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ION ACOUSTIC WAVES IN PLASMAS CONTAINING DUST OR NEGATIVE IONS

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The presence of dust influences the electrostatic plasma waves in different ways. For dust density waves, the dust particles represent a dynamical component of the wave process. For ion acoustic waves, the dust particles remain at rest and influence the wave propagation only by their effect on the overall charge balance, in a similar way as negative ions reduce the density of free electrons. Therefore it is meaningful to compare the propagation and damping of ion acoustic waves in both situations within the same experimental arrangement. An increase of the phase velocity in the presence of negative ions was reported earlier in Refs. [1, 2]. A similar effect in a dusty plasma was found in Refs. [3, 4].

The experiments are performed in a double plasma device of 50 cm diameter and 100 cm length [see Fig. 1(a)]. For experiments with negative ions, the source chamber (left) is operated at an argon pressure of $p_{Ar} = 1 \times 10^{-2}$ Pa, and $I = 400$ mA discharge current, which results in a source plasma with a typical ion density $n_i = 5 \times 10^{15}$ m^{-3} and electron temperature of $T_e = 2$ eV. There is no plasma production in the target chamber (right). Rather, plasma diffuses through the combination of a negatively biased (- 100 V) grid and a magnetic filter. This results in a low density ($n_i = (0.3 \ldots 1) \times 10^{14}$ m^{-3}) and cold ($T_e = 0.8$ eV) target plasma. Only at electron temperaures well below 1 eV negative SF_6^- ions can be formed by electron attachment.

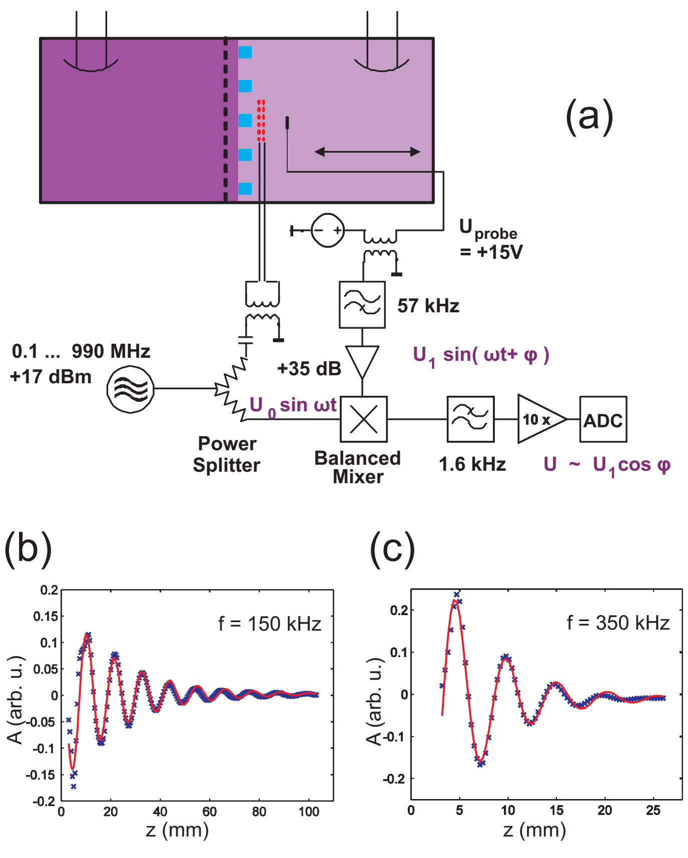

Figure 1: (a) Double plasma device with r.f. interferometer, (b) interferometric trace and fit function in pure argon gas at 150 kHz, (c) same at 350 kHz.

The ion acoustic wave is excited by a

double grid and detected as fluctuation of the electron current to a plane probe, which is biased at +15 V. The wave signal is processed in a r.f. interferometer, which yields the real part of the wave, $U \propto U_1(z)\cos\varphi(z)$, where $U_1(z)$ is proportional to the wave amplitude at the probe position z and $\varphi(z)$ the phase difference with respect to the exciter signal. By shifting the probe along z interferometric traces [see Fig. 1(b),(c)] are obtained.

