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EDITORIAL: HOW TO CONTRIBUTE TO THE NEWSLETTER

Dear Reader,

We are inviting contributions to the following rubrics:

- Research highlights (annotations) presenting the projects pursued by the members of the Consortium.
- Short regular and invited papers.
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- Programs and frameworks for an exchange of visits and mobility of researchers. Job opportunities (especially for young researchers, e.g. postdoctoral positions, specializations, internships).
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- Information and announcements about awards and nominations.
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On the applicability of absorbing rectilinear electron beams in high-frequency gyrotrons

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Abstract. The paper presents theoretical investigation and numerical simulations of the electron-wave interaction in a high-frequency double-beam gyrotron with an absorbing rectilinear electron beam. The expression for the starting current in a double-beam gyrotron with one generating and one absorbing beam is derived within the model with a fixed axial field structure and the results of numerical simulations based on a self-consistent model are discussed. It has been demonstrated that the required currents of the absorbing beam are proportional to $I_{radiating}$*L/λ, thus showing that such an approach is inefficient in the case of high-frequency, low-power gyrotrons with long resonators.

I. Introduction

Nowadays, sources of terahertz radiation are in great demand due to a number of current and perspective applications [1]. The gyrotrons [2,3] are the most powerful sources of continuous-wave radiation in the sub-THz to THz frequency range, with an output power up to several hundreds of watts. Nevertheless, the operating frequency of devices, operating at the fundamental cyclotron resonance is limited by the availability of sufficiently strong superconducting magnets, thus the advance to THz is inevitably tied with operation at the cyclotron harmonics. However, such operation has several problems; the most serious one is the mode competition, especially with modes at lower harmonics. For suppression of the parasitic modes the two groups of methods exist, namely electrodynamical selection (irregular cavity [4], use of reflections [5], echelette systems [6], etc.) and electron selection (using the properties of the electron beam). The second method includes selection of beam radii based on the coupling coefficient [7], usage of axis-encircling beams in large-orbit gyrotrons [8] and systems with several electron beams [9,10].

In this paper we investigate the efficiency of mode selection by an additional absorbing electron beam in high-frequency gyrotrons operating at high cyclotron harmonics. The concept of the gyrotron with mode selection by absorption of the energy of the spurious modes by an additional beam was proposed by Zapevalov and Tsimring [11], and successfully tested in cm-wavelength high-power devices at the second harmonic of the cyclotron frequency [12]. Promotion of this mode selection method to THz frequency range sources has to take into account their peculiarities, such as weak electron-wave coupling, relatively low operating currents and long cavities (in contrast with high currents and short cavities in the powerful devices). Here we consider the low-power sub-terahertz tube with one radiating "1" and one absorbing "2" electron beams (Fig. 1). In order to ensure the conditions for cyclotron absorption, the electrons of the second beam do not rotate and have rectilinear trajectories [11]. We consider the simple adiabatic magnetron-injection gun (MIG), so the energies of the beams launched from cathode are the same.

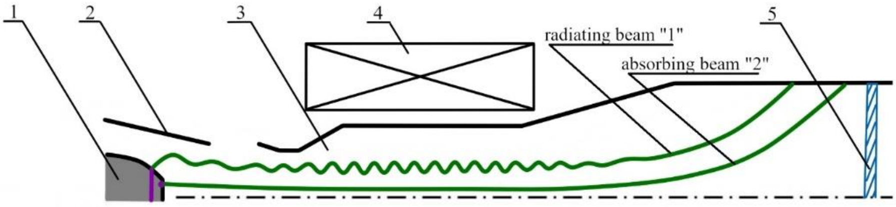

Fig. 1. The scheme of the double-beam gyrotron with radiating "1" and absorbing "2" beams; 1 – cathode, 2 – modulation anode, 3 – resonator, 4 – magnet, 5 – output window

The paper is organized as follows: the general set of equations and parameters, describing the electron-wave interaction efficiency are described in Section II. Section III is devoted to the relation of the general description with the "classical" gyrotron theory and results of numerical simulation, as well as includes a discussion of the applicability of absorbing beams as mode selection tools in sub-THz devices.

