

Time-resolved Imaging of Pulsed Capillary Discharge.

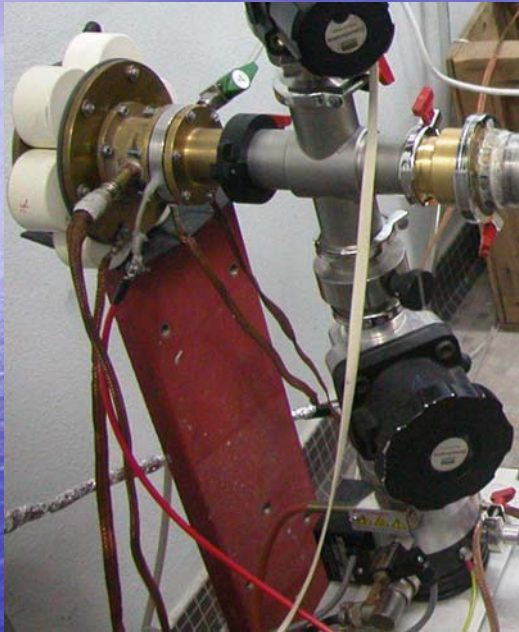
L.S.Chan, S.L. Yap, C.S. Wong

Plasma Research Laboratory, Physics Department, University of
Malaya

INTRODUCTION

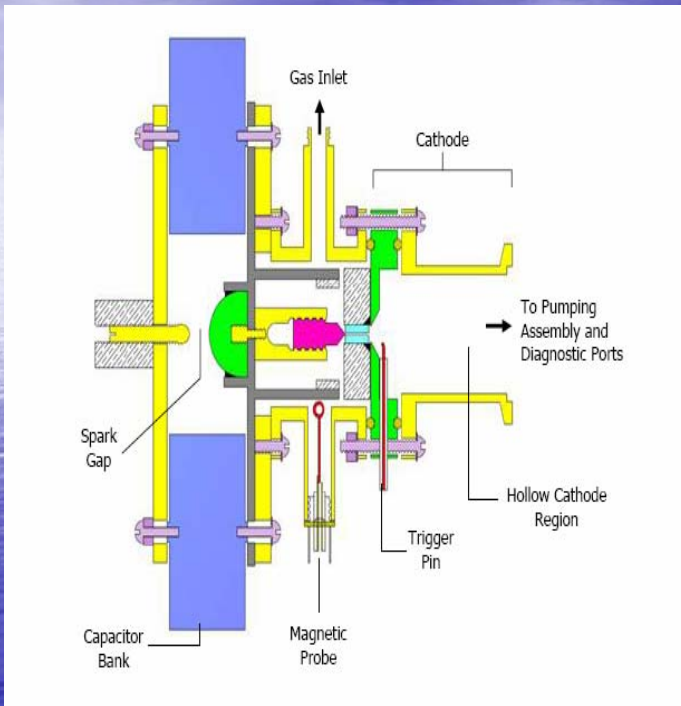
- Pulsed capillary discharge is a device that is used to perform fast electrical discharge and it occurs in a capillary tube that is placed in between the electrodes.
- Besides that, it is also a cost-effective device that is used to produce hot and highly ionized plasma.
- In order to understand the behaviour of the plasma that is formed inside the capillary tube, time-resolved imaging technique is used to study the evolution of the plasma.
- A four frame gated micro-channel plate to capture the time-resolved images of the plasma.
- A CCD camera is employed to record the images.
- Images of the plasma that are in different phases are obtained.

Pulsed Capillary Discharge System

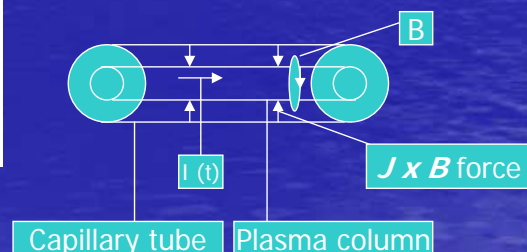


- 6 capacitors with a total capacitance of 21.6 nF.
- Turbomolecular pump backed up by a rotary pump.
- A quartz capillary tube, $d=1$ mm and $l=10$ mm.

