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MEASUREMENTS OF ARGON-ION FLOW IN NEGATIVE ION CONTAINING PLASMAS

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A laser-induced-fluorescence diagnostics was set up for the investigation of ion flows in negative ion containing plasmas. The contingent of negative ions in Ar plasmas is varied by admixing O_2. Results on flow measurements in different plasma devices are reported. First measurements were carried out in the linear double-plasma device, in the sheath region in front of an electrically floating plate, where negative ions are expected to modify the sheath potential and, hence, the ion flow to the wall. In a second step, LIF is used to characterize Ar-ion flows and temperatures in the toroidally confined plasma of the torsatron TJ-K with the aim to study the influence of negative ions on drift-wave turbulence in fusion edge plasmas.

Keywords: Laser-induced-fluorescence, Argon ion flow, negative ions, ion temperature, sheath potential

1. Introduction

In many technical plasma processes, the ion energy has an important influence on the process quality. The ions gain their energy from the potential drop in the sheath region. Negative ions influence the sheath potential and thus the ion energy. Information on the ion-velocity distribution function (IVDF) provide insight into the physics of plasma processes, which is not only important for improving the quality of processes in industrial applications as, e.g., plasma etching, but also for a detailed understanding of plasma-wall interactions as well as plasma dynamics in fusion devices. The laser-induced-fluorescence (LIF) [1, 2, 3] is a well approved diagnostics for ions in low temperature plasmas. It allows to measure, spatially resolved, the ion-velocity distribution function. From the IVDF the ion temperature and the mean ion velocity can be calculated. A main feature of LIF is that it is a non-invasive diagnostics allowing measurements in sheath regions. The objective of this work is to study the impact of negative ions on the sheath formation and plasma dynamics. Details on the LIF diagnostics are given in Sec. 2. In a first step, the dependence of the plasma potential in the presheath of a double-plasma device on different Ar/O_2 mixtures is investigated in Sec.3. In Sec. 4, first results on preliminary LIF measurements in the toroidal plasma experiment TJ-K are presented. A summary is given in Sec. 5.

2. LIF Diagnostics

The spatial resolution of the LIF diagnostics is limited by the observation volume given by the crossing point of the laser beam and the detection optics. The cross section surface of the laser beam is about 10 mm^2 and the width given by the detection optics can be as small as 0.5 mm. The system consists of a diode laser with an optical output of 25 mW at 668.6 nm and a mode-hop-free tuning range of 20 GHz. It is modulated with an acoustic optical modulator. For wavelength measurements, a wave meter from Advantest is used with a resolution of 0.1 pm and an absolute error of 2 pm. The fluorescence light is filtered through an interference filter with a bandwidth of 2.5 nm and is detected with a photo multiplier tube. For data acquisition, a 24-bit 100 kS/s PC card is used. The ion temperature can be measured with a resolution of 0.02 eV and the mean velocity with a resolution of 100 m/s.

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3. Sheath-potential measurements

LIF measurements in the sheath of a double-plasma device have been done by Clair et al. [4]. Takizawa et al. used the LIF-DIP method [5, 6] to measure directly the electric field in the sheath of an electronegative plasma containing Argon and SF_6. Our aim was to use Oxygen to create negative ions. The measurements were done on a double-plasma device with a length of 90 cm and a diameter of 31.5 cm. A grid divides the chamber into two parts: the source and the target chamber. The device was operated asymmetrically, only the filament in the source chamber was driven. The LIF setup was installed in the target chamber. The laser beam was directed axially through the device. The fluorescence light was collected perpendicular to the laser beam at a fixed position. The conducting and floating plate was movable to achieve a variable distance between measurement volume and plate. The ratio of Argon and Oxygen was controlled by mass flow controllers.

