Optical and Electrical Characterisation of Plasmas in Water Vapour Layers

M.L. Karim, K.R. Stalder and W.G. Graham

Queen's University Belfast, School of Mathematics & Physics, Northern Ireland, BT7 1NN, UK

In this study, optical and electrical diagnostic methods are used to characterise the plasmas produced in vapour layers on an electrode surface in a conductive solution. A cathodic discharge, created with a 300 V and 5ms long pulse and with 1 Hz repetition rate, was used in this investigation. The experiment employed shadowgraphic, photometric and electrical characterisation methods to understand the structure of vapour layers and the subsequent ignition of plasmas. The optoelectrical measurement indicated that the plasmas of different character are formed in each individual pulse. The created plasmas vary with time and can be characterised as early (up to 100μs), middle (up to 2000 μs) and later (up to 1000 μs) stages of plasmas based on the event of photometric emission. The early stage of plasmas is identical with each individual pulse. The probability of formation of plasmas in the middle and later stages is higher than early stage of plasmas.

1. Introduction

Electrical discharges in contact with liquid have been extensively investigated during the last few decades for their potential applications in chemical, environmental and biomedical applications e.g. polymer surface modifications, gold nanoparticles synthesis, sterilization of microorganisms [1-4]. The most challenging issue in understanding plasmas in contact with liquid is their stability and reproducibility. There are a number of investigations of both pulse and continuous mode high voltage discharges of in contact with non-conductive liquids were reported [5, 6]. In our case, we are investigating low voltage discharges at lower operating frequencies and in a conductive liquid. These plasmas are formed inside a vapour layer, a highly non-equilibrium state, which expand and dissipate as bubbles. In most cases, the surface of the liquid at the vapour boundary behaves as an electrode, which can be readily deformed [7, 8].

This particular type of discharge in conductive liquids can generate physical, chemical and biological phenomena, such as strong electric fields, streamer propagation, UV radiation, shock waves, active radicals and cell membrane damage. An understanding of the underlying physics and chemistry behind these phenomena is required for the applications of plasmas in liquids are to be fully developed [8-10]. In our previous studies, we have investigated, through both experiment and computer modelling, aspects of the vapour layer formation, temporal changes in the current and power draw of the plasma itself, as well as the optical intensity of the plasma via PMT measurements [8-9]. Here by using multiple simultaneous measurements we will present measurements of the correlation of the electrical and spectral properties of the plasma with the plasma dynamics.

2. Experimental Apparatus

Figure 1 is a schematic diagram of the experimental apparatus. A point-to-plate type electrode configuration is used. All but the last 0.5mm of a 0.5mm diameter cylindrical tungsten wire protrudes beyond a surrounding glass capillary tube with a conical tip to form the powered electrode. A 24 cm^2, and 0.5 cm thick, titanium plate acts as the grounded electrode. The electrode spacing is 4.5 cm. This assembly is immersed in 0.6 L of a solution of 0.9 % NaCl dissolved in distilled water held in a 10.4 x 10.4 x 10 cm rectangular quartz vessel. The aqueous solution has a measured, initial electrolytic conductivity of 14.3mS/cm and a pH of 8.30.

The powered electrode is connected to a pulsed voltage supply consisting of a fast, negative voltage switch (Behlke HTS 31-06) with 22.4 kΩ ballast resistors on the input and output terminals and a dielectric capacitor with a capacitance of 1000μF. This can supply a negative DC voltage of up to 300V with a 20 ns rise time and fall time as determined by the RC constant of the electric circuit. The trigger signal feed to the switch control pulse and repetition rate were generated using a DG535 delay generator. Voltage pulse lengths of up to 5 ms duration were used with a repetition rate of 1 Hz. The applied voltage is measured, immediately after the output ballast resistor, using a LeCroy PP002 350 MHz voltage probe. The current waveform is obtained using a coaxial Pearson current monitor coil 2878.