Schematic diagram of the pulsed capillary discharge and operation procedure

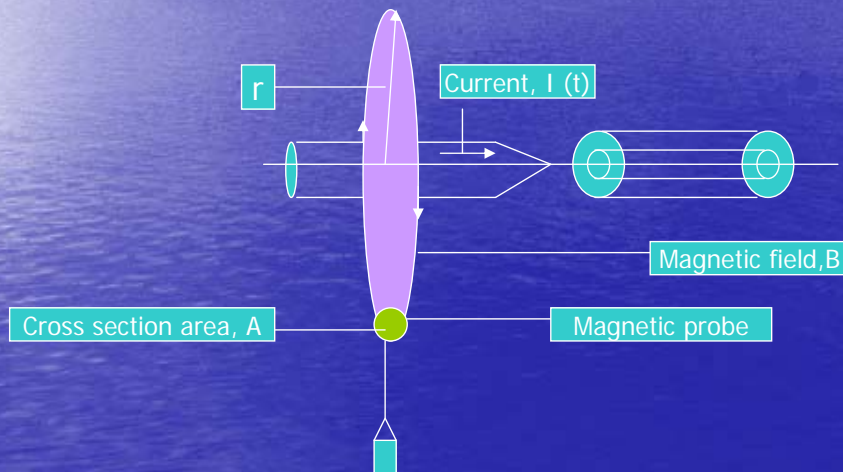


- Evacuated to 10^{-5} mbar.
- Charged up to around 21 KV.
- A SCR triggering unit is used to initiate the discharge.
- Breakdown occurs and plasma is formed in the capillary.



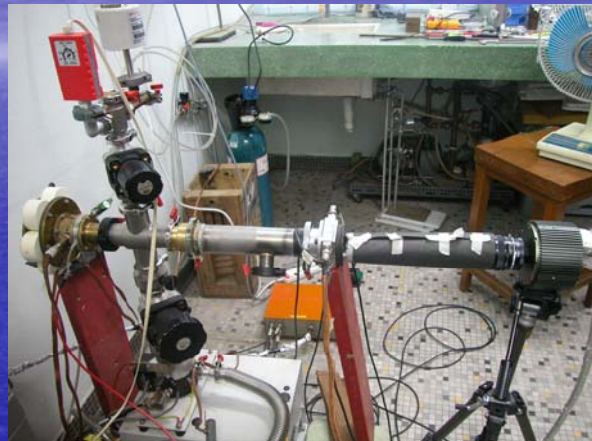
Diagnostic Techniques

- The discharge current $I(t)$ is measured by using a magnetic probe.



Imaging System

- External Triggering unit
- Delay Unit
- Pulse Gating Generator
- GMPI-4Q four-frame gated micro-channel plate
- CCD camera

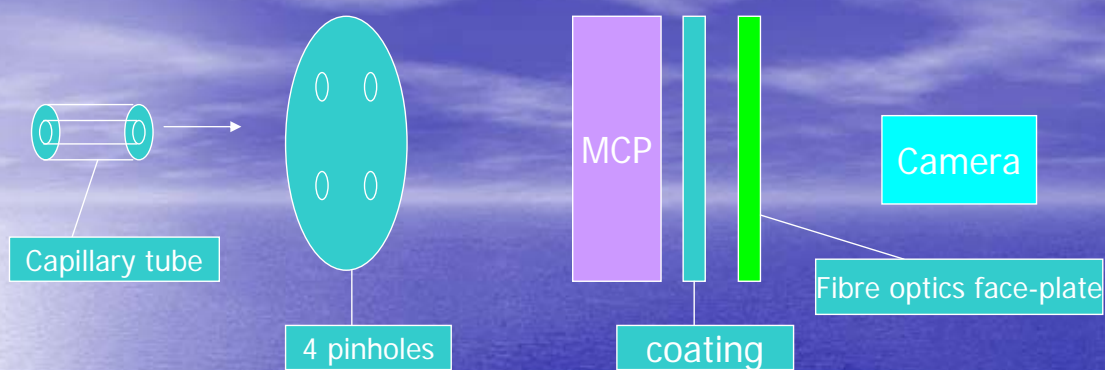


Four-frame gated micro-channel plate

- Divide into 4 quadrants



- Each quadrant is connected to one output from the gating pulse generator.

