Anomalous Helicon Wave Absorption
and Turbulent Electron Heating in a Helicon Source

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Abstract. The helicon wave absorption and electron heating in a pulsed helicon discharge was examined. It was evidenced that the strong damping of the helicon wave as well as the electron heating is closely related to the excitation of turbulent ion-sound fluctuations originating from a parametric instability. The axial helicon wave damping was found to increase with the turbulence level of short-scale density fluctuations. The evolution of the fluctuations is related to the electron heating as shown by emission spectroscopy and compensated Langmuir probe measurements. These findings prove for the first time that the anomalous RF power absorption as well as the electron heating in helicon discharges can be associated with the excitation of small-scale turbulent fluctuations.

1. Introduction

Helicon sources are known to be very effective in producing high-density plasmas. The anomalous helicon absorption, already shown in the pioneering work of Boswell [1], can generally not be explained by collisional damping or electron Landau damping [2], as helicon waves are weakly damped. Recently, a kinetic instability leading to ion-sound turbulence was considered as a candidate accounting for the anomalously strong RF absorption [3]. Motivated by this work, we investigated turbulent plasma fluctuations excited by the helicon wave fields and their effect on the helicon wave absorption and the electron heating.

2. Experimental set-up

The measurements were carried out on the pulsed helicon source HE-L (r_p = 73 mm, l_p = 1.1 m, τ_{pulse} = 2–4 ms, f_{pulse} = 25 -100 Hz, P_{RF} < 2 kW, f_{RF} = 13.56 MHz, m = 1 helical antenna coupling, n_e < 2x10^{19} m^{-3} , T_e ≈ 3 eV, B_0 < 0.1 T, p = 0.2 – 0.5 Pa argon [4]). The helicon field was measured by means of a movable magnetic (B-dot) probe. The frequency spectra of the electrostatic fluctuations were taken by a movable RF electric probe and microwave scattering (Cross-correlation Enhanced Scattering: CES) [5]. The latter technique also provides the wave number spectra of the fluctuations. Langmuir probes, 4 mm interferometry and emission spectroscopy were applied as standard diagnostics.

3. Results

Characteristic for helicon discharges with helical antenna coupling is the pronounced axial asymmetry that can be attributed to the different propagation behaviours of the $m = +1$ and $m = -1$ modes in non-uniform plasma [6]. In Fig.1 we have plotted the wave field showing the $m = +1$ helicon mode travelling in positive magnetic field direction. From such measurements we deduced the RF magnetic energy density being the major fraction of the electromagnetic field energy density. The axial decrease of the energy density integrated over the plasma cross-section gives directly the axial damping decrement (Fig.2). It was found to be significantly larger than expected from a helicon wave guide model taking into account only electron-ion and electron-neutral collisions [6].
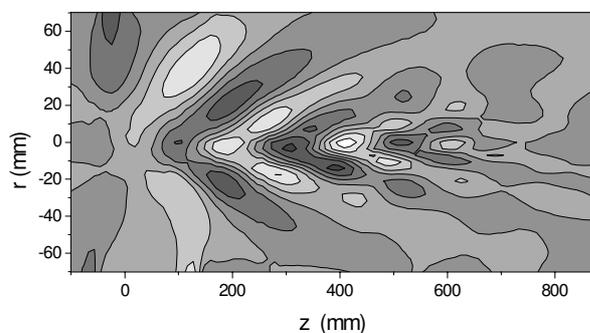

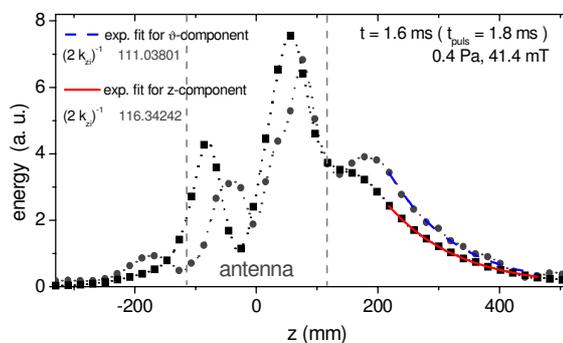*Fig.1: Snap shot of m = +1 helicon mode pattern (antenna position at z = 0)*

Fig.2: RF magnetic energy density integrated over plasma cross-section vs z

To investigate if the RF power absorption is caused by some nonlinear mechanism we measured the power dependence of the helicon wave damping. We applied a *double pulse* technique: The first RF pulse ($P_{RF} \approx 1$ kW) producing the *target* plasma was followed by a second pulse of variable (reduced) RF power. We thus achieve a nearly constant spatial density distribution over a period of the order of a few microseconds after the target pulse while the electron temperature decreases. Indeed, Fig. 3 shows that the damping decrement of the helicon mode decreases when the RF power coupled to the plasma is reduced. This cannot be explained by weaker collisional damping because electron-ion collisions predominate in our discharge and the drop of the electron temperature in the second pulse would lead to stronger damping.

We first studied if the anomalous damping is caused by a wave-particle resonance mechanism and, in particular, if the electrons are accelerated in the helicon wave field as proposed by Ellingboe et al. [8]. However, the temporally and spatially resolved measurements of the

ArII line emission reveal, within the detection limit of 1%, no intensity modulation. Electron trapping can therefore be excluded as a candidate for the anomalous damping or it plays only a minor role in our helicon discharge.

