

TEMPORAL EMISSION BEHAVIOR OF PULSED DISCHARGE IN WATER

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Abstract

To move high energy pulsed power systems from the laboratory to practice requires the development of compact lightweight drivers. To reduce the size and weight of high voltage components, increase in the energy density in dielectrics at high electric stress is required. Therefore, an in-depth understanding of the hold-off voltage and breakdown properties of liquid dielectrics can lead to the optimization of energy storage.

When breakdown is initiated in liquid dielectrics, vapor bubbles are generated, which first expand and later collapse. The total time of expansion and collapse of these bubbles determines the repetition rate at which high voltage switches can be operated.

In this paper, a Blumlein pulse forming network (PFN) and sphere-plane electrode configuration is used for studying a pulsed discharge in water. The diameter of the spherical electrode is 1.7mm and the gap distance between the electrodes is several hundred micrometers. The temporal development of the optical emission in the UV and visible after breakdown was measured by means of an imaging spectrograph. The radiation intensity reaches its maximum 5ns after breakdown. It remains at this level for about 100ns, and then the light intensity decreases to 30% of its peak value on a 10ns time scale. The current was found to be 800A during the pulse. The radiation spectrum of the plasma in the bubble during the 100ns after breakdown was also measured. No line radiation was observed. The measured spectrum was found to follow a blackbody radiation law. Therefore by comparing the measured spectrum with that of calculated blackbody radiation at different temperatures, the plasma temperature was determined. It was found to be in the 1-2 eV range.

I. INTRODUCTION

In recent years, pulsed discharge in water (PDW) has been used in various applications such as an underwater sound source^[1-4], sterilization^[5-9], and switching^[10]. When high voltage is applied on electrodes to produce corona, streamer or spark discharge, light emission occurs. The emitted radiation can be detected and used as a non-intrusive technique to diagnose the plasma. Beroual et

al^[11] studied the light emission during prebreakdown stage, i.e. streamer corona discharge stage. It was found that for negative streamer, light is constituted of bursts, but for positive streamer, light emission consists of a unique pulse, much more regular than that of negative streamer. Bing et al^[12] studied light emission of several millimeter spark discharge in distilled water. A capacitor was used for energy storage, and a point-plane electrode arrangement was used to produce a discharge. The breakdown time was found to be several hundred nanoseconds, and the light pulse lasted for about 2 μ s. In this paper, we use Blumlein PFN as energy storage. A sphere-plane electrode arrangement is used. The distance d between electrodes can be accurately varied up to several hundred micrometers.

In order to investigate the physical characteristics of the plasma in the bubble after breakdown, the plasma emission spectrum is recorded by high-speed CCD camera and spectrometer. The measured results are compared with simulated blackbody emission.

The detail of the experimental arrangement is described in the next section; this is followed by a presentation of the measurement of the temporal behavior of the emitted radiation and the measurements of the plasma temperature.

II. EXPERIMENTAL SETUP

The discharge is generated between a sphere-plate electrode configuration. The spherical electrode has a diameter of 1.7 mm. It is placed in front of a stainless steel disc (diameter: 2 cm) which serves as the plate electrode. The gap distance between the electrodes can be varied up to several hundred micrometers. The electrode assembly is mounted inside a stainless steel chamber, which is filled with pure water (Resistivity 18 M Ω -cm). Two windows in the chamber provide optical access to the discharge. The spherical electrode is connected to ground via a low inductance current viewing resistor of 0.0625 Ohm. The plate electrode is connected to a Blumlein type pulse generator with an impedance of 100 Ohm. The pulse generator provides a voltage pulse of 40 kV and 200 ns duration. The pulse generator is matched by a 100 Ohm resistor. The voltage is measured by means of a high voltage probe (Tektronix P6015A). The current

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is monitored by means of the current viewing resistor. Voltage and current are recorded utilizing a digital oscilloscope (Tektronix TDS 784D). The optical spectrum was recorded by means of a 0.5 meter spectrograph (Acton Research SpectraPro 500i). A photomultiplier tube (Hamamatsu R928) served as detector. For high speed measurements, a CCD camera (Stanford Computer Optics, Inc. Model 4 Picos) with a temporal resolution of 200 ps was used. A schematic of the setup is shown in Fig. 1.

