

# Plasma in a pulsed discharge environment

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**Abstract** – The plasma generated in a pulsed slit discharge nozzle is used to form molecular ions in an astrophysically relevant environment. The plasma has been characterized as a glow discharge in the abnormal regime. Laboratory studies help understand the formation processes of polycyclic aromatic hydrocarbon (PAH) ions that are thought to be the source of the ubiquitous unidentified infrared bands.

Polycyclic aromatic hydrocarbons (PAHs) play an important role in astrophysics. PAHs are found in meteorites and interplanetary dust particles and they are thought to carry some of the 300 diffuse interstellar bands (DIBs) seen in absorption in diffuse interstellar clouds as well as the ubiquitous unidentified infrared emission bands [1]. The plasma produced in a pulsed slit discharge nozzle (PDN) source, see Fig.1, is a perfectly suited environment for generating high column densities of PAH ions [2] due to the combination of two factors: the significant dissociation and ionization yields that can be reached in the discharge combined to the low temperature and density regime that are reached in the supersonic jet flow.

The experimental set-up has been described in detail elsewhere [3]. The pulsed discharge nozzle (PDN) consists of a supersonic slit free jet mounted in a vacuum chamber and two knife-edge electrodes that create a discharge in the stream of the planar expansion. The plasma is thus generated after the gas expands. Two negatively biased jaws forming the cathode are mounted on each side of the slit and insulated from the PDN assembly (anode). The applied voltage ( $-400$  to  $-600$  V through  $1$  k $\Omega$  ballast resistors) ensures that electrons flow against the supersonic stream and that the discharge remains confined as well as uniform within the slit. At typical backing pressure of 760 Torr, detailed flow simulations show that the average pressure within the thin plasma region is of the order of 40 Torr [4].

The typical visible light emission of the Ar plasma generated in the PDN source is shown in Fig.2. The discharge generated in the PDN has been identified as an abnormal glow discharge, characterized by a negative glow, and two

sheaths at the electrodes [5]. Further detailed model simulations based on the micro-discharge 2D (md2d) code have confirmed the presence of these three zones in the discharge [6].

In typical running conditions, the visible light that emerges from the slit in the expansion plane originates from photons emitted by de-excitation of the metastable Ar atoms and ions produced in the negative glow. Electrons that have been accelerated in the cathode region have gained enough energy, once in the negative glow region, to excite Ar atoms (and even ionize a fraction of the gas).

This has indeed been observationally confirmed: Figs.3(a, b) display static images that were captured in various gases with a digital camcorder. The color of the emitted radiation matches the color of the negative glow, which changes from gas to gas (blue for Ar, orange-red for Ne and green for He [7]). The combined effects of the small inter-electrode gap with the steep pressure gradient of the supersonic jet expansion explain why the radiation is visible at the slit's exit.

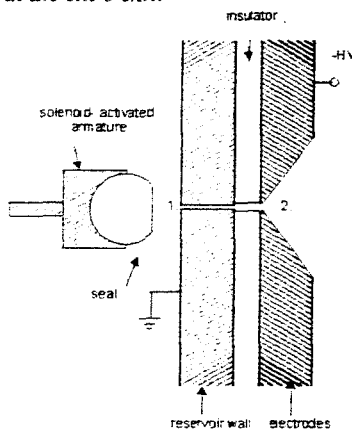


Fig. 1. Cross-section of the PDN source.

A solenoid-activated armature injects a 1.2 ms-pulse of gas into the plasma source. (1) points to the  $200\text{ }\mu\text{m} \times 10\text{ cm}$  slit; (2) indicates the  $400\text{ }\mu\text{m}$  gap between the two jaws forming the cathode. Note that the distance between anode and cathode is 1.5 mm.

The plasma expansion generated in the PDN source is probed either in absorption or in emission. In absorption mode, the plasma expansion is probed transversally several mm downstream by Cavity Ring Down Spectroscopy. In

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emission mode, the plasma expansion is probed frontally in the plane of expansion by Optical Emission Spectroscopy. Absorption and emission measurements of the ArI\* lines in the 700 nm range point to a gas excitation temperature in the expansion in the order of 1.3 eV (15000 K) [4].

This design makes also possible the investigation of carbonaceous nanoparticles (analogs of interstellar dust) generated in significant quantities in the plasma from PAH molecules seeded in the expansion. Accumulation of soot on the electrodes is observed minutes after igniting the plasma. It indicates that complex chemistry (fragmentation, aggregation of precursors, dehydrogenation, formation of large particles, among others) is taking place in the source. Furthermore, the variation of the extinction in the cavity with increased voltage (i.e., at higher plasma energy) is a clear indication of the formation of small nanoparticles in the dusty plasma. Based on a particle growth model by ion-neutral and neutral-neutral reactions, these measurements are interpreted as indicating the presence of small size nanoparticles (maximum diameter of the order of 7 nm) formed during the short residence time (2.5  $\mu$ s) of the molecular precursors in the plasma region. The discharge creates a high number of positive and negative ions that act as nucleation sites for the condensation of the precursor molecules.



Fig. 2. Picture of an Ar plasma generated in the pulsed discharge nozzle source.

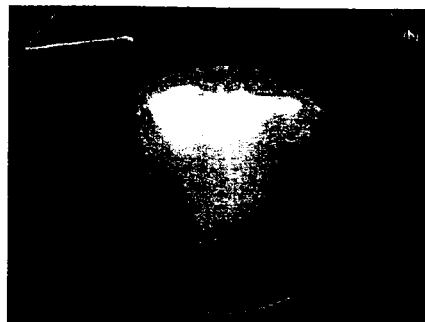


Fig. 3. Pictures of the (a) Ar and (b) Ne plasma that is expanding in the vacuum chamber at a residual pressure of 150 mTorr. Clearly recognizable are the cathode jaws mounted 400- $\mu$ m apart on each side of the 10-cm long slit. The plasma is homogeneous along the slit and its color is characteristic of the carrier gas: blue discharge in Ar (a) and orange-red discharge in Ne (b).

A pulsed discharge nozzle is a complex plasma source that represents an invaluable tool for astrophysics experiments. As shown in this contribution, the nature of the gas mixture injected in the source strongly influences the properties (color, energy, ) of the plasma emerging from the slit. In addition, the plasma is well confined and probing the spectroscopy downstream provides a quantitative estimate of the excitation temperature of the gas and electron and ion densities. Simulations of the pulsed source are in process to further characterize the bulk of the plasma.

#### ACKNOWLEDGMENTS

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