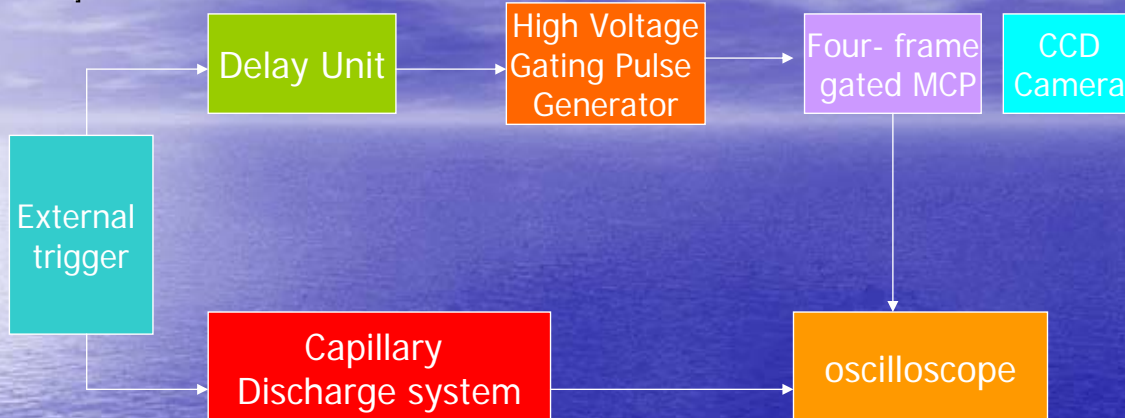


When emission from the plasma or photon strike the input surface of the micro-channel plate (MCP), electron is emitted.

MCP consists of several millions independent channel and each channel function as an independent electron multiplier when a voltage is applied across the MCP.

The electrons that are emitted from the MCP will bombard on the coating and convert into photons and imaged onto the fibre optics face-plate.

