Investigations of enhanced emission regions in a dusty plasma

H. Tawidian, T. Lecas, T. Gibert, M. Mikikian

GREMI, UMR7344 CNRS/Université d'Orléans, 14 rue d'Issoudun, BP6744,

45067 Orléans Cedex 2, FRANCE

Plasma regions with an enhanced light emission are easily found in dusty plasmas. They can appear during some instabilities induced by the presence of a high dust particle density, or in the plasma center. In this last case, this region corresponds to the "void" that is a dust-free region. In this paper, experimental characterizations of these two kinds of regions are presented. Experiments are performed in the PKE-Nefedov reactor where Ar or Kr plasmas are produced by a capacitively-coupled radio-frequency discharge with a typical power of about 3 W at a pressure around 1.6 mbar. Dust particles are grown by sputtering a polymer layer previously deposited on the electrodes [1].

Regions of enhanced light emission during dusty plasma instabilities

When a high density of dust particles is grown in a plasma, the plasma equilibrium is drastically disturbed. Indeed, dust particles attach many plasma free electrons that are no more available to sustain the discharge. In these conditions, the plasma enters in an unstable state characterized by many different types of low-frequency instabilities. Their shape and frequency evolve as dust particles are growing and they can be evidenced on all the plasma or discharge parameters. These instabilities have been observed in several experiments where they are characterized by the filamentary or great void modes [2], or they are called dust particle growth instabilities (DPGI) [3, 4]. During DPGI, a particular behavior has been observed that consists of plasma spheroids appearing close to the electrodes [5, 6] or in the plasma bulk. In this paper, a special attention is paid to the plasma spheroids in the plasma bulk. These delimited regions of enhanced light emission have a size of a few mm and appear stochastically in between the electrodes. They have been recently observed in a Kr plasma as shown in Fig. 1 presenting images taken with a high-speed camera at 16000 frames per second. The electrodes (separated by about 3 cm) correspond to the dark regions on the top and bottom of each frame. The plasma spheroids are the bright plasma regions appearing in between the electrodes. They are often observed by pair, and they have a comet-like shape as well-evidenced in image 150. These spheroids are observed during dust particle growth and the question of their composition is posed: they can contain just plasma (like the "void") or plasma and dust particles. At the moment, no clear experimental indication allows to select one of these possibilities. In Fig. 1, small spheroids are also observed very close to the electrodes [5, 6] but will not be discussed in this paper.

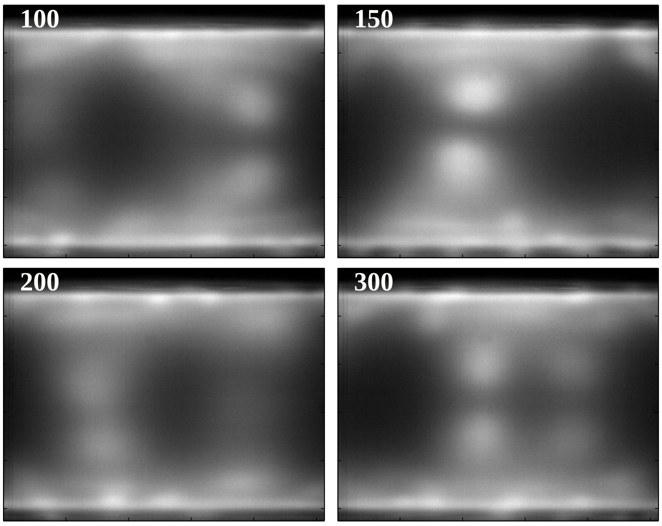

Figure 1: Images of plasma spheroids appearing in the plasma bulk during DPGI. The original movie has been taken at 16000 frames per second.

