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Langmuir Probe Measurements in a Complex Plasma under Microgravity Conditions

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Abstract

The plasma parameters of a complex plasma have been measured under microgravity conditions using a cylindrical Langmuir probe. One- and two-dimensional profiles of dusty and void regions are obtained, which show a flattened distribution of plasma potential and electron density. Characteristic changes of the plasma parameters correlate with the geometry of the particle cloud.

1 Introduction

In laboratory plasmas micron-sized particles are confined only in the lower plasma sheath due to the dominance of gravity [1]. Therefore Langmuir probe measurements in the bulk of complex plasmas are still rare [2]. Under microgravity conditions the particles fill a three-dimensional volume of the bulk plasma [3]. In many cases the particle distribution is inhomogeneous and a large particle free region (void) forms in the plasma center. The mechanism of this phenomenon is still not fully explained. Therefore it is highly desirable to use Langmuir probes under microgravity to obtain the plasma parameters with spatial resolution in dusty plasmas. Such Langmuir probe measurements have been performed for the first time in complex plasmas on parabolic flights in a cooperation between IEAP, University Kiel and MPE, Garching.

The main goals of this campaign are to demonstrate rapid scan techniques with automated Langmuir probes, to study the interacting of probe and dust cloud, and to obtain first sample parameters of the plasma parameters. Interesting investigations are related to the question of electron depletion in the presence of dust as a consequence of particle charging, or the appearance of the void in the center of the plasma [3, 4]. To identify the relevant forces one needs to know the plasma parameters in the presence of dust particles. These experiments are a pre-stage towards a probe diagnostic for the International Microgravity Plasma Facility.

2 Experiment, results and discussion

The experiments have been performed in the PKE discharge chamber, which was designed and extensively used by MPE [3]. It has two symmetrical electrodes at a distance of 30 mm that are driven at 13.56 MHz rf power. The dust particles are spherical plastic particles of 3.4 μm diameter. The results presented below have been obtained in argon at a gas pressure of 37.5 Pa and 80 V_{pp} rf voltage. The Langmuir probe system was developed at IEAP and was specially designed for the use in the small sized rf plasma of PKE and for work under microgravity conditions during parabolic flights.

The probe can be shifted vertically and rotated about the probe shaft to scan a two-dimensional cross section trough the center of the plasma. The dust particles are illuminated by a laser fan and are observed by a ccd-camera. The experiment, field of view for the camera and an example of the dust cloud is shown in figure 2.

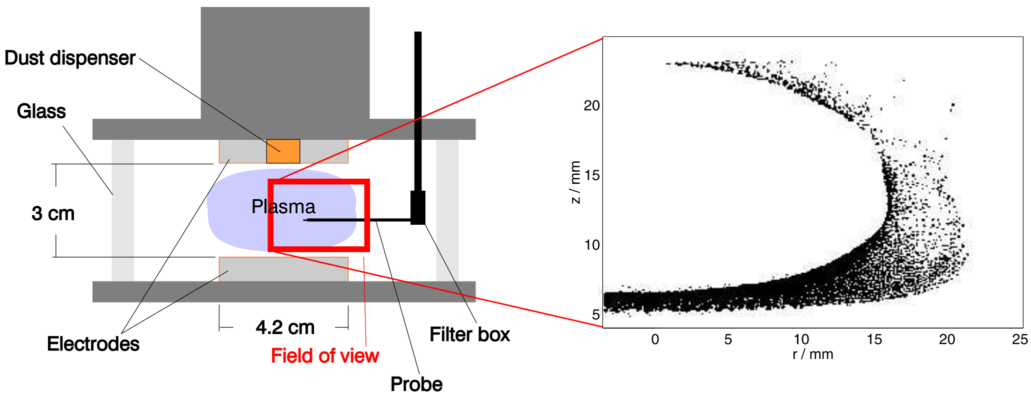

Figure 1: Scheme of the discharge chamber, camera field of view and dust distribution for the parameters of the presented experiment.

For each parabola microgravity conditions are available for 20 s. During this time typically 10 to 36 probe characteristics can be recorded. The presented parameter profiles are composed of 2D-scans during three subsequent parabolas, then comprising 9 $\times$ 12 data points.

