

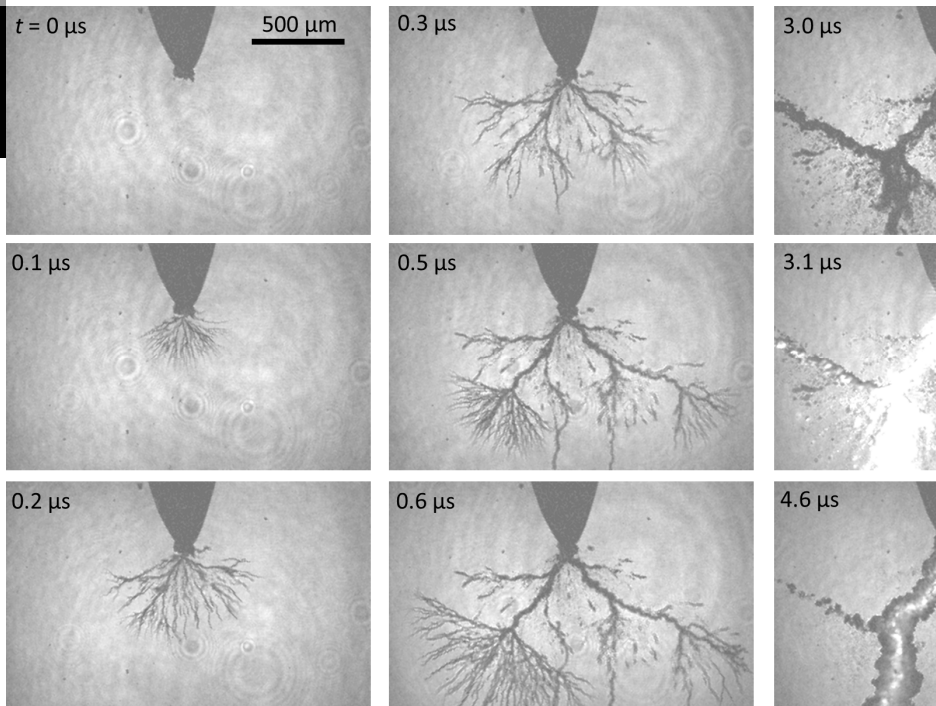
Application Note

No. 46

Electrics and Electronics

Continuous Visualization of Process of Positive Streamer Initiation, Propagation, Spark, and Bubble Expansion in Water

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Electric and Electronic Industry

1. Introduction

Electrical discharge in liquids is a phenomenon which is seen in dielectric breakdown of insulating oils used in transformers and liquids for electric discharge machining, and has been investigated in many studies. Electrical discharge in water has attracted attention in recent years, and application to the environmental and medical fields is progressing, for example, in water purification and surgical operations. How the discharge propagates in the liquid is fundamental to these applications, but in spite of the fact that a bubble theory and an electrical theory (direct ionization theory) of breakdown have been proposed, the process of discharge propagation still has not been elucidated. As one reason for this, experimental clarification is difficult because the pre-breakdown phenomenon of spark discharge called streamers occurs at high speed in a microscopic region. However, with recent progress in recording technology, clarification of these phenomena is continuing.⁽¹⁾⁻⁽⁵⁾

It is known that two types of underwater positive streamers generally occur, i.e., primary streamers and secondary streamers. In low conductivity water, primary streamers take a semi-spherical brush-shaped form and propagate at a speed of approximately 2 km/s, after which filament-like channels with a dendritic shape propagate.⁽¹⁾ Secondary streamers initially propagate at 20-30 km/s as dendritic filamentary channels, but then propagate at the same speed of about 2 km/s as primary streamers.

The difference between primary and secondary streamers can be distinguished because a direct current-like component appears in the discharge current during high speed propagation.⁽²⁾ When a streamer propagates to the counter electrode, the bubble channel joins the two electrodes and the process proceeds to spark discharge. It is also known that streamers occur in an electrical field of a certain minimum strength. As the mechanism responsible for forming a high electrical field, it has been found that a bubble cluster forms at the electrode tip before streamer inception, and a protrusion occurs on surface of the bubble cluster due to the accumulation of charge in the bubbles and concentration of the field.^{(3),(5)} However, continuous recording of the series of changes in the bubble propagation process before streamer inception was difficult, as it is necessary to record a large number of images continuously under conditions of a high frame rate, high sensitivity, and short exposure time. The HPV-X2 high speed video camera used here enables high speed recording at a maximum 10 million frames/second (10 Mfps) and also has a high sensitivity sensor.

