27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 1276 -1279*

Investigation of Long-Wavelength Ion-Acoustic Waves in Plasma with Strong Langmuir Turbulence

Vladimir S. Burmasov, Igor V. Kandaurov, Eduard P. Kruglyakov,
Oleg I. Meshkov, Andrei L. Sanin, Sergey S. Popov, Leonid N. Vyacheslavov

Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia

1. Introduction

The physics of Langmuir turbulence is investigated on GOL-M device [1] for a number of years. Relativistic electron beam (REB) excites Langmuir oscillations due to Cherenkov mechanism. The energy transfer from oscillations to plasma electrons occurs by means of the nonlinear processes. The main goal of the recent work is to examine the physics of energy transfer. The frequency and spatial spectra of the Langmuir oscillations driven by the electron beam measured earlier [2] allowed us to make conclusion that the threshold of the modulational instability of Langmuir waves is exceeded. The presence of strong Langmuir turbulence in the target plasma was confirmed in our previous experiments [3] by an observation of short-wavelength ion-acoustic oscillations.

In the last decade new approaches appeared in the theory of strong Langmuir turbulence (see the reviews by Musher et al. [4] and by Robinson [5] and book by Tsytovich [6]). A problem discussed there is the possibility for weak and strong Langmuir turbulence to coexist at the same time in the plasma.

Under our experimental conditions the most probable weak turbulent process is the three-wave decay of Langmuir wave: $L \rightarrow L' + S$. The wave vector of generated ion sound S is determined from the momentum conservation law, so $\mathbf{k}_S = \mathbf{k}_L - \mathbf{k}_{L'}$. The wavelength of ion sound produced in this process is close to the wavelength of Langmuir oscillation directly excited by REB and is much larger than measured previously [3]. Investigation of this spectral region of ion sound waves provides important information about weak turbulent processes. In the present paper the very recent results of observation of long-wavelength ion-acoustic fluctuations are presented.

2. Experimental setup

Measurements were carried out by newly installed diagnostic of collective scattering of CO_2 laser radiation with a heterodyne detection of scattered at small angles light. The optical layout of the diagnostic is presented in Fig.1. A single frequency continuous-wave CO_2 laser ($P \approx 1$ W, $\lambda = 10.3\ \mu$) was used as a light source. A fraction of its output was split for a reference beam. The probe laser beam was directed into the three-pass pulsed TEA CO_2 amplifier (gain ≈ 800). After the amplifier the laser pulse was focused into plasma. scattered light was optically mixed with reference beam on the CdHgTe photodiode. The analog-to-digital converter with 2 ns read cycle was used to record the signal from the detector. The upper frequency of the registered signals in present experiments was limited by 120 MHz bandwidth of the electronic amplifier.

The parameters of the experiment were as follows. A preliminary hydrogen plasma with the density $n_e \approx 10^{15}$ cm^{-3} and the electron temperature $T_e \approx 1$ eV was created in longitudinal magnetic field of mirror configuration (4.5 T in the end mirrors and 2.5 T in the homogeneous part). The relativistic electron beam ($E_b \approx 700$ keV, $I_b \approx 2 \div 3$ kA, $D_b \approx 2$ cm, $\tau_b \approx 150 \div 200$ ns) was injected into the plasma along the magnetic field. The electron temperature reaches 30÷50 eV after 40 ns from the beginning of the beam injection, so the plasma remains non-isothermal with $T_e >> T_i$ during the REB pulse.