These interferometer traces are fitted by a damped wave with a complex wavenumber $k_r + \mathrm{i}\,k_i$

$$A(z) = \hat{A}\cos(k_r z + \delta)\exp(-k_i z)\ , \qquad (1)$$

where δ is an initial phase at $z = 0$ and $\hat{A}$ the initial amplitude. From such fit functions for various exciter frequencies ω we determine the phase velocity $v_{ph} = \omega/k_r$ and the damping rate k_i. In a plasma where part of the electrons are bound to an immobile species, like heavy negative ions or dust, the influence on the phase velocity of the ion acoustic wave is determined by $n_i \neq n_e$.

The phase velocity then takes the limit

$$v_{ph} = \frac{\omega_{pi}\lambda_{De}}{(1+k^2\lambda_{De}^2)^{1/2}} \rightarrow \left(\frac{n_i}{n_e}\frac{k_B T_e}{m_i}\right)^{1/2} \qquad (2)$$

for $k^2\lambda_{De}^2 \ll 1$. Here m_i is the positive ion mass.

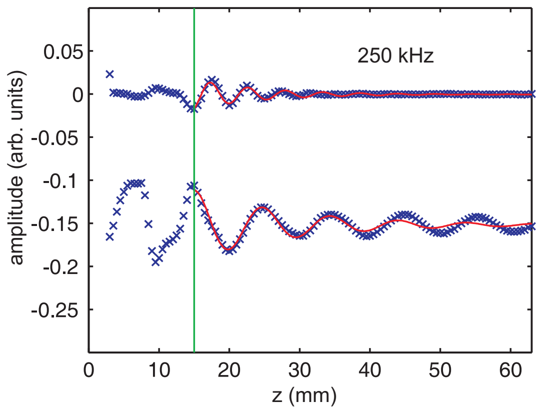

Figure 2: Interferometric wave signal in pure argon (top trace) and Ar-SF_6 mixture (bottom trace; vertically shifted). ($n_e = 5\times10^{15}\ \mathrm{m}^{-3}, T_e = 2$ eV)

Negative ions are produced by leaking SF_6 gas into the argon discharge plasma. The effect on the ion acoustic wave is an increase of the wavelength, as can be seen in Fig. 2, where interferometric traces for pure argon and 10 % SF_6 admixture are compared. The fit function is applied for $z > 15$ mm.

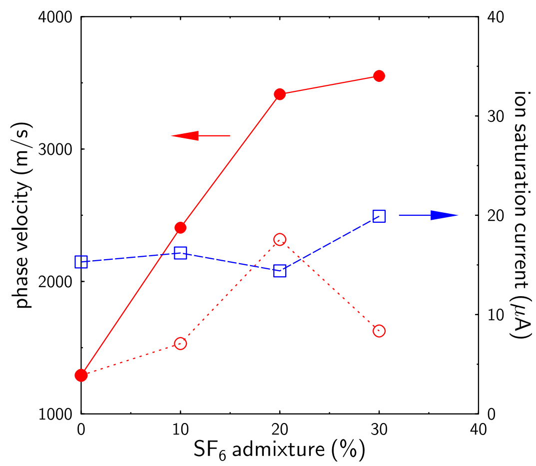

Figure 3: Full circles: phase velocity of the ion acoustic wave as function of the SF_6 admixture. Open circles: phase velocity corrected for increase in electron temperature. Squares: ion saturation current of a plane probe.

With increasing concentration of SF_6, the phase velocity (full circles in Fig. 3) is found to increase above its value in a pure argon plasma. This effect is expected from the decrease of the relative electron density, i.e. the factor n_i/n_e in Eq. (2). We have monitored the positive ion density in this series of experiments by measuring the ion saturation current of a plane probe at a high negative bias (-130 V). The ion density is almost constant with a slight increase at the highest (30 %) admixture of SF_6 (see squares in Fig. 3). This rules out that the increase of phase velocity is affected by a change in ion density. As an additional test we have measured the effect of the SF_6 admixture on the electron temperature. The electron temperature is found to rise up to 3.67 eV at 30 % SF_6 admixture. When we correct the phase velocity by a factor $[T_e/T_e(0)]^{1/2}$ (see open circles in Fig. 3), there still remains an increase of phase velocity, which can be attributed to the reduction in electron density by the formation of negative ions.

