INFLUENCE OF GAP LENGTH ON DISCHARGE CHANNEL PROPAGATION AND BREAKDOWN MECHANISM IN AIR

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Abstract: In order to clarify the discharge propagation mechanism, ultra-high speed electrical and optical measurement was performed in a needle (ϕ1 mm) -plane electrode system with gap length g=15 mm and 100 mm in 0.1 MPa dry air under applying a positive impulse voltage. Discharge current and optical images from initiation to breakdown (BD) were synchronously measured. In gap length g=15 mm, we found that the secondary streamer propagated and reached the grounded plane electrode, and the secondary streamer channel made the high-conductive channel, resulted in BD. In the case of g=100 mm, because the secondary streamer could not reach the grounded plane electrode due to the long gap, the high-conductive path was not made by the secondary streamer. However, BD occurred by a leader-like discharge propagated from the needle electrode. From these results, we found that secondary streamer propagation dominates the formation process of the discharge channel and the mechanism leading to BD.

1 INTRODUCTION

Atmospheric air is used for insulation media of many high-voltage power apparatus. Nowadays, they become more compact with larger capacity. Then, the operating electric field strength becomes higher. To achieve their high reliability, clarification of discharge initiation and propagation characteristics in non-uniform electric field is required.

In the gap discharge in air, a secondary streamer initiates after the primary streamer have reached the plane electrode [1, 2]. If the secondary streamer bridges the gap, breakdown (BD) occurs after a few microseconds [3, 4]. This BD mechanism needs bridging between electrodes by the secondary streamer, and it should be strongly affected by the gap length.

From this background, we aim to clarify the mechanism of discharge from initiation to BD in non-uniform air gap and to quantify influential factors.

2 EXPERIMENTAL SETUP

Figure 1 shows the experimental setup. We set a needle-plane electrode (gap length g = 15, 100 mm) in a tank filled with dry air (0.1 MPa). Electrodes are made by stainless steel, and tip diameter and length of the needle electrode are 1 mm and 20 mm, respectively. We apply positive lightning impulse voltage (1.2/50 μs) and generate the discharge in air gap.

We measure the discharge current waveform through a measuring resistor (50 Ω) and the light intensity waveform using a photomultiplier tube [5]. We observe fast-framing images of the discharge using digital cameras with image intensifiers by controlling their exposure time in nanosecond successively. At the same time, using a streak camera, we obtain ultra high-speed streak images to measure the transition of discharge, which is initiated and propagated in nanoseconds.

We can measure the discharge current and light intensity waveforms, fast-framing images and streak image synchronously in 10-50 ns by a pulse generator.

3 RESULTS AND DISCUSSION

3.1 Initiation of primary and secondary streamer

Figure 2 shows the primary and secondary streamer discharges, not leading to BD, under positive lightning impulse voltage V_a=28 kV in air gap (g=15 mm). Figure 2(b) shows the streak image of discharge propagation from the needle electrode to the plane electrode. Focusing on the discharge current and light intensity waveforms shown in Figure 2(a), there are two peaks; the second peak appeared around 20 ns after the first peak. Together with the luminescence in Figure 2(b) corresponding to the discharge current and light intensity waveforms in Figure 2(a), it is considered that they correspond to the primary and the secondary streamer, respectively [6]. When the primary streamer reaches the grounded plane electrode, discharge current rises rapidly.