The results shown in Fig. 1 were obtained in a plasma with $T_e = 1.7$ eV, $n_e = 9 \cdot 10^{15}$ m^{-3} and $T_i = 0.07$ eV. The ion acoustic speed is $c_s \approx 2100$ m/s and the Debye length is $\lambda_D = 1 \cdot 10^{-4}$ m. Due to

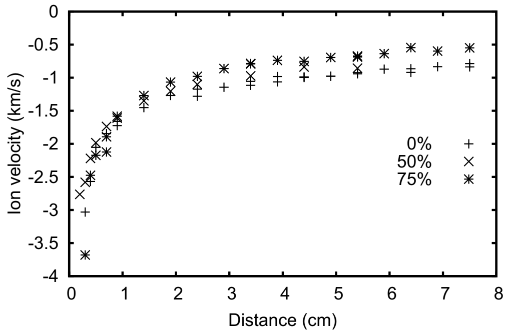

Fig. 1 Ion fluid velocity in the presheath for different Oxygen/Argon mixtures. The ratios are 0, 50 and 75% Oxygen in the mixture.

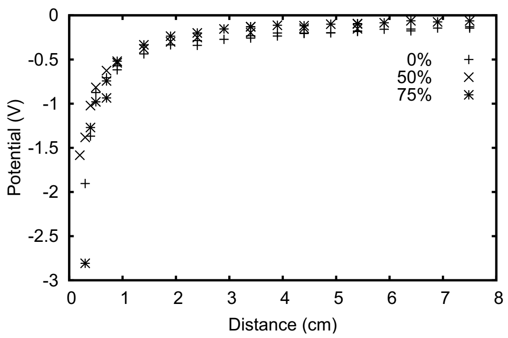

Fig. 2 Plasma potential in the presheath for different Oxygen/Argon mixtures. The ratios are 0, 50, 75% Oxygen in the mixture.

the small extension of the sheath in the range of several λ_D the diagnostics is only capable of resolving the presheath with a length of about 400 λ_D. The measurements show that the ion acoustic speed is reached as the Bohm criterion claims for the sheath edge. Assuming that the ions gain their kinetic energy from the presheath potential this potential can be calculated from the data. The theoretical model [7] for the sheath structure in electronegative plasmas predicts that the potential at the sheath edge between sheath and presheath is decreasing by an order of magnitude if the plasma is dominated by the negative ions. A transition from an electron dominated plasma to a negative ion dominated plasma is predicted if the ratio of negative ions to electrons α is about $\gamma = \sqrt{\frac{T_e}{T_-}}$. As one can see in Fig. 2, there is no significant effect on the ions in the presheath by changing the Oxygen Argon ratio. This leads to the assumption that α is below the critical value. The relevant parameter for this study would be the negative ion/electron density ratio, which will be measured in the future by a probe, which is similar to a ball pen probe [8].

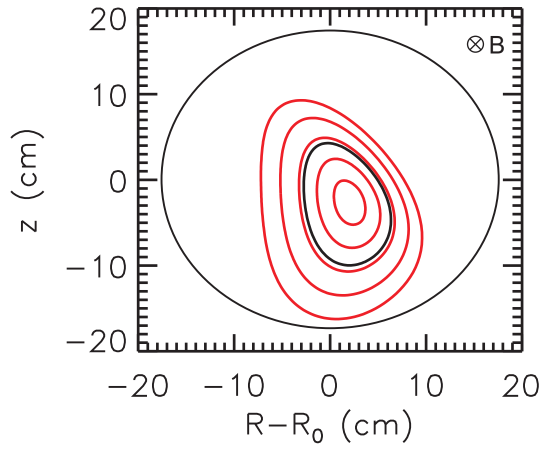

Fig. 3 Flux surfaces in the LIF measurement plane at $\phi = 19°$.

4. LIF on TJ-K

TJ-K [9] is a torsatron with a major radius R_0 of 0.6 m and a minor radius a of 0.1 m. The 2.45 GHz microwave resonance heating produces a low temperature plasma with electron temperatures of $T_e \approx 10$ eV and densities of $n_e \approx 10^{17}$ m^{-3}. Thus, the plasma is accessible with Langmuir probes which allows detailed turbulence investigations. In addition, the LIF diagnostics was installed on TJ-K to measure Argon ion temperature and ion flows. Fig. 3 shows flux surfaces of the poloidal cross section where the LIF measurement was carried out.

