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Investigation of the upper hybrid resonance cross-polarization scattering effect at the FT-2 tokamak

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Magnetic component of small-scale plasma turbulence can play an important role in electron transport disturbing the system of nested magnetic surfaces and leading to huge energy losses along the field lines. The cross-polarization scattering (CPS) diagnostics utilizing microwave probing perpendicular to the tokamak magnetic field provides a unique opportunity for measuring relatively low magnetic turbulence level in the hot plasma core because intensive density fluctuations do not contribute to the CPS signal in this experimental geometry [1]. The CPS effect was used for diagnostic development on Tore Supra [2], where the poor localized extraordinary to ordinary mode ($X \rightarrow O$) conversion was studied in the presence of probing wave cut-off protecting the *O*-mode receiving antenna from the higher level *X*-mode radiation scattered from the density fluctuations. The alternative scheme of the experiment utilizing the CPS effect in the upper hybrid resonance (UHR) of the probing microwave was investigated recently at the FT-1 tokamak, where the RADAR scheme was used to confirm the UHR origin of the CPS signal [3, 4]. The merits of this scheme were analyzed in [5]. They are as follows: 1) absorption in the UHR of the parasitic *X*-mode radiation resulting from $X \rightarrow X$ scattering off density fluctuations; 2) $X \rightarrow O$ and $O \rightarrow X$ CPS cross-section increase in the UHR; 3) suppression of the parasitic CPS caused by density fluctuations in the UHR; 4) wide fluctuation wave number spectrum available for diagnostics in the simple 1D probing scheme; 5) wave number resolution provided by the time-of-flight [3, 4] or correlation measurements; 6) localization of the CPS by the position of the UHR.

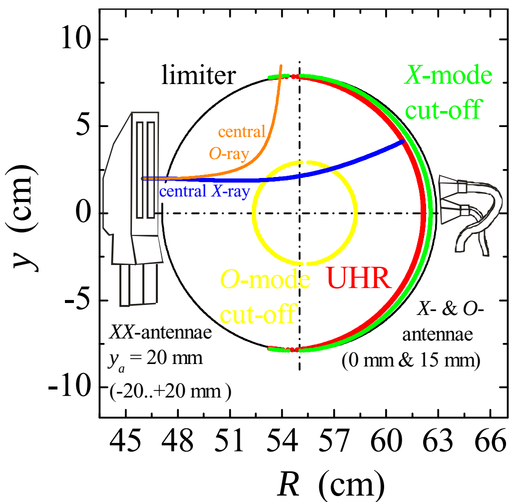

Fig. 1. *Antennae set up and ray trajectories for* $n_e(0) = 6\times10^{19}$ m^{-3}.

In the present paper the first measurements of the CPS spectra performed at the FT-2 tokamak ($R = 55$ cm, $a \approx 8$ cm, $B_T \approx (1.7\div2.2)$ T, $I_p \approx (19\div37)$ kA, $n_e(0) \approx (0.5\div6)\times10^{19}$ m^{-3}, $T_e(0) \approx 500$ eV) where a double antenna set (*X*-mode for $y_a = 0$ mm; *O*-mode for $y_a = 15$ mm), shown in fig. 1, was installed at the low magnetic field side in the same

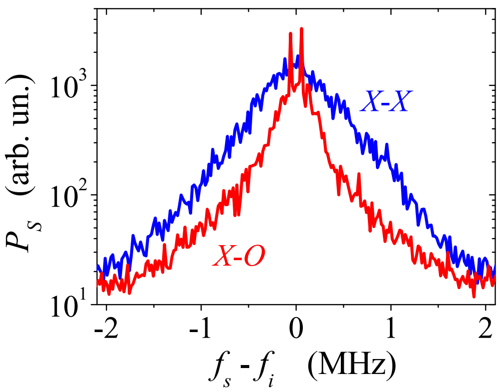

Fig. 2. *Spectra for* $n_e(0) < 4\times10^{19}$ m^{-3}.

poloidal cross-section, but opposite to the steerable focusing *X*-mode antennae, used for UHR microwave backscattering investigation, are reported. The plasma is probed by *X*-mode from the high field side and both *O*-mode and *X*-mode spectra are studied with the new antennae set for different values of plasma density, current and probing antenna vertical position.

The typical spectra measured at low field side in *O*- and *X*-polarization are shown in fig. 2 by red and blue curves correspondingly. As it is seen the signal observed in *X*-mode is comparable or larger than that in *O*-mode, however the excess of the signal is not enough to explain the origination of cross-polarized *O*-mode scattering signal by *X*-mode coupling to *O*-mode antenna, because the mode selectivity of the antenna is better than 10% in power.

