Optogalvanic control of instabilities in dusty plasma

M Y Pustilnik†,‡, A V Ivlev,§ N Sadeghi,∥, R Heidemann∥, S Mitich,‡ H M Thomas† and G E Morfill‡

† German Aerocosmic Centre, Complex Plasma Research Department, Wesling, Germany
‡ Max Planck Institute for Extraterrestrial Physics, Garching, Germany
§ Interdisciplinary Physics Laboratory, Joseph Fourier University Grenoble, France
∥ Justus Liebig University Giessen, Germany

E-mail: Mikhail.Pustylnik@dlr.de

Abstract. This paper presents experimental results on the control of periodic contraction of the void border and proposes a hypothesis on its mechanism, based on the distinctive features of a dusty plasma - its heterogeneity and the presence of the volumetric sink in it.

Instabilities in low-temperature plasmas with negative ions are known for decades [1, 2]. They appear in the form of low-frequency (1-100 kHz) spontaneous discharge fluctuations. Usually, they are global - the discharge glow demonstrates in-phase changes throughout the discharge. These instabilities can be described on the assumption of a homogeneous distribution of the parameters over the volume of the discharge.

Dusty plasma can also be considered as a plasma with very heavy negative ions. However, the macroscopic nature of dust particles adds some features. First, the charge of the dust particles is determined by balance of the flows of electrons and ions onto their surface. The surface of the dust particles, therefore, is a volumetric plasma sink. Secondly, for the dust particles the ion drag force becomes significant. Its presence leads to the formation of so-called voids – cavities free from the dust particles [3]. Such plasma cannot be considered homogeneous.

In the first dusty plasma experiments in microgravity, under certain conditions, spontaneous periodic contraction of the void border was observed. This phenomenon is called "heartbeat". The mechanism of appearance of this instability is still not clear. This paper presents experimental results on the control of this instability and proposes a hypothesis on its mechanism, based on the distinctive features of a dusty plasma - its heterogeneity and the presence of the volumetric sink in it [4].

Experiments were performed in laboratory conditions in the discharge chamber of the earth model of the orbit experiment, PK-3-plus [5]. Monodisperse microspheres of melamine-formaldehyde resin with a diameter of 1.95 micron were injected into the volume of the capacitive HF discharge (argon, pressure of 10-50Pa). Gravity affecting them was compensated by the thermophoresic force: a temperature difference of 19K was maintained between the electrodes. To control the instability, a tunable semiconductor laser utilizing argon transition with the wavelength of 772.38 nm was used. The output power of the laser beam was varied by attenuation through the filters. The maximum

5 To whom any correspondence should be addressed
power was 8 mW. The beam was modulated with a mechanical chopper. The experimental scheme is shown in figure 1.

Figure 1. Experimental setup for studying the “heartbeat” in dusty plasma.

Figure 2. Typical diagram of stability of the dust particle system in a capacitive HF discharge with respect to the “heartbeat”.

A typical stability chart for the system of dust particles with a void in a capacitive HF discharge is shown in Figure 2. The experiments on controlling the "heartbeat" were performed at the pressure of 20 Pa near the lower (in power) border of the instability region. The discharge was brought to a stable state by lowering the discharge power by 0.1-0.2 W below the threshold.

Figure 3a shows the dependency of the "heartbeat" rate on the frequency of the laser beam modulation at the constant power of 3.5 MW. It indicates that excitation of the "heartbeats" has a resonant nature. Figure 3b shows the dependency of the "heartbeat" rate on the laser output power at the constant modulation frequency of 55 Hz. Fourier analysis of the intensity of plasma emission from the void allows one to assume that laser excitation of the "heartbeats" has the character of a parametric instability.

Figure 4 shows the dependency of the "heartbeat" rate on the fraction of the volume of the void illuminated by the laser beam. One can see that it is the impact on the area of the void that is responsible for laser excitation of the "heartbeats.

Therefore, the mechanism of occurrence of the "heartbeat" must include some critical phenomenon inside the void. The hypothesis presented in this paper is that this critical phenomenon is the appearance of a near-electrode sheath-like structure on the border of the void.

In fact, the inner surface of the void is a porous wall. If this wall is sufficiently loose, the plasma losses occur mainly on the inner surfaces of the discharge chamber. The void border does not appear to be a special point. However, if the density of the dust component is being gradually increased, it will eventually reach the level at which the plasma loss at the void border is so great that the drift velocity of the ions reaches the Bohm speed. Then, the quasi-neutrality near the void border will inevitably be broken and the sheath will appear. The electric field at the void border will increase dramatically, while the ion drag force will not change much (the ion flux changes continuously). This will lead to the observed collapse of the void.
Estimates of the initial velocity of the dust particles during the collapse, the plasma parameters and the dynamics of the radiation intensity made based on this hypothesis confirm its plausibility, although no direct formation of the sheath at the void border by excitation of the "heartbeat" has been observed yet.

References
[1] Alexandrov N L, Napartovich A P 1993 Uspekhi Phys. Nauk 163 1 (in Russian)
[2] Chabert P, Lichtenberg A J, Lieberman M A, Marakhtanov A M 2001 Plasma Sources Sci. Technol. 10 478
[3] Morfill G E, Thomas H M, Konopka U, Rothermel H, Zuzic M, Ivlev A, Goree J 1999 Phys. Rev. Lett. 83 1598
[4] Pustylnik M Y, Ivlev A V, Sadeghi N, Heidemann R, Mitic S, Thomas H M, Morfill G E 2012 Phys. Plasmas 19 103701
[5] Thomas H M et al 2008 New J. Phys. 10 033036

Figure 3. Dependency of the “heartbeat” rate (a) on the frequency of modulation of the laser beam with the permanent emission power of 3.5 MW and (b) on the emission power at the constant modulation frequency of 55 Hz.

Figure 4. Dependency of the “heartbeat” rate on the laser beam coverage of the void area.