Comparison of temporal evolution of the X- and O-mode anomalous absorption in the plasma filament

A.B. Altukhov[a], V.I. Arkhipenko[b], A.D. Gurchenko[a], E.Z. Gusakov[a],
A.Yu. Popov[a], L.V. Simonchik[b], M.S. Usachonak[b]
[a] *Ioffe Institute, St-Petersburg, Russia*
[b] *Institute of Physics NAS of Belarus, Minsk, Belarus*

1. Introduction

The theoretical model proposed in [1] explains the anomalous backscattering of the extraordinary (X) wave observed at electron cyclotron resonance (ECR) heating in tokamaks [2] as a result of the low-threshold two-plasmon parametric decay instability transferring substantial part of the pump power to upper-hybrid (UH) waves trapped in the vicinity of the local density maximum. Model experiments [3, 4] performed to check this prediction have demonstrated strong anomalous absorption presumably related to the decay instability taking place in a plasma filament for both the X- and O-mode pump. In the present paper we investigate in detail the temporal evolution of anomalous absorption for these two pumps.

2. Experimental setup

The plasma filament is produced in long glass tube with the inner diameter of 22 mm filled with argon (pressure about 1.5 Pa) oriented in the direction of the magnetic field (Fig. 1). The magnetic field created by the external electromagnet can be varied from 0 to 45 mT. The glass tube passes through the holes in the wide walls of waveguide (72×34 mm^2). The short high voltage pulses were supplied to the ring electrodes. The afterglow plasma with electron density decay time constant of about 53 μs is formed. The volume averaged plasma density is measured using the cavity diagnostics. Time evolution of plasma luminosity is registered as well.

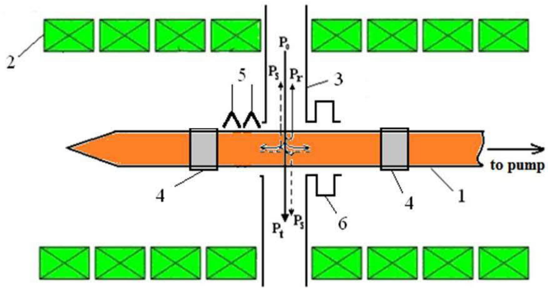

Fig. 1. Schematic of experimental setup. 1 – plasma filament, 2 – magnet coils, 3 – weveguide, 4 – electrodes, 5 – antennas and 6 – 10-cm cavity.

The microwave pulses (up to 200 W) were incident onto the plasma along the waveguide. The O-mode incidence takes place, when the glass tube passes through the holes in the wide walls of the waveguide, whereas the pump takes the X-mode form, when it passes through the narrow walls. As the frequency of the launched waves f_0 = 2.35 GHz is higher than the upper hybrid resonance (UHR) frequency and second harmonic of the ECR frequency, there were no linear mechanisms of the pump absorption, but the collisional one, which is not effective at the experiment conditions.

3. Anomalous absorption of the X-mode

According to the theory [1] the threshold density needed for switching on of the anomalous absorption due to the two-UH-plasmon decay instability should be close to the theoretical UHR density dependence on the magnetic field for the half pump frequency given by

$$n_{UH} = \frac{m_e}{4\pi e^2}\left[(\pi f_0)^2 - \left(\frac{eB}{m_e c}\right)^2\right], \quad (1)$$

The dashed curve in Fig. 2*a* represents this dependence.

In experiment at plasma densities substantially smaller than the threshold one ($n_e << n_{UH}$) no distortions of the microwave pulses in waveguide are observed (Fig. 2*b*). At plasma density close to or exceeding the threshold value n_{UH} after a time delay t_d=1 – 5 μs a fast decrease of