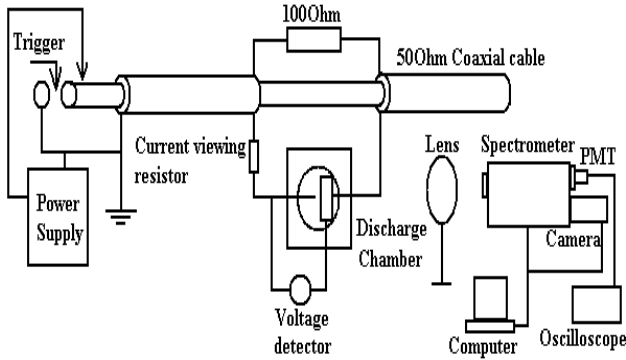


Figure 1. Experimental Set-up

III. EXPERIMENTAL RESULTS

A. Temporal Emission Behavior

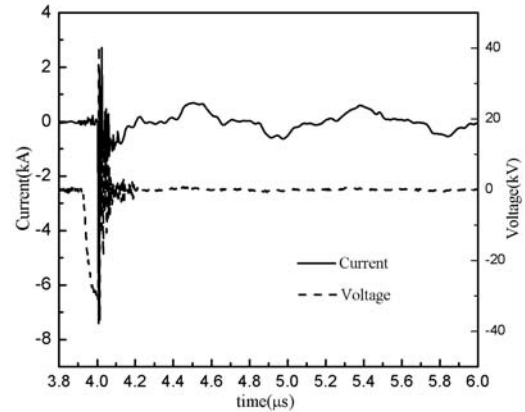
After pulse application, the voltage at the plate electrode increases on a 100 ns time scale. After it reaches a threshold level V_{th} , breakdown occurs, and after a short transient period the voltage settles to a very small value, V_s . The characteristic time for the voltage drop from V_{th} to V_s can be defined as the switching time (ST). The switching time is an important parameter of the device when it is used as a high power electrical switch. In order to study the switching time, voltage, current, and optical emission of the discharge are recorded.

Figure 2(a) shows the typical breakdown voltage and current waveforms. The voltage decay time from V_{th} to zero and the current rise time from zero to a maximum (I_{max}) were found to be 4 ns. This is consistent with results obtained by Fuhr et al.^[13]. During the first hundred nanoseconds after breakdown, the voltage oscillates, and the current oscillates with a DC part ($I_{DC} = 800A$). During the subsequent 100 ns, the current decays to zero and the voltage also decreases to zero. The oscillation of the current is due to inaccurate impedance matching.

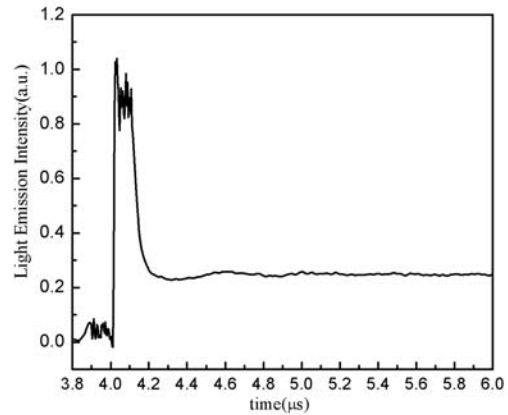
The ST was measured by observing the temporally resolved light emission. The spectrograph was tuned to 486 nm as a representative for the relative light intensity emitted by the plasma. The photomultiplier signal was recorded by means of a wide band oscilloscope. The

relative light intensity emitted during breakdown is shown in Fig. 2b.

The evaluation of the PMT signal shows a rise time (the light intensity from zero to its maximum value) of 4.8 ns. The light intensity remains at its maximum for about 100 ns and it decays on a 100 ns time scale to 30 % of its maximum value. The temporal characteristic of the relative light intensity and the current are similar, indicating that the optical emission can be used in order to determine the breakdown time.



