Novel THz Sources with Profiled Focusing Field and Photonic Crystal Electrodynamic Systems

Yevhen Odarenko, Oleksandr Shmat'ko

Abstract - **Methods of the efficiency enhancement of the vacuum terahertz and subterahertz sources based on the resonance of O-type generators with a prolonged interaction (orotron, diffraction radiation oscillator, ledatron, laddertron) are considered. Theoretical analysis is performed on the basis of multidimensional nonlinear self-consistent theory of beam-wave interaction.**

Keywords – **Terahertz devices, Nonlinear multidimensional theory, Photonic crystal structures, Profiled focusing field.**

I. INTRODUCTION

Development of the effective terahertz electron devices (generators and amplifiers) is the one of basic tendencies of the modern vacuum electronics [1, 2]. Efficiency of the classical microwave devices decreases in this frequency range. The most critical problems are the slow-wave structures fabrication and coupling impedance decrease. These problems stimulate the searching of the novel electron devices schemes with more effective beam-wave interaction.

We propose two methods to increase the interaction efficiency:

- application of the profiled focusing magnetic field;
- application of the electrodynamics systems containing photonic crystal structures.

Non-uniform and inclined focusing magnetostatic fields provide the enhancement of the device efficiency due to change of the electron trajectories in the interaction region [3, 4]. Therefore non-linear multidimensional theory is necessary for investigation of the beam-wave interaction regularities in such devices.

Results of the numerous experimental and theoretical investigations of the photonic crystals show possibilities of their wide application in active and passive elements for different frequency ranges [5, 6].

In this report the different schemes of the O-type electron devices with profiled focusing field are considered. Moreover the electrodynamic properties of the photonic crystal structures that can be used for interaction with sheet and pencil electron beams in terahertz electron devices are investigated.

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II. ELECTRON DEVICES WITH PROFILED FOCUSING FIELD

The first method allows controlling the charged particles trajectories in the interaction region and supports the passing of the electron beam near the surface of the slow-wave structure, where the maximum intensity of the RF field is realized. The settling of the electrons on the surface of the slow-wave structure provides the phase sorting of beam particles and can leads to further increase of the device efficiency.

Fig. 1 shows electronic devices schemes with different spatial distributions of the focusing magnetic field induction. Profiling of the focusing magnetic field is carried out by inserting the local magnetic nonuniformity (LMN) (Fig. 1(a) and 1(c)). Fig. 1(b) shows a scheme with homogeneous focusing field that provides the inclined movement of the electron beam relative to the surface of the slow-wave structure (clinotron-like scheme).

Experimental results and theoretical studies indicate

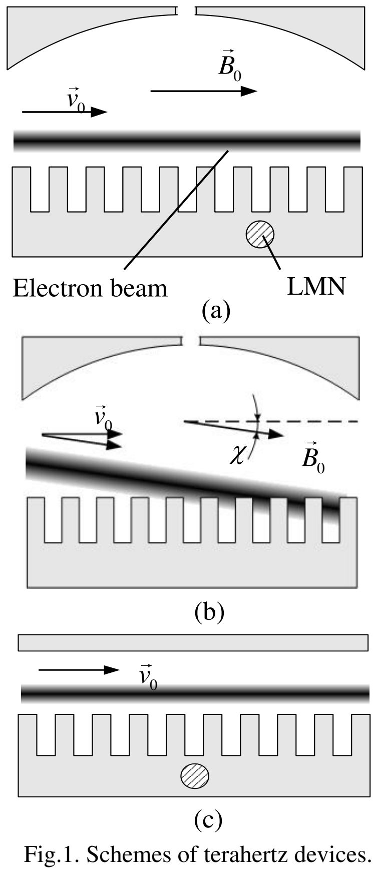

Fig.1. Schemes of terahertz devices.

the possibility of reducing the starting current and increase the output power by a factor of 1.5-2 compared to the basic design with uniform magnetostatic focusing field. Moreover, an improvement in spectral characteristics of the output radiation is realized.

