Parametric Decay Instability Control by Complementary Pump

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Introduction

The parametric decay instabilities (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. Using the harmonic frequency modulation of the pump wave, we have demonstrated recently [1, 2] an experimental possibility of significant resonant suppression of absolute PDI leading to the strong pump anomalous reflection. It takes place when modulation frequency is equal to the differences of absolute instability eigen mode frequencies. Unfortunately, the PDI suppression method developed in [1, 2], is difficult to realized at high (lasing) frequencies or/and with powerful RF generators. In the present paper, a possibility of the deep PDI suppression by launching of the complementary (small power) pump wave possessing a slightly shifted frequency is demonstrated experimentally.

The experimental situation

The experiment is carried out at the linear magnetized plasma device with magnetic field of 0.35 T, a schematic diagram of which is shown in Fig. 1. Inhomogeneous plasma ($n_e = n_e(z, r)$) possessing longitudinal and transverse plasma inhomogeneity scales correspondingly a = 4 cm and b = 0.43 cm was produced by ECR discharge in argon at pressure 1-2 Pa. The electron plasma pump wave (EPW) at frequency f_0 = 2335 GHz — was excited in this plasma using a waveguide system (see Fig.1). In vicinity of the hybrid resonance 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 EPW increases so significant, that a parametric decay instability of stimulated backscattering (BS) $l \rightarrow l' + s$ is excited at a relatively small pump power P_0 of 20 mW.

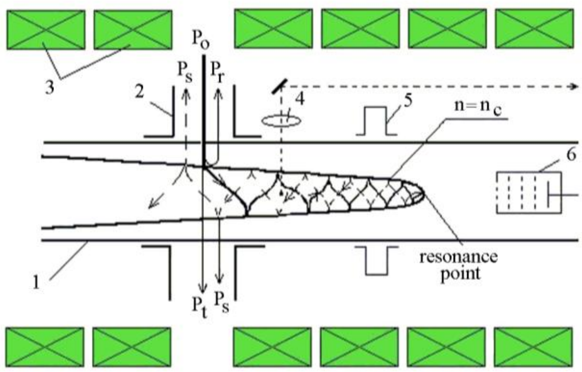

Fig. 1. *The experimental device and wave propagation scheme.* P_0, P_r, P_s, P_t – *incident, reflected, scattered and transmitted waves;* $n = n_c$ – *the critical density surface;* 1 – *quartz tube;* 2 – *waveguide;* 3 – *magnetic field coils;* 4 – *optical system;* 5 – *microwave cavity;* 6 – *the fast electron multi grid analyzer.*

The instability excitation mechanism, according to [3], 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. As the result, a red-shifted satellite is observed in the scattering spectrum of pump (Fig. 2 (*a*)). 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. This lines not always observable in continuous measurements (see Fig.2a), nevertheless can be seen utilizing the pulse spectral analyses (see Fig. 2 (*b*)). Typically the red-shifted satellite consists of 1-3 narrow lines changing amplitudes and frequencies slowly [4]. At a factor of 2-3 absolute instability power threshold excess it leads to strong anomalous reflection of the pump.

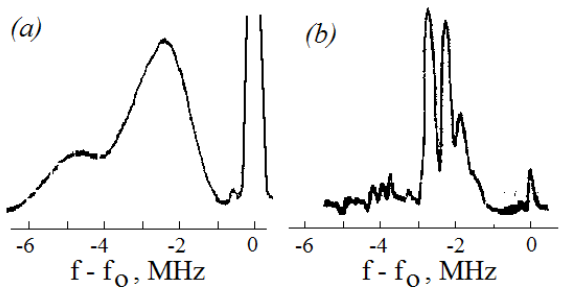

Fig. 2. *Parametrically scattered signal spectra at continuous (a) and pulse (10 μs) spectra analyses (b).*

Due to substantial slowing down of the EPW pump in the vicinity of the hybrid resonance point its phase velocity in the magnetic field direction approaches electron thermal velocity. Therefore intensive Landau damping and acceleration of electrons takes place. The effective temperature of the super thermal electron tail T_h grows with the pump power however above the instability threshold this growth saturates, thus indicating reduction of the power fraction absorbed due to the Landau damping [5].

PDI suppression by complementary pump

In the experiment, parametric decay instability $l \rightarrow l' + s$ was excited by the EPW pump at frequency f_0 = 2335 MHz and power of about 40 mW resulting in red-shifted satellite observed in BS spectrum. When additional EPW at frequency $f_p = f_0 + 6$ MHz and small power ($P_p \sim 15$ mW) was launched into plasma by the same waveguide sys-

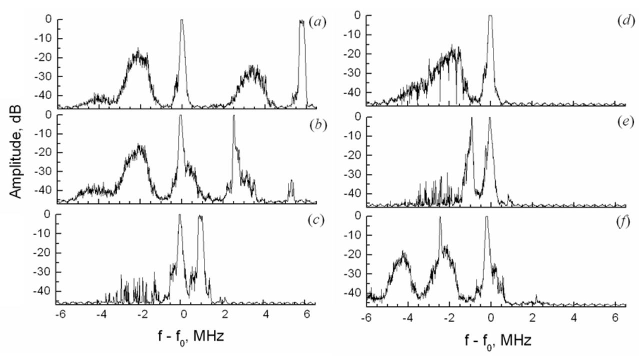

Fig. 3. *Scattered signal spectra at different frequencies of additional pump wave.*

tem a complicated BS spectrum consisting of two pump lines and two down shifted satellites was observed due to BS of the additional pump off the parametrically driven small scale ion-sound wave (Fig. 3 (*a*)).

