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Feed-back control of inhomogeneous plasma parametric decay instability

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Introduction.

The parametric decay instability (PDI) excitation is a reason for anomalous reflection and absorption of electromagnetic waves in experiments on laser fusion and RF heating in magnetic confinement devices. Based on results of homogeneous plasma theory [1], the random pump phase modulation was proposed in [1] for the PDI control. On contrary, a more detailed theoretical analysis performed in [2] in the framework of inhomogeneous plasma model demonstrated a weak sensitivity of the PDI to the random pump phase modulation. Experimental investigations of the harmonic pump frequency modulation influence on the inhomogeneous plasma PDI performed in [3] had recovered even more complicated picture. As it was shown in [3], the weak PDI sensitivity to the pump frequency modulation is only observed for the fast modulation. In the case of slow modulation, on contrary, enhancement or the resonant suppression of the instability was reported. The PDI enhancement observed at slow frequency modulation was explained by the effect of convective losses suppression from the moving decay region investigated in [3, 4], whereas the resonant suppression effect observed only at fixed modulation frequency values was not explained. In the present paper the effect of strong resonant suppression of the most dangerous absolute inhomogeneous plasma PDI by the pump frequency modulation is studied experimentally in detail and explained. Moreover, the possibility to use this effect for feed back control of the backscattering PDI is demonstrated.

The experimental situation.

The experiment is carried out at the linear magnetized plasma device with magnetic field of 0.35 T, in which inhomogeneous plasma ($n_e = n_e(z, r)$) was produced by ECR discharge in argon at pressure 1-2 Pa. The electron plasma pump wave at frequency f_0 = 2.5-2.7 GHz – (EPW) – was excited in this plasma using a waveguide system. In vicinity of resonant (focal) point, where $n_e(z, 0) = n_c$ (i.e., $2\pi f_0 = \omega_p = (2\pi n_e e^2/m_e)^{1/2}$), the electric field of the electron plasma wave increases. The growth of electric field in the vicinity of focal point is so significant, that a parametric decay instability of stimulated backscattering $l \rightarrow l' + s$ is excited at a relatively small pump wave power P_0 of 20 mW. The instability excitation mechanism, according to [5], is related to the complicated spatial structure of pump wave, namely to the small fraction of the first radial mode present in the pump along with the dominant fundamental radial mode ($P_1 \leq 0.1P_0$) This small fraction interacting with the back scattered wave leads to excitation of the ion acoustic wave in spatial point shifted by $\delta z \approx 0.5\ cm$. This ion acoustic wave propagates back to the decay region where it experiences amplification, thus leading to formation of the feedback loop and onset of the absolute PDI. The absolute decay instability is a coherent process with the limited number of oscillatory modes excited, which close to the threshold manifest themselves by narrow lines in the acoustic wave frequency spectrum. The instability growth rate and an unstable spectrum structure are determined by the time of the ion-sound wave circulation in the feedback loop $\tau = \approx 2.5\ 10^{-5} s$.

Investigation of the resonant PDI suppression.

Unfortunately, the pump backscattering spectrum is not useful for investigation of PDI in the case of the pump frequency modulation experiment. Therefore the enhanced scattering [5] technique was applied to study the decay ion acoustic wave. For this purpose the probing electron plasma wave at frequency $f_p = 2.35$ GHz $< f_0$ and small power ($P_p < 5$ mW) is launched into plasma by the same waveguide system. In the vicinity of its own resonance point the probing wave is effectively back scattered off the parametrically driven small scale ion-sound wave. The scattered wave amplitude, proportional to the ion–sound one, was used for studying the effect of modulation on the PDI. The $l \rightarrow l' + s$ absolute instability lines observed experimentally in the probing wave backscattering spectrum are shown in fig. 1 (solid red curve). The spectrum consist of several (usually less than 3) stable narrow pikes. The lines spectral separation varied depending on experimental conditions being in the range 0.4 MHz – 0.7 MHz in agreement with the estimation given above. As it was shown in [3], the harmonic pump frequency modulation at specific modulation frequency values provides strong stabilizing influence on the absolute $l \rightarrow l' + s$ PDI.

