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Plasma afterglow with large dust density

I. Stefanović [(1,*)], I. Denysenko [(2)], B. Sikimić [(1)] and J. Winter [(1)]

[(1)] Institute of Experimental Physics II, Ruhr-Universität Bochum, D-44780 Bochum, Germany

[(2)] School of Physics and Technology, V. N. Karazin Kharkiv National University, Svobody sq. 4, 61077 Kharkiv, Ukraine

[(*)] **ilija.stefanovic@rub.de**

Recently, the properties of dusty plasma afterglow have been investigated experimentally [1, 2] and some of the afterglow properties like different diffusion modes have been analyzed by using of numerical simulations [3]. The properties of plasmas with large dust density, which satisfy the condition that total dust charge density is larger then free electron density, are strongly determined by the presence of dust particles. It is already known that in the active plasma phase the dust particles induce additional electron losses making the plasma electronegative with much higher electron temperature [1]. The dust generation and suppression can be regulated by appropriate pulsing [2, 4] and the pulsing frequency and duty cycle are important parameter for understanding the plasma chemistry of dust formation [5]. Beside that, a very interesting phenomenon of the increase of electron density in the early dusty plasma afterglow has been observed [2].

A spatially-averaged numerical model for an argon plasma afterglow with nano- and micro-sized particles (dust particles) is developed. The model consists of the balance equations for electrons, ions and Ar*($^3P_2$) metastable atoms, the equation for the dust particle charge and the power balance equation. The electron and ion losses and the electron energy loss on chambers' walls as well as on dust particles are accounted for. The large dust charge density n_dZ_d compared to the electron density n_e, is considered.

In the model different sources of the increase of electron density in the afterglow are assumed: ionization of Ar atoms (i), secondary electron emission on dust particles due to the ion – dust collision (ii), re-ionization due to metastable-metastable collisions (iii) and secondary electron emission due to the metastable-dust particle collisions (iv). The model is used to analyze the afterglow properties (the electron and metastable densities, the electron temperature, the dust charge, the electron and ion losses and the electron energy losses). The calculations are related to experimental conditions [1], and the calculated electron and metastable densities in the afterglow are compared with those measured in the experiments.

In Figs. 1 (a) and 1 (b), the metastable densities as a function of time are shown for the dust-free and dusty plasma afterglows. The metastable density in the dusty plasma is about one order of magnitude larger than the density in the dust-free plasma. The metastable density enlargement is due to enhancement of the electron temperature in the steady-state dusty plasma comparing with that in the dust-free plasma. In the dust-free as well as dusty plasma afterglows, the metastable atoms are lost from the discharge mainly due to their diffusion to the electrodes. In the dusty case, the diffusion loss dominates over the loss in metastable-dust collisions [1].

In Figs. 2(a) and 2(b), the electron densities as a function of time for the dust-free and dusty plasma afterglows are shown. In the dust-free case, the electron density decrease is dominated by diffusion of electrons to the chamber walls. In the dusty plasma experiment, the electron density first decreases with increasing of time *t*, then increases and reaches a maximum at $t \sim 0.5$ ms, and then again decreases. By using the model, different sources of increase of n_e in the early dusty plasma afterglow (processes (i) to (iv)) are included to calculate the electron density time decay and compare it with the experimental results (see Fig. 2 (b)). The preliminary result of the comparison rules out that the re-ionization due to metastable-metastable collisions (process (iii)) is one of the most important processes for the electron density increase in the dusty plasma afterglow containing a large amount of dust particles.

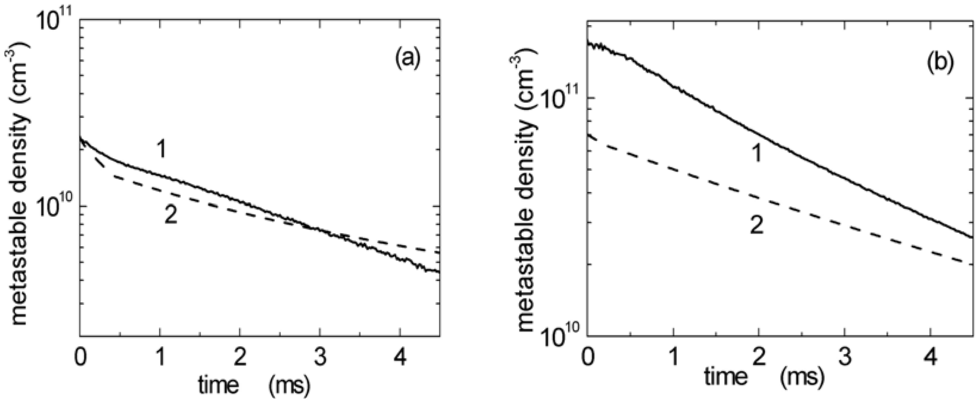

Fig. 1: The metastable densities as a function of time in the dust-free (a) and dusty plasma (b) afterglows. The solid curves: experimental results; dashed: model.

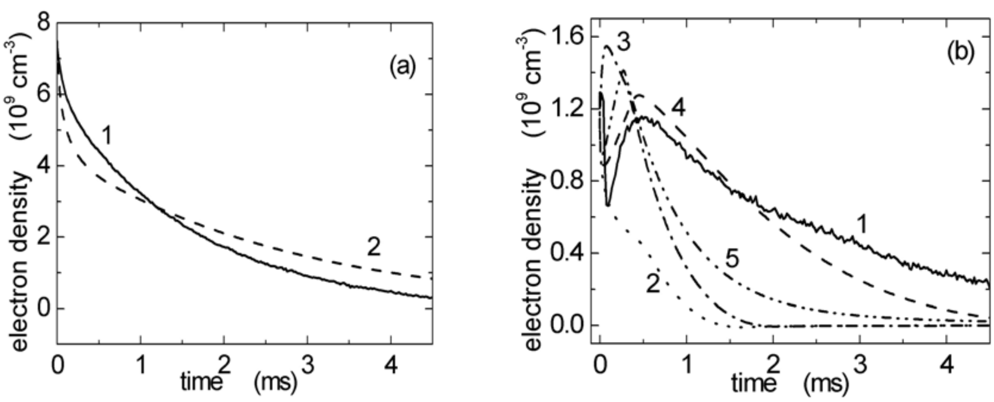

Fig. 2: The electron densities as a function of time in the dust-free (a) and dusty plasma (b) afterglows. (a) Solid curve: experimental results; dashed: model. (b) Solid curve: experimental results; curves 2, 3, 4 and 5 are calculated assuming that electrons are generated in the afterglow due to the processes (i), (ii), (iii) and (iv) , respectively.

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