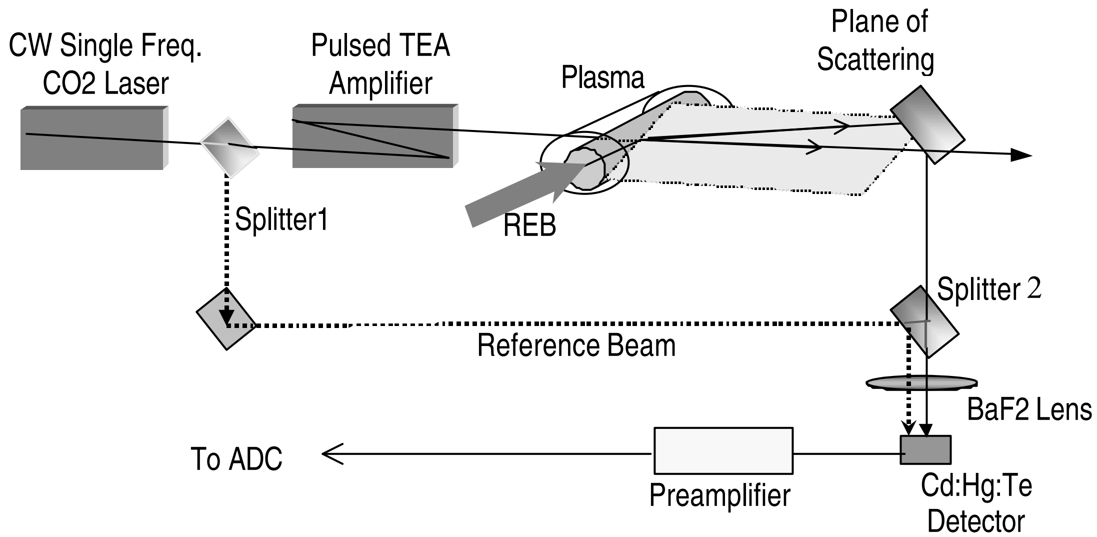

Fig.1. A layout of the CO_2 scattering by ion sound waves with heterodyne detection.

3. Results

Geometry of the experiment was arranged to study the long-wavelength ion-sound waves travelling parallel to the REB direction. The scattering angle was 1.1° that corresponds to the value of the wave vector of the oscillations $|\mathbf{k}_S| \approx 118$ cm^{-1}. Typical raw signal from the detector and REB current are shown in Fig.2. The frequency spectra of the signal are presented in Fig.3. The spectra were obtained numerically by means of the fast Fourier transform algorithm. To distinguish a signal due to ion-acoustic waves from noise

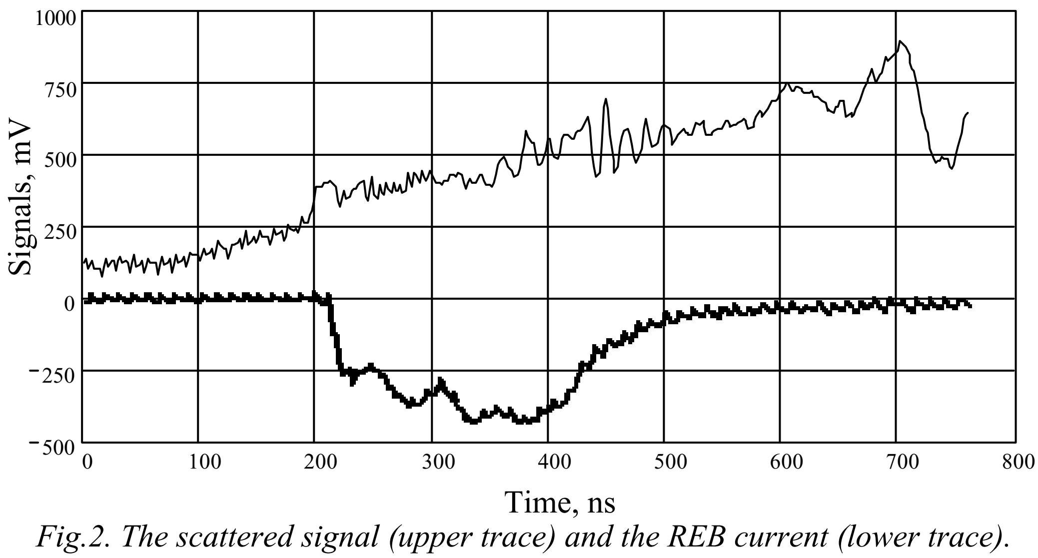

Fig.2. The scattered signal (upper trace) and the REB current (lower trace).