II. Asymptotic equations of the double-beam gyrotron

As a first step, we can get a simple analytical formula, which estimates the effect of the presence of the absorbing rectilinear beam «2» on the starting current of a parasitic wave excited by the radiating beam «1». Since there is no interaction of the rectilinear electron beam with modes at cyclotron harmonics [13], we will consider only modes at the fundamental.

Evidently, the total RF wave power emitted by electrons in the double-beam system is the difference between the power radiated by the beam "1" and the power absorbed by the beam "2":

$$P_e = U_0\left(I_1\Delta\gamma_1 - I_2\Delta\gamma_2\right) \, , \qquad (1)$$

where, $U_0 = mc^2/e$, I_1 and I_2 are the currents of the radiating and absorbing beams respectively, $\gamma = 1/\sqrt{1-(v/c)^2}$ is the relativistic Lorentz-factor, $\Delta\gamma_1$ is the averaged decrease in the relativistic energy of the electrons of the radiating beam "1", and $\Delta\gamma_2$ is the averaged increase in the relativistic energy of the electrons of the absorbing beam "2". In the starting small-signal regime of the electron-wave interaction, the changes in the electron energy are proportional to the squared wave amplitude *a* [14,15],

$$\Delta\gamma_{1,2} = a^2\eta_{1,2} \, ,$$

where $\eta_{1,2}$ are the normalized electron efficiencies. The power of the microwave losses in a cavity having a finite quality factor Q is also proportional to the square of the wave amplitude:

$$P_w = Ca^2$$

Here, the constant $C \propto N_s/Q$ includes both the norm of the operating mode N_s and the Q-factor. The starting current of the parasitic wave, I_1, is described by the energy balance condition, $P_e = P_w$:

$$U_0\left(I_1\eta_1 - I_2\eta_2\right) = C \qquad (2)$$

On the other hand, the same relation describes the starting current of the parasitic mode $I_1^{(0)}$ in the case when the absorbing beam is absent ($I_2 = 0$):

$$U_0 I_1^{(0)}\eta_1 = C \qquad (3)$$

Having compared equations (2) and (3), one can get the following formula describing the increase in the starting current of the parasitic wave provided by the presence of the absorbing beam:

$$\frac{I_1}{I_1^{(0)}} = \left[1 - \frac{I_2}{I_1}\frac{\eta_2}{\eta_1}\right]^{-1} \, . \qquad (4)$$

According to this formula, a significant $(I_1/I_1^{(0)} \gg 1)$ increase in the starting current of the parasitic wave is provided, when the ratio between currents in the absorbing and radiating beams is as big as

$$\frac{I_2}{I_1} \sim \frac{\eta_1}{\eta_2} \, . \qquad (5)$$

Let us estimate the normalized efficiencies $\eta_{1,2}$. We consider a gyrotron-type interaction between a particle and a quasi-critical TE wave having the transverse electric field $E_\perp \propto a\exp(i\omega t)$. Evidently, the change in the electron energy is determined by the work of the wave on the particle, $d\gamma/dt \propto v_\perp E_\perp$. Therefore, one can get an equating like the following [14,15]:

$$\frac{d\gamma}{dz} = \frac{\beta_\perp}{\beta_\parallel}\chi a\cos\theta \, . \qquad (6)$$

Here, χ is the factor of the electron-wave coupling determined by the transverse structure of the wave, $\beta_{\perp,\parallel} = v_{\perp,\parallel}/c$, $\theta = (\omega - \Omega_0/\gamma)t + \varphi$ is the resonant (slow) phase of the particle with respect to the wave, $\Omega_0 = eB/mc$ is the non-relativistic electron cyclotron frequency, and φ is the initial phase of the electron cyclotron rotation. We introduce the transverse and axial components of the normalized electron momentum, $p_{\perp,\parallel} = \gamma\beta_{\perp,\parallel}$, and use the general relativistic relation:

