Sub-THz Spectrally-Selective Quasi-Optical System

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Introduction

Generation of second and higher harmonics of the plasma frequency is a well-known phenomenon that occurs in plasmas with high-level Langmuir turbulence [1]. Such plasmas are typical in beam-plasma interaction experiments as well as in astrophysics. In the case of plasma with $n_e \sim 10^{20}$–10^{22} m^{-3}, the radiation frequency lies in the sub-terahertz range. Studies of plasma heating by a powerful high-current electron beam are carried out at the multiple-mirror magnetic trap GOL-3 where the plasma gains electron and ion temperatures of ~1 keV as a result of collective interaction with the beam [2]. The plasma emits by different physical mechanisms in the frequency band from the cyclotron frequency up to double plasma frequency [3]. We found that plasma radiated in an irregular spiky regime if the beam was thin enough [4]. This means that there was a small number of randomly emitting spots within the field-of-view of the detector. Theory predicted that the modulational instability of a high-intensity Langmuir waves can lead to formation of localized cavitons and then to the Langmuir collapse [5, 6]. These processes are dynamical; their study requires adequate experimental techniques.

A set of sub-THz diagnostics that allows studies of spatial, angular and polarization properties of the radiation with ns-scale temporal resolution was developed for the GOL-3 facility. It consists of an eight-channel quasi-optical spectrally-selective system (polychromator) that is the subject of this paper, a separate two-channel detector for polarisation measurements and several movable single-channel detectors. Full set of microwave diagnostics covers the 37–530 GHz band. Spectral resolution of detecting channels is provided by specially-developed bandpass filters that use isotropic resonance frequency-selective surfaces. The first four-channel version of the polychromator that was previously dicsussed in [7] used less advanced filter technology.

The diagnostics

The eight-channel polychromator has a quasi-optical design approach. It uses changeable filters for setting frequency response of specific channels. Technology of large-aperture filters

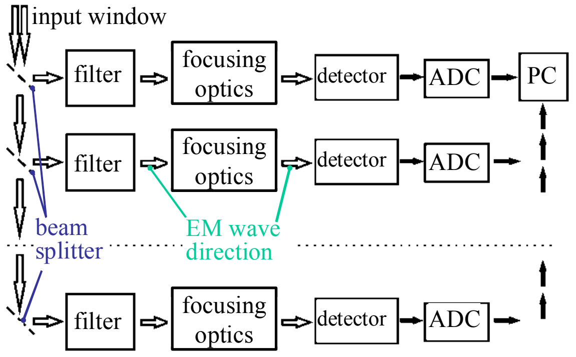

Fig. 1. Block diagram of the quasi-optical polychromator.

that use isotropic resonance frequency-selective surfaces was developed in Novosibirsk State University [8]. Block diagram of the system is shown in Fig. 1. It consists of two almost identical four-channel layers. EM wave is targeted to detection channels by polarizing beamsplitters, then is analyzed by quasi-optical filters and measured by fast detectors with Schottky diode and fast preamplifier. This arrangement scheme of elements permits changing of a filter in a separate channel for spectral tuning of the system.

The layout of the polychromator is shown in Fig. 2 that shows the upper plane of the polychromator. The incoming radiation is divided by an input polarizing splitter that directs half of EM flow into the second four-channel level. Three other polarizing splitters that are positioned in this plane divide radiation between the detection sections. The detectors are polarization-sensitive, the beamsplitters provide polarisation-insensitive measurements. The analyzing of EM wave spectrum is provided by quasi-optical filters based on FSS, see Fig. 3. The first FSS is placed at an angle to the axis therefore cut off by filters the EM wave is reflected sideways and dumped by diaphragms and collimators. Close to the filter the detector section is fitted. It consists of fast Shottky detector (STC «PRITEKS», Kiev, Ukraine), placed in the focal plate of hyperbolic Teflon lens with 70 mm aperture. The polycromator in general and signal detecting hardware in particular have good electromagnetic shielding that is suitable for operation in hard electromagnetic and radiation environment of GOL-3. On the wall of the lens barrel and in focal plate except for the detector entrance window the EM wave absorbers are placed.

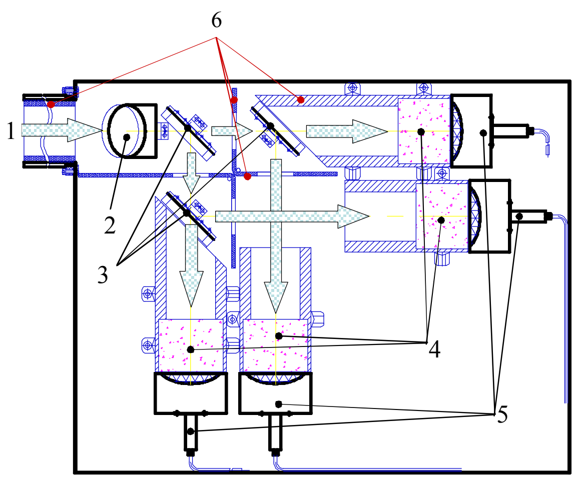

Fig. 2. Scheme of the eight-channel polychromator showing position of the four channels that are located above the base plate, the other four channel floor is located similarly at the lower surface of the base plate. Designations: 1 – incoming EM wave, 2 – polarizing splitter directed half EM flow into second four-channel floor, 3 – polarizing splitters dividing EM wave between the detection sections “5”, 4 – quasi-optical filters, 6 – EM wave dumping diaphragms and collimators.

