CHAPTER 4

EXPERIMENTAL RESULTS OF THRUSTER PLUME IMAGING

4.1 Imaging plasma plume at I = 4500 A and B = 0 mT

As previously reported in the chapter 2, the quantum efficiency of the CCD camera has got a peak of 40% at 500 nm. So, the light recorded comes predominantly from singly ions argon emission. In order to collect only the light for which the plasma is optically thin, the camera is used coupled with a high pass filter, centred over the wavelength of 646 nm. So, the greater part of ions emissions are below that wavelength and the filter stops them.

In this section, the results of the plume imaging are presented for thruster working condition of discharge current I = 5000 A and without the applied magnetic field. Only the stationary phase is observed.

In the following, the exposition time will be denoted as t_{exp} and the delay time respect to the trigger event as t_d. The trigger event is fixed at the beginning of the rising edge of the current.

In the figure 4.1 the plasma plume observed with t_{exp} = 10 μs and t_d = 0.5 ms is shown.

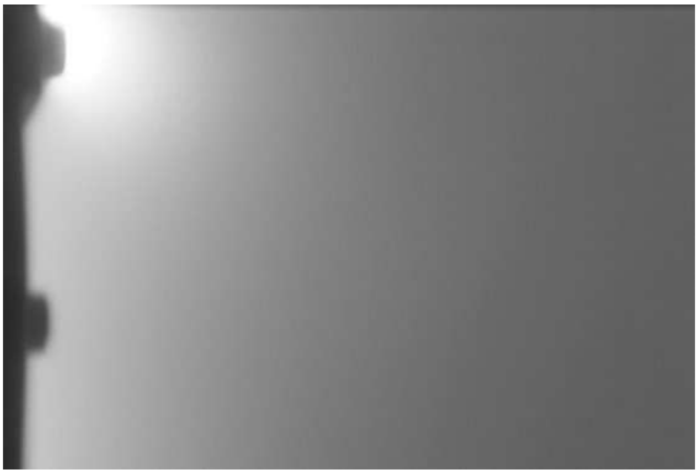

Figure 4.1 *- A close up image of the plasma plume observed at I = 5000 A and B = 0 mT with t_{exp} = 10 μs and t_d = 0.5 ms.*

Any particular structure is evidenced. This results seems to be in accord to the fact that in low pressure case the discharge is spatially uniform.

In order to observe the arising of arc attachments on the anodic straps, the camera objective is focused into the mouth of the thruster.

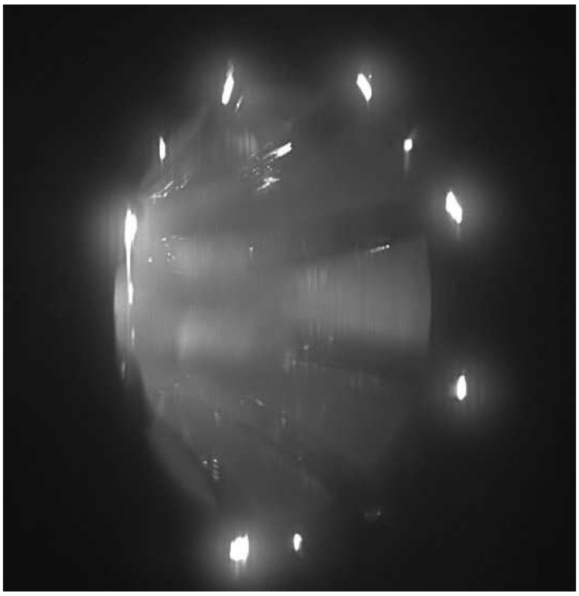

Figure 4.2 *– Image of the thruster mouth recorded with t_{exp} = 100 ns and t_d = 0.5 ms.*

The resulting image with t_{exp} = 100 ns and t_d = 0.5 ms is shown in the figure 4.2. These spots are distributed on the whole surface of the straps. The most intense are mainly located in correspondence of the connection strews.