Fig. 2 shows the normalized starting current of

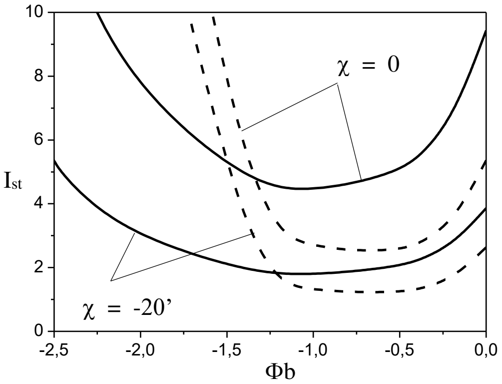

Fig.2. Starting current vs velocities mismatch parameter for different values of the incline angle.

diffraction radiation oscillator (DRO, orotron) and BWO (dashed curves) for two values of focusing field incline angle. $\Phi b = \omega L\left(v_0^{-1} - v_\varphi^{-1}\right)$; L – interaction space length; v_φ – phase velocity of the slow wave. Incline angle increase results in the efficiency enhancement of both devices.

It should be noted that further increase of the incline angle is followed by decrease of the starting current and efficiency owing to electron beam settling on the electrodynamic system surface. In this case the interaction region length is reduced.

Application of the LMN focusing field also provides the change of the beam-wave interaction conditions due to control the current spatial distribution in the interaction region. To increase the interaction efficiency the electron beam must pass as close as possible to the slow-wave system surface in the region where the strongest high-frequency field is acting. In terahertz band the fulfillment of this condition without the electron beam settling is the difficult problem owing to fast decrease of the field amplitude near the slow-wave system surface. But in DRO with the non-uniform focusing field the highest interaction efficiency was achieved when all of the beam electrons settle onto the slow-wave system at the interaction space end. Hence in this case the current settling plays a key role in the efficiency enhancement due to phenomenon of electrons phase selection. It should be noted that these results was obtained for DRO mode with Gaussian form of the high-frequency field longitudinal amplitude distribution in the interaction space. In this case the field amplitude maximum realizes in the center of the interaction space.

III. Photonic Crystal Slow-Wave Systems in Electron Devices

The application of photonic crystal structures for the formation of electrodynamics systems of the terahertz devices can overcome one of the main factors that reducing the interaction efficiency in electronic devices with increasing frequency – decrease of the interaction impedance due to the localization of high-frequency field near the surface of slow-wave structures.

Due to the periodicity of the material parameters changes in one or more dimensions in photonic crystals formed band gaps in which the radiation propagation becomes impossible. This physical phenomenon is used to form a quasi-optical and optical waveguides and cavities based on defects in photonic crystals, i.e. violations of translational symmetry.

Different kinds of the linear defects that can be used for transmission of the electron beam and its interaction with the electromagnetic field are considered. The dispersion characteristics and spatial distributions of the electric field for the localized modes of the photonic crystal waveguides are calculated. Numerical calculations were performed using software package MIT Photonic Bands (MPB) [7].

Fig. 3(a) is a scheme of the photonic crystal

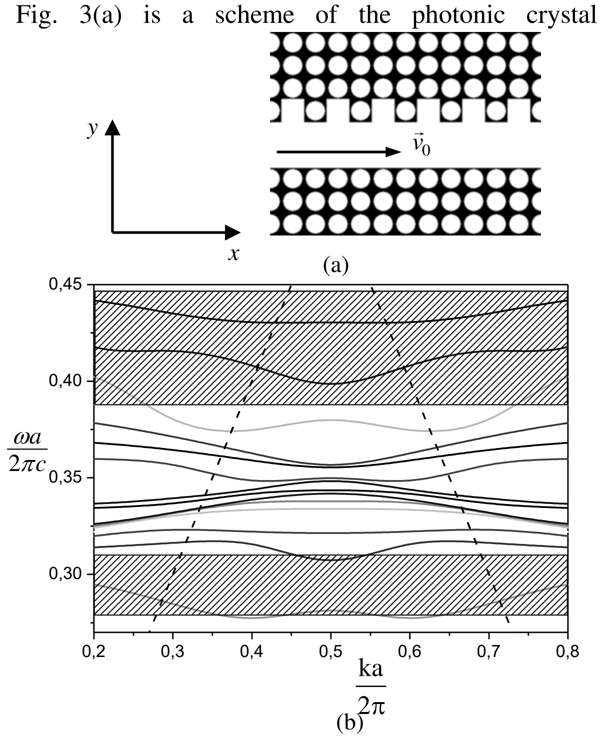

Fig.3. Photonic crystal waveguide scheme and dispersion diagram.

waveguide which is used as a channel for passing the sheet electron beam with initial velocity $\vec{v}_0$. Fig. 3(b) shows the dispersion diagram of photonic crystal waveguide. a is the lattice constant of photonic crystal. Dielectric permittivity $\varepsilon = 12$.

