Investigation of a Parametric Decay Instability in the Helicon Discharge by Correlation Enhanced-Scattering Technique

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As it was shown recently [1], parametric decay instability can play an important role in the energy balance of the low pressure helicon discharge leading to heavy anomalous absorption of the pump wave. According to measurements performed with microwave enhanced scattering (ES) technique and probe diagnostics at modest magnetic field on the helicon device HE-L, electron plasma and ion acoustic decay waves excited by this instability propagate out of the active discharge zone in the radial direction. In the central region of helicon discharge the parametric decay lead to the ion acoustic density perturbation up to 10% in relative amplitude [2]. In this paper detailed measurements of the decay waves frequency and wave number spectra, carried out with correlative ES diagnostics [3] at high and low helicon discharge magnetic fields, are presented.

Experimental results.

The plasma in the large-volume helicon source HE-L was produced by RF power pulses ($P_{rf} \leq 2$ kW, $f_{\rm rf} = 13.56$ MHz, $\tau_{pulse} = 2$-3 ms, $f_{pulse} = 25$ Hz) excited with an inductive antenna surrounding a quartz tube of inner diameter $r_p = 73$ mm and length $L_p = 1.1$ m. We used a half-turn helical (*Shoji-type*) antenna of length $L_a = 220$ mm providing $m = +1$ ($m = -1$) helicon mode excitation in positive (negative) magnetic field direction. We applied 4 mm interferometry to measure the line-integrated electron density and used Langmuir probes to obtain the spatial distribution of the electron density and temperature. The plasma parameters were: $n_{\rm e} \leq 3\times10^{19}$ m^{-3}, $T_{\rm e} \approx 3$ eV in the center of the plasma and $T_e \approx 5$ eV at the plasma edge, $p = 0.2$-0.5 Pa.

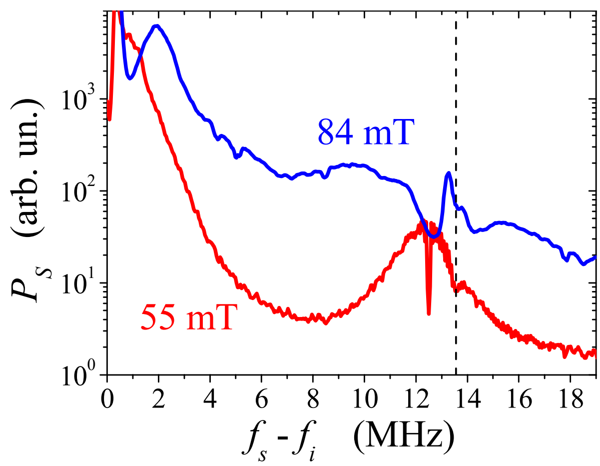

Fig. 1. *Homodyne ES spectra.*

The ES measurements, utilizing backscattering in the UHR vicinity [1, 2], were performed in 26 GHz frequency range at magnetic field $B_0 = 0.055$ T and $B_0 = 0.084$ T to visualize small-scale waves excited by parametric decay in the discharge central region. Quite unexpectedly at these magnetic fields substantially different homodyne scattering spectra are observed (fig. 1). At lower field the spectrum decreases quickly at 0.3 MHz < $|f_s - f_i|$ < 6 MHz, but possesses pronounced maximum at $|f_s - f_i|$ = 12.5 MHz (f_s, f_i – corresponds to scattered and incident wave frequencies). At higher magnetic field, on contrary, a strong maximum is observed at small frequency $|f_s - f_i|$ = 2 MHz, but no dominant component is observed in high frequency part at 6 MHz < $|f_s - f_i|$ < 12 MHz.

Even stronger difference of decay wave turbulence in these regimes was observed with correlation ES technique [3]. The plasma microwave probing was performed simultaneously at two frequencies in reference and signal channels. The variation of the frequency in the signal channel up to 5 GHz was used. Unlike previous experiments [1, 2], where real part of a cross-correlation function (CCF) was measured directly on low frequency detector, in this paper the homodyne detection signals provided by both channels of the correlation scheme were stored in the data acquisition and used afterwards for calculation of CCF as a function of the