4.2 Imaging plasma plume at I = 7500 A and B = 0 mT

Start-up phase

During the start-up phase a plasma shockwave coming out from the mouth of the thruster is clearly visible. This is present in all the observations made, even if it does not assume any particular shape. In the figure 4.3 an image of the plasma plume recorded during the start up phase with t_{exp} = 6 μs and t_d = 50 μs is shown.

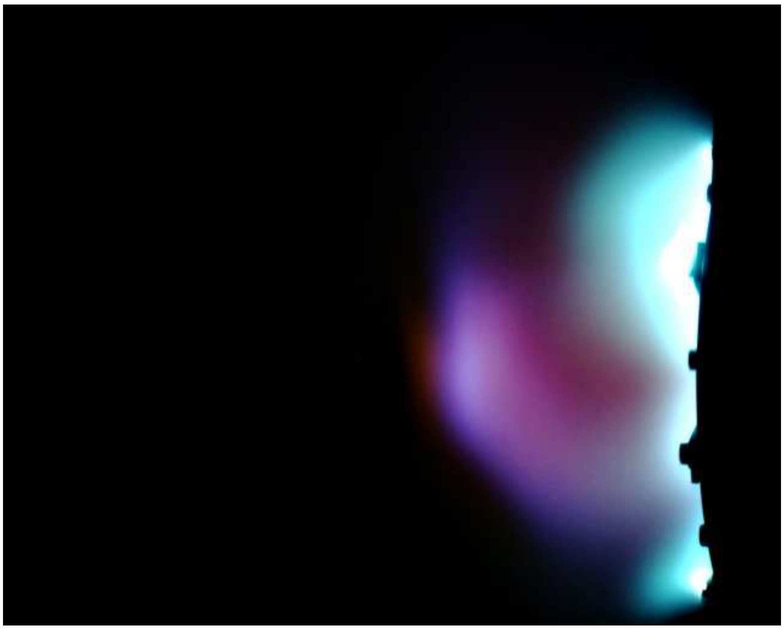

Figure 4.3 *– Image of the plasma plume recorded with t_{exp} = 6 μs and t_d = 50 μs.*

Regime phase

During the regime phase of current, as shown in the figure 4.4, no particular structure in the plasma plume is observable. There are some non-uniformity in the region near the outlet of the thruster. Particles (probably copper due to electrode erosion) coming out from the thruster are also visible.

Figure 4.4 *- Plasma plume in regime conditions recorded with t_{exp} = 5 μs and t_d = 1 ms.*

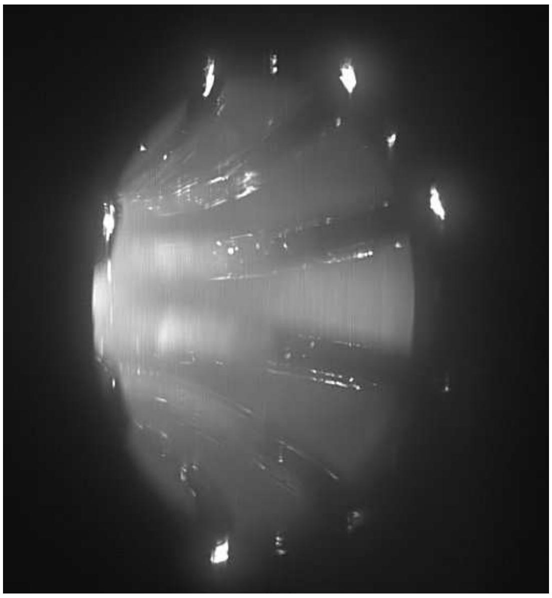

Figure 4.5 *- Image of the thruster mouth recorded with t_{exp} = 100 ns and t_d = 0.5 ms.*

As performed for the low current working conditions, the camera objective is focused into the mouth of the thruster to observe the arising of arc attachments on the anodic straps. The resulting image is shown in the figure 4.5. The total amount of spots on the anode surfaces increase considerably with the discharge current and are distributed on the whole surface of the straps. As before, the camera is used coupled with the same high pass filter.

4.3 Imaging plasma plume at I = 4500 A and B = 80 mT

Start-up phase

When the impressed magnetic field is applied, it's visible, as shown in figure 4.6, a weak "clot" that is expelled by the thruster during the start-up phase. Due to its weak intensity, it is not possible to verify a possible periodicity of this structure.