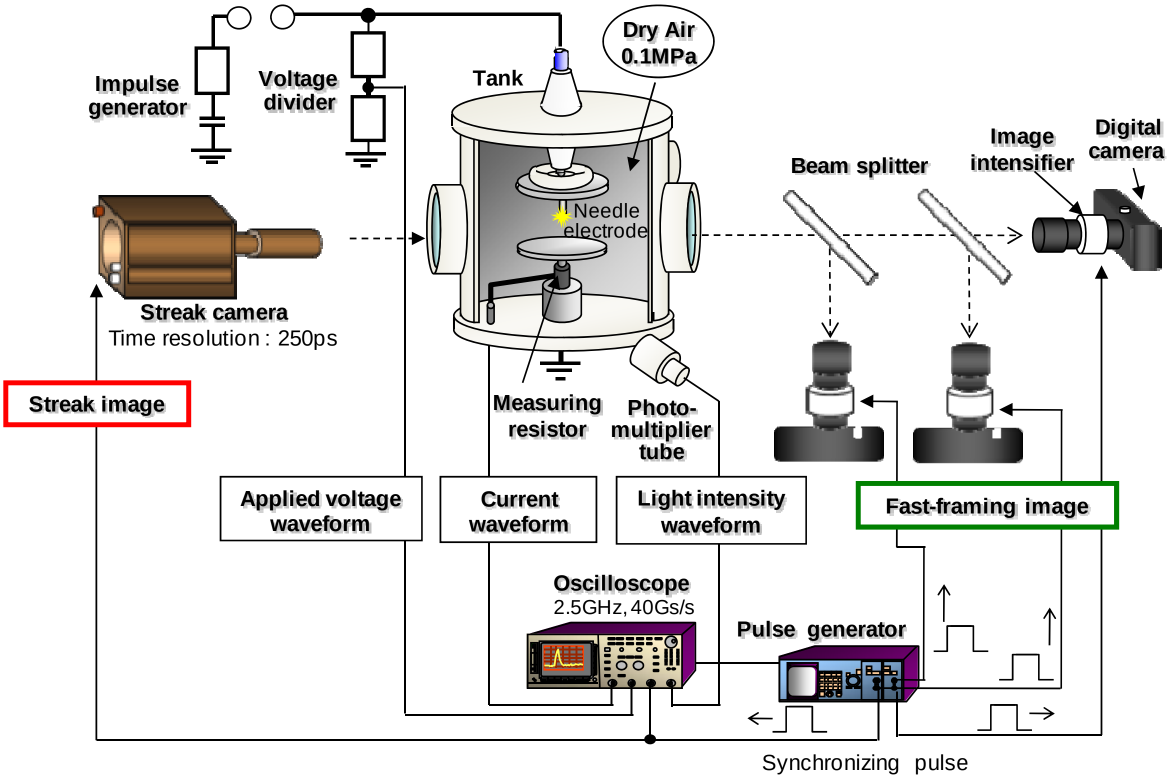


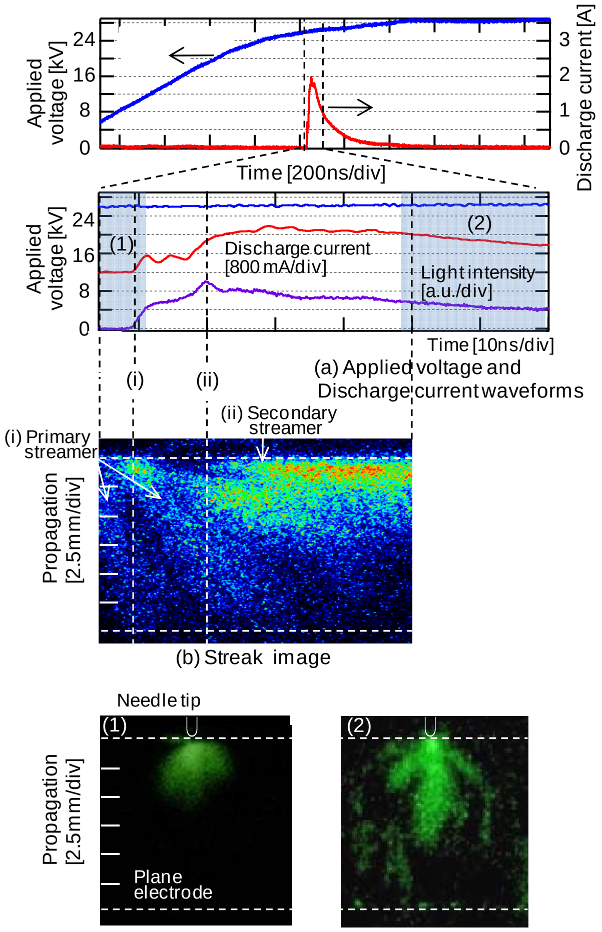
Figure 1: Experimental setup

This implies that the electron is injected from the grounded plane electrode into the channel formed by the primary streamer. Then electrical potential in the channel is re-distributed and electric field at the needle tip is re-stressed. Therefore, a secondary streamer is initiated from the needle electrode.

3.2 Breakdown mechanism (g=15 mm, at BD voltage)

Figure 3 shows the discharge progress leading to BD with applied voltage, discharge current and fast-framing images at g = 15 mm under the application of BD voltage (29 kV). After the secondary streamer current reached a peak, it decreased rapidly to almost zero. But after 800 ns, discharge current rose again and breakdown occurred. The optical gate signals of cameras were adjusted to take the framing images of discharge for each 100 ns during its propagation.

In this case, after several secondary streamers arrive at the plane electrode, the conducting paths are formed as shown in Figure 3(b) (1) and (2). Then, the shortest conductive channel brightens more, because the conductivity of this channel is raised by the temperature rise of the plasma channel due to Joule heating. In other words, when the current flows in the shortest conducting path, the discharge current concentrates to the higher conductive channel. Other channels disappear because the current does not flow and the energy maintaining the channel is not supplied. After that,