In addition to their stochastic appearance and disappearance, the spheroid behavior shows other interesting features. In particular, before they disappear, plasma spheroids can move horizontally and vertically in between the electrodes. This behavior is underlined in Fig. 2 where different images are represented in false colors in order to enhance the luminosity variations. A clear spheroid is observed in the plasma center and it is moving first downward (from image 3552 to 3561) than upward. A slight displacement in the horizontal direction can also be detected. Interactions with other spheroids originating from the up and bottom presheath is also observed in Fig. 2. The origin of these possible interactions and motions is currently under investigation. Some new experiments show that plasma spheroids can interact with each other and very interesting phenomena have been evidenced. Indeed, in some conditions the merging of two spheroids or the splitting of a spheroid in two parts has been observed thanks to the high speed camera. These behaviors raise the question of the type of interaction involved in these processes and additional experiments are required to go further in their understanding.

Region of enhanced light emission: the void

Due to the geometry of typical laboratory discharges, a dust-free region is often observed close to the discharge center. This region, called the "void" is suspected to be sustained by two counteracting forces, an inward electric force and an outward ion drag force [7]. The ion drag force expels the dust particles from the plasma center while the electric force acts as a restoring force. The place where these two forces equilibrate, defines the void boundary. It can be expected that the plasma inside the void is quite different than the surrounding one containing dust particles. This is confirmed by a direct visual observation of the void that appears brighter

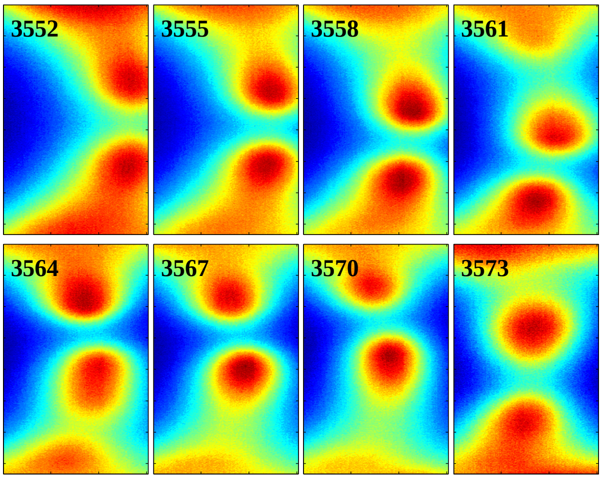

Figure 2: Plasma spheroid motions in between the electrodes of a Kr plasma. Images are in false colors (luminosity from blue to red). The original movie has been taken at 16000 frames per second.

when a huge density of dust particles has been grown as observed in Fig. 3(a). To study the plasma characteristics inside and outside the void, an optical non-intrusive diagnostics has been used: Laser Induced Fluorescence (LIF) that can bring important information in dusty plasmas [8, 9]. Experiments are performed in Ar with a laser at 667.9125 nm to pump the $4s[3/2]_1$ level of neutral Ar to the $4p'[1/2]_0$ level. De-excitation to the $4s'[1/2]_1$ level is observed at 750.5934 nm [10]. Measurements are performed along the two main axes of symmetry of the discharge. The LIF relative intensity corresponding to the density of excited neutral atoms is deduced from the maxima of the fluorescence profiles. In the radial direction, the LIF signal decreases while moving away from the central void as observed by comparing the amplitudes of the 3 curves of Fig. 3(b). In the direction perpendicular to the electrodes, the analysis from the void center to the bottom electrode is also shown in Fig. 3(b). The void region is clearly evidenced between 0 and 0.4 cm. In this region, a continuous decrease of the LIF intensity is observed from the void center to the void edge. Then, the LIF signal increases slowly and continuously as approaching the bottom electrode. This intermediate region corresponds to the plasma region in between the void and the presheath (see also Fig. 3(a)). As approaching the electrode, the intensity increases sharply due to the entrance into the bright presheath region. These results confirm that the density of excited neutral atoms is higher in the void region than in the rest of the plasma (excluding the presheath). This could be due to an enhanced electron density inside the void region as proposed in some models [11].

Concerning the Ar neutral atom temperature, no clear difference between inside and outside the void has been measured. This is mainly due to a poor signal to noise ratio. New experiments with an improved detection are foreseen to get access to this important parameter.

