

OBSERVATION OF CROSS-POLARIZATION SCATTERING IN THE UPPER HYBRID RESONANCE AND NEW POSSIBILITIES FOR TOKAMAK MAGNETIC TURBULENCE DIAGNOSTICS

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The cross-polarization scattering (CPS) effect provides a unique opportunity for diagnostics of small scale magnetic turbulence in the hot region of tokamak discharge [1,2]. This effect was used for diagnostic development on Tore Supra [2], where the extraordinary to ordinary mode ($X \rightarrow O$) conversion by magnetic fluctuations was studied for the incident wave propagating transverse to tokamak magnetic field. The O-mode receiving antenna in [2] was protected from the higher level X-mode radiation scattered from the density fluctuations by the cut off and thick evanescent layer. The different scheme of the experiment firstly mentioned in [3] is being developed jointly in the FOM and Ioffe institutes. This scheme is based upon the CPS effect in the Upper Hybrid Resonance (UHR) of the probing microwave. The merits of the approach under development are as follows: 1) absorption in the UHR of the parasitic $X \rightarrow X$ radiation scattered from density fluctuations; 2) $X \rightarrow O$ and $O \rightarrow X$ CPS cross-section increase; 3) suppression of the CPS caused by density fluctuations; 4) wide fluctuation wavenumber spectrum available for diagnostics in the simple 1D probing scheme; 5) wavenumber measurements using experiments with time of flight resolution [4]; 6) localization of the CPS by the position of UHR.

The first observations of the CPS effect in the UHR in a tokamak and measurements of the time delay of the scattering signal are reported in the present paper.

The experiments were carried out on the FT-1 tokamak in two regimes with typical parameters $B = 1$ T, $I_p = 5$ kA, $n_e(0) = 4 \cdot 10^{12}$ cm⁻³ and $B = 1$ T, $I_p = 30$ kA, $n_e(0) = 9 \cdot 10^{12}$ cm³, which are mentioned below as 5 kA and 30 kA discharges. In the first one plasma is not completely ionized, where as the second one is usual tokamak ohmic discharge with central electron temperature $T_e = 400$ eV. The geometrical parameters of the tokamak are $R = 62$ cm, $a = 15$ cm. A set of electromagnetic diagnostics and 4-channel interferometer was used in the experiment. The lower hybrid (LH) wave launched into the plasma at frequency

$f_{LH} = 360$ MHz and power up to 35 kW was used as a test wave providing backscattering in the UHR. The LH loop antenna was situated on the low magnetic field side of the torus in the limiter shadow. Three microwave scattering diagnostics antennae were standing in the poloidal cross-section shifted from LH antenna by 180° in toroidal direction. The X-mode emitting and receiving horn antennae position is at high magnetic field side in the equatorial plane. The antennae pattern width is $\pm 10^\circ$. The O-mode fraction is less than $2 \cdot 10^{-2}$ of total power. The O-mode antenna was situated in the equatorial plane at low magnetic field side. The O-mode antenna directivity was also $\pm 10^\circ$. The probing was performed by X- and O-mode at frequency 27.6 GHz and power 50 W, produced by TWA with amplification width ~ 1 GHz. The LH wavenumber was estimated from the time delay of the scattered signal, which, according to [4], is given by

$$t_d = \frac{2\omega_i \mathcal{Q}}{\left| \frac{\partial \omega_{pe}^2}{\partial x} + \frac{\partial \omega_{ce}^2}{\partial x} \right|} \quad (1)$$

The amplitude modulation of the incident wave at frequency 10 MHz was used for this purpose. The time delay of the scattered signal was determined from the value of the phase shift of its modulation in respect to the incident wave. The superheterodyne scheme was used for analysis of the scattered signal, down shifted by 360 MHz from the probing frequency. Both the spectrum and AM phase delay of the signal in the 60 MHz band was studied. For the last purpose the quadratic detection of the signal was performed and the phase of 10 MHz oscillations of the scattered signal was measured using the phase detection scheme. The 1 kHz phase inversion of the 10 MHz signal used for control of AM microwave modulator was utilized to make the phase detector measurements easier. The tunable phase output of the 10 MHz oscillator provided the reference signals for calibration of the scheme during which the signal in the «sin» channel-S was put equal to zero. The transparent X-mode signal at probing frequency was used for calibration.