The ion temperature was measured under variation of the neutral gas pressure. For comparison with experimental results, a diffusion model was developed. It consists of diffusive particle- and energy-balance equations for ions and electrons taking into account ionization, recombination, collisions with neutrals and electron-ion energy transfer. The input parameters are the neutral gas pressure, the heating-power profile and the transport coefficients D_e, D_i (particle diffusivities) and χ_e, χ_i (heat diffusivities) for electrons and ions, respectively. The neutral gas pressure, the heating-power profile, D_e and χ_e are known from experiments, and the ion-transport coefficients were assumed to be $D_i = D_e$ and $\chi_i = 0.1\chi_e$. For information on the collision cross sections we refer to C. Lechte et al. [10] where they are described in detail. The equations are solved numerically for the density and the temperature of electrons and ions. This model was used to compare calculated ion temperatures with the values from the LIF measurement.

In Fig. 4 the pressure dependence of the ion temperature is shown. The ion temperature T_i is decreasing with increasing pressure. The solid line shows the numerical result, which is in reasonable agreement with the measurements. Higher values of χ_i would lead to lower temperatures. Hence, no indication of

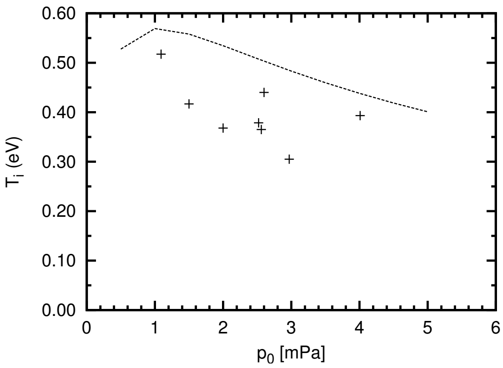

Fig. 4 Pressure dependence of the ion temperatures in TJ-K. Crosses represent experimental data, the solid line represents simulated data from the diffusion model.

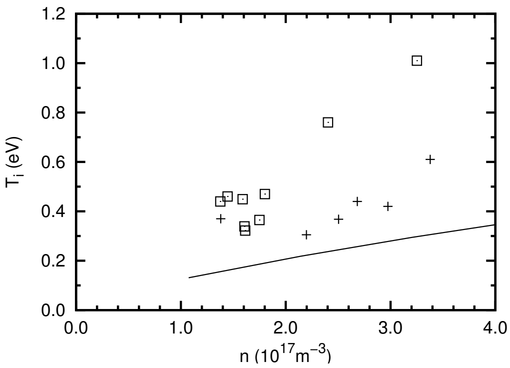

Fig. 5 Ion temperature versus the central plasma density. Crosses represent the measurements without biasing, boxes represent the measurements during biasing and the solid line represents the simulation data.

anomalous electron-ion coupling can be derived.

In Fig. 5 the ion temperature is plotted over the plasma density in the plasma center. Crosses represent the measurements with normal parameters, boxes represent the measurements during biasing [11] and the solid line represents the simulation data. The simulation shows qualitatively the same behavior as the measurements without biasing. The biasing changes the plasma profile so the parameters for the model do not represent this situation. But the trend of an increasing ion temperature with increasing density is still given.

5. Summary

A LIF diagnostics was set up to study the ion-temperature and -flow characteristics under the influence of negative ions. In a first step, the impact of different Ar/O_2 mixtures on the sheath potential in a double-plasma device was investigated. Even at Oxygen ratios of 75% in the gas mixture, the effect on the presheath was found to be marginal. As an outlook for the sheath measurements, pulsed discharges will be used to create higher fractions of negative ions. In the afterglow, the ratio of negative ion/electrons is increasing [12].

The measured ion temperatures are in reasonable agreement with a combined particle ion-energy balance model if the energy transfer to neutrals by elastic collisions is taken into account. Especially the trend to lower T_i at higher neutral gas pressure is recovered. Further experiments will investigate the ion behavior in drift waves and the influence of negative ions on it.

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