Contents

Chapter 1

Shape and dynamics

Importance of plasma shape in its application. General description of bullets. What it's studied and how. Observation of plasma bullets in other studies. Shape, size, velocity, example (image of helium and argon bullets). Rebound signal and long time evolution. Frontal shape.

1.1 Experimental setup

The scope is to visually observe dynamics of plasma formation and propagation, so it's needed an acquisition setup with an high-speed camera (little integration time), around 10 ns, and an image intensifier that permits to visualize light emitted in such a short time interval.

This is a measure where we need coincidence between discharge and frame measure so it is necessary to consider instruments and plasma source specific delays and give appropriate triggers.

Experimental setup is shown in photo 1.1 and a scheme is presented in 1.2, there are the trigger signal lines, optical acquisition pointed at source exit and measure acquisition composed by a computer and an oscilloscope.

1.1.1 Source and optical setup

Source head is positioned vertically and emitted light is collected from the side. Optical apparatus is composed by a lens coupled with a Micro Channel Plate image intensifier (MCP). An MCP works as in figure 1.3: for every photon received, thanks to an high-voltage power supply, it emits many photons.

Those photons are received by an high-speed camera *Point Grey Flea* ([1]) equipped with a CCD of 1024×768 square pixels $4.75\,\mu m$ wide. Every frame is sent to the pc where FLIR software elaborates and saves them in pgm format ([2]).

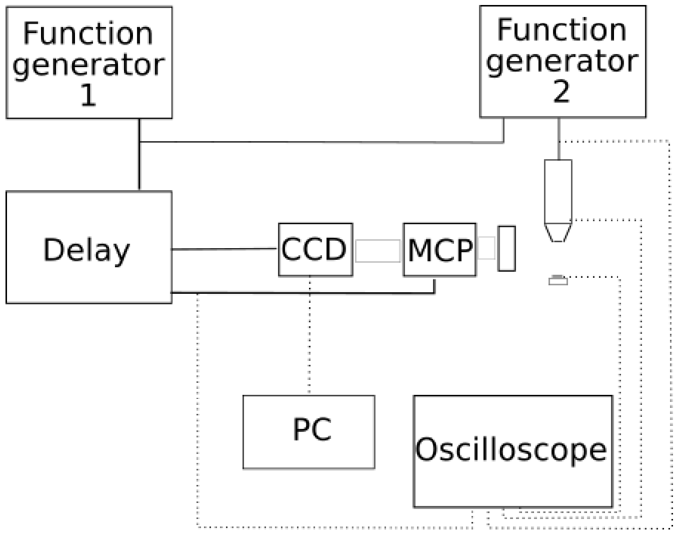

Figure 1.1: Photo of the experimental setup.