Block Diagram of the Imaging System and Operation Procedure

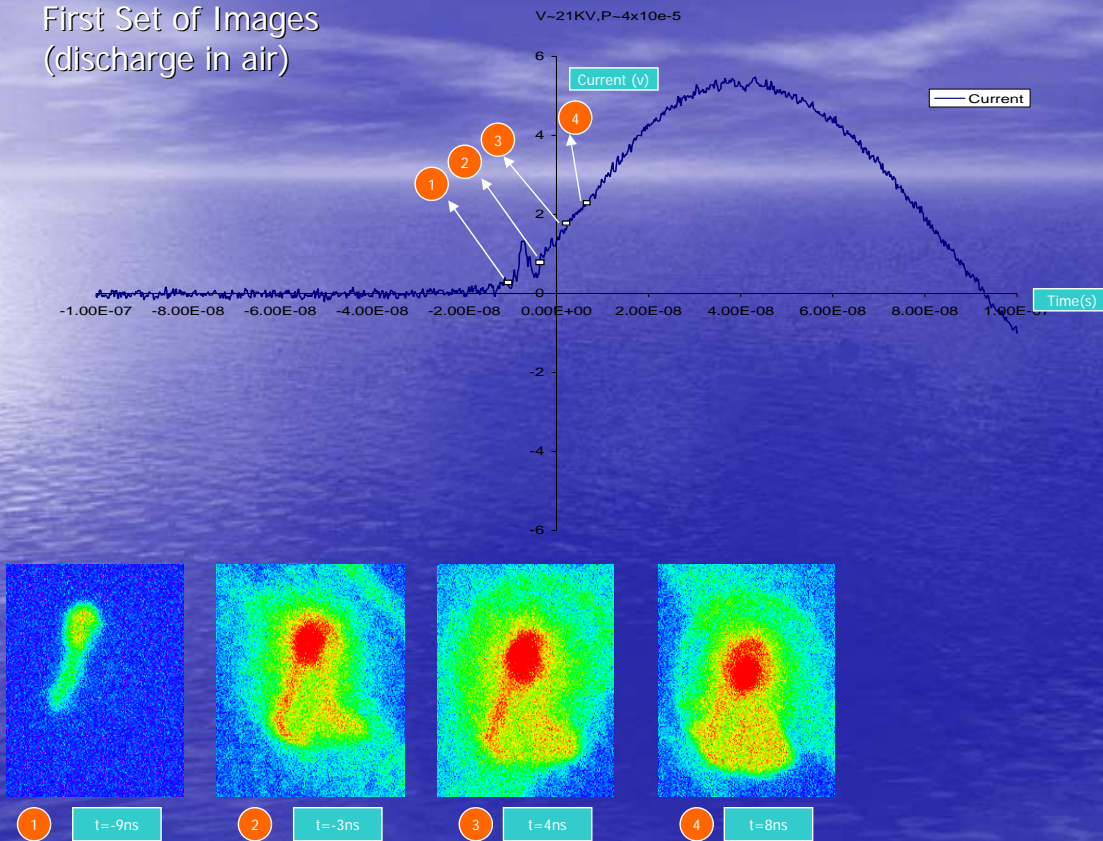


- External trigger-trigger the discharge and imaging system simultaneously.
- When the triggering button is pressed, the discharge is initiated. On the other hand, the delay unit is triggered and a pulse is generated. This pulse can be delayed and the delay time is adjustable so that current signal is able to coincide with the MCP signal.
- When the pulse from the delay unit triggered the high voltage gating pulse generator, a high voltage pulse is produced.
- This high voltage will switch on and off each quadrant of the four-frame gated MCP separately. Thus, the four-frame gated MCP functions as a 4 independent detectors.

- Each quadrant is switched at different times.
- The time difference is determined by the difference of the length of each cable that connects each output from the high voltage gating pulse generator to the input of each quadrant of the MCP.
- When one of the quadrant is switched, image is captured on that particular quadrant.
- The time difference for each quadrant to be switched is equal to the time difference for each image to be captured.
- The time-resolved images are captured when the current signal coincides with the MCP signal and are recorded by the CCD camera on the same frame.

Results and Discussion

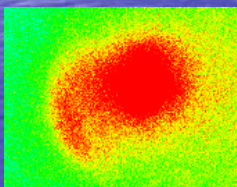
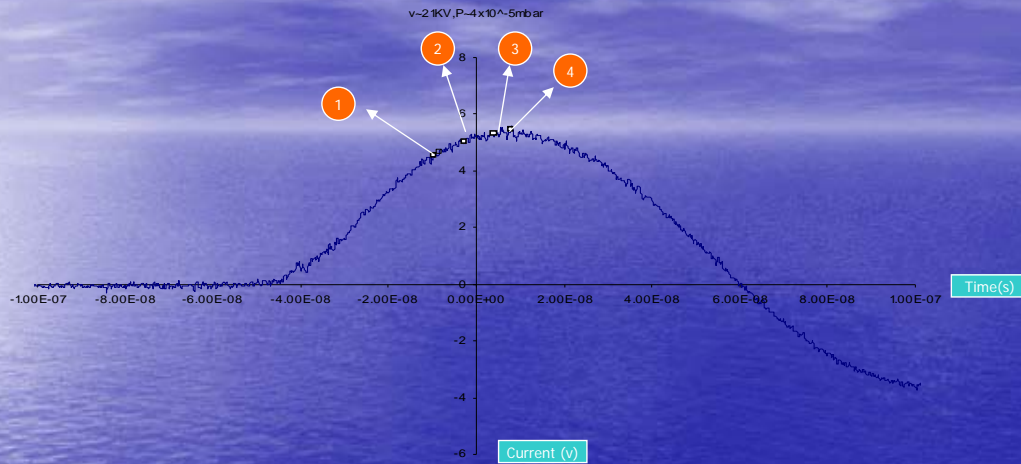
First Set of Images (discharge in air)



First Set of Images (captured at the beginning of the discharge)

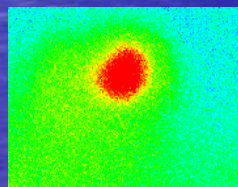
- The first image is taken right after the initiation of the discharge. The tail of the image represents the triggering pin. Only a small emission from the plasma can be observed.
- Emission from the plasma increases gradually as shown in the next images which are taken 6ns, 7 ns and then 4 ns later respectively. The intensity increases because the current is rising and heats up the plasma.