Measurements of the fluctuation spectra for different RF powers reveal that the fluctuation level increases and the spectra broaden above a certain threshold (Fig. 4). Fig.5 shows the evaluation of these results: The axial damping decrement of the helicon modes as well as the level of the fluctuations turns out to increase with RF power, thus proving the close relation between the helicon damping and the excitation of the fluctuations.
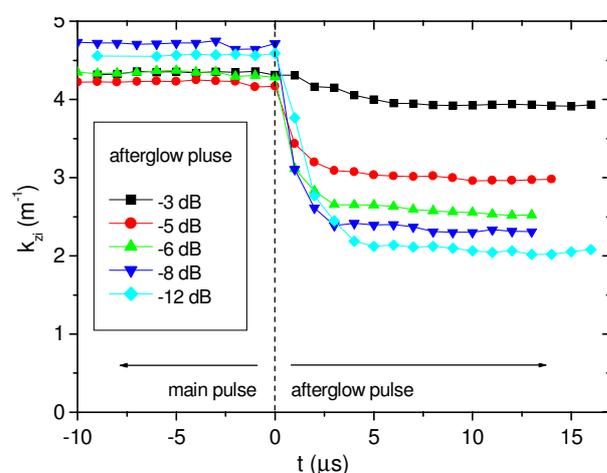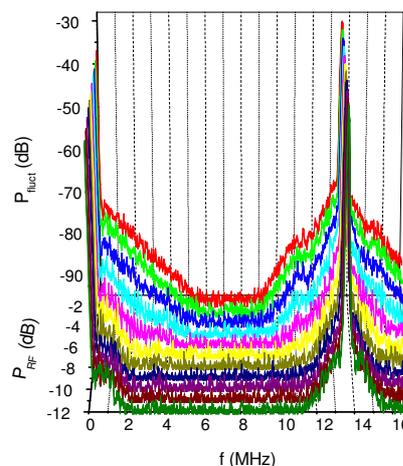
Fig.3: Snap shot of m = +1 helicon mode pattern

Fig.4: Fluctuation spectra for different RF powers

The RF probe measurements are in accordance with <u>C</u>ross-correlation <u>E</u>nhanced <u>S</u>cattering measurements [8,9]. In particular, the frequency spectra obtained from the two techniques are very similar. Moreover, the wave number spectra in the frequency range from 0 to 6 MHz reveal that the fluctuations have short wavelengths (down to 0.5 mm) and obey the ion-sound dispersion relation originating from a parametric decay instability. This is also supported by the threshold behaviour of the fluctuations as well as their rise-time at the beginning of the second RF pulse showing a linear dependence on the RF fields [9].

To study whether the electron heating is associated with the excitation of the short-scale turbulence we measured the temporal evolution of various quantities. Fig.6 shows the fluctuation amplitude measured by the RF electric probe, the damping decrement k_{zi} of the helicon wave field and the ArII line emission from which the evolution of the electron temperature can be deduced. The electron heating rate is approximately proportional to the time derivative of the temperature (bold line in Fig.6) and is expected to scale with the absorbed RF power

that is proportional to the axial damping decrement k_{zi}. The evolution of the various quantities in the second pulse is rather complicated because it occurs in two stages. In the second stage we observe a significant correlation between the heating rate and k_{zi}. Moreover, there is also a
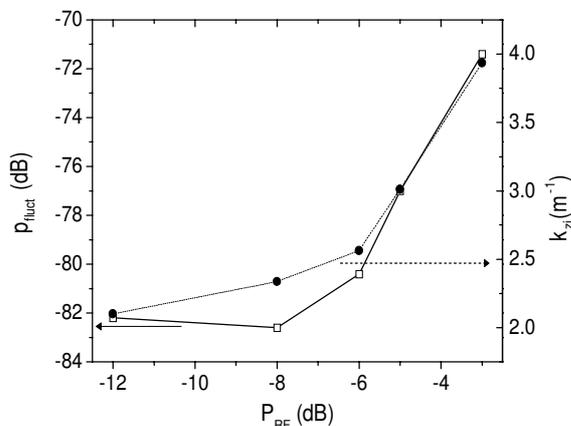
Fig.5: Dependence of fluctuation level and axial damping decrement on the RF power
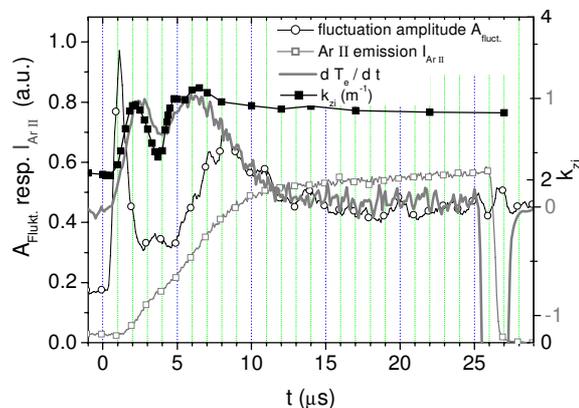
Fig.6: Fluctuation level, axial damping decrement and ArII emission in the second pulse

correlation between the two quantities and the fluctuation amplitude although the interdependence is more complicated and deserves more detailed investigations. Indeed, preliminary measurements show that the fluctuation level follows roughly the helicon wave amplitude, but it is also affected by the radial density profile, that is, the level is high where the gradient is steep. In conclusion, we state that the helicon wave absorption and the electron heating can be attributed to turbulent fluctuations excited by the helicon wave fields.

Acknowledgements

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