$$\gamma^2 = 1 + p_\parallel^2 + p_\perp^2 \, . \qquad (7)$$

Having taken into account the conservation of the axial momentum, $p_{\|} = const$, one easily gets the equation for the transverse momentum:

$$\frac{dp_\perp}{dz} = \frac{1}{\beta_\|}\chi a \cos\theta . \tag{8}$$

First, we consider an electron from the rectilinear absorbing beam "2". Since this particle has only an axial velocity at the input of the cavity, one should put in Eq. (8) $\beta_\| = \beta_0$ and $\theta = 0$. The latter means that the initial (acquired at the beginning of the process of cyclotron acceleration of the electron) phase of the gyro-rotation, φ, corresponds to the maximum of the accelerating transverse electric field of the wave. Therefore, the transverse momentum acquired in the process of cyclotron acceleration during the motion of the particle along the cavity with the length L is $p_\perp = \chi a L/\beta_0$. Having taken into account Eq. (7), one obtains $\Delta\gamma_2 = \frac{p_\perp^2}{2\gamma}$ and, therefore, efficiency of the absorbing beam is equal to:

$$\eta_2 = \frac{\Delta\gamma_2}{a^2} = \frac{\chi^2 L^2}{2\gamma\beta_0^2} . \tag{9}$$

As for the electrons from the radiating beam "1", they possess some initial pitch-factor (the ratio between rotational and axial velocities) $\alpha = \beta_{\perp 1}^{(0)}/\beta_{\| 1}^{(0)} \sim 1$. We assume that the initial energies of electrons from the both beams "1" and "2" are the same and, therefore, $\beta_0^2 = \beta_{\perp 1}^{(0)2} + \beta_{\| 1}^{(0)2}$. In the small-signal approximation, Eq. (6) for the change of the particles energy from the radiating beam is transformed as follows:

$$\frac{d\gamma}{dz} = \alpha\chi a \cos\theta . \tag{10}$$

Since at the beginning of the electron-wave interaction all electrons are uniformly mixed over their initial phases in the interval $0 \le \theta_0 < 2\pi$, we should also describe the bunching of particles in the process of the interaction by the following equation for the phase:

$$\frac{d\theta}{dz} = \frac{\omega - \Omega_0/\gamma}{v_\|} = \frac{k}{p_\|}(\gamma - \Omega_0/\omega) = \delta - \mu\Delta\gamma , \tag{11}$$

where $\mu = k/p_\|$ is the factor of the inertial electron bunching. The solution of Eqs. (10) and (11) obtained in the small-signal approximation is well known [14,16]:

$$\left\langle \Delta\gamma_1 \right\rangle_{\theta_0} \approx (\chi\alpha)^2 \mu L^3 \times \frac{a^2}{4} \times \phi' . \tag{12}$$

Here, $\phi' = \frac{d\phi}{d\Psi}$,

$$\phi = \left| \int_0^1 \exp(i\Psi x) dx \right|^2$$

is the "spectrum" of the effective high-frequency force acting on the electrons inside the cavity, and $\Psi = \delta L$ is the incursion of the particle phase relative to the wave for its passage through the resonator. Thus, we obtain the following normalized efficiency for the radiating beam "1":

$$\eta_1 \approx \frac{\varphi'}{4}\chi^2\alpha^2\mu L^3 . \tag{13}$$

We should take into account also that $\phi' \approx 0.3$ at the optimal phase ($\Psi \approx \pi$).

The small beam radius in the resonators of the THz gyrotrons complicates the development of multi-beam electron-optical systems and limits the overall dimensions of the electron gun, which does not allow installation of insulators between emitter rings. Due to this fact, the energies of the electrons in different beams in conventional magnetron-injection guns are usually the same. Then, estimation (5) together with the expressions for the efficiencies for both beams with equal energies leads to the following estimation for the required ratio between electron currents in the radiating ("1") and absorbing ("2") beams:

$$\frac{I_2}{I_1} \sim \frac{L}{\lambda}\alpha^2\frac{\beta_0^2}{\beta_\|} = \frac{L}{\lambda}\beta_0\alpha^2\sqrt{1+\alpha^2} . \tag{14}$$