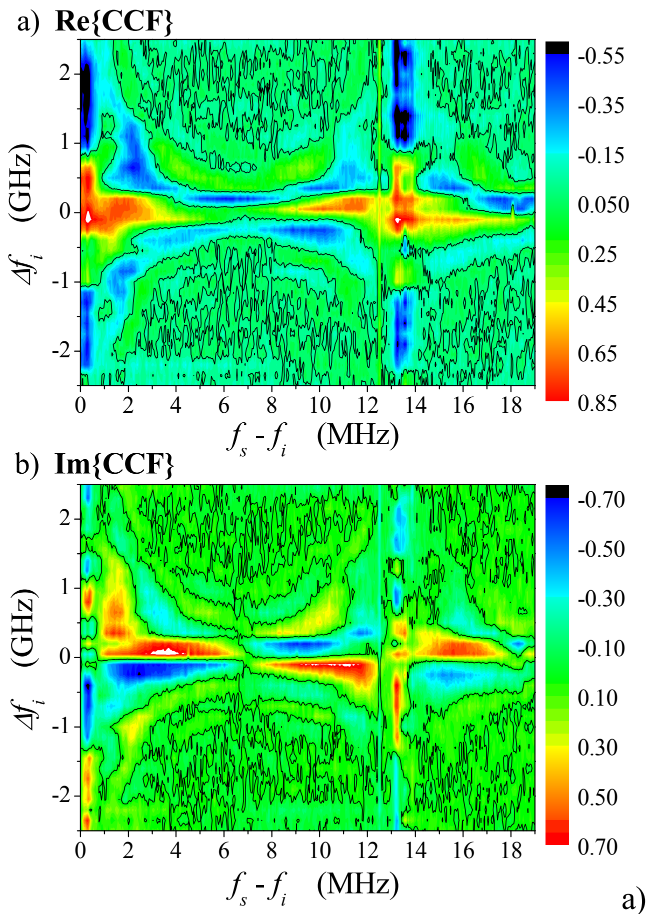

Fig. 2. *CCF real* (a) *and imaginary* (b) *parts.*

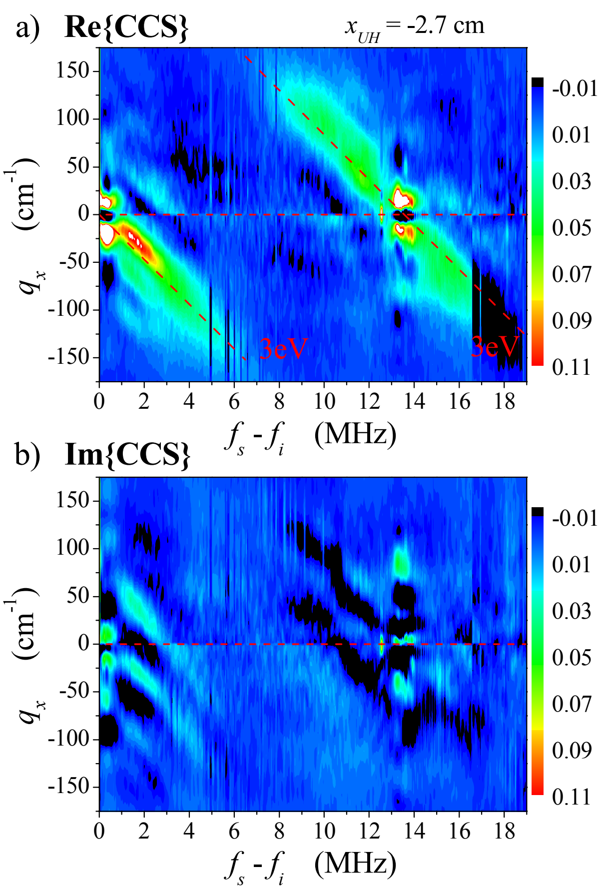

Fig. 3. *CCS for* 84 mT.

probing frequencies difference proportional to the radial separation of corresponding UHR points. The real and imaginary parts of the CCF are shown correspondingly in fig. 2(a, b) for $B_0 = 0.084$ T. The oscillatory structure, possessing Δf_i periodicity dependent on the decay wave frequency is clearly seen in both figures.

The wave number cross-correlation spectrum (CCS) obtained from the CCF by Fourier transform is shown in fig. 3. It is important that the real part of the CCS is much higher than the imaginary part, which gives the estimation of the CCS reconstruction accuracy. As it is seen in fig. 3a, at low frequency $f_a = f_s - f_i < 6$ MHz the CCS is maximal along the line $f_a = -qc_s/2\pi$, where $c_s \approx 3.8$ cm/s, corresponds to ion acoustic velocity at $T_e \approx 3$ eV. It allows identifying the low frequency waves, excited in the helicon discharge as ion acoustic waves, propagating to the discharge centre. At higher frequency the CCS is maximal along the parallel line $f_l = f_s - f_i = f_{rf} - qc_s/2\pi$. The phase velocity of these waves at $f_l < f_{rf}$ is directed to the plasma edge. It should be stressed that the propagation direction of the waves excited in helicon discharge at high magnetic field $B_0 = 0.084$ T is different from that in the case of $B_0 = 0.055$ T. The corresponding CCS obtained in the last case is shown in fig. 4. As it is seen there the low frequency – acoustic wave is propagating towards the plasma edge, whereas the phase velocity of the high frequency satellite is directed oppositely. Nevertheless the frequencies and radial wave numbers of these waves at both magnetic fields satisfy three-wave resonance conditions $f_l = f_{rf} - f_a$ and $q_l = -q_a$ which are typical for the parametric decay instability of long scale pump wave. According to [3], the CCS obtained in fig. 3a or fig. 4a can be used for reconstruction of density perturbation spectrum of the decay waves. It is obtained from the CCS by multiplying by the ES homodyne spectrum, shown in fig. 1 and

