

## Ceramics' sheath probed using Laser Induced Fluorescence

V. Pigeon, N. Claire, C. Arnas, F. Doveil

*Aix-Marseille Univ, CNRS, PIIM, Marseille, France*

### I. Introduction

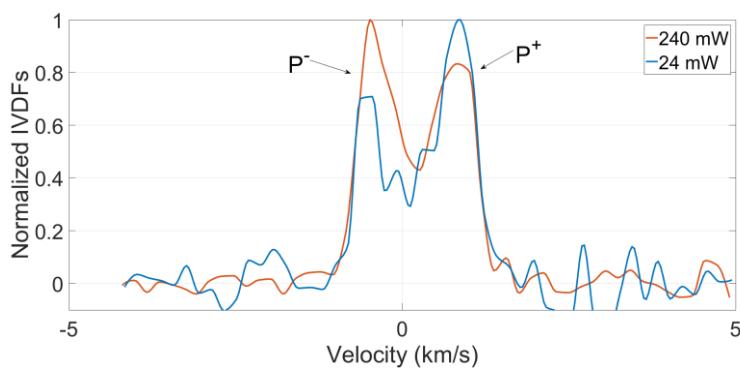
The sheaths standing in front of ceramics used in Hall thrusters' channels are studied thanks to the non-intrusive Laser Induced Fluorescence (LIF) diagnostic. This study aims at evaluating the effect of the secondary electron emission (SEE) on the sheath structure, and check that the SEE yields provided in literature [1,2] are consistent with measurements in a low temperature plasma. A low SEE is required in the thrusters, because a too large emission is responsible for plasma temperature lowering and can even trigger some instabilities [3]. We present here three different results. First, we briefly discuss an experimental bias that occur when performing LIF in front of surfaces. Then are presented the LIF measurements of the sheaths standing in front of 6 different wall materials (BN, BNSiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, Si, Steel). Finally, the ion density in the sheath is presented, which exhibits non-monotonic variations. Such variations are not expected in a sheath/pre-sheath were the density theoretically decreases from the plasma to the wall.

### II. Experimental set-up

The experiments are performed in a multipolar device that provides a quiescent, non-magnetized, low temperature Argon plasma, which is characterized by a bi-maxwellian electron distribution function. The hot electrons represent 10% of the total electrons and their temperature is 13 eV, while the cold plasma electrons' temperature is between 1 and 2 eV. The ions remain at the room temperature and the plasma density is 10<sup>15</sup> m<sup>-3</sup>. The LIF is operated thanks to a tunable dye laser on metastable Argon ions, which resonance wavelength is 611 nm. The laser beam is propagated perpendicularly to the materials samples (2 cm disks). The LIF signal is collected thanks to a photomultiplier and is extracted from the raw plasma emission by a lock-in detection device. This set-up allows the measurement of the Ion Velocity Distribution Function (IVDF) along the laser beam propagation direction, with a velocity resolution around 50 m/s and a spatial resolution up to 0.1 mm.

### III. Performing LIF in front of surfaces

We identified an experimental bias that occurs when the LIF is performed in front of surfaces, especially when the latter are rough, which scatters the reflected laser beam. When operating the laser at high laser powers, the well-known optical pumping saturation occurs and as a result the LIF signal intensity no longer linearly varies with the laser power density. On the other hand, the reflected laser beam is scattered so its power density is decreased and the space it occupies in the photon detecting volume increases (defined by the photon detection optics assembly). As a result, the measured IVDF exhibit more ions moving away from the wall, as shown in Figure 1. If one considers in first approximation that the larger peak in the IVDF corresponds to the incident beam signal, this can lead to misinterpretations of the data. It is shown in Figure 1 that decreasing the laser power cancels the optical pumping saturation for the incident beam, which results in the inversion of the hierarchy between the two peaks' intensities of the IVDF.



**Figure 1** Same IVDF measured for two different laser powers. The hierarchy between the peaks' intensity varies between the high power and the low power.

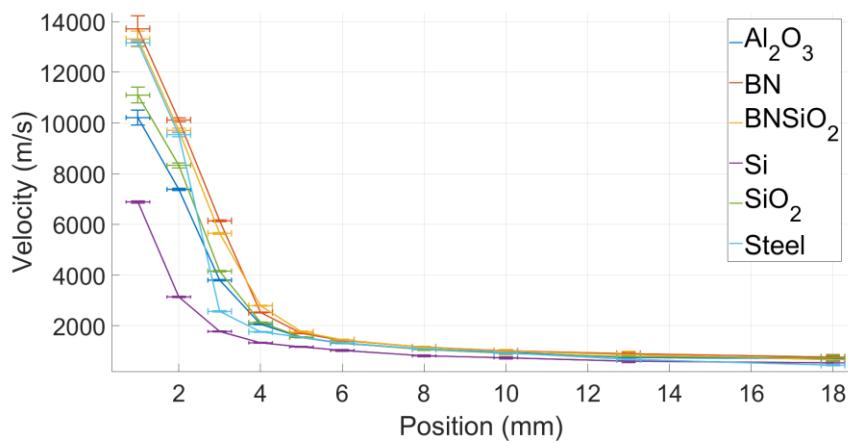
The scattering of the reflected beam may also be identified with the shape of the IVDF. Considering that the scattering follows the Lambert's cosine law, the reflected laser beam should excite the parallel (to the surface) part of the IVDF (which is a non-drifted Maxwellian). Using these hypotheses, one can show that the reflected beam signal reads:

$$f_r(v_r) = \frac{A}{V^2} \left[ \sqrt{\frac{\pi}{2}} v_r \operatorname{erf} \left( \frac{V - v_r}{\sqrt{2}} \right) + \sqrt{\frac{\pi}{2}} \operatorname{erf} \left( \frac{v_r}{\sqrt{2}} \right) - e^{\frac{(V-v_r)^2}{2}} + e^{\frac{v_r^2}{2}} \right]$$

This function provides a good fitting of the experimental data, and correctly predicts the increase of the asymmetry of the reflected beam signal as the wall distance decreases (i.e. the drift velocity in the perpendicular direction increases).