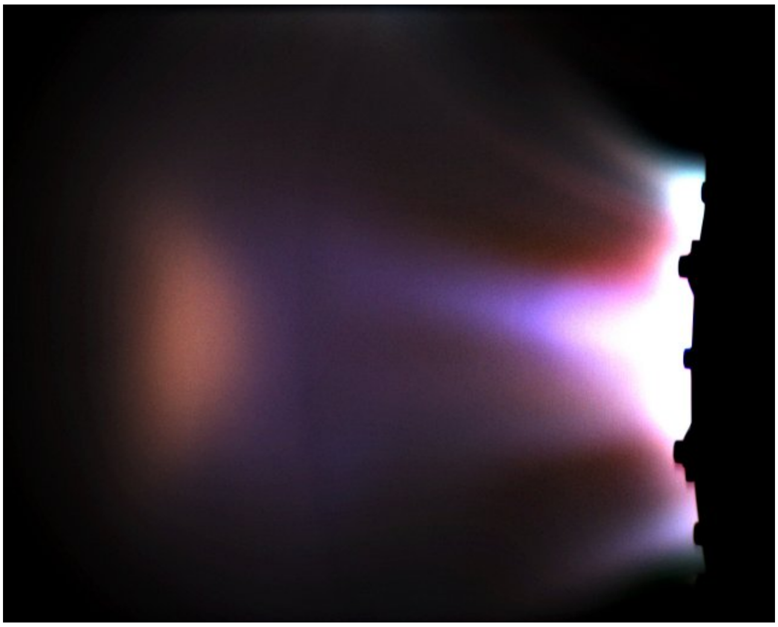

Figure 4.6 *- Image of the plasma plume during the start-up phase with* $t_{exp} = 8\ \mu s$ *and* $t_d = 75\ \mu s$.

Observing the figure 4.6, it seems the “clot” drags some plasma filaments, which wrap themselves up as helicoidal structures. Their thickness changes, but, they don’t reach the “clot” spatial dimension that is of 8 - 10 cm. Other filaments are observed in the peripheral region.

Regime phase

Both the central and peripheral filaments observed during the start-up phase persist also in the regime condition, as shown in figure 4.7, in which the plasma plume with t_{exp} = 8 μs and t_d = 1 ms is observed.

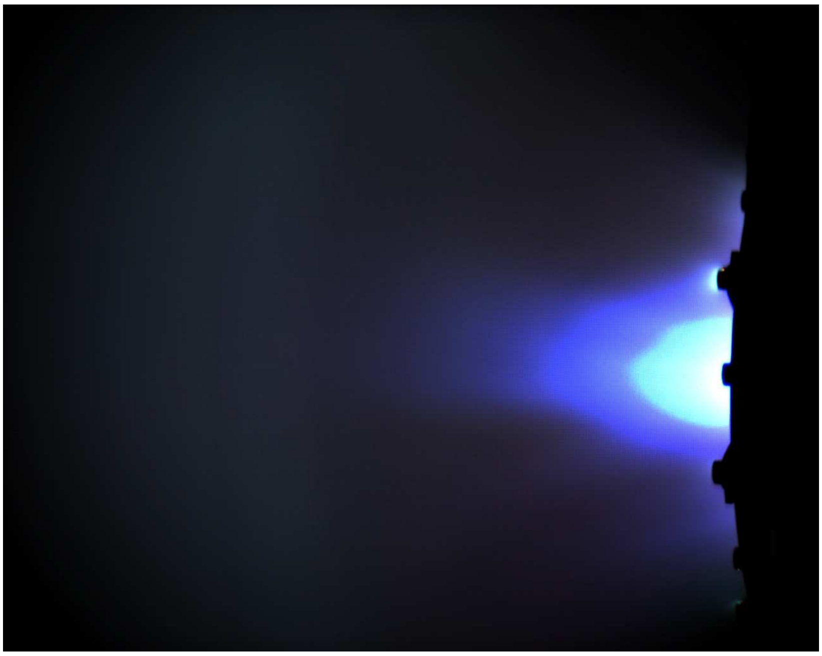

Figure 4.7 *- Image of the plasma plume during the regime phase with t_{exp} = 8 μs and t_d = 1 ms.*

The central filaments have a spatial dimension of about 3 – 6 cm that is exactly the same of the structures following the clot during the start up phase. Due to their weak intensity, the plasma images do not consent to express any hypothesis about their rotation. As observed in figure 4.4, particles coming out from the thruster are clearly visible.