two time intervals were processed: the interval before the beginning of the REB current (thin curve) and the interval within the limits of the current duration (thick curve). The increased level of signal in the vicinity of 60 MHz is produced by the scattering on the oscillations in the plasma. A time behavior of the 60 MHz harmonic of the signal is shown in Fig.4 by the thick curve. The thin curve represents the REB current averaged over the time interval

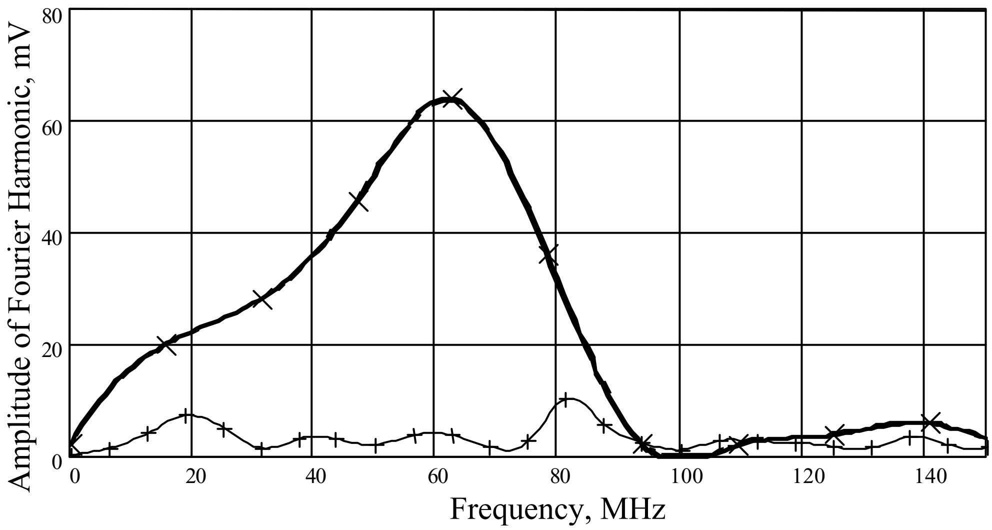

Fig.3. The Frequency spectra of the signal: before REB injection (thin trace), during REB injection (thick trace).

of the Fourier transform (64 ns). Scattering signal with duration of 100 ns appears with delay of more than 150 ns after beginning of the REB pulse.