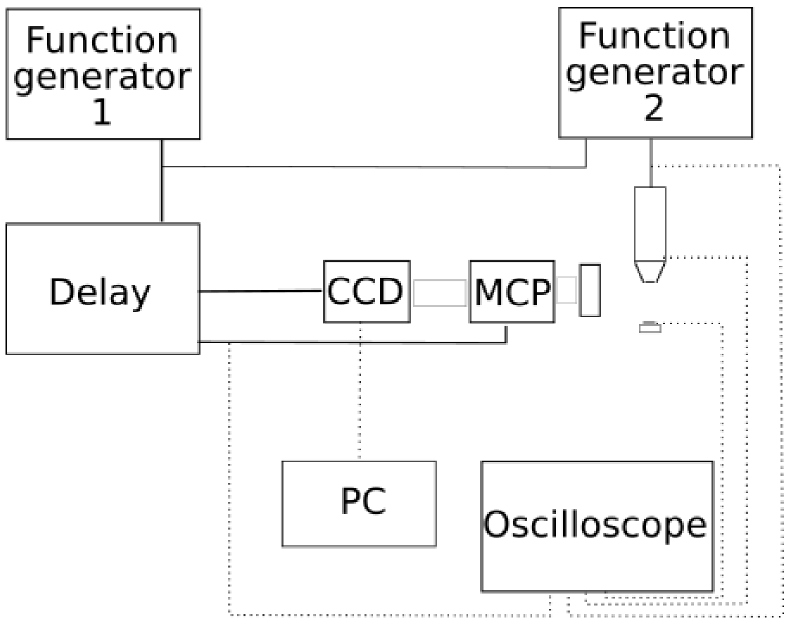

Figure 1.2: Experimental setup scheme. Function generator 1, function generator 2 and delay generator send trigger signal to camera (CCD), to source and to image intensifier (MCP), full lines in the scheme. Camera sends measured frame to a computer (PC) and from source, source's target, function generator 2 and delay are taken signals read on the oscilloscope, pointed lines in the scheme.

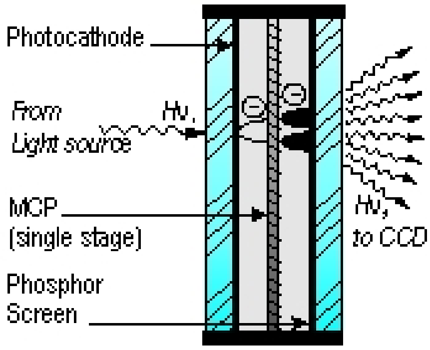

Figure 1.3: Micro Channel Plate image intensifier functioning.

1.1.2 Source, power lines and electric signals

It's used a source with electric features and functioning similar to those described before, with an output between 3 and 8 kV, variabile changing Δt of the trigger signal (see **??**), that is always given through an optical fiber with frequency f. Differances are that tension is positive and not negative, because it helps formation of the plume with gasses harder to ignite (e.g. Argon), and that trigger signal is given by a generator function (2 in the scheme) to define discharge time respect to the trigger of other instruments.

The source is positioned vertically at a distance of 42.0 ± 0.1 mm from optical bench, with the glass nozzle that permits to observe plasma formation inside it (external diameter 8.0 ± 0.1 mm, internal diameter 6.0 ± 0.1 mm), with a distance from the end of the electrode to nozzle exit of 12 mm.

Under the source is possible to put targets where plasma impact, are used two different targets at different heights: conductive target and insulator target. The first one is a copper square sheet of dimensions 10 mm × 10 mm × 1 mm (used for current measures in chapter **??**), the second one is a simple plastic material.

CCD camera is powered by the connection to acquisition computer while image intensifier MCP is powered by an high-voltage supply, both are triggered by the delay generator, with different times (see next section).

On an oscilloscope are measured the trigger signal given to source head, the trigger signal given to MPC, the voltage electrode with high-voltage probe *Tektronix P6015A* and the current intensity when it's used the conductive target. Current intensity measure is done measuring voltage drop on a resistance of 1 MΩ with a probe $x10$.

1.1.3 Trigger synchronization

Experiment's scope is to know plasma dynamics at a specific point on voltage waveform, so it's necessary to know precisely discharge and measure times.

To compose the necessary trigger line are utilized:

- function generator *Or-x 310*, 1 in figure, that sends a square wave with set amplitude, width and frequency f;
- function generator *Lecroy 9210*, 2 in figure, that sends a square wave with frequency given by the trigger, amplitude set, and variable width Δt;
- delay time generator *Stanford DG535*, that sends square wave with set amplitude, frequency given by the voltage input and starting times given by voltage input startin time plus settable delays (4 channels).

Every intrument has it's own time that elapse between trigger signal and effective measure. The longer one is arming time for high-speed camera in the order of ms, the tinyest one is integration time for acquisition system, that starts from the activation of the image intensifier and span 15 ns.