This Application Note introduces the results of continuous recording of the process from the formation of the bubble cluster at the electrode tip to initiation of an underwater positive primary streamer, the condition of primary streamer propagation resulting in spark discharge, and the process of expansion of the bubbles.

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2. Recording Method

Fig.1 shows a schematic diagram of the experimental setup. As the visualization method, recording was performed with a microscope lens mounted on the HPV-X2 high speed video camera using a laser backlight. For discharge, ultrapure water was introduced into a quartz cell with dimensions of $10 \times 10 \times 45$ mm, a needle electrode and a wire-shaped earth electrode were

immersed at an inter-electrode gap distance of 2 mm, and discharge was initiated by applying a high voltage of +14 kV to the needle electrode. The recording speed of the high speed video camera was 10 Mfps, the exposure time was 50 ns, and 256 continuous images were recorded. Fig. 2 shows the HPV-X2 high speed video camera used in the experiment.

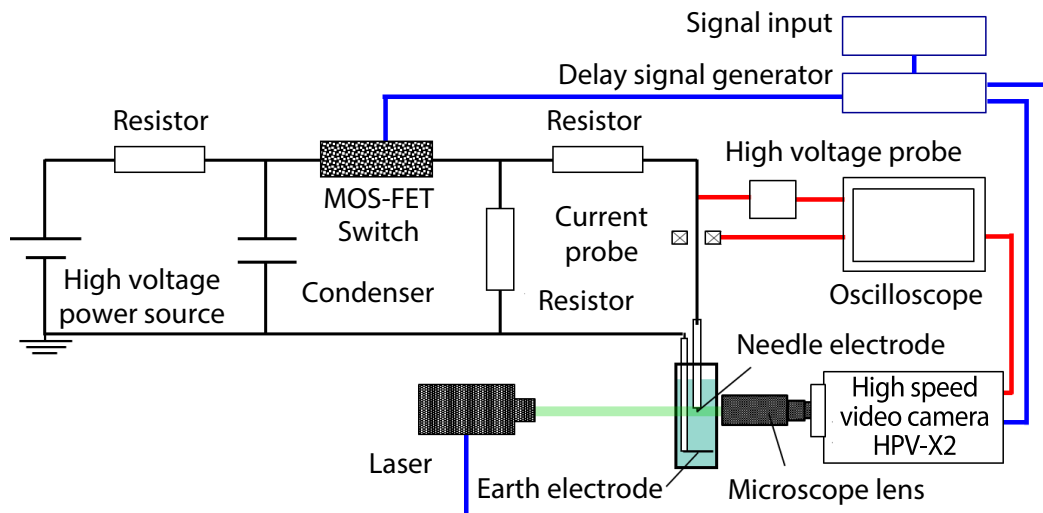


Fig. 1 Schematic Diagram of Experimental Setup



Fig. 2 Appearance of HPV-X2 High Speed Video Camera

3. Recording Results

Fig. 3 shows continuous images of the process from formation of the bubble cluster at the electrode tip to initiation of the underwater positive primary streamer. The time interval between the images is 100 ns, and the horizontal width of the images is 690 μm . Initially, as shown by the arrows, small bubbles form on the electrode surface, and after 100 ns, those bubbles have grown to about 10 μm . Next, with bubble growth, multiple bubbles begin to form and grow from different locations on the electrode surface. After about 1 μs , contact occurs between the bubbles that have grown at different points on the electrode surface, a bubble cluster is formed, and growth continues.

After about 2 μs , further local bubble growth from the unified bubble cluster begins. Approximately 0.5 μs later, the tip of this local bubble changes to a protruding shape, and a streamer initiates from the tip of the protruding bubble. After the streamer propagates in a semi-spherical shape, the streamer channel expands due to heat. In the conventional method, it was necessary to record sequential images of multiple discharges while shifting the recording time of each discharge. On the contrary, successful visualization of the continuous changes during one discharge process was possible, as shown in this series of images.