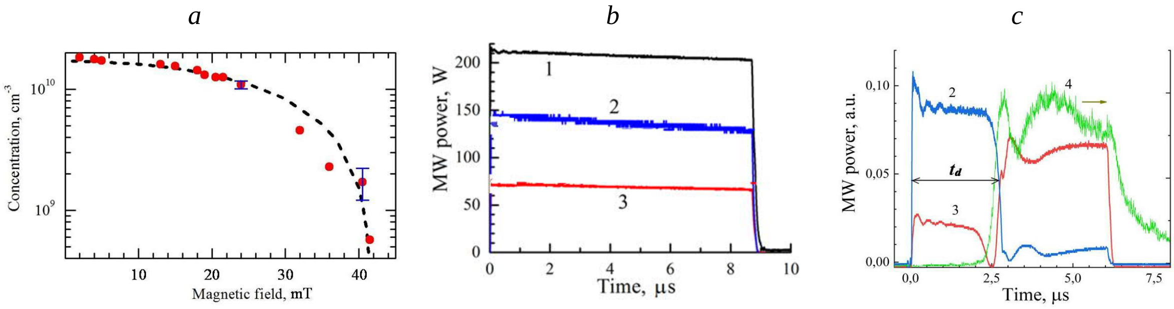

Fig. 2. The UHR density dependence on the magnetic field (*a*) and waveforms of incident (1), transmitted (2) and reflected (3) MW pulses and light intensity (4) at small plasma density (*b*) and close to hybrid concentration (*c*).

both transmitted and reflected power is observed indicating the turning on of the strong anomalous absorption (see Fig. 2*c*). The power threshold of anomalous absorption is about 25 W. The experimental results satisfactory coincide to the dependence (1) at large plasma density or high magnetic field. A minor deviation from (1) is observed only at magnetic fields in an interval 30-35 mT (Fig. 2*a*).

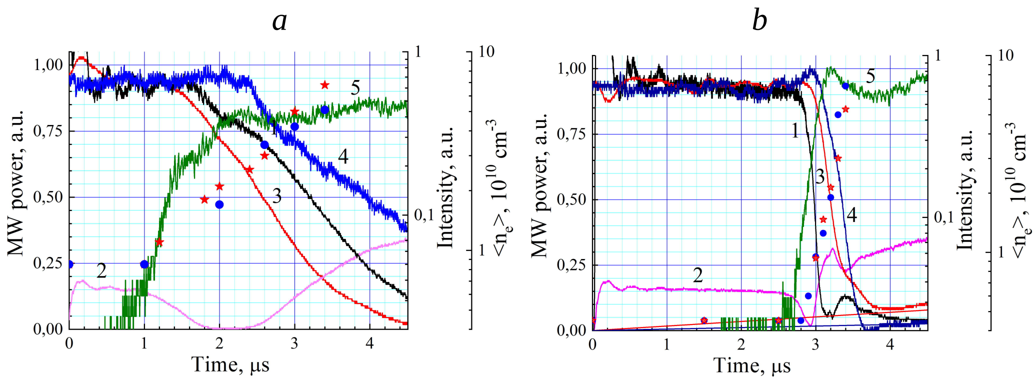

Fig. 3. Waveforms of transmitted (1), reflected (2), probing waves 2150 MHz (3) and 2600 MHz (4) signals and light intensity (5) at magnetic field of 20 mT (*a*) and 33 mT (*b*) and electron densities 8×10^9cm^{-3} and 4×10^9cm^{-3} correspondingly. Symbols – average electron density according to probing waves.

The low power probing waves at different frequencies (2150 MHz and 2600 MHz) propagating simultaneously with pump through the waveguide were used to trace the electron density temporal variation. For this purpose, we had obtained previously dependencies of waveguide transmission at these frequencies on electron density. In Fig. 3, the waveforms for two cases of initial plasma conditions are shown. It is seen that the rate of increase of both the electron density and light intensity is much higher for case (*b*). This increase of density starts already after the anomalous absorption of the pump is on. This indicates that pump absorption begins before reaching of the upper hybrid density for the half pump frequency ($n_{UH} \approx 6.6\times10^9\ cm^{-3}$) at magnetic field of 33 mT, when the effective linear pump absorption mechanism appears in plasma. At the smaller magnetic field of 20 mT (see Fig. 3a) the increase of plasma luminosity and decrease of the transmitted microwave is much slower and the beginning of this effect is observed at the background of already increased density. In this case one is not able to exclude the possibility of the UH resonance for the pump frequency to be present in the plasma volume.

Based on experimental power balance, we can estimate the efficiency of the anomalous microwave power absorption using the absorption coefficient k_{abs} given by $k_{abs} = 1 - (P_t + P_r)/P_0$, where P_0, P_t and P_r are incident, transmitted and reflected powers, P_{abs} is the absorbed power. The absorption coefficient varies drastically during the pump pulse in the second case (Fig. 4, curve 2), corresponding to Fig. 3*b*. It is close to zero at $0 < t < 2.6$ μs (collisional absorption), sharply reaches about 70% (in some cases up to 80%) at $t = 3$ μs. It should be mentioned that it was shown in [3] that the sharp growth of the anomalous absorption is accompanied by a burst of plasma microwave radiation registered by the heterodyne detection scheme in the half pump frequency range. In the case of smaller magnetic field the growth of absorption is much slower thus providing an argument for non-anomalous origin of this effect.

