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Carbon dusts formation and transport in a radiofrequency discharge

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In fusion devices, physical and chemical erosion of plasma facing material components produce dusts. Dusts can cause numerous problems: they lower the efficiency of the fusion reaction, contribute to fuel retention [1] and their deposition on the first wall lower the efficiency of cooling and further contribute to wall erosion… Thus, it is necessary to limit their formation and to control their transport in the plasma. Dusts transport is essentially studied through models and numerical simulations, and there is a big need of experimental data. Progresses in fast imaging techniques and analysis tools can provide data and key elements to better understand this transport, as it is shown in our laboratory experiment.

The experiments were performed in a RF parallel plate reactor working at 13.56MHz. Carbonaceous radicals that enter into the composition of dusts can be brought by two means. A first method consists in working in argon gas with a carbon cathode; the impact of argon ions on the cathode causes sputtering, spraying carbon particles of very small size into the plasma. In a second method, a stainless steel cathode is used and carbon is provided by the gas, composed of a mixture of acetylene and argon. In the latter case, under given condition the dust particles may combine into larger aggregates with a diameter close to the micron [2]. Whatever the configuration used, the stainless steel anode is grounded. Both electrodes are 5cm in diameter and the distance between them is 8cm. In this contribution, a graphite cathode was used but a fraction of acetylene was also introduced into argon gas, in order to obtain micron-sized dusts that can be directly observed with a camera. In our study, a PHOTRON SA1.1 camera was used to observed fast dusts dynamics at 1000fps with a 1Mpixels resolution. The reactor was operated at room temperature. The percentage of acetylene was chosen in the range 0-30% by using mass flow controllers. The total gas pressure was in the range 150-600mtorr and the applied RF power was chosen between 20 and 50W. In such conditions, micron-sized dusts can be observed in the cathode’s sheath after a few minutes (Fig. 1). Exact location and size of the dust clouds vary from one to the other experiment and with the discharge time. The cause of that is certainly the roughness of the cathode, altered by the deposition of dusts during the experiments, as it can be seen in Fig. 1. Indeed, this roughness modifies the symmetry of the electric field to which the dusts are very sensitive.

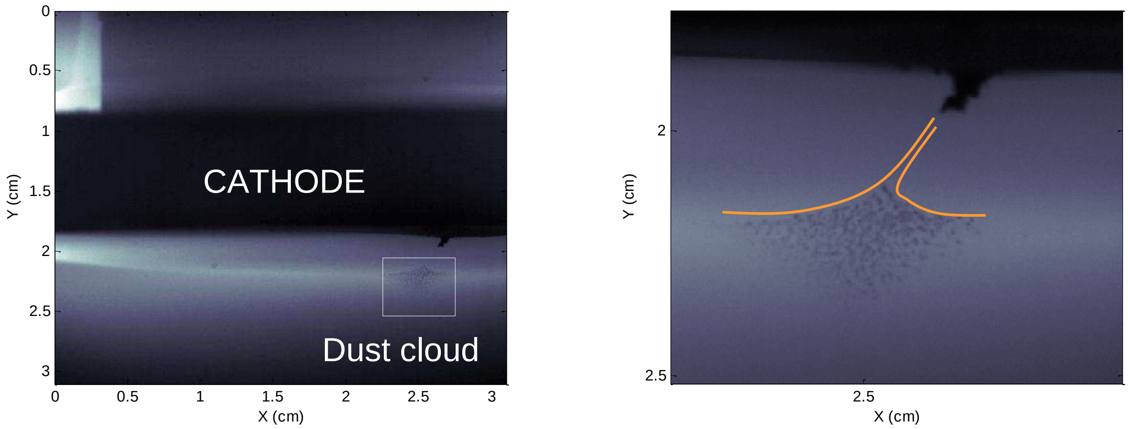
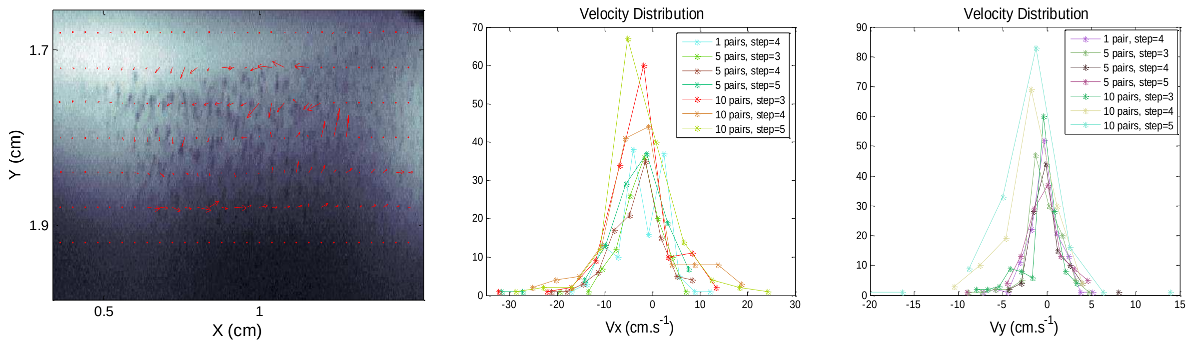


