Observation of intensified scattering of microwaves by waves in the lower hybrid frequency range in a tokamak

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The first tokamak experiments on intensified scattering of microwaves near the upper hybrid resonance by externally excited lower hybrid waves are described. Some highly retarded waves which are observed cannot be explained in the linear theory for the propagation of lower hybrid waves.

Experiments have been carried out to observe short waves in the lower hybrid frequency range in a tokamak by the method of intensified scattering, i.e., scattering from the region of the hybrid resonance of the probing wave,[1–4] in the FT-2 tokamak ($R = 55$ cm, $a = 8$ cm, $B_T = 10$–14 kG, $I_p = 20$ kA, $n_0 = 2\times10^{12}$–2×10^{13} cm^{-3},

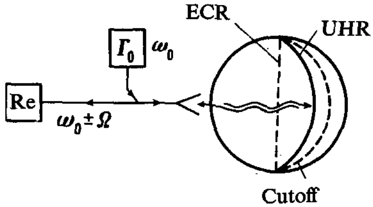

FIG. 1. Experimental layout.

$T_e = 300$ eV, and $T_i \cong 70$ eV). The experimental layout is shown in Fig. 1. A two-wave grill launches an rf power of 40–150 kW at the frequency $f_L = 925$ MHz into the plasma. This frequency is twice the frequency of the lower hybrid resonance. The probing radiation, an extraordinary wave at the frequency $f_0 = 35$ GHz with a power of about 1 W, is launched by a horn from the side of the strong magnetic field. The same horn is used as a receiving antenna for the scattered signal.

According to the theoretical understanding, the scattering of the probing wave by the low-frequency waves should increase sharply when there is an accessible upper-hybrid-resonance surface for this wave in the plasma. In this case the scattered signal is formed in a narrow layer near the hybrid resonance, where the probing wave is retarded, and its amplitude is increased. Experimentally, the plasma is probed at various values of the toroidal magnetic field B_T and at various values of the axial density n_0. The scattered signal, which consists of two lines, at the frequencies $f_S = f_0 \pm f_L$, of roughly the same intensity, is observed only at those values of n_0 and B_T for which the conditions for the upper hybrid resonance for the frequency f_0 are satisfied inside the chamber. When the polarization of the probing wave is changed from extraordinary to ordinary, the signal decreases sharply (by a factor of 20). Each of these facts indicates that the observed scattering is related to the upper hybrid resonance of the probing wave. Taking the scattering mechanism to be a settled matter, we can then obtain information on the spatial distribution of the source of the signal by varying B_T to vary the position of the hybrid-resonance surface in the chamber. In the absence of a lower hybrid resonance, a $\pm$ 15% change in B_T would presumably have no significant effect on the propagation of the waves launched into the plasma. At low densities ($n_0 \leqslant 2.5 \times 10^{12}$ cm^{-3}), the entire cross section of the chamber is accessible for probing, while at large values of n_0 only the outer periphery is accessible. Figure 2 shows some illustrative results on the intensity of the scattered signal versus the position of the upper hybrid resonance. The theory has the scattered signal being proportional to the integral of the spectral density of the fluctuations, with a weight function which emphasizes large values of the wave vectors. The curves in Fig. 2 may thus reflect both a change in the intensity of the fluctuations and a change in their spectrum. At any rate, these curves show that the waves which are responsible for the scattering fill the entire chamber volume. We can estimate the wavelengths of these waves by comparing the calculated "intensification factor" (the ratio of the scattered power levels in the presence or absence of the upper hybrid resonance), which depends on an average wavelength $\bar{\lambda}$ of the target waves, with the measured value of this factor. This factor turns out to be $\geqslant 100$. We thus find $\lambda \leqslant 2$ mm for the scale wavelength of the fluctuations.

Figure 3 shows some illustrative frequency spectra of the scattered signal (of one

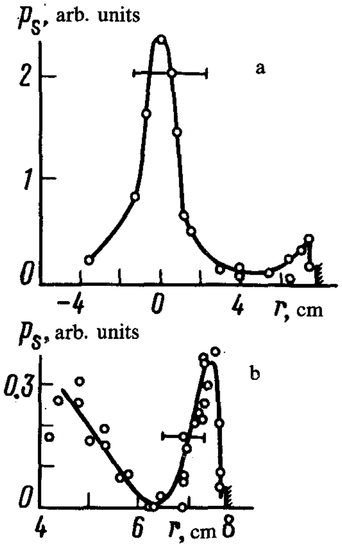

FIG. 2. Spatial distribution of the scattered signal. a—$n_0 = 2.5\times10^{12}$ cm^{-3}; b—$n_0 = (0.5\text{–}2)\times10^{13}$ cm^{-3}.

line). The intensity of the scattered signal turns out to be a linear function of the lower hybrid power. The ratio of the scattered power to the probing power is 10^{-7}–10^{-9}.

