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Electrodynamic system for two-stage THz-generator on the base of two-channel planar FEM

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Introduction

Two-dimensional (2-D) distributed feedback gives the opportunity to create generators of a coherent flowof electromagnetic radiation with very wide cross-section. We study such mechanism of spatial synchronization of electromagnetic oscillations for the case of a planar free electron maser (FEM) at the ELMI-device (BINP, Novosibirsk) [1]. To produce high-power THz-radiation few schemes of two-stage generators basing on this mechanism were suggested and investigated [2, 3]. Theory predictsMW-power levelin THz-radiation pulse [3].To get the first experience the simple two-stage scheme similar to our experiments on mm-wave generation in two-channel planar FEM [4] was chosen. The idea is to use single channel of this planar FEM driven by the first sheet beam as a low frequency (LF) section of THz-generator in which the following parameters of the radiation pulses have been achieved: frequency ~75 GHz, spectrum width ~20 MHz, pulse duration ~200 ns and power from single channel ~20 MW. This pulse is planned to be delivered to the high frequency (HF) section by means of Bragg wave deflector. After transformation of the pulse to the cutoff wave in the wave transformer it will be scattered by the second sheet e-beam with the frequency conversion to 1 THz band. The parameters and technical solutions for the elements of electrodynamic system obtained on the base of 3D-modeling and tested in “cold” experiments will be presented in the paper.

Electrodynamic System for Two-Stage Generator

The design of electrodynamic systemincludes two planar channelswith the length of 1.1 m separated by a metal baffle (see Fig. 1). Two sheet e-beams (1 MeV / 1 kA / 5 µs) are transported in a guiding uniform magnetic field $B \le 1.7$ T inside the lower (cross-section 0.95×9 cm) and the upper (0.6×9 cm) vacuum channels referred as LF- and HF- sections respectively. Besides that, the LF-section is placed in an undulator magnetic field with amplitude $B_\perp \le 0.17$ T. The electrodynamic system of the LF-section is composed of the two-mirror cavity consisting of 2D and 1D Bragg reflectors connected by a regular waveguide, and the wave deflector to deliver mm-wave to the HF-section. Both 1D and 2D reflectors are formed by two parallel conducting plates with corrugation of their surface in the form of parallel rectangular grooves and “chessboard” corrugation respectively. The 2D-reflector of the cavity has the length $l_{2D} = 20$ cm with its corrugation depth $a_{2D} = 220$ µm and the period of corrugation $d_{2D} = 0.4$ cm. The main Fourier harmonic of the corrugation has the amplitude: $A_{1,1} = 16a_{2D}\left[\cos\left(h_{2D}z - h_{2D}x\right) + \cos\left(h_{2D}z + h_{2D}x\right)\right]/\pi^2$, where $h_{2D} = 2\pi/d_{2D}$ – x and z components of translation vector. The same parameters for 1D-reflector are: the length $l_{1D} = 20$ cm, depth of corrugation $a_{1D} = 70$ µmand its period $d_{1D} = 0.2$ cm. The amplitude of main Fourier harmonic is: $A_1 = 4a_{1D}\cos\left(h_{1D}z\right)/\pi$, where $h_{1D} = 2\pi/d_{1D}$ - translation vector of grating.

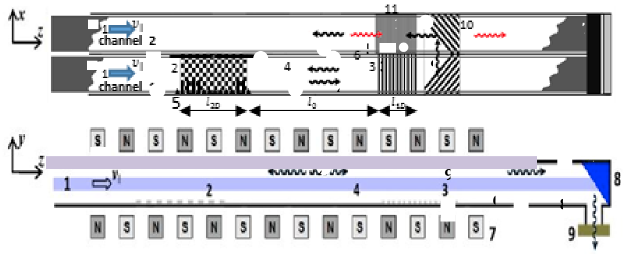

Fig. 1. Layout of the ELMI experiment to study the two-stage scheme for THz generation. 1 – parallel sheet electron beams, 2 – 2D-Bragg reflector, 3 – 1D-reflector, 4 – regular waveguide section, 5 – baffle between channels, 6 – planar undulator (shown in the y-z plane), 7 – beam collector, 8 – output window, 9 – wave deflector,10 – Bragg transformer of travelling to cutoff wave

Wave deflector

The main task for the design of the wave deflector is the achieving the high efficiencyof the radiation transmission from the LF-section to the HF-section and the required wave structure at the exit of the deflector.

To find the optimal configuration of the deflector, two main features of its corrugation were varied in the modeling: the shape of the corrugated region and the corrugation depth. In the result of the numerical solution of the coupled wave equations the optimal expression for the corrugation border was found: $z = 2.69 \cdot \exp\left(|x|/2.9\right) - 3.58$ cm, $x = -10 \div 10$ cm, $z = 0 \div 13$ cm. Then the optimal depth of the corrugations was determinedin 3D full electro-dynamic calculations. Fig. 2 shows the results of modeling and measurements for the transformation of H_{10} mode passing in LF-section to the modes of HF-section for the corrugation depth of the deflector 370 µm.

Both 3D calculations and “cold” tests demonstrate the high transmission efficiency (~80%) from the LF-section to the HF-section in the band 74÷76 GHz. As to the mode purity, some parasitic conversion to highest modes increasing with the increase of the corrugation depth was observed.