The applied probe voltage sweep was a simple sawtooth function. One result of this campaign was that the negatively charged particles were effectively attracted and deposited on the probe when the voltage sweep exceeded the plasma potential despite of the short duration of this phase. As can be seen in the camera observations and from later experiments in the laboratory the particles reach the probe from outermost tip and contaminate the probe during the measurement period. The probe contamination eventually results in a reduction of the electron current by a factor of 4 to 5. The data presented subsequently were obtained in the early

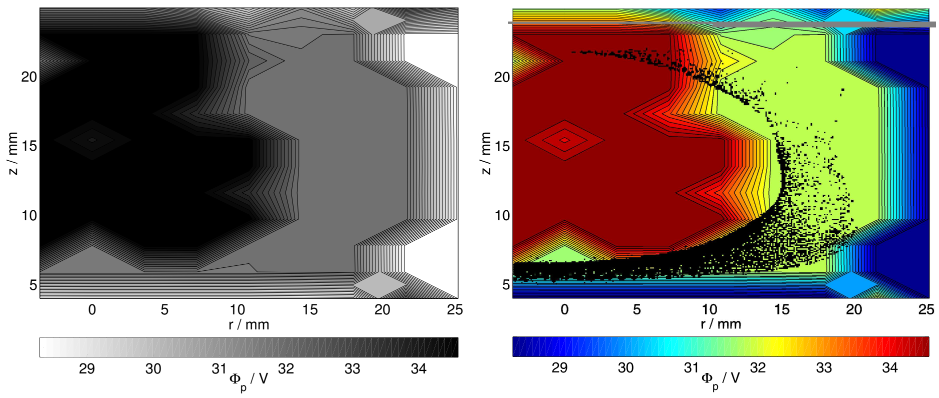

Figure 2: (a) plasma potential and (b) the plasma potential profile with the superposed particle cloud. The electrodes extend to $r = 21$ mm.

phase of this contamination process, were the reduction in ion current is less than 40%. The presented data have not been corrected for this effect, yet. Recent laboratory experiments have shown that the contamination of the probe can be effectively suppressed by using a random probe voltage that consists of alternating voltage settings at a high frequency.

Figure 2(a) shows the plasma potential profile. As expected the plasma potential increases in vertical direction from the electrodes to the center. However, here we find a sharp potential drop of $\Delta\Phi = 2V$ at a radial position of r =10 mm. The inner, high potential side corresponds to the dust-free void region, whereas the low-potential region is correlated with the presence of the dust cloud (see fig. 2(b)). The boundary of the dust cloud and the steps in plasma potential show remarkable agreement.

As further finding, the plasma potential profile very well matches the electron density profile. There, a density drop of $\Delta n_e = 3 \cdot 10^7 cm^{-3}$ is found in the transition to the dust region (see fig. 3(b)).

From the probe characteristics a quite high electron temperature T_e in the plasma area between the electrodes is derived (see figure 3(a)). The electron temperature profile attains its maxima near the electrodes. A similar trend for the electron temperature was found in numerical simulations from Akdim $et\ al.$ [5].

To judge the influence of the dust on the plasma, the charge density of the dust cloud was calculated using the average interparticle distance of 300 μm, the particle diameter, the measured electron temperature and the corrected density. The Havnes depletion parameter[6] $P = \frac{4\pi\epsilon_0 a}{e}\frac{kT_e}{e}\frac{n_d}{n_e}$, with particle radius a, the dust density n_d and the undisturbed electron density n_e, of the order of unity is found. This means that the charge bound on the particles is comparable to the free electrons in the plasma. The presence of dust then results in a relevant

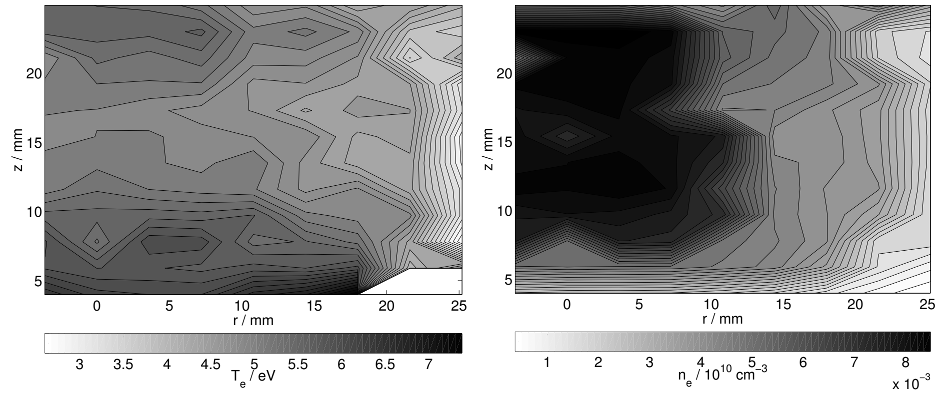

Figure 3: (a) electron temperature and (b) electron density for $p = 37.5\ Pa$ and $U_{rf} = 80\ V_{pp}$.

depletion of free electrons and a plasma potential reduction in the particle cloud. This is in a good agreement with the observed plasma parameter profiles.

This first Langmuir probe experiment under microgravity conditions demonstrated the applicability of this diagnostic to study inherent effects of complex plasmas.

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