At high enough pump frequency difference $|f_p - f_0| \geq 2$ MHz (Fig. 3 (*a*) (*b*) and (*f*)) the complementary pump do not influence the pump BS spectrum. However, as it is seen in Fig.3 (*c*) and (*e*), at frequency difference $|f_p - f_0| \approx 1$ MHz the main pump BS decreases by several orders of magnitude, thus indicating the next to total absolute PDI suppression. At $|f_p - f_0| <$ 1 MHz the BS signal recovers, however possessing different spectrum shown in Fig.3 (*d*) .

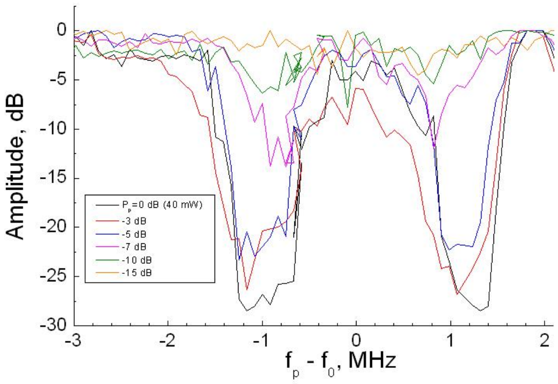

Fig. 4. *Dependence of the BS signal on the frequency difference at several powers of additional pump.*

The dependence of the pump wave BS satellite at frequency $f - f_0 = 2$ MHz on the frequency separation of two pumps is shown in Fig.4 for different complementary pump power. As it is seen, for decreasing complementary pump power the frequency separation providing the deepest suppression is also decreasing. So that for variation of complementary pump power from 40 mW to 4 mW the optimal suppressing frequency changes from 1.2 MHz to 0.8 MHz. The physical reason for this change is related to the variation of ion acoustic eigen mode frequency due to density profile flattening caused by growth of absorbed microwave power. A more detailed analysis of suppression efficiency dependence on frequency in Fig.4 reveals several suppression maxima corresponding to easier and deeper suppression of the absolute instability. The pump frequency difference corresponding to these maxima is equal to the frequency difference of ion acoustic eigen modes excited by the instability and observable as separate lines in BS spectrum in Fig.2b.

It should be also mentioned that the strongest suppression occurs at the complementary pump power comparable to the main pump power.

Enhancement of the EPW absorption at the PDI suppression

It is natural to assume that the anomalous backscattering suppression due to the complementary pump influence should result in enhancement of power absorbed in plasma and accordingly in growth of fast electron production and plasma luminosity. This assumption was confirmed by measuring axial plasma luminosity distribution and fast electron current with the help of set up shown in Fig.1. The measured luminosity distribution is shown in Fig.5a for the cases of $f_p - f_0$ = 6 MHz and $f_p - f_0$ = 1 MHz corresponding to spectra (*a*) and (*c*) in Fig.3. The rhybrid esonance position is given in Fig.5 by arrow. As it is seen in Fig.5a, suppression of the instability at $f_p - f_0$ = 1 MHz is accompanied by plasma luminosity growth compared to the case $f_p - f_0$ = 6 MHz and by shift of the luminosity maximum further from the EPW excitation region indicating suppression of the anomalous reflection and absorption growth.

The fast electron analyzer situated in the low density plasma at 5 cm from the hybrid resonance also registered evidences of the RF power absorption growth at the PDI suppression. As

(*a*) (*b*)

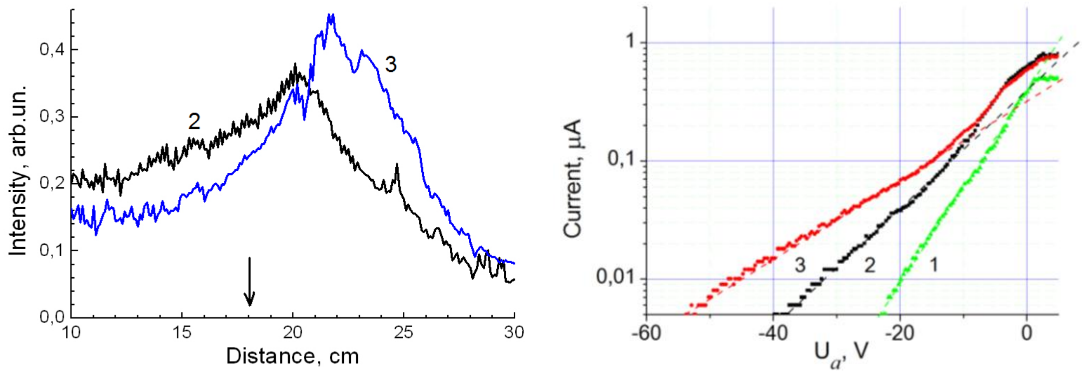

Fig. 5. *Axial plasma luminosity distribution (a) and analyzer voltage current characteristics (b) registered at pump frequency difference of 6 MHz (2) and 1 MHz (3), 1 – background plasma. Arrow corresponds to the hybrid resonance position.*

it is seen in Fig.5.b, the effective temperature of the fast electron tail, which was 4.2 eV in the unperturbed plasma, enhanced up to 7.1 eV at application of the two-frequency pump in the case $f_p - f_0$ = 6 MHz and further increased up to 9.3 MHz when the pump frequency difference take the resonance value $f_p - f_0$ = 1 MHz providing the deepest instability suppression.

Conclusions

Substantial suppression of absolute parametric decay instability was achieved by launching a weak additional pump wave at frequency shifted from the main pump by the value equal to the frequency separation of ion acoustic eigen modes excited in plasma. The recovery of microwave power absorption at the second pump turn on was demonstrated using measurements of the plasma luminosity and accelerated electron fluxes. In our opinion, such an approach is feasible for the PDI control in high power laser or RF plasma heating experiments.

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