4.4 Imaging plasma plume at I = 7500 A and B = 80 mT

Start-up phase

At high discharge current values and with the external magnetic field applied, the same "clot" previously described is again visible. The figure 4.8 shows a plasma plume image during the start up phase with t_{exp} = 10 μs and delay t_d = 75 μs.

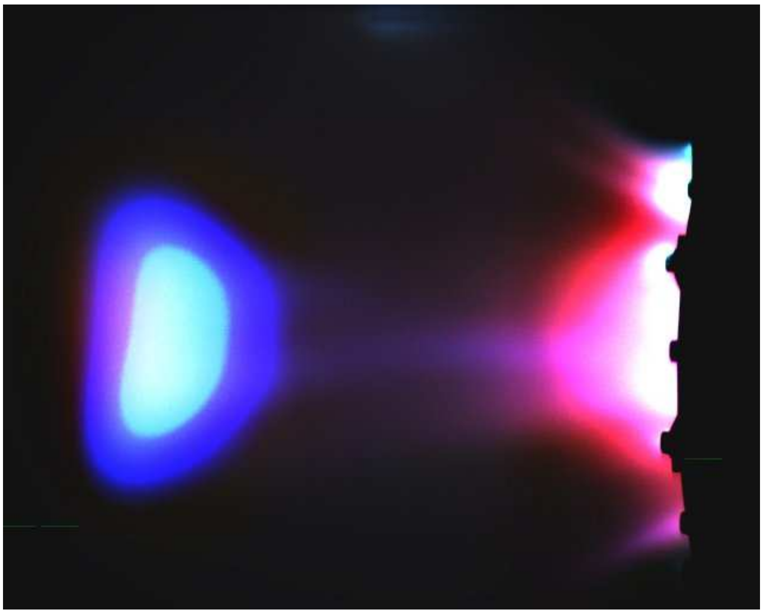

Figure 4.8 *- Plasma plume during the start-up phase with t_{exp} = 10 μs and delay t_d = 75 μs.*

Respect to the low current case, this "clot" is more evident. It looks like formed by a central region with high density and high temperature and an external boundary. It is not possible to verify a possible periodicity of this structure. The velocity of the "clot" is estimated by means of the possibility of the CCD camera to perform a double exposition. The two frames are saved together in the resulting final image. A velocity of about 3.32 km/s is found. This velocity is about ten times lower than the gas velocity.

Again, observing the figure 4.8, it seems the “clot” drags some plasma filaments, which wrap themselves up as helicoidal structures. Their thickness is lower than the “clot” spatial dimension that is of about 8 - 12 cm. Other filaments are another time observed in the peripheral region.

In order to understand if any correlation exists between the plasma filaments observed and the spatial distribution of the impressed magnetic field lines, an electromagnetic code has been utilized. The discretization of the geometry domain is carried out by means of a finite element method. The results are presented in figure 4.9, where the computed field lines are overlapped to the real image recorded with exposition time of t_{exp} = 5 μs and delay of t_d = 100 μs.