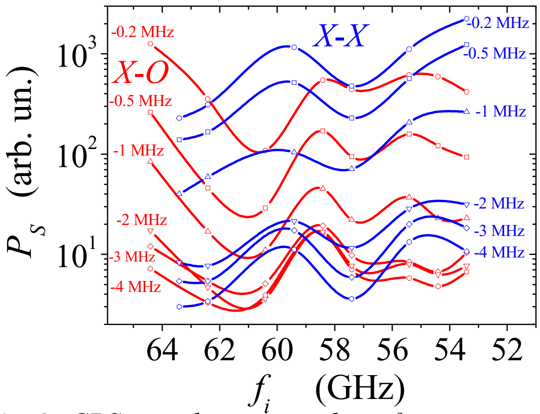

Fig. 3. *CPS signal versus probing frequency.*

The independent origin of these two signals is also supported by clear difference of the spectra form (see fig. 2) as well as by probing frequency dependencies of spectra, shown in fig. 3, which clearly not coincide. It should be mentioned, as well, that at higher current regime and at larger probing frequencies, corresponding to the inner UHR position, as it is seen in fig. 3, the *O*-mode signal is higher in wide range of $|f_s - f_i|$, where f_i and f_s are frequencies corresponding to the incident and scattering waves. Dependencies of the *O*-(fig. 4a) and *X*-mode (fig. 4b) spectra, measured at the low field side on the probing antenna position, were also investigated. As it is seen in fig. 4a, the *O*-mode (CPS) spectra are sharp and their amplitude decays quickly when the probing antenna is shifted downwards. On contrary, the *X*-mode spectra are diffusive and vary substantially weaker when the probing antenna is shifted. The typical feature of the *O*-mode spectra, which is seen in fig. 4a at 15 – 20 mm positive vertical displacement of probing antenna, is an intensive single or double line at frequency close to $|f_s - f_i| = 0$. The doublet splitting of 100 kHz is close to twice MHD mode frequency in FT-2 tokamak. Origination of this intensive single or double line, seen also in fig. 2 is probably associated with spurious *O*-mode excited by the probing antenna. Its excitation as well as propagation can be influenced by MHD mode perturbation

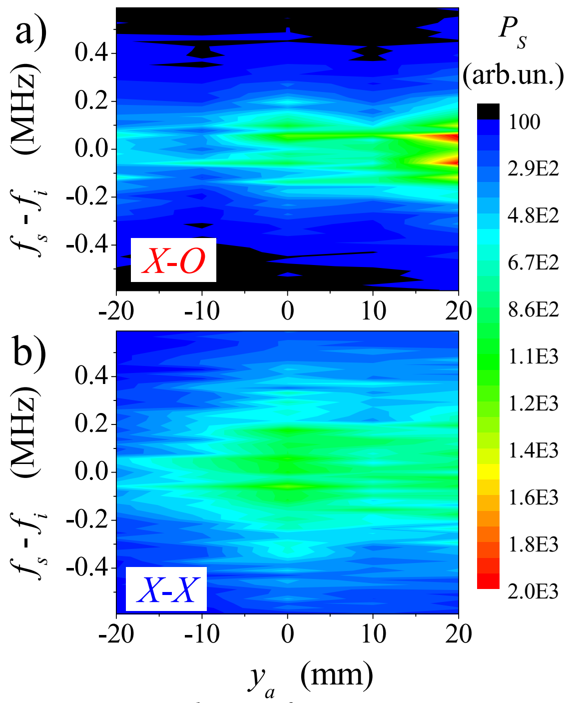

Fig. 4. *Dependence of scattering spectra on probing antenna vertical displacement.*

(magnetic island), which finally results in strong amplitude modulation of received *O*-mode signal. To suppress this spurious signal, which complicates determination of the real CPS, the measurements were performed at densities exceeding critical for the incident wave ($n_e(0) > 5.5\times10^{19}$ m^{-3}). Under these conditions the receiving antenna is protected by cut-off layer (yellow curve on fig. 1) from direct influence of the spurious *O*-mode and the spectra measured by the *O*-mode antenna for $y_a = 2$ cm takes a form shown in fig. 5. As it is seen, the spectrum frequency shift is 100 kHz and width 500 kHz. The signal in the *X*-mode polarization here appears to be substantially smaller. Its spectrum is shown by blue line in fig. 5.

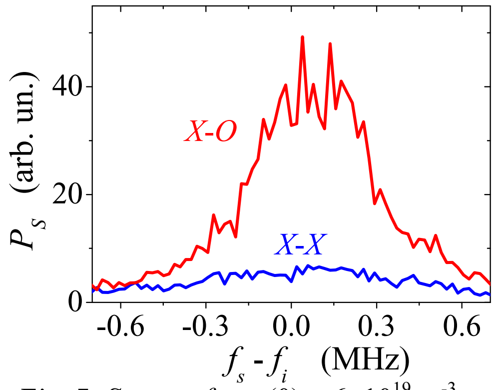

Fig. 5. *Spectra for* $n_e(0) = 6\times10^{19}$ m^{-3}.