A time line is shown in figure 1.4, an example of signal taken with the oscilloscope is in figure 1.5. There are three relevant times defined by function and delay generators:

1. t_0 is the starting time for the square wave given by *Function generator 1*, with an amplitude of 5 V and a frequency f, that goes as external trigger to *Function generator 2* and as voltage input to *Delay generator*. From *Function generator 2*, at t_0, starts the square wave that triggers discharge and arming of camera, for a time given by Δt that will define voltage amplitude (see chapter **??**) and the same trigger frequency f. From *Delay generator*, at t_0, without delays, starts the trigger signal to arm the camera with the CCD.
2. t_{DIS} is the effective discharge time, when the amplitude peak starts. From trigger signal end to amplitude peak start there is a time delay given mainly by the response time of photodiode. Measuring the signals as in figure 1.5, it's possible to estimate this delay as 987.7 ± 96.7 ns, constant for every f and Δt. Once the discharge starts, in the grey zone in figure, there are the events that we want to measure, plasma formation and propagation.
3. t_{MIS} is the measure time, when the MCP is triggered on. The delay between t_0 and t_{MIS}, t_D, is given by the *Delay generator* with possible steps of 1 ps. Changing t_D during measure it's possible to see plasma dynamics at different times that corresponds to different points on electrode tension waveform, as in figure 1.5.

1.1.4 Frame analysis and calibration

1.1.5 Different setups

Plasma formation is influenced by many parameters such as frequency of high-voltage pulses, their rise time and maximum, gas type, gas flow, presence of a target and its features (see [4], [3]).

For pulse frequency we find a lower limit value, different for each ignition gas, under which there is no discharge. For frequencies higher then this value we don't expect

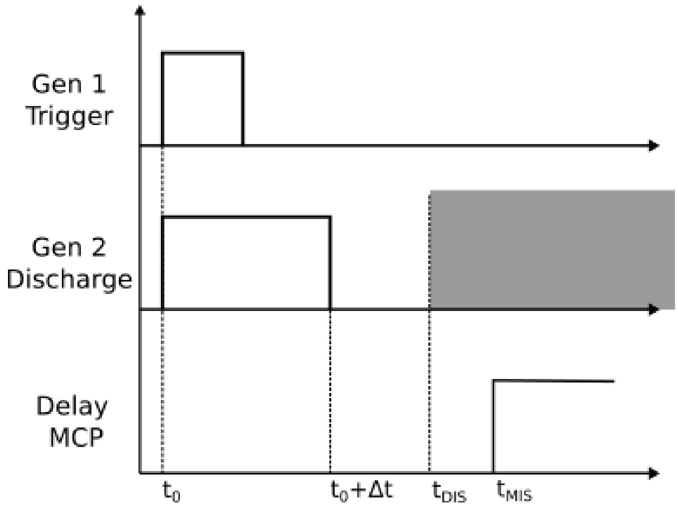

Figure 1.4: Time signal synchronization scheme: t_0 is the starting trigger time, Δt is the opening time for plasma source (see chapter **??**), t_{DIS} is the starting time for the discharge and t_{MIS} the starting time for the MCP i.e. the measure time

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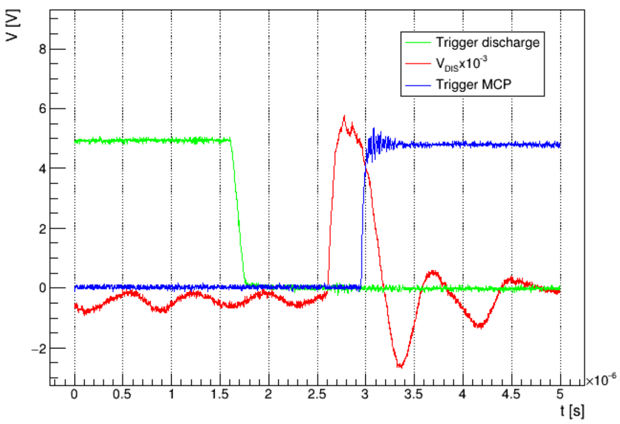

