Time-resolved Imaging of Plasmas in a Pulsed Capillary Discharge

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Abstract

Dynamics of the plasma that is formed inside a pulsed capillary discharge is studied by using time-resolved imaging technique. A four frame gated micro-channel plate that is switched at different times by a gating pulse generator are used for time resolved imaging. A CCD camera is employed to capture the time-resolved images of the plasma. Current signal is measured while the images are captured. A set of images are captured at the peak of the current and the images exhibit the heating phase of the plasma while the other set that are captured when the magnitude of the current is minimum represents the cooling phase of the plasma.

1. Introduction

Pulsed capillary discharge is a device that is used to perform fast electrical discharge through a capillary tube that is placed between the electrodes. It is one of the devices that uses gas discharge produced plasma process (GDP) for EUV generation [1]. In order to understand the behaviour of the plasma that is formed inside the capillary tube, various studies have been reported [2,3].

The evolution of the plasma can be investigated by using time-resolved imaging technique. As reported in [2], the plasma that was formed in the capillary tube was compressed and heated followed by expansion and cooling down. However, the image of the evolution of the plasma in the capillary showed no evident of compression as reported in [3]. This is due to the skin thickness which is about the same size as the inner diameter of the capillary [3].

A pulsed capillary discharge is investigated in this laboratory and time-resolved imaging is performed in order to understand the behaviour of the plasma that is formed in the capillary tube. A four frame gated micro-channel plate is used to capture the time-resolved images of the plasma. A CCD camera is employed to record the images. Images of the plasma at different phases of the plasma dynamics are obtained.

2. Experimental Setup

Six capacitors each rated 30 kV, 3.5 nF are connected in parallel to give a total capacitance of 21 nF are used. The discharge voltage used is 21 kV. A SCR triggering unit is used to initiate the discharge. The system is evacuated to10^{-5} mbar by using a turbomolecular pump backed up by a rotary pump. The quartz capillary tube has an inner diameter of 1 mm and a length of 10 mm. The discharge current is measured by using a magnetic probe. The gated micro-channel plate (MCP) and a CCD camera are used to obtain the time resolved images of the plasma. Emission of the plasma is projected by the four pinholes onto the MCP as shown in Figure 2. The MCP is divided into four quadrants and each quadrant is switched by an external high voltage pulse which is generated by a gating pulse generator. Each cable that connects from the gating pulse generator to each quadrant of the MCP has different length. The length of the cable determine the time for each quadrant to be switched on. The images are recorded by a CCD camera. An oscilloscope is employed to register the signals of the current and MCP.

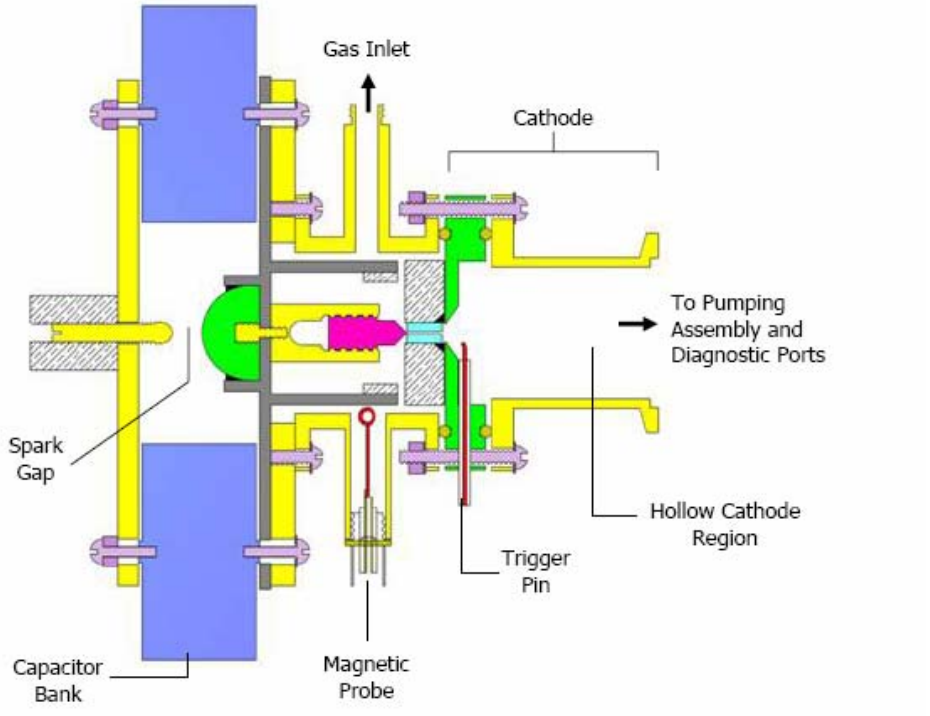


Figure 1. Schematic of the pulsed capillary discharge.

