Subterahertz electromagnetic emission of strong turbulent plasma driven by high current REB

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I. INTRODUCTION

A distinctive feature of Langmuir turbulence is a possibility of electromagnetic emission at plasma frequency (ν_{pe}) as a result of plasmon conversion on plasma density fluctuations and gradients and emission on double plasma frequency ($2\nu_{pe}$) due to plasmon-plasmon merging [1]. This feature can be used to analyze dynamics of the Langmuir oscillations driven by high current relativistic electron beam (REB) in plasma confined in a long multimirror trap. In our recent experiments at GOL-3 facility on plasma heating by the high current REB we started investigation of these emission processes in order to obtain more detail information on the beam-plasma interaction [2].

Our previous plasma heating experiments with submicrosecond E-beams (1–10 kA/cm^2, $\tau_b \sim 100$ ns) showed that the Langmuir turbulence energy density W_l at the strong beam-plasma interaction may reach a relatively high values (limited by nonlinear processes): $W_l / nT_e \sim 10^{-1}$, where nT_e is the energy density of the heated plasma electrons [2, 3]. The same level of W_l / nT_e one can expect in GOL-3 experiments on the plasma heating by the 10 μs REB [4]. We started the GOL-3 experiments on the subterahertz emission at the plasma density in the interval of $2\div4\cdot10^{14}$см$^{-3}$ so a multichannel quasi-optical radiometric diagnostics was developed for spectral measurements in the range 100÷550GHz corresponding to ν_p- and $2\nu_p$-emission [5, 6].

II. EXPERIMENTAL SETUP

Experimental studies were carried out at the multimirror magnetic trap GOL-3, where a long

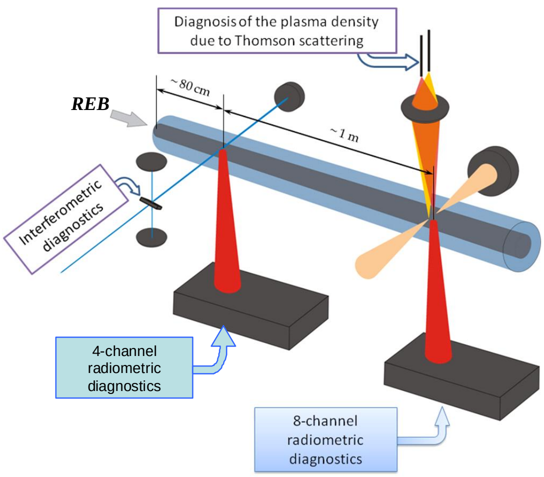

Fig. 1. Layout of the diagnostics system.

(12 m) plasma column is confined in a strong corrugated magnetic field ($B_{max}/B_{min} \cong 4.8/3.2$ T). The electron beam with the current density up to 2 kA/cm^2 and the particle energy up to 0.8 MeV is injected during 10 μs through the left end of the plasma column as it is shown in Fig.1. Measurements of the $2\nu_p$ -emission were performed at the distance 80 cm and 180 cm from the beam injection plane ($B \cong 4$ T) where the maximum efficiency for the beam-plasma interaction is identified from diamagnetic signals. The radiation output from the plasma chamber was observed normally to the axis of the GOL-3 solenoid through a teflon window with the aperture size 70×30 mm joined with a quasi-optical transmission line. Plasma density in these cross-sections was measured by interferometer (λ=10.6 μm) at the distance 80 cm and by Thompson scattering system (λ=1.06 μm) at 180 cm.

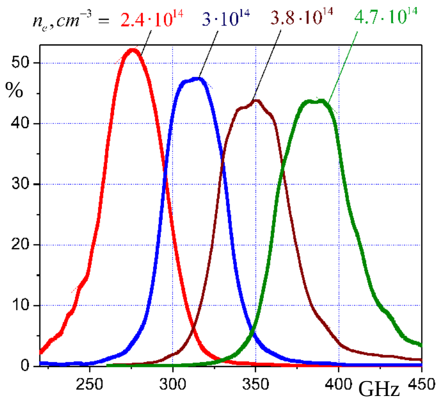

Fig. 2. Measured filter transmission of 4-channel radiometric system.

An original 4-channel radiometric system capable of measuring power of submillimeter-emission in four parallel frequency-shifted spectral bands was installed at the distance 80 cm from the beam injection plane. An 8-channel radiometric system is operated at the distance 180 cm. The systems employ a scheme with quasi-optical demultiplexing of the input radiation beam onto four spatially separated channels with subsequent frequency filtering by quasi-optical filters and spectral signal detection by calibrated Shottky-detectors matched with receiving horn-lens antennas. The filters are made on the basis of photolithographically produced self-resonant metal meshes with topology of anisotropic slots [6]. They are embedded into polypropylene wafers to form the robust double-mesh configurations with a quarter-wavelength inter-mesh separation. Selective