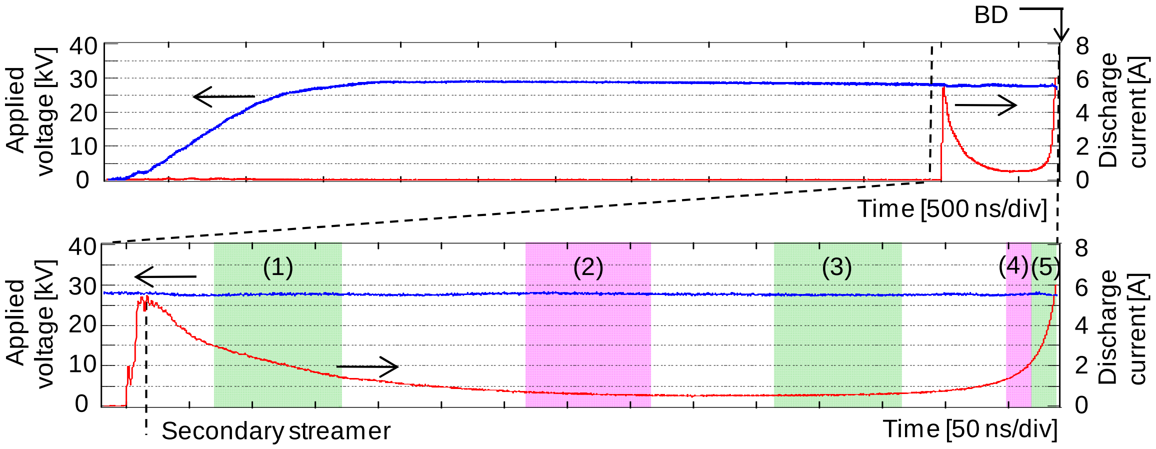


(a) Applied voltage and Discharge current waveforms

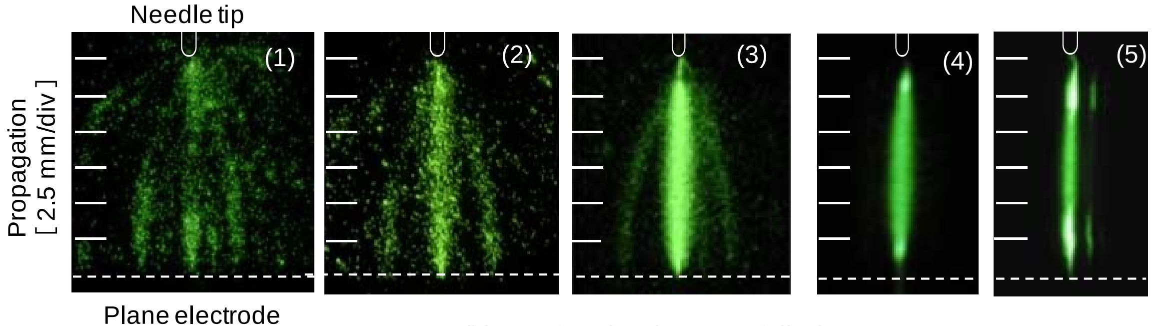
(b) Streak image

(c) Fast-framing images

Figure 2: Discharge waveforms and images (V_a = 28 kV, g = 15 mm)



(a) Applied voltage and Discharge current waveforms



(b) Fast-framing images of discharge

Figure 3: Discharge current waveform and fast-framing images leading to BD (V_a = 29 kV, g = 15 mm)

BD initiates from the both directions of the needle and the grounded plane electrode as shown in Figure 3(b) (4) and (5). This means that the current concentrates on the hot spot on the needle and grounded plane electrodes when the channel is heated, and the high conductive region appears of both electrodes just before BD.

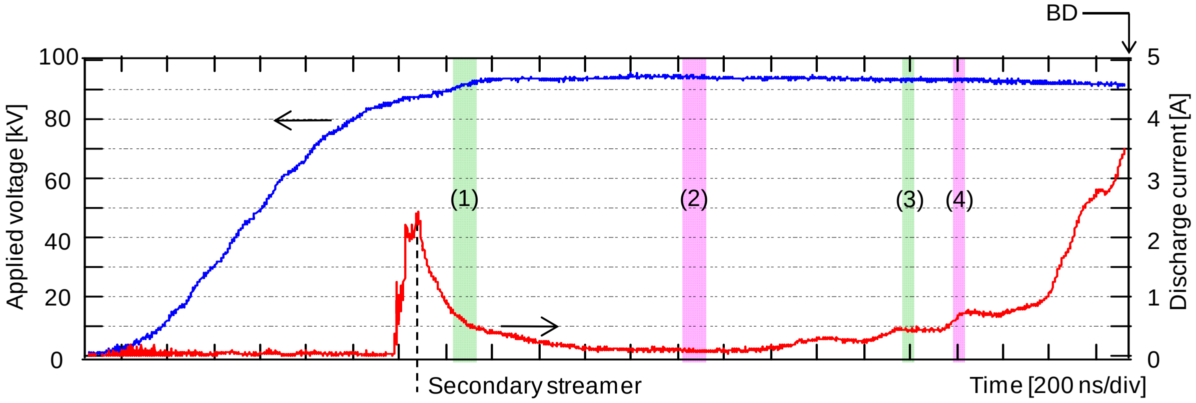
3.3 Breakdown mechanism (g=100 mm, at BD voltage)

Figure 4 shows an example of the discharge leading to BD at g = 100 mm under the application of BD voltage (94 kV). From Figure 4(a), after the secondary streamer propagates, the discharge current decreases. But after 1.5 μs the discharge current rise again and BD occurs similar to the case of g=15 mm. Nevertheless, when the discharge current rises again before BD, it increases step by step.