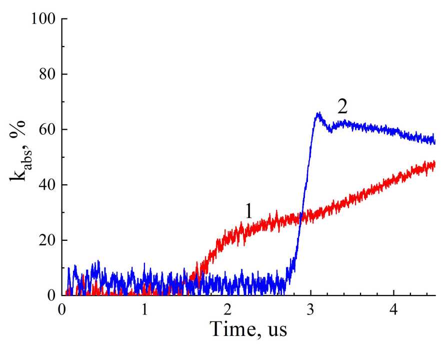

Fig. 4. Time evolution of absorption coefficient for data shown in Fig. 3 (curve 1 corresponds to *a*, 2 - *b*.

4. Absorption of the O-mode pump

The O-mode pump regime is realized when the glass tube passes through the wide waveguide wall and electric field in the waveguide is parallel to the external magnetic field. The experiments are performed at magnetic field induction of B= 33 mT and electron density $4\times10^9 cm^{-3}$ as in previous experiment for X-mode. Pump power is 150 W, but no any absorption is observed (Fig. 5*a*). The absence of luminosity growth and constant level of probing wave confirm this. If electron density of initial plasma is larger than the upper-hybrid one

(1.7×10^{10}cm^{-3}) for half pump frequency, for example, $n_e \approx 2.3\times10^{10}\ cm^{-3}$, a weak absorption is

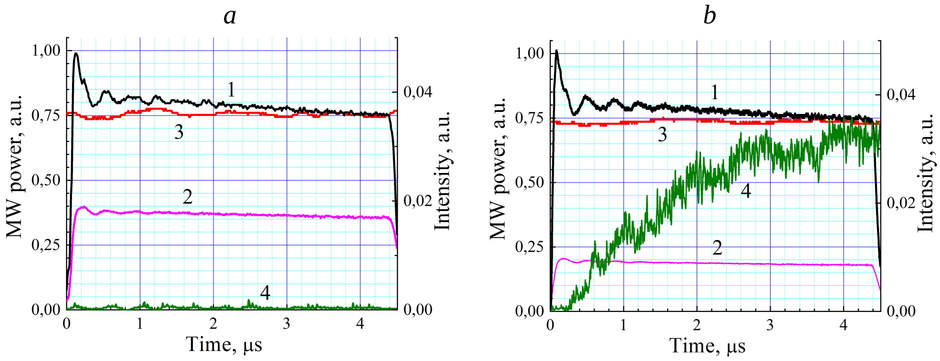

Fig. 5. Waveforms of transmitted (1), reflected (2), probing waves 2150 MHz (3) signals and light intensity (4) at magnetic field of 33 mT and electron densities 4×10^9cm^{-3} (*a*) and 2.3×10^{10}cm^{-3} (*b*).

observed (Fig. 5*b*). This is seen by light intensity waveform (4) in this figure. However the magnitude of intensity is the order of magnitude less in comparison with X-mode. The changes in electron density are almost invisible. Therefore efficiency of microwave absorption is very low and is about 5%. Even weaker absorption is observed when magnetic field is larger than electron cyclotron field B_c= 0.42 mT for frequency equal to a half of the pump frequency. Some results for these cases were presented in [4].

Conclusions

The strong anomalous absorption effect for X-mode was observed under conditions when electron density is higher than the upper-hybrid one for the half pump frequency, but smaller than the upper-hybrid one for the pump frequency. The two-UH-plasmon decay is possible in this case. The experimental anomalous absorption threshold is about 25 W. The efficiency of anomalous absorption of X-mode is determined at the level of 80%.

The absorption effect for O-mode was observed under conditions when magnetic field higher than a cyclotron one and electron density is larger than critical one for half frequency. The power threshold is higher in this case (about 100 W). Efficiency of O-mode anomalous absorption does not exceed 5%.

The obtained results could be considered as an argument confirming the predicted theoretically possibility of substantial anomalous absorption due to the two upper hybrid plasmon decay in the X2-mode ECRH experiments in toroidal magnetic fusion devices.

References

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