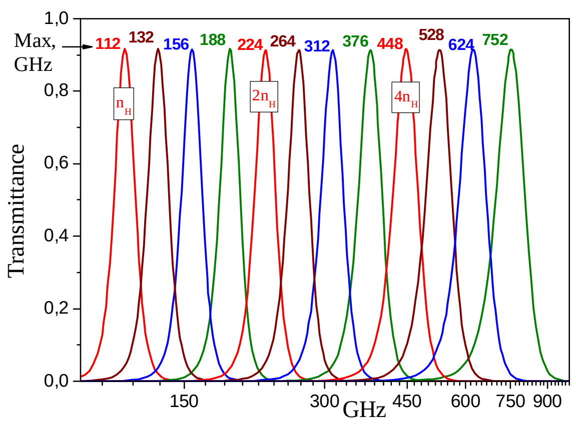

Fig. 3. Result of computer simulations of filters transmittance for 8-channels radiometric system.

properties of the 4-channel and 8-channel systems are demonstrated by Fig.2-3. After passing through the filters, subterahertz beams are further focused by aspheric teflon lenses (∅70 mm) into the receiving horn antennas of the GaAs Shottky-detectors units. Each detector, initially developed for operation at frequencies 210-450 GHz, is equipped with a built-in 900 MHz-band operational preamplifier. At 50 Ω loading resistance the typical values of the detector volt-watt sensitivity and dynamic range precisely measured with calibrated 280 GHz-solid-state radiation-source are within $1 \div 4 \cdot 10^3$ V/W and 50 dB respectively. The broadband calibration of the detectors by means of a tunable backward-wave oscillator showed an acceptable level of their sensitivity up to ~530 GHz.

III. EXPERIMENTAL RESULTS AND DISCUSSION

For standard regimes of REB-plasma heating the radiometric measurements of $2\nu_p$ -emission from GOL-3 plasma were carried out. The experiments revealed a significant level of emission during the beam injection with total duration 7÷10 μs (Fig. 4). The observed emission sometimes exceeded saturation power of Shottky-detectors. For the experiment geometry, a specific power of emission was estimated on the level of ~ 100 W/cm^3 that is consistent with theoretical predictions [1]. Emission power increased typically during the process of plasma heating by REB which is also qualitatively consistent with theoretical expectation of strong increase of the emission power with plasma electron temperature. Thomson scattering data show that T_e increases more than two orders of magnitude during the REB plasma interaction. The radiometric signals disappeared after termination of the REB injection into plasma. It also was at zero-level in the test experiments with REB injection into vacuum. Hence, a cyclotron emission from REB and plasma electrons can be ignored.

The experiments demonstrated a good agreement between the estimated value of the initial plasma density and the maximum of the power spectral density of emission associated with the "$2\nu_{pe}$-process" (Fig. 4). Inspection of the $2\nu_{pe}$ -emission polarization via a grid-polarizer mounted at the radiometry system entry showed predominance by a factor of 2-3 for radiation polarized transversely to the magnetic field.

IV. SUMMARY

In this work the investigations of subterahertz electromagnetic emission produced by strong Langmuir turbulence driven by a high-current 10 μs REB were realized for the first time. An original diagnostics was used for measuring power spectral density at frequencies

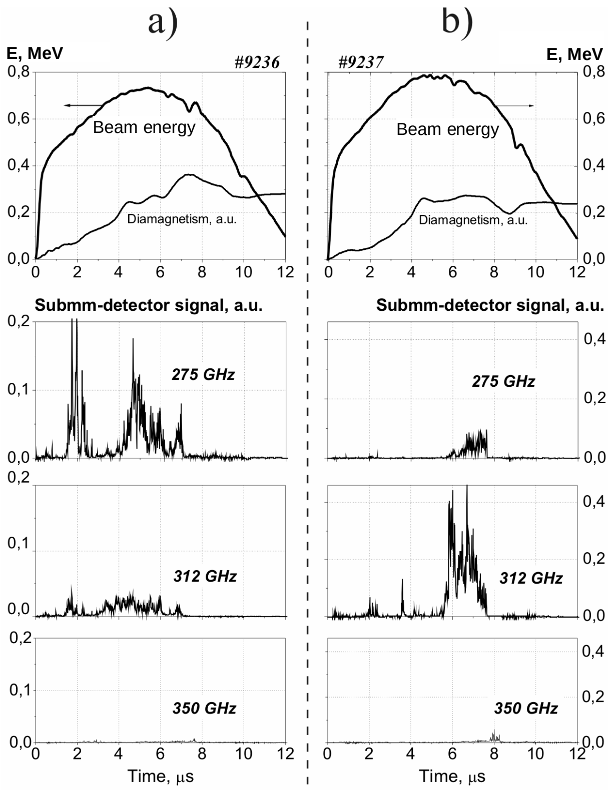

Fig. 4. Illustration of the "blue shift" in the submm-emission spectrum due to increasing the initial plasma density: a) $n_0 \approx 2{\cdot}10^{14}$ cm^{-3}; b) $n_0 \approx 4{\cdot}10^{14}$ cm^{-3}.

250÷420 GHz. The emission associated with a plasmon-plasmon merging process is confirmed by means of the developed multichannel radiometric diagnostics. The experiments revealed a significant level of emission during the major part of beam injection time at a specific emission power ~ 100 W/cm^3 and the prevailing component of polarization transverse to the magnetic field.

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