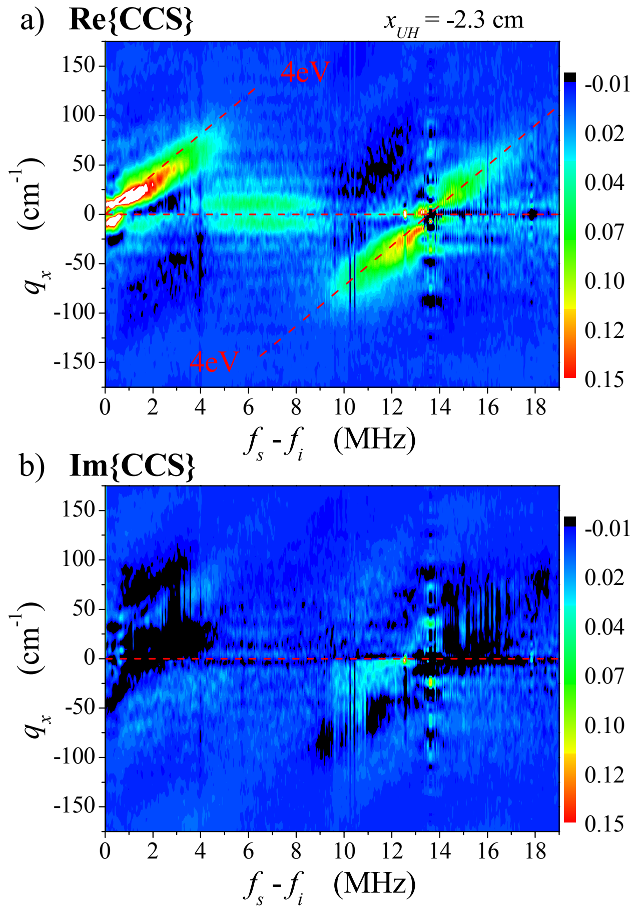

Fig. 4. *CCS for* 55 mT.

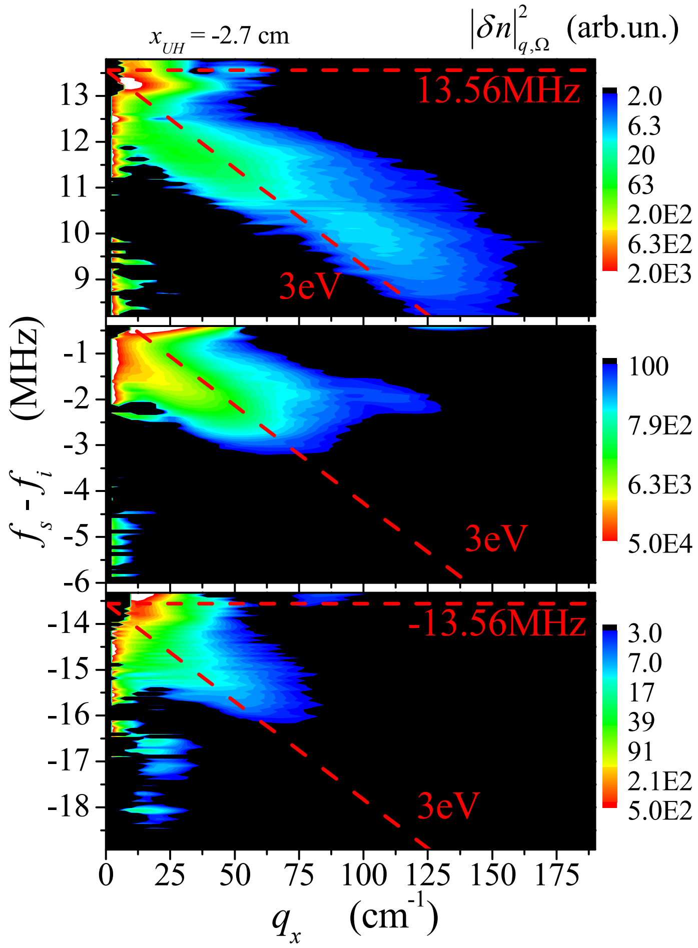

Fig. 5. *The density perturbation spectrum for* 84 mT.

dividing by the ES efficiency, proportional to the radial wave number squared. The density perturbation spectrum corresponding to CCS obtained in fig. 3a is shown in fig. 5. As it is seen, it quickly decays with growing wave number, however remains aligned along the line determined by the dispersion relation of ion acoustic wave.

Conclusions.

The correlation ES diagnostics applied for investigation of small-scale turbulence in the helicon discharge has demonstrated potential not only for measurement of dispersion relation of plasma fluctuations, but also for reconstruction of there wave number spectra. The measurements performed at different magnetic fields recovered the inversion of propagation direction of decay waves with growing magnetic field. This effect is probably related to the change of high frequency daughter wave dispersion at higher magnetic field due to the gradient terms contribution growing at higher magnetic field [4].

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