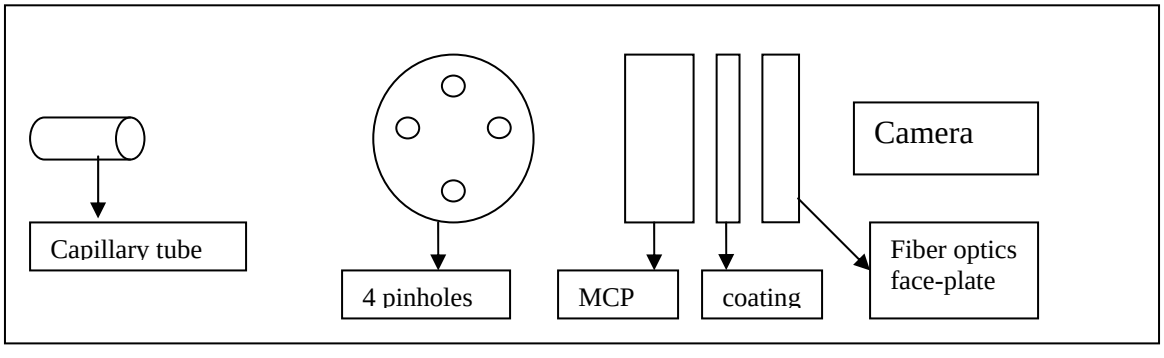
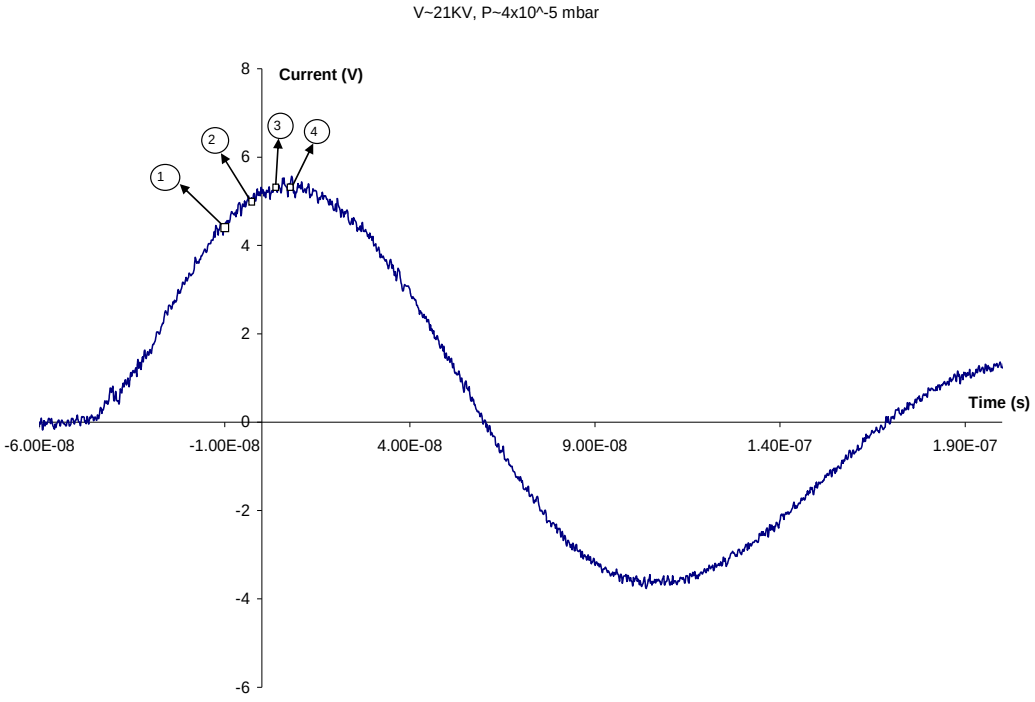


Figure 2: Schematic representation of the experimental setup.