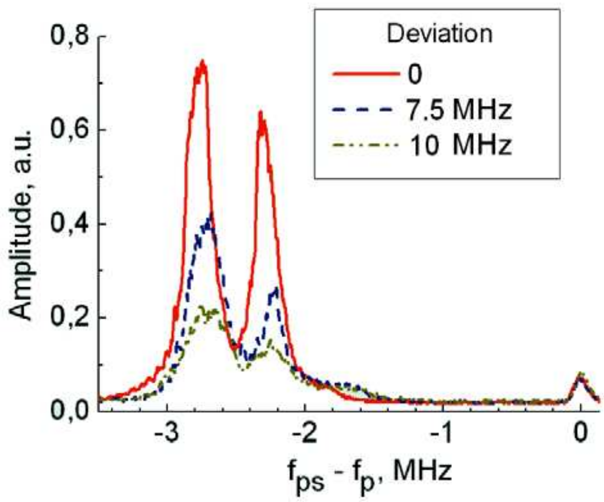

Fig. 1. *The PDI spectra at different frequency deviation.*

The detailed investigations performed in the present paper in the regular instability regime, when the line structure shown in fig. 1 was observed in the ion acoustic wave spectrum, have shown that even at very small harmonic pump frequency modulation additional lines shifted by the modulation frequency from the instability pikes ($f_{PDI} \pm f_m$) are observable in the ion

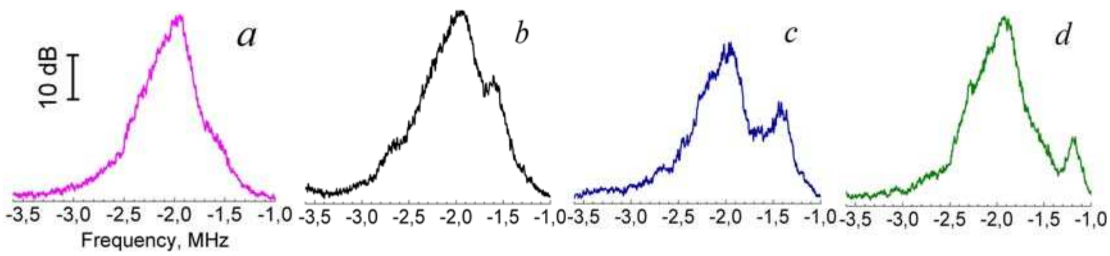

Fig. 2. *Scattered signal spectra at harmonic frequency modulation (deviation of 3.5 MHz). a – feedback off, b – modulation frequency is 0.4 MHz, b – 0.75 MHz and d – 0.9 MHz.*

acoustic wave spectrum (see fig. 2 *a-d*, where the effect is demonstrated in the case of a single pike spectrum (*a*) for modulation frequencies f_m= 0.4 MHz (*b*); 0.75 MHz (*c*); 0.9 MHz (*d*)). In the case of a double pike PDI spectrum the number of observable lines doubles. At a small deviation of 3.5 MHz no suppression of the PDI was seen, however, when it was increased to 7.5 MHz the suppression effect was observed at modulation frequency equal to frequency separation of stable PDI pikes observed in the ion acoustic wave spectrum (or its double value). At higher deviation the suppression domain became wider.

The PDI feed-back control experiment.

Based on the observations of a very high sensitivity of PDI to the pump frequency modulation at the PDI eigen frequencies it was proposed to use a signal obtained as a result of the back-scattering signal double frequency down-conversion for the pump frequency modulation. The corresponding scheme providing the control signal at the absolute PDI eigen frequency is shown in fig. 3. As it is seen the scheme filters the backscattering signal suppressing the signal at pump frequency. It also amplifies the PDI eigen frequencies suppressing simultaneously the signal at the ion acoustic wave frequency. The possibility of substantial (a factor of 5) suppression of PDI ion-acoustic wave and anomalous pump wave reflection using this scheme is demonstrated in fig. 1 for frequency deviation of

