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Modelling of argon-acetylene dust-forming plasma

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The properties of an Ar/C₂H₂ dusty plasma (neutral, ion and electron densities, effective electron temperature and dust charge) are studied using a volume-averaged model. The steady-state plasma is considered, as well as the case when the dust radius varies with time in the same way as in our experiments. It is analysed how different process conditions (absorbed power, input flux of acetylene, electron energy distribution function and nanoparticle density) affect the plasma properties. The results of our calculations are compared with our experimental results on growth of nanoparticles in an Ar/C₂H₂ plasma and the results are found to be in a good qualitative agreement.

A volume-averaged model of an argon-acetylene dusty plasma is developed. The model accounts for the most important neutral species and positive ions evidenced in our experiments [1, 2]. The case of a steady-state plasma is considered as well as the case when the dust radius varies with time in the same way as in our experiments.

For the steady-state case, it is studied how different process conditions (absorbed power, input flux of acetylene, electron energy distribution function (EEDF) and nanoparticle density) affect the densities of ions and neutral species in the plasma, including the densities of species taking part in the nanoparticle nucleation [1, 2]. The processes responsible for the production and loss of different ions and neutrals in the discharge are also analysed and the most important ones are identified. As a result of these studies and analyses, recommendations on the controlled growth of nanoparticles in Ar/C₂H₂ plasmas are formulated. In particular, it is concluded that Ar/C₂H₂ plasmas at moderate input flux of acetylene, low discharge power and with the electron energy distribution close to the Druyvesteyn EEDF are preferable for the production of carbonaceous nanoparticles.

For the nonstationary case, it is assumed that the duration of a nanoparticle-growth cycle is 108 s. During the first 20 s (phase I), the nanoparticle size is small and the nanoparticles do not modify any plasma properties (the dust density equals zero). For the next 88 s (phase II), the dust radius a_d increases linearly from 10 nm up to 70 nm at a fixed dust density ($\sim 10^7 \text{ cm}^{-3}$). At the end of a growth cycle, because of the interplay of different forces, the dust particles leave the plasma and a new growth cycle starts.

Using these assumptions based on our experimental observations [3], the time-dependent properties of an Ar/C₂H₂ dusty plasma (neutral, ion and electron densities, effective electron temperature and dust charge) are studied for conditions corresponding to our experiments on nanoparticle growth. The calculated density evolutions for C₂H₂, H₂ and C₄H₂ molecules are compared with time-resolved measurements of the mass peaks of the neutral species. In Fig.1 the results of this comparison for C₂H₂ and C₄H₂ molecules are presented, where the calculated densities of C₂H₂ and C₄H₂ are normalized on $9.56 \times 10^{12} \text{ cm}^{-3}$ and $3.346 \times 10^{13} \text{ cm}^{-3}$, respectively, to have the calculated maxima of these densities close to the maxima of the mass peaks in the experiment. The calculated densities of C₂H₂ and C₄H₂ are increasing during phase I. For phase II, the densities of these species first decrease, reach a minimum and then increase.

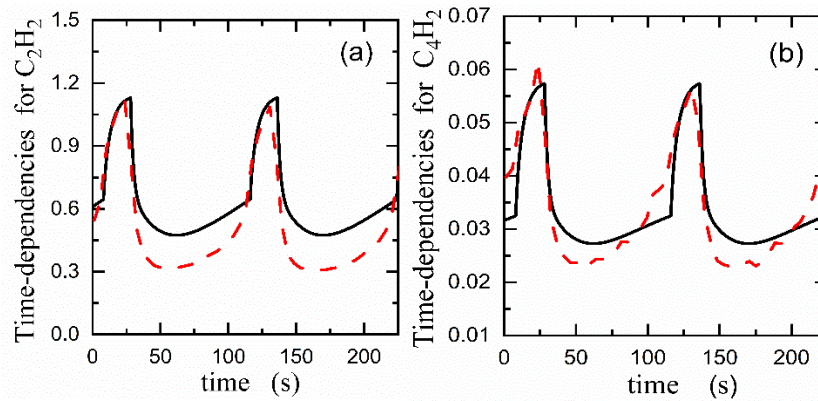


Fig. 1: The measured mass peaks (dashed lines) and the normalized calculated densities of neutral species (solid lines) for C_2H_2 (a) and C_4H_2 (b). Here, the phase I is between 8 s and 28 s, while the phase II is between 28 s and 116 s.

The decrease of C_2H_2 and C_4H_2 densities in phase II is due to an enhancement of losses of these nonradical species in collisions with positive ions, radicals and excited argon atoms [2]. The densities of C_2H_2 and C_4H_2 are increasing at large times in phase II due to a reduction in the densities of electrons, excited argon atoms and C_2H radicals with growing dust radius.

We also calculated the dust radius as a function of time (Fig. 2). The calculations were carried out assuming that the dust particle growth is due to deposition on the dust surface of positive hydrocarbon ions and C_2H radicals. It was assumed that the dust material density is 1 g cm^{-3} and that the dust radius is 10 nm at the beginning of phase II. The calculated radii were found to be in a good qualitative agreement with the experimental measurements presented in [4]. The results of our calculations also showed that the positive hydrocarbon ions contribute more essentially to the particle growth than the C_2H radicals.

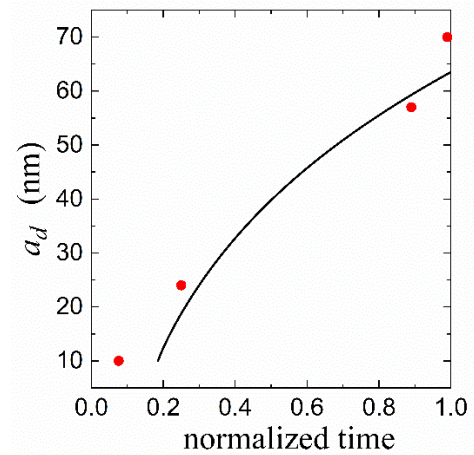


Fig. 2: The calculated dust radius (solid line) and the measured dust radius (circles) from [4]. The normalized times 0 and 1.0 correspond to the beginning of phase I and the end of phase II, respectively.

Acknowledgments

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