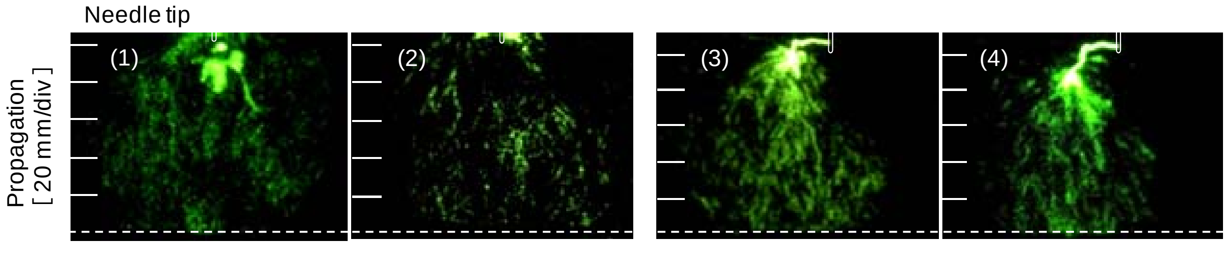
The intense light emission propagated from the needle electrode in Figure 4(b) (1) is the secondary streamer and it does not reach the grounded plane electrode due to the long gap length. Therefore, high-conductive channel is not formed as shown in Figure 4(b) (2), however the leader channel propagation occurs from needle electrode as Figure 4(b) (3) and (4). Then leader channel is initiated not from needle-tip, but from needle-side. It results from the effects of space charge made by secondary streamer, which did not reach grounded plane electrode [7, 8].

BD occurs when the leader discharge reached the grounded plane electrode and the high conductive channel is formed in the gap. Several streamers arise from the leader head and they bridge the gap. One of them is selected and turns to the leader channel. The discharge current rises with repeating the step-like increase, but the discharge current does not become 0 A after it rises again. It is thought that the leader channel bridges the both electrodes constantly. Because the conductivity of this streamer is low, light emission from the streamer region is weaker than that of the leader channel.

As a result, we consider that the mechanism of BD is changed like Figure 5. Figure 5 shows the ratio of the secondary streamer propagation length to the gap length at BD voltage, and the type of BD mechanism. BD occurs with the conductivity rise of the secondary streamer channel at less than g=30 mm. The leader propagation leads to BD at g=30 mm and above. This implies that the behaviour of the secondary streamer is the key of BD mechanism.

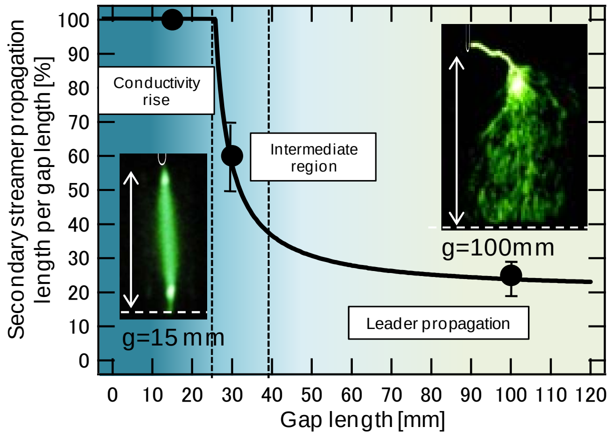


(a) Applied voltage and Discharge current waveforms



(b) Fast-framing image of discharge

Figure 4: Discharge current waveform and fast-framing images leading to BD (V_a=94 kV, g = 100 mm)



Needle : ϕ1 mm, ℓ=20 mm

Figure 5: Summarised the discharge propagation mechanism led from measurement results, on a influence of gap length

4 CONCLUSION

We measured current waveforms, light intensity waveforms, fast-framing images, and streak image in impulse breakdown in dry air. We focused on the mechanisms of the discharge propagation process. As a result, we clarified the followings;

(1) In the case of shorter gap length, electrical conducting path with the largest conductivity is selected after secondary streamer has reached the plane electrode. It is heated by Joule heating and the conductivity of the channel rises and BD occurs. It is the key of this process that the secondary streamer reaches the grounded plane electrode due to the shorter gap length.

(2) In the case of larger gap length, because secondary streamer cannot reach the plane electrode, secondary streamer does not form high-conductive channel. However, if the voltage level is high, BD occurs by leader propagation.

(3) The gap length influences the behaviors of secondary streamer, and the behaviors of secondary streamer dominate the mechanism of BD.

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