#### IV. Sheaths comparison between materials

Six different wall materials are compared: BN and BNSiO<sub>2</sub> (Hall thrusters' ceramics), Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> (insulators broadly used in plasma discharges), stainless steel and silicon. The comparison is performed in the multipolar device for various discharge biases (the other discharge parameters are kept constant). The results are shown in Figure 2 for the 100V discharge. The drift velocity is plotted against the wall distance for the different materials. The variations differ from one material to another, and especially the maximum velocity near the wall is different for the Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> and silicon samples. This indicates that the sheath potential drop is not identical and therefore the sheath is material-dependant.



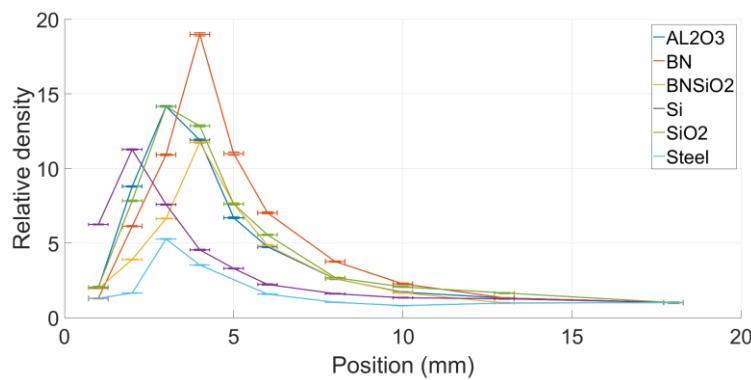
**Figure 2** Ion drift velocity vs wall distance for the 6 different materials. The sheath potential drop varies from one material to another.

We explain the lower sheath potential drop (compared with the Hall thrusters' ceramics and stainless steel) of the Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> by the larger SEE yields for these two materials, which is coherent with the yields provided in the literature. The even lower potential drop measured for the silicon sample may not be explained by the SEE, since it is very low according to previous studies [4]. However, ion surface charging effects have previously been observed in ion implantation experiments in RF discharges [5]. The positive charging of the surface lowers the sheath potential drop, since the global negative charge of the wall is reduced and the required screening is decreased. Finally, the Hall thrusters' ceramics exhibit higher sheath potential drops that are comparable with the stainless-steel sample's one. This indicate that their SEE yields are comparable, which is coherent with experimental data and confirms the good emission properties of these ceramics [1].

#### V. Ion density variation in the sheath/pre-sheath

The last result presented in this section deals with the measured ion density variations in the sheath. The ion density was computed from the IVDFs for all the materials samples and is

shown in Figure 3. A peak in the density appears for all the samples, with various relative intensities (from a factor 5 to 18). The peak's location nearly corresponds with the sheath entrance (the location where the ion drift velocity equals the Bohm velocity). This non-monotonic ion density variation, which was previously observed in front of a Tantalum sample, is surprising since it goes against what is known about plasma sheaths. Theoretically the ion density monotonically decreases from the plasma to the wall as the ion accelerate. When this was firstly measured this was attributed to the optimization of the metastable Argon ions' cross-section [6]. However, regarding the characteristic electron energy of the metastable cross section (threshold at 30 eV, maximum at 50 eV), this hypothesis may not be relevant. This phenomenon is still under investigation.



**Figure 3** Ion density variations vs wall distance for all the wall samples. The ion density peaks near the sheath entrance.

## VI. Conclusion

The sheaths standing in front of different wall materials were measured and compared using the LIF diagnostic. An experimental bias was identified and shown to be due to the combination of the optical pumping saturation and the laser beam scattering at the wall surface. The different wall samples exhibit different sheath potential drop that are related to their respective SEE yield (except for the silicon sample which short sheath potential drop is attributed to ion surface charging effects). Finally, a large ion density peak was measured at the sheath entrance for all the sample, which is still unexplained and under investigation.

- [1] T. Tondu, M. Belhaj, and V. Inguimbert, *Journal of Applied Physics* **110**, 093301 (2011).
- [2] E. Oyarzabal, A. Martin-Rojo, and F. Tabarés, *Journal of Nuclear Materials* **452**, 37 (2014).
- [3] J.-P. Boeuf, *Journal of Applied Physics* **121**, 011101 (2017).
- [4] J. Seon and E. Lee, *Plasma Science and Technology* **15**, 1093 (2013).
- [5] X. Tian, R. K. Fu, J. Chen, P. K. Chu, and I. G. Brown, *Nuclear Instruments and Methods in Physics Research Section B* **187**, 485 (2002).
- [6] N. Claire, G. Bachet, U. Stroth, and F. Doveil, *Physics of Plasmas* **13**, 062103(2006).