The shaded areas show the forbidden zones of the bulk photonic crystal for the TE polarization of the radiation. Sloping dashed lines represent light lines for positive and negative spatial harmonics. Dispersion diagram shows that the slow wave modes exist in the waveguide (phase velocity less than the speed of light).

Fig. 4 displays spatial distributions of the electric field amplitude in the cross-section of the photonic crystal waveguide shown in Fig. 3(a). Three solid curves correspond to different values of longitudinal coordinate. Dashed lines indicate the boundaries of hollow waveguide channel where sheet electron beam is passed. In this case we can see the localized mode of the phonic crystal waveguide. Furthermore the phase velocity for this mode less than speed of light.

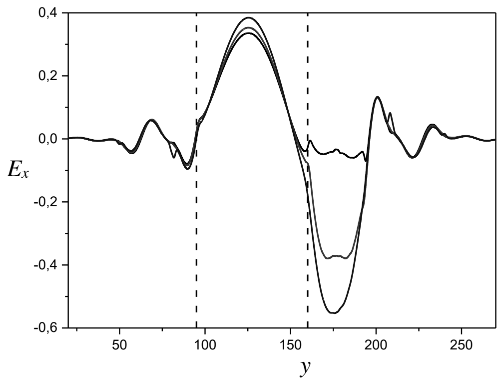

Fig.4. Transverse spatial distribution of the electric field.

As seen in Fig. 4 the dependence of electric field amplitude on transversal coordinate has a maximum in the center of the channel. Therefore this localized mode of the photonic crystal structure is not a surface mode in the ordinary sense. At the same time modes of the conventional metal slow-wave systems are purely surface. This fact results in the coupling resistance decrease and complicate the usage of the metal electrodynamic systems in the terahertz electron devices.

It is clear from Fig. 4 that in the photonic crystal slow-wave systems electron beam may be passed in the center of the waveguide channel. This configuration is suitable for miniaturized electron devices since in this case strong requirements for current density, sizes and electron-optical system are absent.

Fig. 5 shows effect of the electron beam thickness Δ on the beam-wave interaction efficiency. Curves 1-4 correspond to different values of normalized electron beam size Δ / D along axis Oy. Here D – width of the waveguide channel. Curve 1 – $\Delta / D = 1$; 2 – $\Delta / D = 0.75$; 3 – $\Delta / D = 0.5$; 4 – $\Delta / D = 0.25$. Decrease of the Δ / D results in the efficiency enhancement. Moreover efficiency maximum is reached for less longitudinal coordinate.

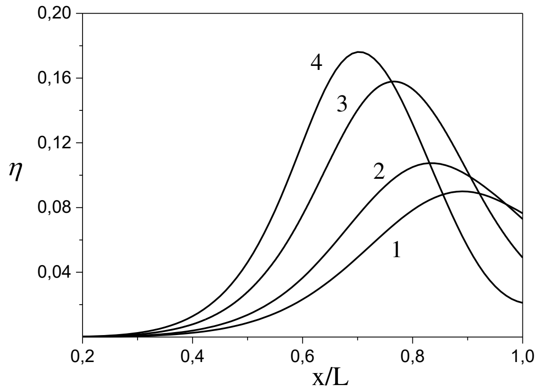

Fig.5. Beam-wave interaction efficiency vs longitudinal coordinate.

IV. CONCLUSION

The use of profiled focusing field in the O-type oscillators and amplifiers results in efficiency enhancement and provides the possibility of these devices application in the terahertz band.

It was found that in the photonic crystal waveguides can be implemented regime of slow waves with a transverse electric field amplitude distribution, which provides the increase of the coupling resistance compared to standard electrodynamics systems of vacuum terahertz devices.

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