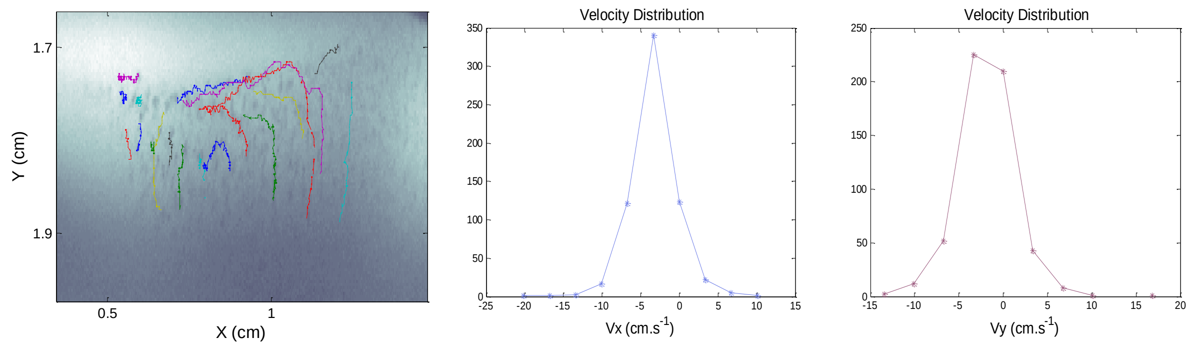
Figure 1: Side view of the cathode showing a dust cloud in the cathode's sheath (left), and detail of the cloud (right). An aggregate made of dusts deposited on the cathode is clearly visible, influencing the shape of the dust cloud.

In order to retrieve the dusts particle movement from the images recorded with the camera, different techniques can be used. Particle Image Velocimetry (PIV) performs pattern matching in order to recover displacement between successive images [3]. This technique is widely used to get an image of the flow field in fluid motion studies. The fluid motion is evidenced by the use of tracers illuminated by a source of light, but its application to dusty plasmas is not straightforward, for several reasons. Pattern matching is realized by dividing the images into sub-windows and performing cross-correlation calculations between subsequent sub-windows. It requires that the size of each sub-window is small compared to the typical scale of the flow and that the density of tracers in each sub-window is not too large. In order to apply this technique to our dusty plasmas, it is necessary to use macro-photography to spatially resolve the dusts. Only the largest are accessible, lowering our capability to illuminate them, since visible wavelengths are smaller than the size of the dusts, resulting in a forward scattering of the incident light (Mie theory). As a consequence, no additional light source was used in our experiment, requiring the use of a very sensitive camera sensor. Another consequence of using macro-photography is that the focus is possible only on a thin slice of plasma (typically 1mm). Thus, only 2D motion in the focus plane of the camera can be recorded. However, the main difficulty comes from the high density of dusts, and their reciprocal influence due to the Coulomb force. Practically, only some regimes can be correctly analyzed with this technique, such as the one depicted in Fig. 2. In this regime, a convection roll is easily observed. Comparisons with eye-tracked dusts show a good agreement, both qualitatively (Figs. 2a & 3a) and quantitatively (Figs. 2b-c & 3b-c). However, the velocity distribution in x and y directions highlight the variability of PIV results according to some parameters: number of images considered, time resolution (in addition to the sub-windows size and overlapping).