For typical parameters of the modern sub terahertz gyrotrons (accelerating voltage U = 20-30 kV, pitch factors α = 1.2- 1.4) the normalized initial electron velocity can be found as $\beta_0 = \sqrt{2U\left[kV\right]/511}$, so the estimate (14) gives the ratio of the currents

$$\frac{I_2}{I_1} \sim \frac{L_{resonator}}{\lambda_{parasite}} \qquad (15)$$

III. Relation with the conventional gyrotron theory

The estimates given above are based on the general theory of microwave devices operated in the regime of inertial electron bunching with a low electron efficiency. More complex calculation of the effect of an absorbing electron beam on the starting current in the gyrotron with equal beam energies can be done in the framework of the nonlinear gyrotron theory with the fixed axial field structure [15,17], which is applicable to the resonators with high Q-factor. The coupling factor for the electron beams with the $TE_{m,p}$ mode on the fundamental can be given by a well-known equation:

$$G_{1,2} = Q\frac{e}{mc^3}\frac{2}{\beta_{\perp 1}^2\beta_{\parallel 1}\gamma_0}\frac{J_{m-1}^2\left(k_\perp R_{1,2}\right)}{\left(\nu_{m,p}^2 - m^2\right)J_m^2\left(\nu_{m,p}\right)}\frac{1}{\int\limits_0^{Z_{end}}\left|f\left(Z\right)\right|^2 dZ}\ , \qquad (16)$$

where, $Z = \frac{\beta_{\perp 0}^2}{2\beta_{\parallel}}\frac{\omega_H}{c}z$ is the normalized axial coordinate, *f(Z)* is the axial field profile, $k_\perp = \nu_{m,p}/R$ is the transverse wavenumber and $\nu_{m,p}$ is the root of the equation $J_m'(\nu) = 0$ corresponding to the $TE_{m,p}$ mode.

Following the standard procedure for derivation of the starting current in the model with a fixed field structure [15], we can get the equation for the starting current of the parasitic mode at the fundamental cyclotron resonance in presence of an additional absorbing beam in the following form:

$$I_{start} = \frac{1 + G_2 I_2\frac{\beta_{\parallel 1}^2}{\beta_0^2}\left|\int\limits_0^{Z_{end}} f\left(Z\right)e^{i\Delta Z}dZ\right|^2}{-G_1\left(1 + \frac{d}{d\Delta}\right)\left|\int\limits_0^{Z_{end}} f\left(Z\right)e^{i\Delta Z}dZ\right|^2}\ , \qquad (17)$$

where $\Delta = \frac{2}{\beta_{\perp 1}^2}\left(\frac{\omega_c - \Omega_0}{\Omega_0}\right)$ is the normalized cyclotron resonance mismatch and ω_c is the cutoff frequency of the considered parasitic mode. The resulting equation resembles the classic one for the case of a single generating beam [15] with an addition of an energy drain by rectilinear electron beam.

The influence of the additional rectilinear electron beam on the starting currents of the parasitic modes in a 25 GHz gyrotron [12] and in a 780 GHz gyrotron [10] was investigated using both the fixed field profile model and the self-consisted gyrotron model with a non-fixed field structure [18,19]. For the equation (17), the axial profile of the parasitic modes at the fundamental resonance and their Q-factors were calculated in the cold-cavity approximation.

The powerful 25 GHz gyrotron has rather short cavity, with $L/\lambda \simeq 3$, so the Q-factor of the parasitic $TE_{4,1}$ mode is equal to 300. The calculated dependence of starting current is presented on the Figure 2.