Second Set of images (discharge in air)



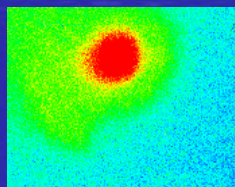
1

t=-9ns



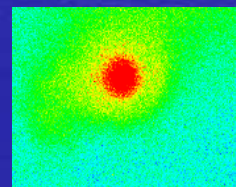
2

t=-3ns



3

t=4ns



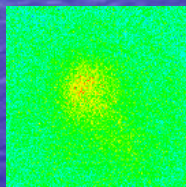
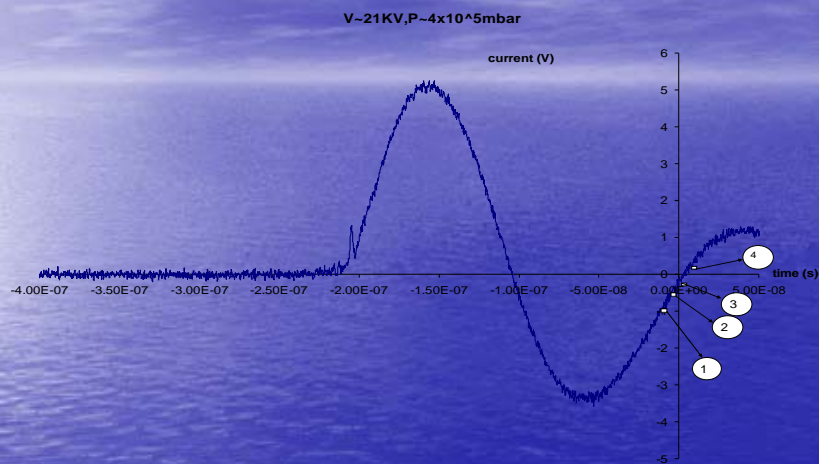
4

t=8ns

Second Set of images (captured at the first current peak)

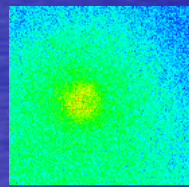
- The first image is taken 37 ns after the initiation of the discharge. A hot and bright plasma is formed. This shows that the plasma is highly ionized due to the heating of the high current.
- The size of the plasma column reduces as exhibited in the image that is captured 6 ns later. This is because there weak compression and the emission is mostly from the core of the plasma column.
- The next image that is captured 6 ns later shows that the intensity of the core of the plasma column increases compared to the previous one and the size of the plasma column is about the same-weak compression effect is still there.
- The emission of the hot plasma column is fading away as can be observed 4ns later. The emission intensity is lower compared to the three previous images. This shows that the plasma column is entering that cooling phase.

Fourth set of images (discharge in air)



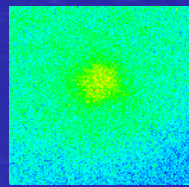
1

t=-9ns



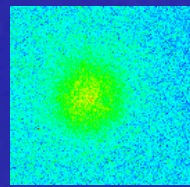
2

t=-3ns



3

t=4ns



4

t=8ns

Fourth set of images (in the end of the first current cycle)

- Emission from the plasma is very dim when the magnitude of the current reaches its minimum value. This indicates the cooling phase of the plasma.

Conclusion

- It is noticed that the plasma 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 minimum.
- A more economical camera which is Nikon Coolpix is used to replaced the CCD to record the images.

References

- [1] C.H.Zhang, S.Katsuki, H.Horta, H.Imamura, Y.kondo, T.Namihira and H.Akiyama, "Xenon Discharge Produced Plasma Radiation Source for EUV Lithography," Industry Applications Conference 2005, Fourtieth IAS Annual Meeting Conference Record of the 2005, 2320-2323 (2005).

THANK YOU