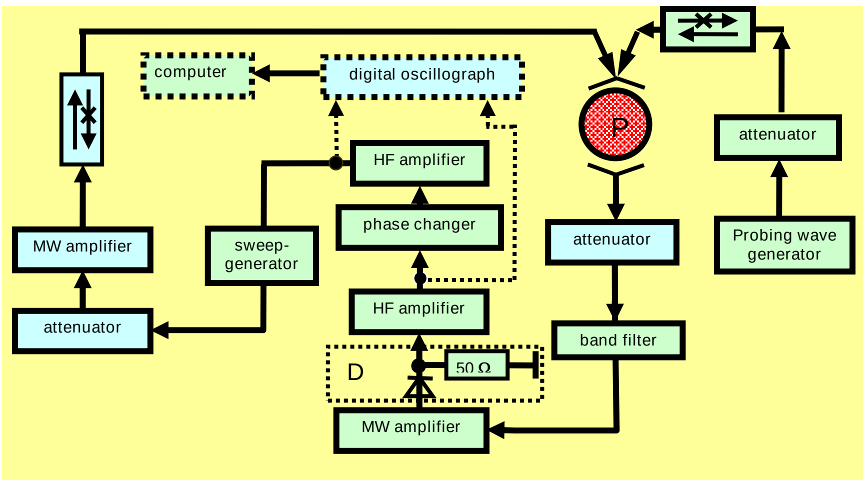

Fig. 3. *The function diagram of the PDI feedback control experiment.* D – *microwave detector*, P – *plasma*.

7.5 and 10 MHz. It is important to note that the PDI suppression was not possible with a control signal proportional to the ion acoustic wave amplitude provided by the scheme shown in fig. 3 in the case when the pump wave frequency was not filtered out.

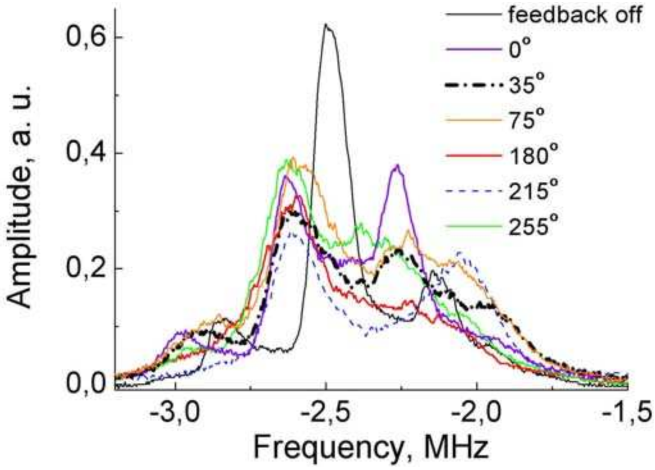

Fig. 4. *Scattering signal spectrum for different feedback signal phase.*

The output signal of feedback controlled amplifiers is usually very sensitive to the feedback signal phase variation stabilizing them or converting to unstable regime. In our experiment the feedback signal phase was varied using the phase changer connected to the sweep-generator in the feed-back scheme (see fig. 3). As one can see in fig. 4, the feedback phase variation influenced the eigen frequency values, however not reducing the suppression effect.

The dynamics of the PDI suppression due to the feedback control was investigated in the feedback switching on/off experiment. The strong suppression effect is seen in fig. 5, where both the detected backscattering and feed-back control signal are shown. Quite naturally the PDI suppression was more pronounced close to the threshold.

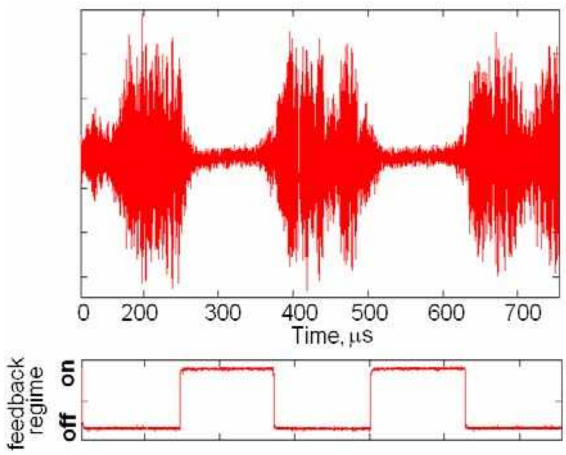

Fig. 5. *Oscillogram of the homodyne detection signal from plasma (above) and feedback regime (below).*

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