The X to O-mode CPS spectrum observed in the 5 kA discharge is shown in Fig. 1a. It consists of several lines. The left one corresponds to CPS from the LH pump, where as other satellites are scattered from smaller frequency parametric decay waves. The phase detector traces corresponding to Fig. 1a are shown in Fig. 1b, where the 1 kHz modulation of the signal is seen in both channels. The phase delay determined from this traces is higher than $\pi/2$, that corresponds to $t_d > 25$ ns. The dependencies of scattered signal and its time delay on the density in the UHR are shown in Fig. 1c, 1d. Open circles there correspond to

the beginning of RF pulse where as the solid ones to its end. The scattered signal increases by factor of 4 for density changing from $1 \cdot 10^{12} \text{ cm}^{-3}$ to $2.5 \cdot 10^{12} \text{ cm}^{-3}$. The CPS signal time delay changes from 15 ns to 30 ns. It is maximal at $n_e \approx 3 \cdot 10^{12} \text{ cm}^{-3}$ and than decreases to $t_d \approx 20$ ns for density $n_e = 4 \cdot 10^{12} \text{ cm}^{-3}$ closed to the central one. The scattering signal also decreases at this density. The LH fluctuation wavenumber calculated from Eq. (1) varies from $q = 100 \text{ cm}^{-1}$ for $n_e = 1 \cdot 10^{12} \text{ cm}^{-3}$ to $q = 160 \text{ cm}^{-1}$ for $n_e = 3 \cdot 10^{12} \text{ cm}^{-3}$ and then decreases to $q = 80 \text{ cm}^{-1}$ for $n_e = 4 \cdot 10^{12} \text{ cm}^{-3}$. Such a high fluctuation wavenumber could correspond to the LH waves in the LH resonance vicinity possessing high value of electron velocity perturbation parallel to magnetic field, which could lead to the CPS effect.

In the 30 kA discharge the O to X-mode CPS spectrum, as well as the X to O one, consists of a single broad satellite downshifted from the probing wave frequency by 360 MHz (Fig. 2a). The phase detector traces for this signal are shown in Fig. 2b. The phase delay determined from these curves is exceeding $3\pi/4$, that correspond to $t_d \approx 40$ ns. The time variation of the delay and signal amplitude is due to the increase of the plasma density by a factor of 1.5 during the RF pulse. The distribution of the CPS signal and time delay against plasma density is shown in Fig. 2c,d. The signal distribution is homogeneous, where as the time delay increases steeply from 15 ns to $30 \div 45$ ns at $n = 2.5 \cdot 10^{12} \text{ cm}^{-3}$. The LH wavenumbers determined from these delays using Eq. (1) are $K_{\perp} \approx 160 \text{ cm}^{-1}$ for $n_e = 2 \cdot 10^{12} \text{ cm}^{-3}$ and $320 \div 500 \text{ cm}^{-1}$ for $n_e > 3 \cdot 10^{12} \text{ cm}^{-3}$. The only mode existing in the LH frequency range possessing such a large wavenumber could be the ion Bernstein wave excited by lower hybrid pump after linear wave conversion in the LH resonance.

