5cm)

number of streamer per unit length increases from 0.6 to 2.4 $cm^{-1}$ when the applied voltage varies from 30 to 40kV.

## 4. Conclusion

We have investigated streamer corona discharge phenomenon and discharge mechanism, which is induced by laser irradiation at positive polarity DC glow corona discharge in atmospheric air. And we have developed the laser induced method of long curtain-shape streamer corona for wire-plane gaps. Using this laser induced discharge characteristics instead of the pulsed power technology, it will be carried out in near future about the application of the chemical processing of plasma, such as the removal of NOx, SOx, $H_2S$, $CO_2$, etc. from exhaust gas.

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