(a)



(b)

Figure 2. Typical (a) current, voltage and (b) light emission intensity waveforms after breakdown for a charging voltage of 35kV and electrodes distance of 450 μ m.

B. Plasma Temperature Measurement

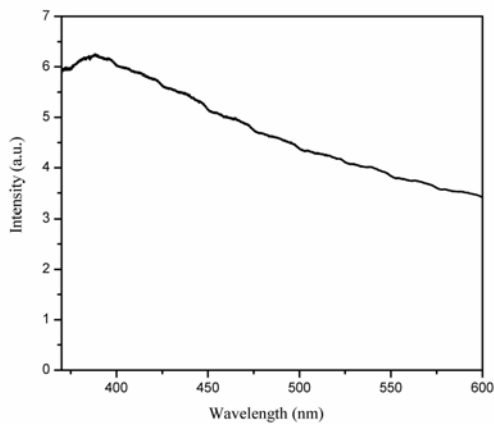
The gas temperature in the water discharge was measured by comparing the emission spectrum with a simulated blackbody radiation distribution. The temperature in the simulation was varied for best fit. This experiment was performed using the spectrograph with

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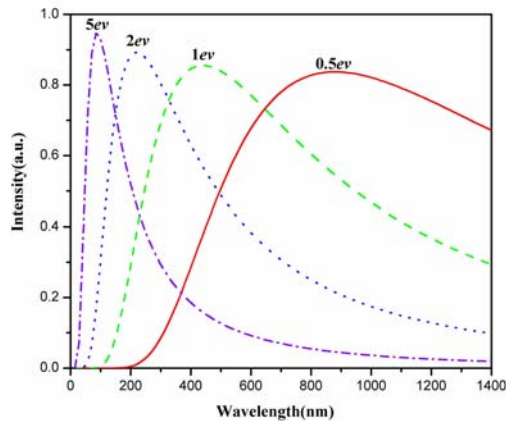
the high speed CCD camera. The camera was triggered with the voltage pulse. The exposure time was set to 80 ns.

Figure 3(a) shows the recorded emission spectrum. No line radiation was observed. Instead a continuous light intensity distribution with a maximum at 380 nm was found. In Fig. 3, the blackbody radiation for temperatures between 0.5 eV and 5 eV are plotted. Comparison with the calculated radiation distribution provides a plasma temperature corresponding to an energy between 1 eV and 2 eV.

It is interesting to point out that even at an increased resolution of 80pm, no line radiation could be observed.



(a)



(b)

Fig. 3. (a) Measured plasma emission spectrum and (b) blackbody emission for different temperature

III. DISCUSSION AND CONCLUSION

Spark gaps in a gas atmosphere are known to serve as high voltage switches with a typical rise time of 1 ns. With increasing voltages, the geometrical dimensions of

the switch become big. Filling the gap between the electrodes with a dielectric increases the breakdown voltage and leads to a more compact design of the switch.

In these experiments, water has been used as dielectric between the electrodes. A gap distance of 450 μm could stand a voltage of approximately 30 kV, before a breakdown occurred. A typical switching time of 4 ns was found by electrical measurements.

The temporal development of the optical emission intensity also shows a typical rise time of 4 ns, representing the switching time. While the switch is closed, the light intensity is constant at its maximum value. Monitoring the temporally resolved radiation emission is a good method to remotely determine the switching characteristic.

The spectral intensity distribution shows a continuum only. This means that the plasma is optically thick. Spectral emission lines could not be observed. This in turn provides the opportunity, to obtain the temperature in the discharge by comparing the continuum radiation with calculated black body radiation distributions. The temperature in the discharge provides an indication of energy transfer, and it can also provide a relative pressure. The pressure or pressure change in the discharge is an important parameter in applications such as when the device is used as a wide band acoustic wave source.

IV. ACKNOWLEDGMENT

Work supported by an AFOSR/DOD MURI grant on Compact Portable Pulsed Power, administered through the University of New Mexico. The authors would like to thank Dr. Frank Leipold for helpful suggestions.

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