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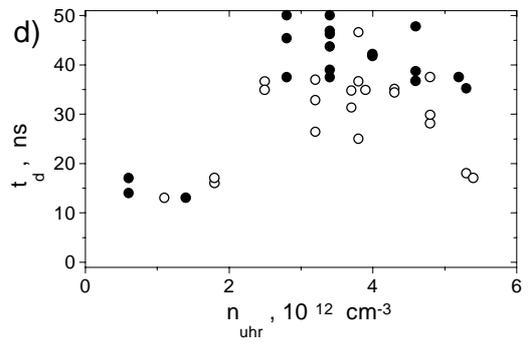
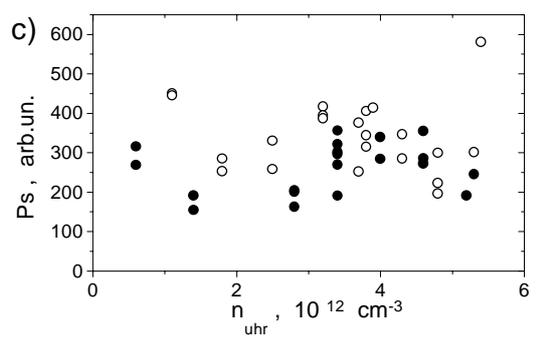
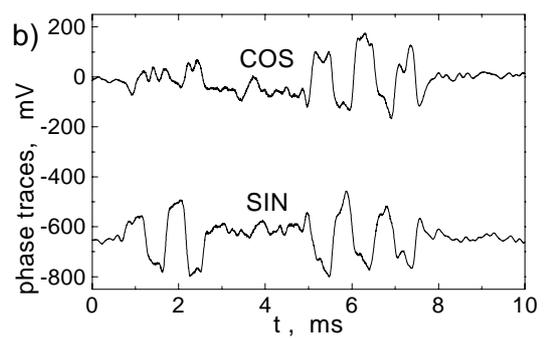
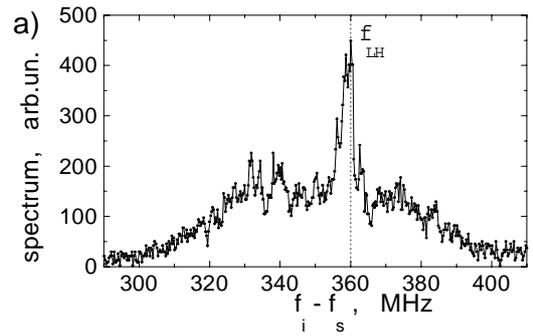
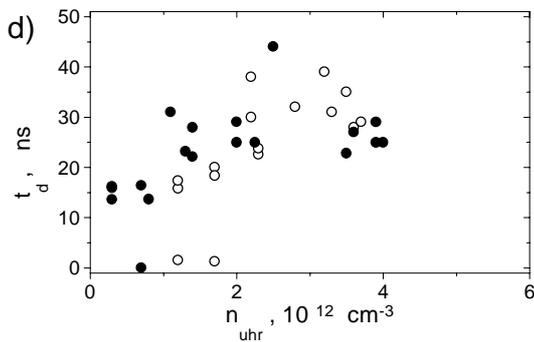
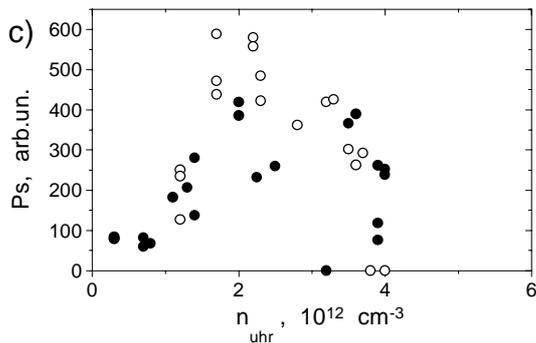
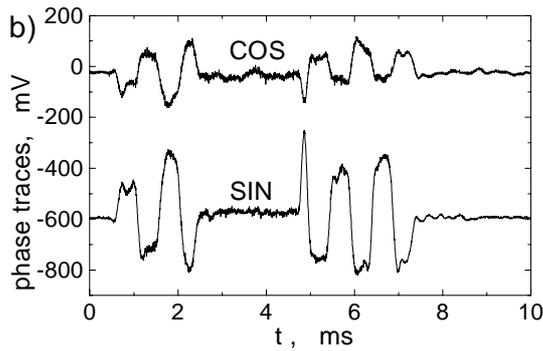
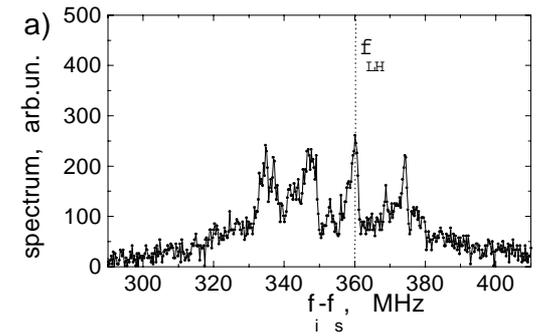


Fig. 1. CPS in the low current discharge.
 a) scattering spectrum for $B = 1.02$ T;
 b) phase detector traces;
 c) dependence of CPS power on density in the UHR;
 d) dependence of CPS signal time delay on density in the UHR.

Fig. 2. CPS in the high current discharge.
 a) scattering spectrum for $B = 0.85$ T;
 b) phase detector traces;
 c) dependence of CPS power on density in the UHR;
 d) dependence of CPS signal time delay on density in the UHR.