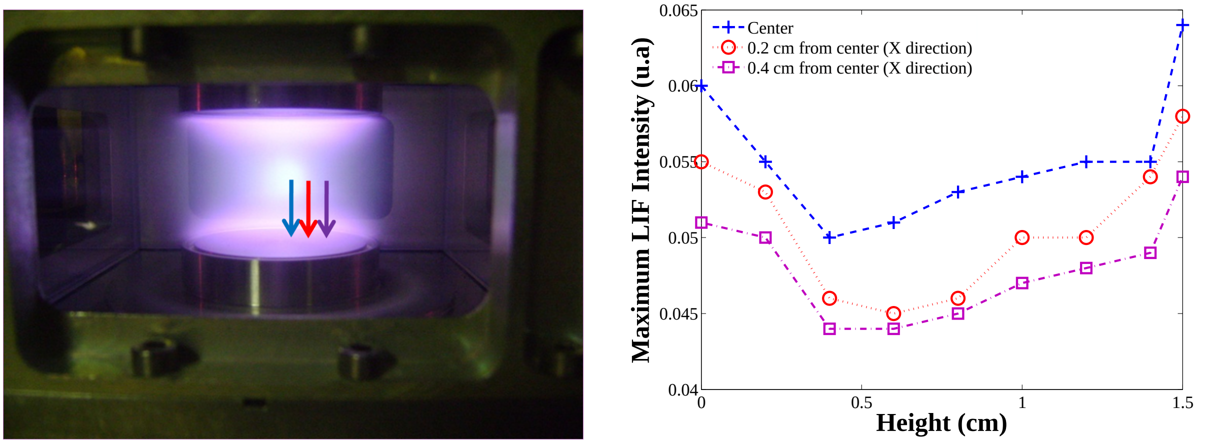

Figure 3: (a) Image of an argon plasma with a huge density of grown dust particles. The void in the discharge center appears brighter than the surrounding dusty plasma. (b) Maximum LIF intensity profile in the vertical direction for 3 different horizontal positions illustrated in Fig. 3(a).

Acknowledgments

The PKE-Nefedov chamber has been made available by the Max-Planck-Institute for Extraterrestrial Physics, Germany, under the funding of DLR/BMBF under grants No.50WM9852.

J.-M. Bauchire and H. Rabat are acknowledged for providing the high-speed camera.

This work was partly supported by the French National Research Agency (ANR), project INDIGO n°ANR-11-JS09-010-01.

References

[1] M. Mikikian, L. Boufendi, A. Bouchoule. H.M. Thomas, G.E. Morfill, A.P. Nefedov, V.E. Fortov and the PKE-NEfedov team, New J. Phys. **5**, 19 (2003)

[2] D. Samsonov, J. Goree, Phys. Rev. E **59**, 1047 (1999)

[3] M. Mikikian, M. Cavarroc, L. Couëdel, L. Boufendi, Phys. Plasmas **13**, 092103 (2006)

[4] M. Mikikian, L. Couëdel, M. Cavarroc, Y. Tessier and L. Boufendi, IEEE Trans. Plasma Sci. **36**, 1012 (2008)

[5] H. Tawidian, M. Mikikian, L. Couëdel, T. Lecas, Eur. Phys. J. Appl. Phys. **56**, 24018 (2011)

[6] M. Mikikian, L. Couëdel, Y. Tessier, L. Boufendi, IEEE Trans. Plasma Phys. **39**, 2748 (2011)

[7] J. Goree, G.E. Morfill, V.N. Tsytovich and S.V. Vladimirov, Phys. Rev. E **59**, 7055 (1999)

[8] C. Arnas, M. Mikikian, G. Bachet, F. Doveil, Phys. Plasmas **7**, 4418 (2000)

[9] C. Arnas, M. Mikikian, F. Doveil, Phys. Scr. **T89**, 163 (2001)

[10] A.M. Keese, E.E. Scime, Rev. Sci. Instrum. **77**, 10F304 (2006)

[11] V. Land, W.J. Goedheer, New J. Phys. **9**, 246 (2007)