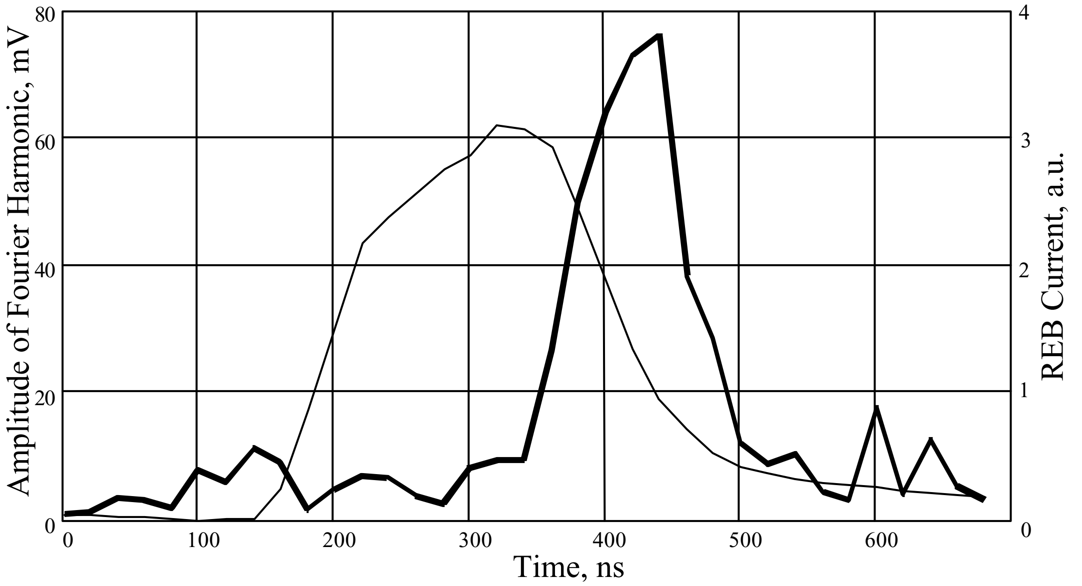

Fig.4. Time evolution of the 60 MHz harmonic of the scattered signal (thick curve) and REB current averaged on the time interval of the Fourier transfer (thin curve).

4. Discussion

The delay of the scattering signal (about 9 periods of ion sound) can be explained by the strong dumping of ion-acoustic oscillations in the initially isothermal plasma and by finite value of growth rate of the sound waves.

The measured frequency of oscillation (60 MHz) is less than calculated one for the given value of wave vector $\mathbf{k}_S$: $\nu = \frac{1}{2\pi} k_S \sqrt{T_e / M_i} \approx 100\ \mathrm{MHz}$. The decrease in the frequency of the ion sound can be explained by the influence of the high level of Langmuir oscillations. The Miller force produced by the HF oscillating electric field withstands to the plasma pressure and the ion sound should reduce. The dispersion law of ion-acoustic perturbations in the magnetized plasma with Langmuir oscillations was determined in the work of Ryutov and Pozzoli [7]. The ion sound frequency $\omega_S = k_S \sqrt{(T_e - T_{eff}) / M_i}$ where T_{eff}W can be calculated from the spatial spectrum of Langmuir waves $\mathbf{k}$ $T_{eff} = \frac{\omega_p}{4n} \int \frac{\mathbf{k}_S \cdot \partial W_{\mathbf{k}} / \partial \mathbf{k}}{\mathbf{k}_S \cdot \mathbf{v}_g} d^3\mathbf{k}$. T_{eff} corresponding to the observed decrease of frequency of ion sound can be estimated as $T_{eff} \approx 0.6 T_e \approx 18$ eV. Calculations of T_{eff} performed earlier [2] give the value near the electron temperature. Taking into account the accuracy of the absolute calibration and precision of the determination of Langmuir spectra it is possible to say that experimental results lie in the reasonable agreement with calculations.

The measured value of spectral density of ion sound more than order of magnitude less than calculated by the weak turbulent formulas [8] $(W_{\mathbf{k}}/T_e)_{calc} = 3 \cdot 10^7$. The decrease of the probability of all weak turbulent processes in the presence of strong Langmuir turbulence was predicted in the theoretical works [4÷6].

Acknowledgement

This work was made under the partial support of the Russian Foundation for Basic Research grant 98-02-17788.

References

1. V.S.Burmasov et al., Questions of Atomic Science and Engineering: Nuclear Fusion Series, No 2, 31, (1987), [in Russian].
2. L.N.Vyacheslavov et al., Physics of Plasmas, **2**, 2224, (1995).
3. V.S.Burmasov et al., 22nd European Conf. Contr. Fusion Plasma Phys, **19**C1, 445, (1995).
4. S.L.Musher, A.M.Rubenchik, and V.E.Zakharov, Phys.Rep., **252**, 177, (1995).
5. P.A.Robinson, Rev. Mod. Phys, **69**, 507, (1997).
6. V.N.Tsytovich. Lectures on Non-linear Plasma Kinetics, Springer, Berlin, 1975.
7. R.Pozzoli, D.Ryutov, Phys. Fluids, **22**(9), 1782, (1979).
8. V.N.Tsytovich. Theory of turbulent plasmas, Atomizdat, Moscow, 1971 [in Russian].