Figure 1.5: Oscilloscope measure example, in green the discharge trigger, in red the electrode tension output and in blue the MCP trigger.

changes (as there aren't in the electric behavior in chapter ??), so we use a single chosen value that permits plasma ignition and doesn't stress the experimental setup. High-voltage values and gas type determine plasma bullet formation and affect its expulsion velocity. In particular, different gasses have different atomic mass and ionization energies, they will have different voltage ignition values and reactive species formed in plasma will have different velocities. Gas flow influences how much gas there is when the ignition starts, so varying it we observe different bullets diameter and velocity. Target influences bullet expulsion, propagation and plasma rebound signal. With a conductive target near plasma exit we will have an easier path seen by charges that propagates and, once the bullet hits the target, its observed higher luminosity going from the target to the electrode. With an insulator target we don't find the ionization channel closing on the target, but we observe charge deposition on the insulator with a shape that depends from the gas and the target. In some setups, to help plasma ignition it's also used a conductor ring at ground potential or at floating potential, placed around source nozzle, after the electrode position.

In this study we present different setups with three different gasses, as shown in table 1.1.

1.2 Measures presentation and analysis

1.3 Neon flow

It's an easy to ignite gas and with high luminosity

1.3.1 High-voltage influence

1.3.2 Target influence

1.4 Helium flow

Description of bullet with helium flow.

1.4.1 High-voltage influence

1.4.2 Target influence

1.5 Argon flow

It's a very hard to ignite gas and with medium luminosity.

1.5.1

1.6 Simple 1D-model

General desription, why and Comsol.

Gas	Setup	Δt	Target	Target distance	Flow rate	Other
He	A	$30, 35, 40$	Conductor	24 mm	2 L/min	-
	B	$30, 35, 40$	Conductor	32 mm	2 L/min	-
	C	$30, 35, 40$	Insulator	24 mm	2 L/min	-
	D	$30, 35, 40$	-	-	2 L/min	-
	E	35	-	-	2 L/min	Ground ring
	F	35	-	-	1 L/min	-
	G	35	-	-	3 L/min	-
	H	35	-	-	4 L/min	-
Ne	A	$20, 25, 30$	Conductor	24 mm	2 L/min	-
	B	$20, 25, 30$	Conductor	32 mm	2 L/min	-
	C	$20, 25, 30$	Insulator	24 mm	2 L/min	-
	D	$20, 25, 30$	-	-	2 L/min	-
	E	30	-	-	2 L/min	Ground ring
Ar	A	35	-	-	2 L/min	Ground ring
	C	35	-	-	2 L/min	Floating ring
	D	35	Conductor	20 mm	2 L/min	Ground ring
	E	35	Conductor	20 mm	2 L/min	-
	F	35	-	-	2 L/min	-
	G	35	Conductor	32 mm	2 L/min	-

Table 1.1: Description of measure setups.

1.6.1 Theory

1.6.2 Results and measure comparision

Bibliography

[1] URL: https://www.ptgrey.com/Content/Images/uploaded/Flea.pdf.

[2] URL: http://netpbm.sourceforge.net/doc/pgm.html.

[3] Julien Jarrige, Mounir Laroussi, and Erdinc Karakas. "Formation and dynamics of plasma bullets in a non-thermal plasma jet: influence of the high-voltage parameters on the plume characteristics". In: *Plasma Sources Science and Technology* 19.6 (2010), p. 065005. DOI: 10.1088/0963-0252/19/6/065005. URL: https://doi.org/10.1088%2F0963-0252%2F19%2F6%2F065005.

[4] N Mericam-Bourdet et al. "Experimental investigations of plasma bullets". In: *Journal of Physics D: Applied Physics* 42.5 (2009), p. 055207. DOI: 10.1088/0022-3727/42/5/055207. URL: https://doi.org/10.1088%2F0022-3727%2F42%2F5%2F055207.