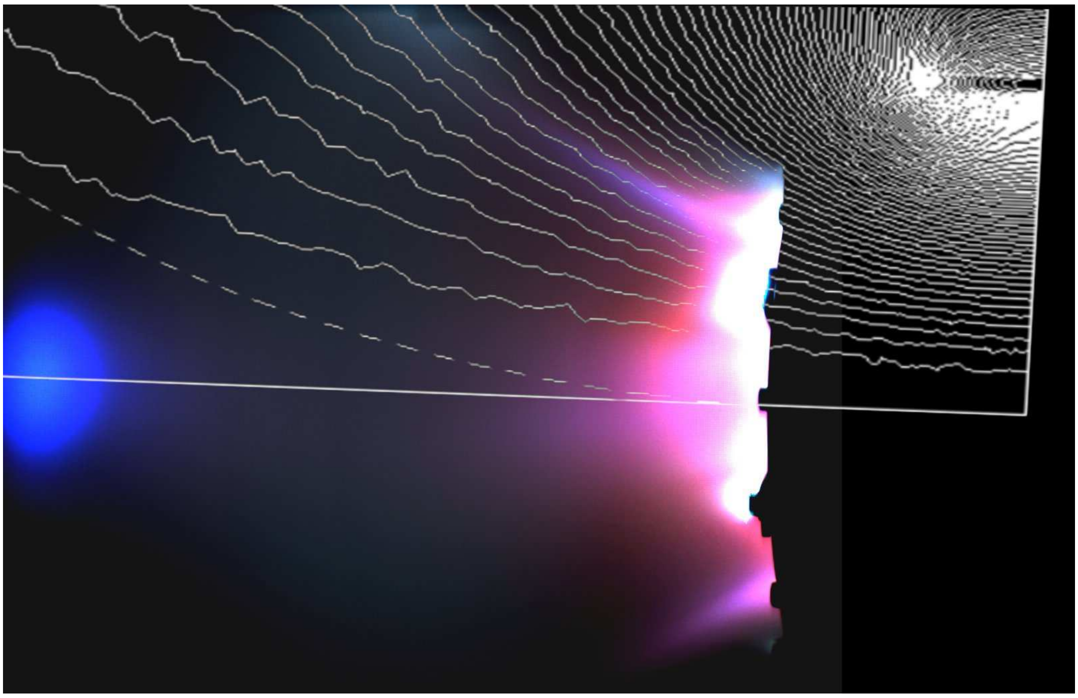

Figure 4.9 - *Plasma filaments with t_{exp} = 5 μs and delay t_d = 100 μs. The peripheral filaments follow up the lines of the impressed field. The computed field lines are overlapped to the real image.*

From the figure 4.9, it appears clearly that the peripheral filaments follow up the lines of the impressed magnetic field.

Regime phase

Also in the regime condition, the central and peripheral filaments observed during the start-up phase are visible. The figure 4.10 shows the plasma plume with t_{exp} = 2.5 μs and t_d = 1 ms.

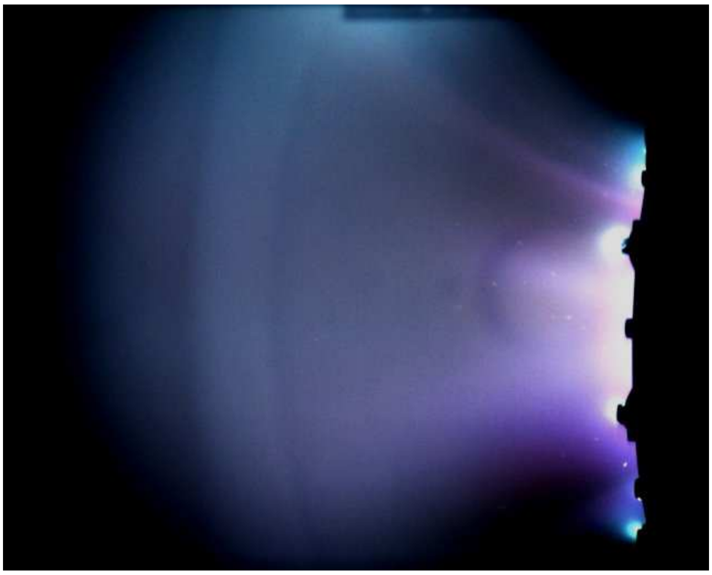

Figure 4.10 *- Image of the plasma plume during the regime phase with t_{exp} = 2.5 μs and t_d = 1 ms.*

The central filaments have the same spatial dimension of about 3 – 6 cm. From the observation of various images recorded with the identical exposition time and delay time of figure 4.10, it looks like that the central filaments turns around over the thruster axis. Again, particles coming out from the thruster are clearly visible.