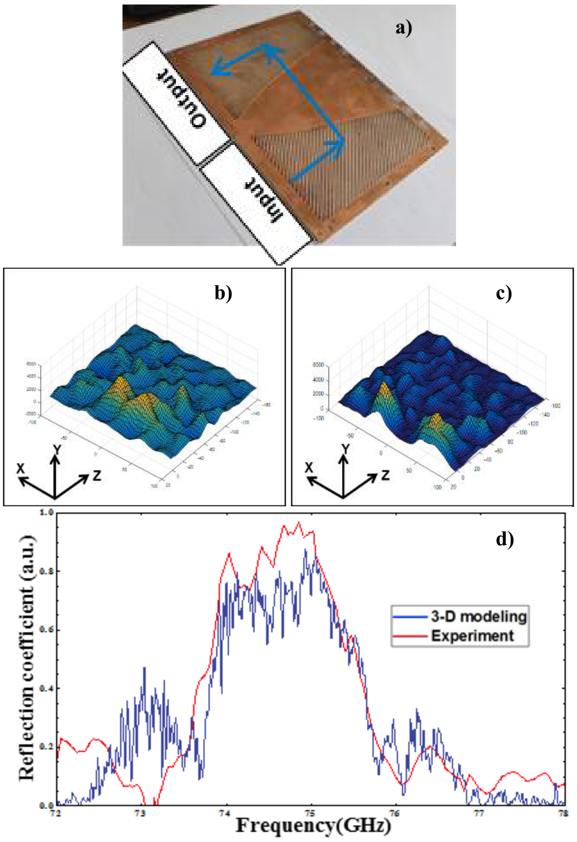

Fig. 2. (a) – photo of the wave deflector plate, (b),(c) – flux density distributions P_x and P_z in the plane (x,z),(d) – transmission efficiency of the deflector from input to outputmeasured in "cold" tests

Wave Transformer

In order to intensify the interaction of the beam with the mm-wave, the transformer of the travelling wave to the cutoff one is planned to be applied in HF-section. Such wave conversion will serve to some decreasing the frequency of scattered radiation to the range 0.6 ÷ 1 THz that is more suitable for further mode selection by means of the cavity with advanced Bragg structures [5]. For this purpose, we developed 1D Bragg structure with one leap phase equal to π in the center of the structure. Such transformer with sizes of its plates $l^{tr} = 19.6\,\text{cm}$, $l_{\perp}^{tr} = 10\,\text{cm}$ and the gap between them $a_0 = 0.6\,\text{cm}$, has rectangular corrugation with the depth $a_{tr} = 70\,\mu\text{m}$ and the period $d_{tr} = 0.4\,\text{cm}$ (see Fig. 3, a).According to 3D-modeling this wave structureprovides substantial increase of the scattering wave amplitude(~10 times) but only in the narrow frequency band 75.05 ÷ 75.12 GHz (see Fig. 3, b).This will make difficultiesfor ingress of the operating mode of LF-section in this band. To overcome them, new Bragg transformer with two leaps of phase is under development now that will allowobtaining more wider band with effective conversion to cutoff wave and larger gain factor.These conditions should provide more effective beam-wave interaction resulting in the increase of the THz-radiation power in the future experiments at the ELMI device.

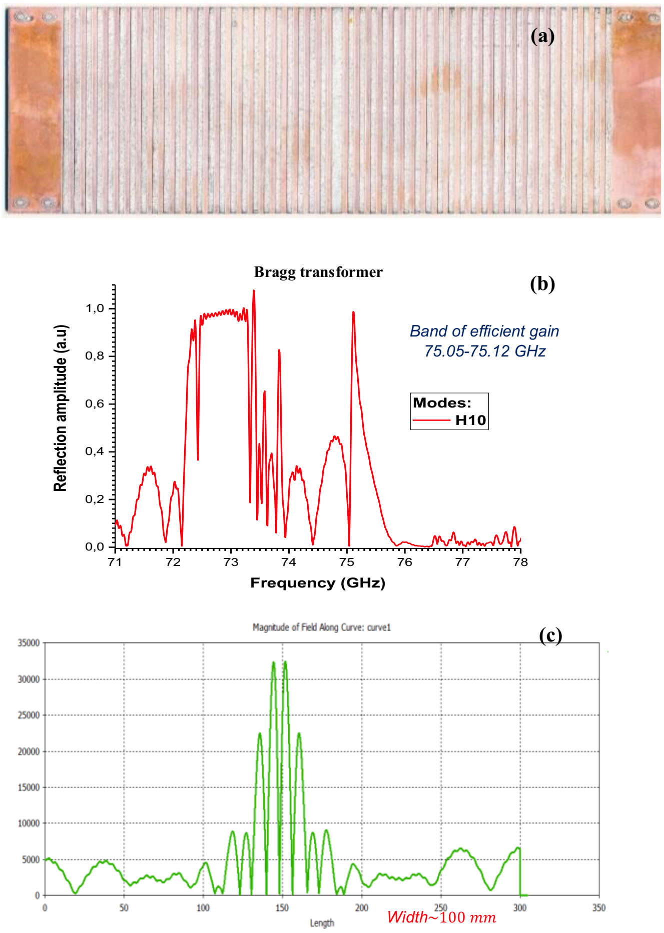

Fig. 3. (a) – photo of the Bragg transformer with aleap phase, (b) – reflection coefficient of Bragg transformer, obtained in 3D modeling, (c) – amplitude amplification

Acknowledgements

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