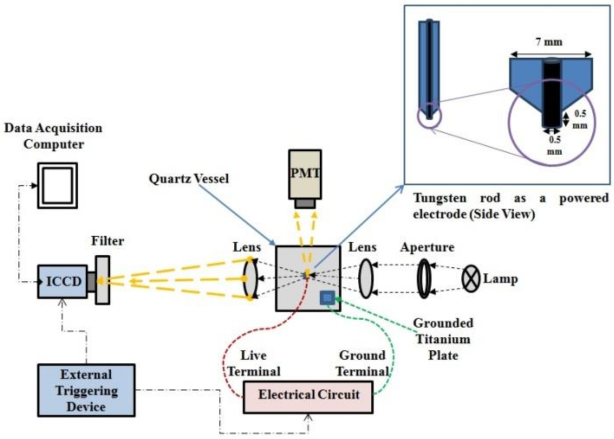

Figure 1: A schematic diagram of the experimental apparatus (Top view).

Time-resolved images of the vapour layer development and expansion were obtained by using a shadow graph technique. The electrode tip region is backlit a parallel, white light beam from a 10 W halogen lamp viewed by an Andor iStar DH 334T-18U-03 ICCD camera. The temporal behaviour of the total light emission from the plasma was determined by the photomultiplier tube (PMT) synchronised with the current and voltage measurement.

3. Experimental Results

Unless otherwise stated, the results presented here were obtained during the application of a 5 ms, -300V voltage pulse to the powered electrode with the solution at a temperature of about 295 K.

A typical time dependence of an electrical response i.e. current and voltage along with photometric emission are shown in figure 2. As reported by Schaper et al [9], under these conditions, the first approximately 300μs the electrical behaviour of the system is essentially reproducible. In this initial phase shadow graphs showed that a layer of water vapour developed around the powered electrode can be found in figure 4(a). The current waveform showed the sequence of high current drawn with associated voltage decreases. The observed voltage drops when current was drawn by either vapour layer formation or partial regrowth or the discharge being ignited by the limit on the available instantaneous power input.

It is only after this time i.e. 300μs that light emission is observed as is shown from the PMT signal in figure 3 and 4(b). The time dependence of the current in figure 2 reflects the sequence of high current draw and this correlates well with the PMT signal i.e. light emission events, given that the light may be shielded from the PMT by the electrode.

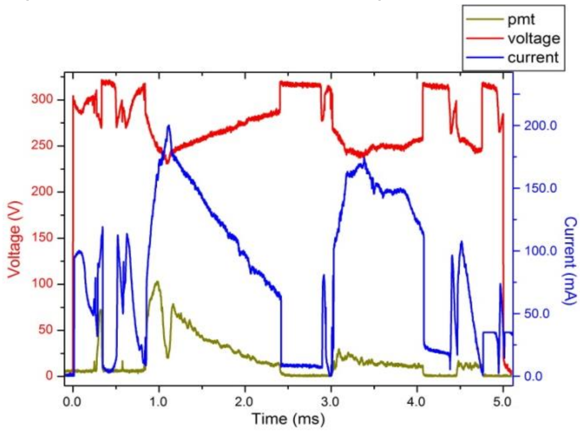

Figure 2: A typical time dependence of the measured current, voltage and PMT output (The plots are shown in a positive scale).

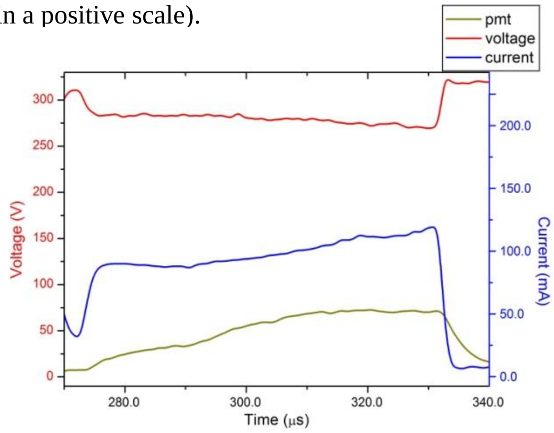

Figure 3: A time dependence of the measured current, voltage and PMT output in an early stage (The plots are shown in a positive scale).

