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Plasma non-stationarity as a precursor for nanoparticles growth

V. Vekselman[1], M. N. Shneider[1], and Y. Raitses[1]
[1] Princeton Plasma Physics Laboratory, Princeton USA
e-mail (speaker): vekselman@pppl.gov

In many different fields of nanoscale science, the pathway by which particles are formed is a critical knowledge. In many laboratory and industrial plasmas production of nm- and µm-scale particles are commonly observed. These particles surrounded by a stationary plasma are subjected to charging processes resulting in formation of unipolar charge distribution as predicted by theory. As a result, Coulomb repulsion forces inhibit growth rate and limit the size of particles forming in plasma. However, numerous dusty plasma studies reported about formation of large agglomerated particles thus questioning the validity of theory predictions. In attempt to explain this contradiction, several models predicting attraction between similarly charges macroparticles were proposed. It was also proposed that the particles in plasma have opposite charges. A number of physical mechanisms which could potentially explain the formation of specific size and charge distributions of dusty particles were suggested including the electron emission from these particles (secondary, thermionic, photoelectric, etc.) [1], charge fluctuations, effects of imaginary potential and ion trapping [2]. A modified orbit-motion limited OML theory (so-called, OML+) for the description of dust-plasma interactions was also developed [3] and included a more accurate description of particle charging and heat exchange processes. However, most of these models are lacking experimental validation and verification.

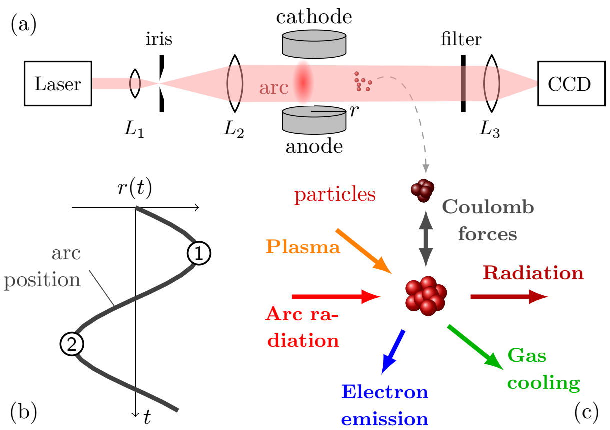

Fig. 1. (a) Schematics of the experimental setup used to study growth of nanoparticles in a non-stationary plasma discharge, (b) a motion of the arc used in modeling which consider (c) a variety of interactions between nanoparticles and plasma species.

In this work we demonstrate how non-stationarity of atmospheric pressure plasma [4] can promote formation of bipolar charge distribution of nanoparticles (Fig. 1 and 2). As a result, Coulomb forces reversal from repulsive to attractive between nanoparticles accelerates the growth rates (Fig. 3). This mechanism may explain an experimental observation of the grow of large micron size particles in the carbon arc (Fig. 2) [5].

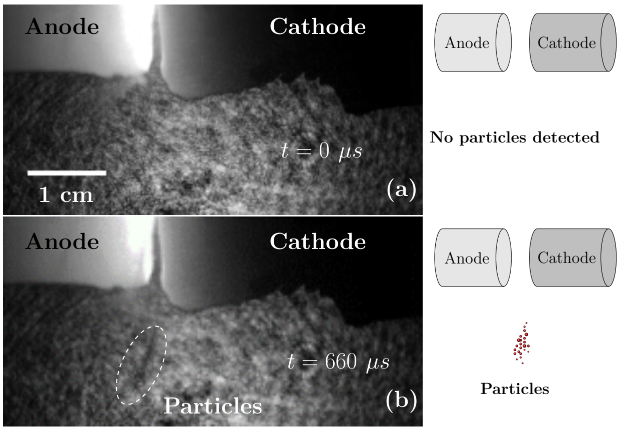

Fig. 2. Recorded images where particles are (a) not detected and (b) detected with a time difference of 660 µs. Detected particles are encircled at the bottom of the image (b) and schematically shown in the cartoon on right hand size.

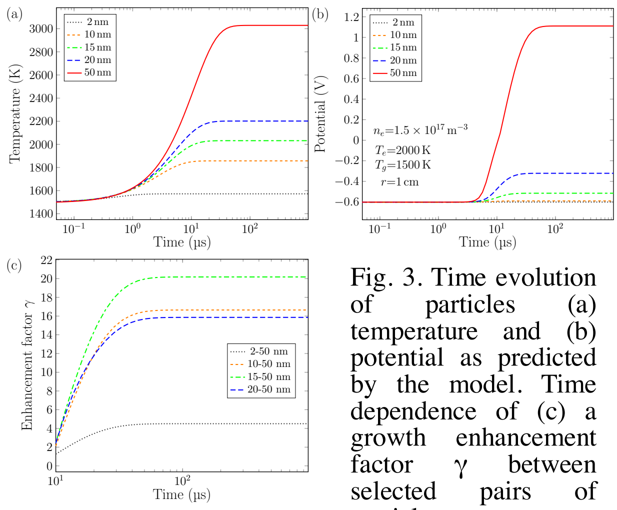

Fig. 3. Time evolution of particles (a) temperature and (b) potential as predicted by the model. Time dependence of (c) a growth enhancement factor γ between selected pairs of particles.

References

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