Cyclic growth dynamics of nanoparticles in low-pressure rf dusty plasmas

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This work investigates the dust formation dynamics in a low-pressure, axially-asymmetric, rf argon discharge with pulse injection of hexamethyldisiloxane (HMDSO, $Si_2O(CH_3)_6$). Light scattering and optical emission spectroscopy (OES) revealed oscillations over two time scales: a low-frequency cycle ascribed to the precursor injection and a very-low-frequency cycle linked to the dust formation and disappearance. It is found that the amount of injected HMDSO and the rf power significantly modify the period of the formation and disappearance cycle. The impact of these parameters on the low- and high-energy electron populations will be discussed.

When nanoparticles, or dust, grow inside a plasma, they are subjected to numerous forces. The most important ones, that allow or deny confinement of the dust cloud, are the electrostatic and ion drag forces. Their significance comes from the negative charge carried by the dust. However, since dust acts as a sink of the free electrons, it is not obvious that an equilibrium will be reached, in which dust would float indefinitely inside the discharge. In fact, a great number of temporal and spatial instabilities can be observed in low-pressure dusty plasmas.

In our experiment, the plasma is generated between two electrodes separated by 3.5 cm, with the top, smaller, RF driven electrode made of silver and a larger, grounded, bottom electrode. One of the most important specificity in our procedure is the pulsed injection of the precursor, HMDSO ($Si_2O(CH_3)_6$), with a complete cycle of 5 s. It was found that under specific experimental conditions, mainly low rf power (< 50 W) and enough injected precursor, expressed here as flow rate averaged over the injection period (> 0.16 sccm), a dust cloud appears in the plasma. More importantly, the dust cloud presents a formation/loss cyclic behavior with a period of a few hundred seconds (see Fig. 1). Fig. 2 shows the evolution of the period of dust formation/loss cycle with the relevant operating parameters. HMDSO flow rate accelerates this cycle by providing a greater quantity of radicals needed for the dust growth. On the other hand, the rf power increases the period of the cycle, most likely due to an increased fragmentation of the precursor providing more atomic hydrogen, known to act as dust nucleation inhibitor.

In a recent study, we have used optical emission spectroscopy to examine the influence of the dust growth on the low- and high-energy electron populations [1]. It was shown that the electron temperature (T_e) follows the same trend as the dust cyclic formation and loss, while the electron density (n_e) has the opposite behavior. In this study, we will report on the influence of the injected HMDSO amount and the rf power on T_e and n_e.

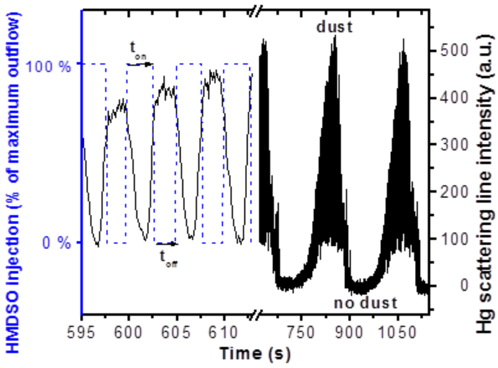

Fig. 1. Time evolution of the injection of the HMDSO precursor (dash-dot) for a duty cycle of 0.56 (t_{on} = 2.8 s) and the intensity of the Hg line at 546 nm (solid line).

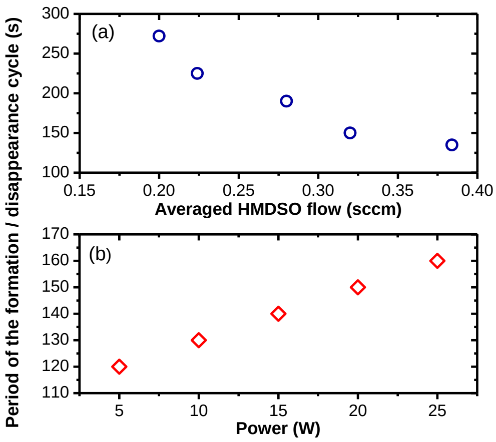

Fig. 2. Evolution of the formation / disappearance period with the averaged HMDSO flow rate (a) and rf power (b).

[1] V. Garofano, L. Stafford, B. Despax, R. Clergereaux, and K. Makasheva, Appl. Phys. Lett. **107**, 183104 (2015).