For experiments with dust (see Fig. 4) we use a dust dispenser consisting of a sieve with 125 μm mesh width and 95 mm diameter that is agitated by three DC-motors with an attached eccentric mass. The dust particles are glass microballoons of $(20\ldots25)$ μm diameter. The resulting dust density is $n_D = (20\ldots80)\times10^6\mathrm{m}^{-3}$.

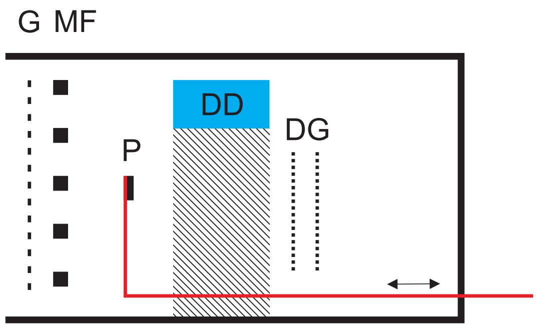

Figure 4: Dust is released from a dispenser (DD) with 95 mm diameter and fills the hatched region between the double grid exciter (DG) and the moveable probe (P).

Interferometric traces for the case of a pure argon plasma and a dusty plasma are compared in Fig. 5. The presence of dust leads to a generally lower amplitude of the wave. In addition, the damping rate of the wave is higher in the presence of dust. For comparing the wavelengths in the two situations, a region was selected (marked by the green vertical lines) where the wave can be described as an exponentially damped cosine. The lower trace shows that additional structures appear at larger distances from the exciter, which cannot be described by such a fit function. The wavelengths in pure argon plasma and dusty plasma are indistinguishable. This means that the reduction of the mean electron density by the presence of dust is still too small.

Comparing with the situation in Ref. [4], those authors were using particles of 8.8 μm diameter whereas our microballoons had (20 – 25) μm diameter. Therefore, and because of a high mass flow rate, the dust number density in Ref. [4] was higher by 2–3 orders of magnitude. On the other hand, in our experiments the particle charge, which is proportional to the particle radius, was larger by a factor of 2.5 and the ion density lower by one order of magnitude. Hence, the parameter $P = 4\pi\lambda_{De}^2 r_p n_D$ introduced by Havnes to describe the attachment of electrons to the dust particles, has values of $P = 0.1\ldots12$ with a mean value of $P = 1.2$ in [4] whereas $P = 0.014$ in this work. Consequently, the dust density in our experiments was still too low to affect the phase velocity of the ion acoustic wave.

On the other hand, the presence of large dust particles leads to a reduction of plasma density, approximately by a factor of 2, as obtained from the ion saturation current. A similar effect was observed earlier by Trottenberg et al [5] with microballoons of the same size and similar plasma conditions. The density reduction was attributed to additional plasma losses on the surface of the dust particles ("internal wall effect"). In the present experiment, the addition of dust has also led to a reduction in wave amplitude, to an enhanced damping rate, and to interference phenomena that might be related to scattering by the large dust particles.

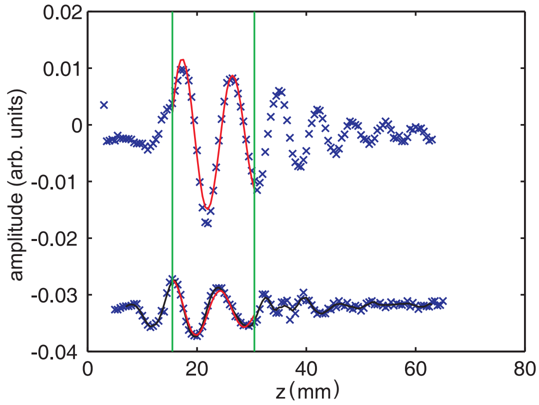

Figure 5: Interferometric traces in a dust-free (top trace) and dusty (bottom trace; vertically shifted) argon discharge.

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