(a) PIV velocity field (b) PIV Vx distribution (c) PIV Vy distribution

Figure 2: PIV estimation of the dusts velocity field and of the x- and y- components of the velocity distribution, showing the influence of the time interval and number of images pairs considered.



(a) Individual dust trajectories (b) PIV Vx distribution (c) PIV Vy distribution

Figure 3: Dusts trajectories and x- and y- components of the dusts velocity distribution, obtained from individual tracking applied to the same data used for PIV calculations in Fig. 2.

Under some experimental conditions, light fluctuations can be recorded, evidencing sheath oscillations propagating towards the cathode (Fig. 4). These oscillations seem to be related to pumping and gas injection. In such regimes, a clear distinction can be made between the dust transport in the directions parallel or transverse to these oscillations (Fig. 5). This observation is highlighted by the estimation of the Hurst exponent, using the Rescaled Range analysis (not figured in this contribution): wherease the motion in the x direction is in between a fractional Brownian motion (H>1/2) and a ballistic one (H=1), in the y direction we observe a transition from a persistent motion at small correlation times to a antipersistent (H<1/2) at long correlation times, the transition occuring at a correlation time equal to the period of the dust oscillations in the y-direction. This result demonstrates that the sheath oscillations influence strongly the transport of dusts. Although the frequency of sheath oscillations is much larger than the frequency of the dust oscillation in the y-direction, it looks reasonable to assume that this difference can be explained by the inertia of the dusts. This point will be further investigated in future studies.

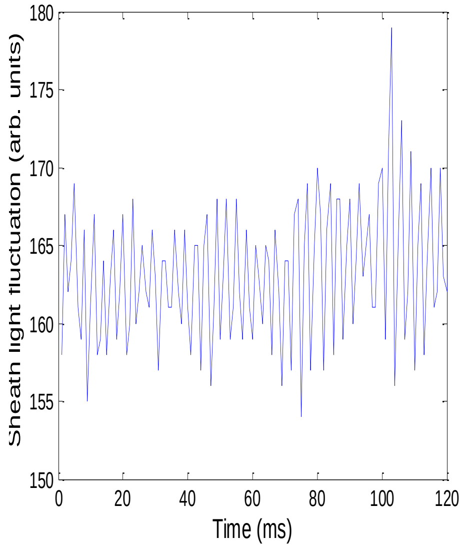


Figure 4: Light intensity fluctuations recorded in the sheath.

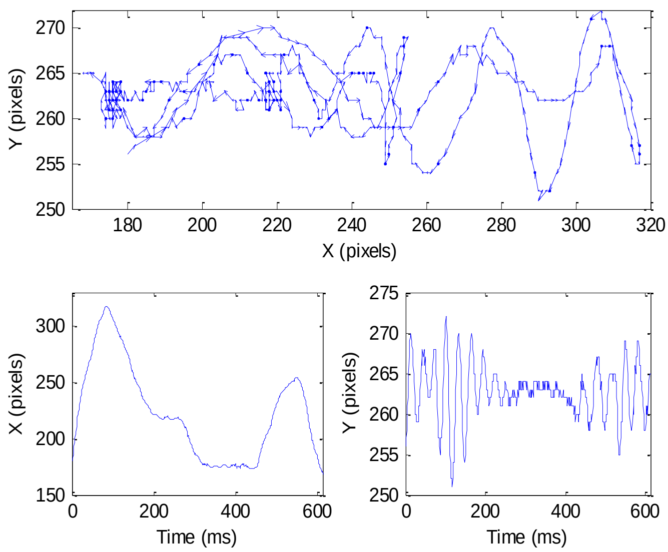


Figure 5: Trajectory of a single particle in a dust cloud showing a different behaviour in x- and y-directions.

References

[1] J. Linke et al., Fus. Eng. 66-68, 359-399 (2003)

[2] Y. Peng et al., Journal of Quantitative Spectroscopy and Radiation Transfer, in press, doi: 10.1016/jqsrt.2007.10.012 (2008)

[3] J.K. Sveen, http://www.math.uio.no/~jks/matpiv/, (1998-2008).

[4] H.E. Hurst, Nature 180, 494 (1957).