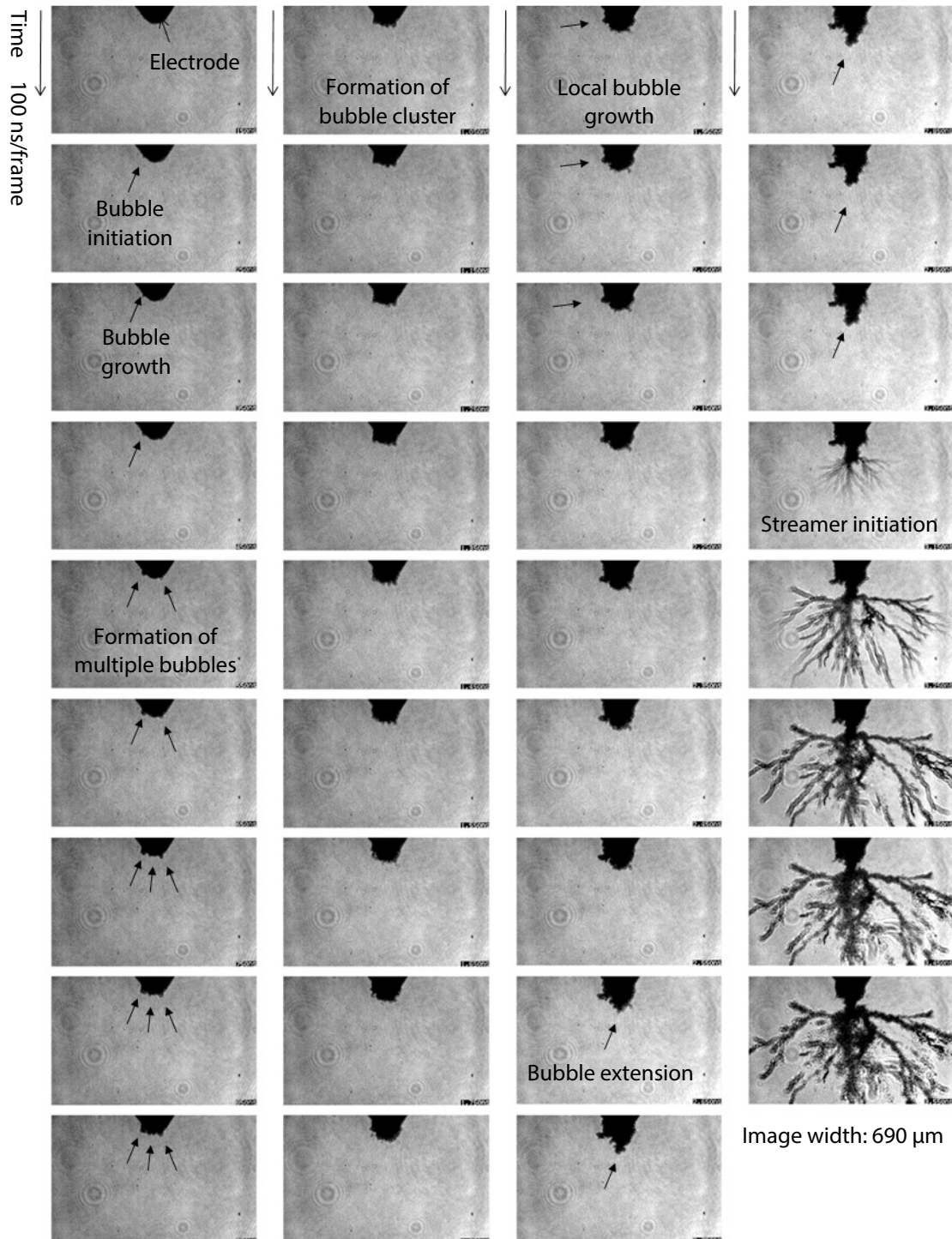


Fig. 3 Continuous Images from Formation of Bubble Cluster at Electrode Tip to Initiation of Primary Streamer

Fig. 4 shows continuous images of the process until the underwater positive primary streamer propagates and reaches spark discharge and the subsequent condition of bubble expansion. The horizontal image width is 3.08 mm, and the time is indicated in the figure. Inception of the primary streamer occurs at 3.2 μs . Propagation stops once and then resumes at 6.9 μs , and the streamer reaches the earth electrode at 7.8 μs . Spark discharge occurs simultaneously in the two streamer channels at 7.9 μs .

The light emission by the spark discharge of the finer streamer channel disappears at 8.0 μs , but the emission from the thicker streamer channel continues until 9.4 μs . Thereafter, the thicker streamer channel begins to expand due to the heat of the spark discharge, and at 25 μs , the channel diameter is approximately 3 times larger than its original size.