Attempts to identify the waves responsible for the scattering run into significant difficulties. The estimate given above for $\bar{\lambda}$ corresponds to a refractive index $N_\perp \cong 150$.

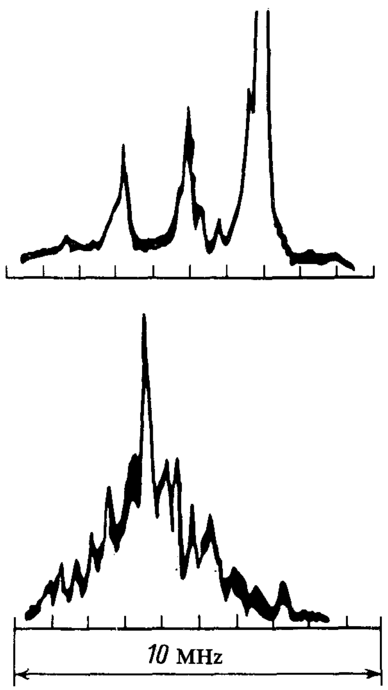

FIG. 3. Spectra of the scattered radiation.

In the frequency range under consideration here, there are two wave modes with a pronounced retardation of this type: oblique plasma waves (the shortest-wave part of the spectrum launched by the grill falls in this category) and ion Bernstein modes. In the case of the oblique plasma waves, we find $N_{\parallel} \geqslant 15$ from the dispersion relation, corresponding to a very strong damping by electrons. According to the linear propagation theory, waves with such a large longitudinal retardation could not, at any rate, penetrate into the central part of the discharge.

Turning to the Bernstein modes, we note that they might be excited in a scattering of plasma waves by low-frequency short waves. Waves with $\lambda \cong 1$–5 mm and $f = 3$–15 MHz have been observed previously in the FT-2 tokamak in measurements of the scattered beam from a CO_2 laser. Their wave vector lay in the plane of the minor cross section of the torus.[5] Scattering by such waves would increase $N_{\perp}$ while conserving $N_{\parallel}$. In the presence of Bernstein modes, however, we would expect to find a structure on the radial profiles of the scattered signal (Fig. 2) stemming from the surfaces of harmonics of the ion cyclotron resonance. We do not find such a structure experimentally, possibly because the radial profiles were constructed from data obtained in different discharges.

Independent indications of the existence of intense short waves in the plasma are the ion heating which is observed under these experimental conditions, with an efficiency of 0.5 eV/kW, and the formation of high-energy tails on the ion distribution function.

[1]A. D. Piliya, Zh. Tekh. Fiz. **36**, 2195 (1966) [Sov. Phys. Tech. Phys. **11**, 1639 (1967)].

[2]V. N. Budnikov, V. I. Varfolomeev, K. M. Novik, and A. D. Piliya, Fiz. Plazmy **6**, 1050 (1980) [Sov. J. Plasma Phys. **6**, 576 (1980)].

[3]V. I. Arkhipenko, V. N. Budnikov, E. Z. Gusakov, I. A. Romanchuk, and L. V. Simonchik, Pis'ma Zh. Eksp. Teor. Fiz. **39**, 453 (1984) [JETP Lett. **39**, 549 (1984)].

[4]V. N. Budnikov, L. V. Kondrat'eva, K. M. Novik, A. D. Piliya, and V. L. Selenin, International Conference on Plasma Physics, Vol. 11, Lausanna, 1984, p. 307.

[5]L. G. Askinazi, V. N. Budnikov, V. V. Bulanin, L. A. Esipov, D. O. Korneev, I. E. Sakharov, A. Yu. Stepanov, and S. N. Ushakov, Pis'ma Zh. Tekh. Fiz. **10**, 1517 (1984) [Sov. Tech. Phys. Lett. **10**, 641 (1984)].

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