To prove the UHR origin of the CPS signal the first correlation measurements using the approach of [6] were performed. The plasma was probed simultaneously at two close frequencies. Their difference was varied on discharge to discharge basis. The CPS signals at both probing frequencies were stored in the data acquisition and used for computation of the cross-correlation function (CCF). The CCF obtained at the reference probing frequency 62.4 GHz in discharge with $I_p = 25$ kA and $n_e(0) \approx 6\times10^{19}$ m^{-3} for $y_a = 2$ cm is shown in fig. 6a (real part) and fig. 6b (imaginary). As it is seen, both parts of CCF are clearly seen at $|f_s - f_i| < 1$ MHz. The Δf_i width of the region of high coherency decreases with growing CPS frequency. As a result, the higher wave numbers should correspond to higher frequencies in the cross-correlation spectrum (CCS), obtained by Fourier transform from the CCF dependence on the UHR spatial separation, proportional to channel frequency difference Δf_i. The corresponding CCS proportional to the product of magnetic fluctuations spectral power density and the CPS efficiency is shown in fig. 7a. The imaginary part of the CCF Fourier transform, shown in fig. 7b, which should be zero in

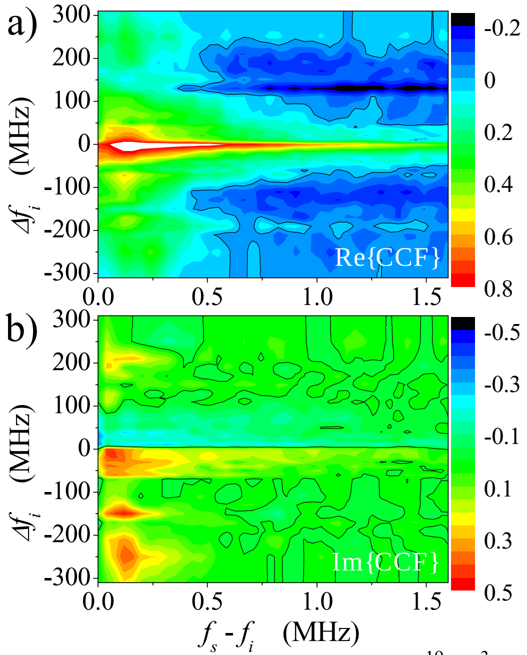

Fig. 6. *CCF for* $n_e(0) = 6\times10^{19}$ m^{-3}.

theory, determines the accuracy of our procedures. The CCS is not reliable at $|f_s - f_i| > 1.5$ MHz where it is comparable to the real part. The huge maximum of the CCS at small frequencies and wave numbers at fig. 7a is probably related to the spurious *O*-mode not suppressed completely in the experiment. The meaningful component of the CCS related to the CPS in the UHR is represented by the part at $|f_s - f_i| < 1$ MHz. The corresponding wave number interval where the spectrum is localized lies at $q < 250$ cm^{-1}, which corresponds to small-scale fluctuations producing CPS only in the UHR.

Summarizing the obtained experimental results we can state that the observed signal in *O*-mode polarization contains a substantial fraction related to the UHR CPS phenomena. Taking into account strong suppression of the CPS off the density fluctuations in the UHR and its enhancement in the case of magnetic field fluctuations [5] we come to the conclusion that the latter are most likely observed with the CPS technique at FT-2 tokamak.

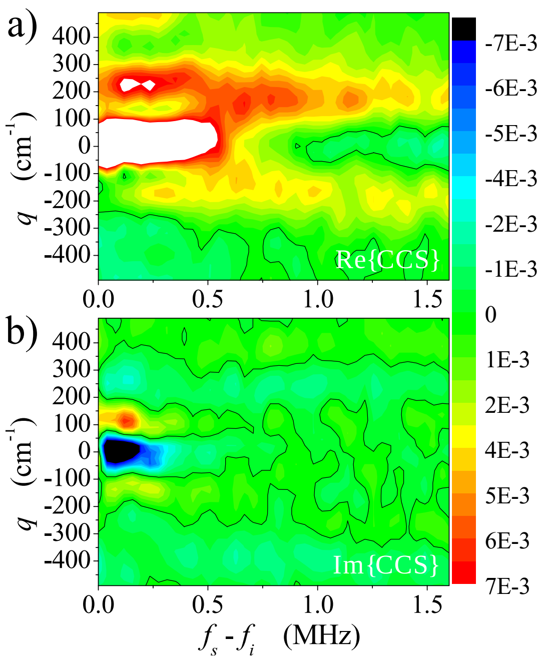

Fig. 7. *CCS for* $n_e(0) = 6\times10^{19}$ m^{-3}.

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1. T. Lehner, D. Gresillon, et al., Proc. 12 EPS Conf. on Control. Fusion and Plasma Physics, Budapest, 1985, Vol.II, p.644.
2. X.L. Zou, L. Colas, M. Paume, et al., Phys. Review Lett. 75, 1090 (1995).
3. D.G. Bulyiginskiy, A.D. Gurchenko, E.Z. Gusakov, et al., Phys. Plasmas 8, 2224 (2001).
4. A.D. Gurchenko, et al., Plasma Physics Reports, 31, 476 (2005).
5. E.Z. Gusakov, Plasma Physics Reports 28, 580 (2002).
6. E.Z. Gusakov, et al., Plasma Phys. Controlled Fusion 42, 1033 (2000).