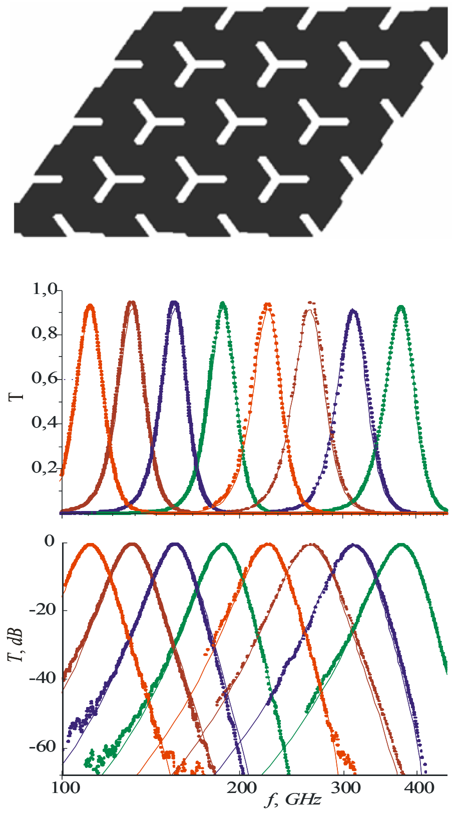

Fig. 3. Top: structure of a frequency-selective surface. Bottom: example of transmission of separate filters based on triple-grid isotropic inductive tripole surfaces used in the polychromator. Dot lines are measurements, continuous lines are design calculations.

Temporal resolution of the system is 2 ns that is defined by the detectors combined with ADC-200 (BINP-developed). The existence of absorbing diaphragms and collimators all over the EM wave path allows reaching suitable optical cross-talking attenuation that exceeds 100. Directional pattern of the system of 2º is determined by diffraction on the diaphragms placed along the beam path of EM wave and entrance collimator.

After the assembling, the polychromator was absolutely calibrated in full working diapason wuth special THz calibration facility in NSU that uses several backward wave oscillators as radiation sources and THz calorimeter as a reference receiver – see Fig. 4 as the example of measurements with one particular filter set.

Sub-THz Spectrum of Plasma Emission

The polychromator was used in plasma experiments on GOL-3 device as well as the other mentioned microwave diagnostics. We observed radiation in a broad frequency band. Note that in our experiments numerical values of the plasma and the cyclotron frequencies are close. The lowest-frequency channel in Fig. 4 was set to the cyclotron frequency of 112 GHz that corresponds to 4 T field in the observation plane.

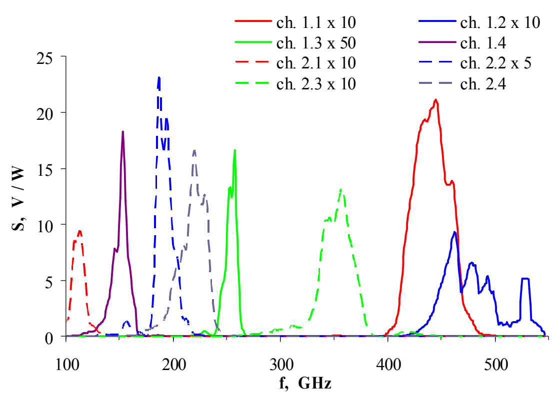

Fig. 4. Spectral sensitivities of different channels in the assembled system fit a filter set prepared for a specific experimental run.

Some new results are presented in Fig. 5. In the experiment the plasma density was changed to shift the radiation spectrum. In the Figure the mean plasma densities in are indicated

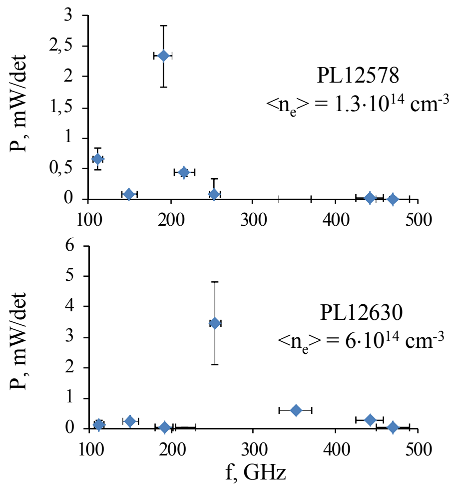

Fig. 5. Instantaneous spectrum of EM emission measured at coordinate z = 193 cm from the beam injection point in two shots at different density. Power at the detecting module is shown.

for each shot. The maximum in the spectrum corresponds to double plasma frequency. It shifts to higher frequencies with the density increase.

Summary

A high-level Langmuir turbulence can generate electromagnetic radiation in a wide frequency range extending from the plasma frequency to its second harmonic (see, e.g., [9]). Frequency of radiation at $2\omega_p$ increases with the density. At $n_e \approx 3\cdot10^{21}$ m^{-3} it reaches ~1 THz band.

The multichannel quasioptical diagnostic system was developed for GOL-3 experiments. This system uses bandpass filters with isotropic resonance frequency-selective surfaces and fast detectors with Shottky diodes. Current version of the system can measure eight channels in 37–530 GHz band simultaneously. Design of the polychromator allows extending its capabilities to higher frequencies with proper detectors and filters.

Acknowledgments

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