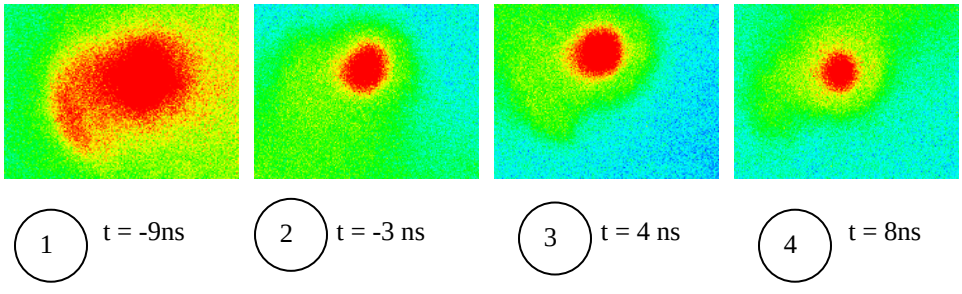
3. Results and Discussion

The set of images shown in Figure 3 are taken around the peak of the discharge current. A hot and bright plasma column is formed and this indicates that the plasma column has been heated up to high temperature due to the high current. The plasma column is observed to be compressed slightly and remains in this compressed state for at least 11 ns as observed in the time-resolved images in Figure 3. The emission is mostly from the core of the plasma column. The peak current is 13 kA.

In contrast, Figure 4 shows the result obtained during the time when the discharge current has dropped to almost zero. Emission from the plasma is very dim. This indicates the cooling phase of the plasma.

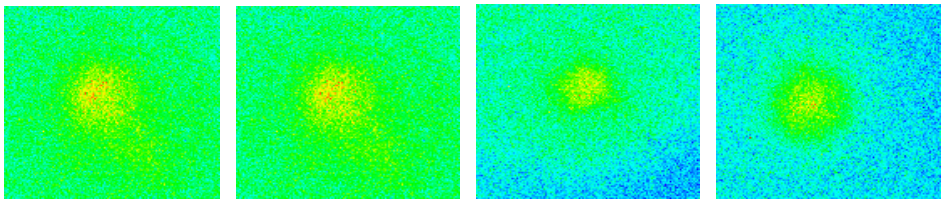


(a)



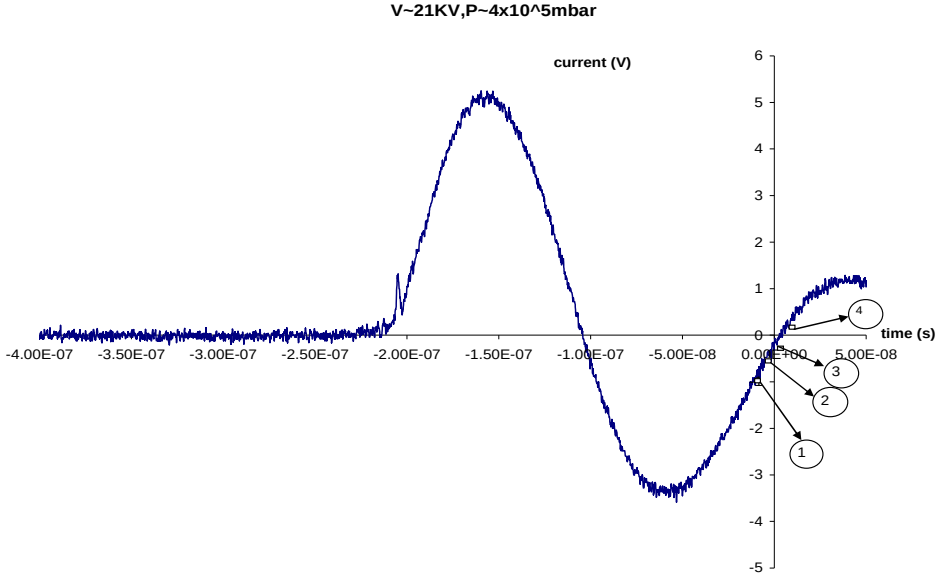
(b)

Figure 3. (a) Current waveform with four different time marks. (b) Four images that are taken at that four different times that are correspond to the four different time marks.



1 t = -9 ns 2 t = -3 ns 3 t = 4ns 4 t = 8ns

(a)



(b)

Figure 4. (a) Four images that are taken at four different times that are correspond to the different time marks. (b) Current waveform with four different time marks**.**

Conclusions

The time-resolved images of the plasma formed by passing a pulsed current through a quartz capillary tube with an inner diameter of 1 mm and a length of 10 mm are obtained using a 4-frames MCP coupled to 4 pinholes. The images formed are captured using a CCD camera. It is noticed that the plasma column is slightly compressed and is heated up by joule heating effect when the magnitude of the discharge current is maximum. The plasma is in the cooling phase when the magnitude of the discharge current is at the minimum. The technique developed in this project will be used to study the dynamics of plasma emission from pulsed plasma sources such as the argon pulsed capillary discharge and the vacuum spark.

Acknowledgements

This project is supported by the FRGS Grant Scheme provided by the Ministry of Higher Education of the Malaysian Government(FP073/2006A) and the Research University Grant of University of Malaya (FS041/2007A).

References

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