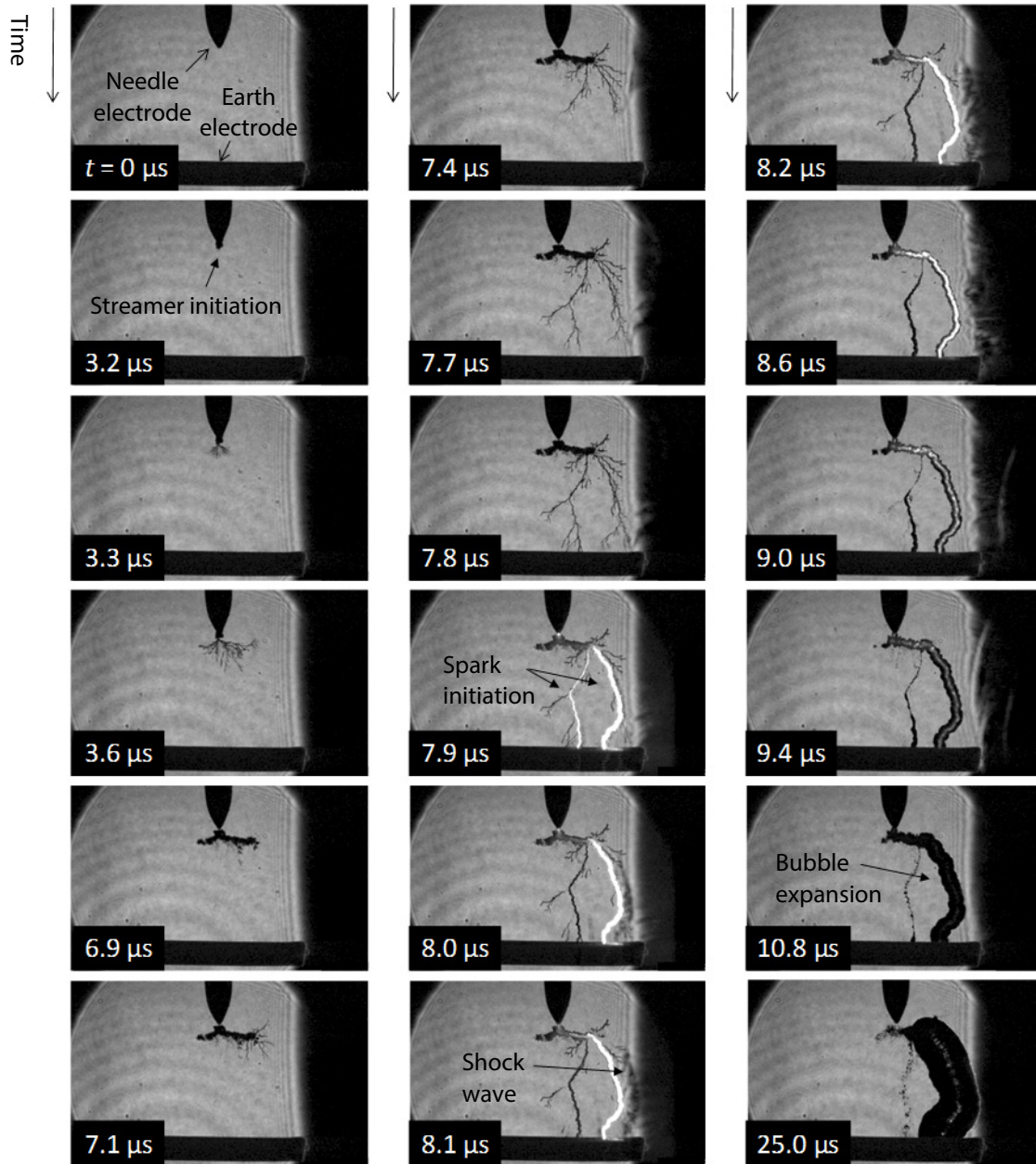


Fig. 4 Continuous Images of Transition Process from Propagation of Underwater Positive Streamer to Spark Discharge and Process of Bubble Expansion

4. Conclusion

The initiation and propagation of a positive streamer in water, the transition to spark discharge, and the condition of bubble expansion were recorded continuously during a single discharge. Conventionally, this phenomenon was recorded by shifting the recording time in each of multiple discharges. The continuous images visualized here solve the problem of differences in the condition of the streamers recorded during multiple discharges. Because discharge is an extremely rapid phenomenon, visualization is sometimes difficult, even at the frame speed of 10 Mfps. However, at 10 Mfps, it was possible to adequately clarify the changes in phenomena such as the formation of the bubble cluster and expansion of the bubble channel, which are fluid phenomena. Because a photomultiplier was not used in the recording device, it was possible to record spark discharge and other phenomena which are accompanied by sudden changes in brightness.

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