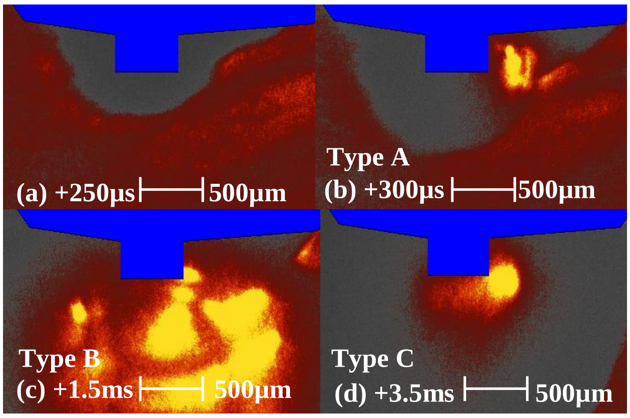

Figure 4: (a) Time dependence shadowgraph of vapour evolution in the electrode tip region; (b)-(c) time dependence ICCD images of typical discharges at 300μs, 1.5ms and 3.5ms respectively.

4. Characterisation of plasmas

The plasmas were characterised using the electrical and optical responses of the system. The plasmas were produced in a 5ms long pulse could be categorised in three distinct physical phenomena i.e. type A, type B and type C. The type A, plasmas are formed in the early stage of pulse and the typical photometric emission is up to 100µs (figure 3). These types of plasmas are also found in a single event of PMT lines. The typical current drawn with voltage and PMT in a single event is shown in figure 5. The type B and C are formed in the middle and later stages of the pulse. The type B, plasmas are the most sustainable and intense. The typical photo emission duration is up to 2ms. The multiple photo emission are found in this occasion and can be characterised as multiple event or a longer event. The typical current drawn with voltage and PMT in multiple event is shown in figure 6.

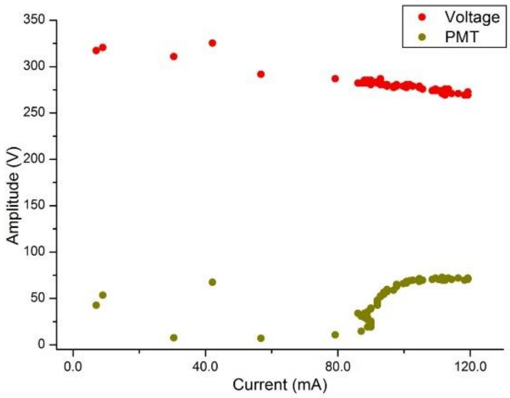

Figure 5: A typical electrical response of a single event for type A plasmas.

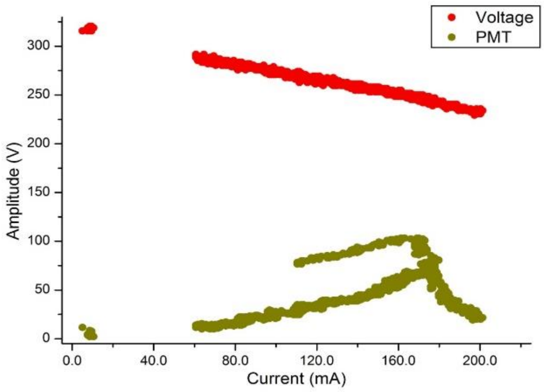

Figure 6: A typical electrical response of multiple event for type B and C plasmas.

The type B and C are the most reproducible plasmas are found in this investigation. The below table summarised the probability of reproducibility of the plasmas produced in vapour layers.

Type	No. Of Short taken	Discharge found	Probability
A	100	15	15%
B	100	83	83%
C	100	35	35%

Table 1: The probability of formation of plasmas in a single and multiple events.

5. Conclusion

In this study, Electrical discharges in the vapour phase are investigated. The structure of plasmas are characterised using the optoelectrical measurement. A 5ms long voltage pulse was investigated in various stages based on the photometric emission. The physical phenomena of early stage plasmas were not varied by pulse to pulse. The probability of formation of discharges at the stage is least among the other stages of the pulse. The dimension of plasma plumes is various by each individual pulse due to inhomogeneous development of vapour layers.

6. References

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