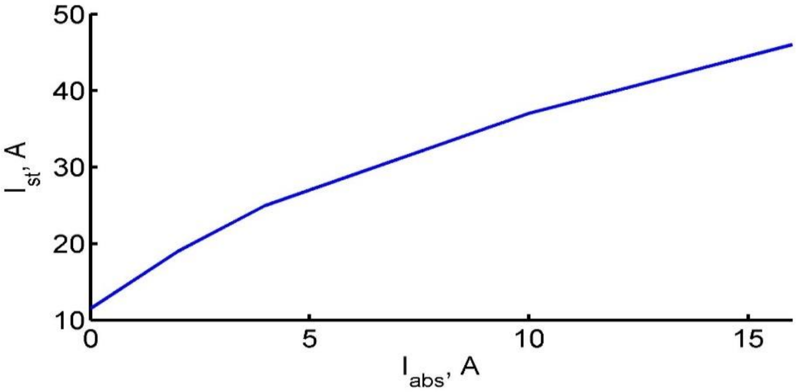

Fig.2 Minimal starting current of $TE_{4,1}$ mode in the powerful low-frequency gyrotron vs absorbing beam current for the self-consistent model with a non-fixed field.

Due to low quality factor of the short resonator which leads to variation of axial field profile with an increase of the absorbing beam current, the resulting dependence of the parasitic mode starting current is not linear, however, already at 5 A of the absorbing beam current the operating current of the desired second harmonic mode can be increased more than two times. The obtained dependence is consistent with the experiments in which the $TE_{4,1}$ mode was successfully suppressed by introducing of an absorbing beam. Since the needed absorbing beam current makes up a small part of the total current, the decrease in total efficiency is smaller than the gain in the output power, which proves the effectiveness of the mode selection method by an absorbing beam in the high-power gyrotrons with short resonators.

The existing 780 GHz gyrotron, in contrast with the described above powerful gyrotron, has a resonator with $L/\lambda \cong 15$ and Q = 5500. In this case the axial profile of the electromagnetic field is practically undisturbed by the additional beam, and the estimates of the starting current made by the simple formula (17) are consistent with the results of self-consistent simulation (Fig. 3).

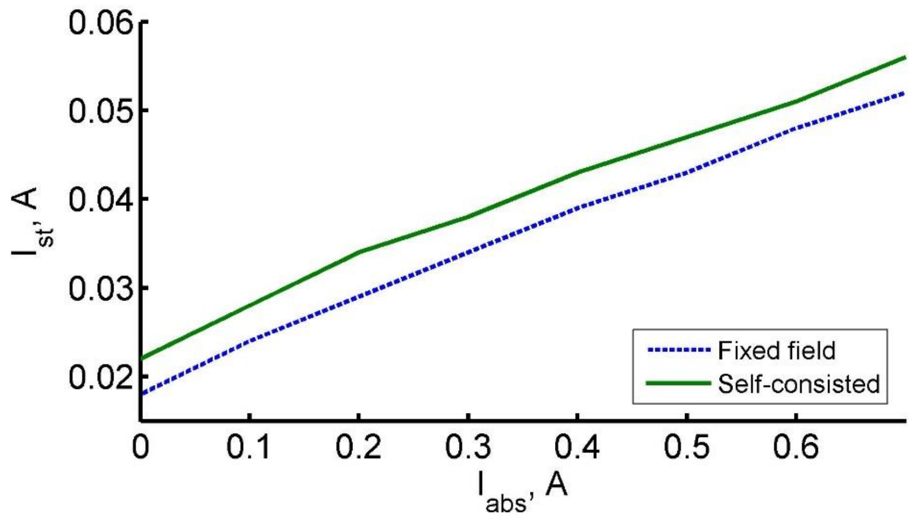

Fig. 3 Minimal starting current of $TE_{1,4}$ mode in the terahertz gyrotron vs absorbing beam current for the model of fixed field structure and for the self-consistent model with non-fixed field.

The calculated dependencies of $TE_{1,4}$ starting current vs. magnetic field without absorbing beam (I_2 = 0) and with absorbing beam current I_2 = 0.7 A are presented in Fig. 4. For considered sub-THz gyrotron with a long resonator, the required current of the absorbing beam is greater than the current of the radiating beam, which demonstrates the inefficiency of the absorbing beam as mode selection tool in the high-frequency low-power gyrotrons.

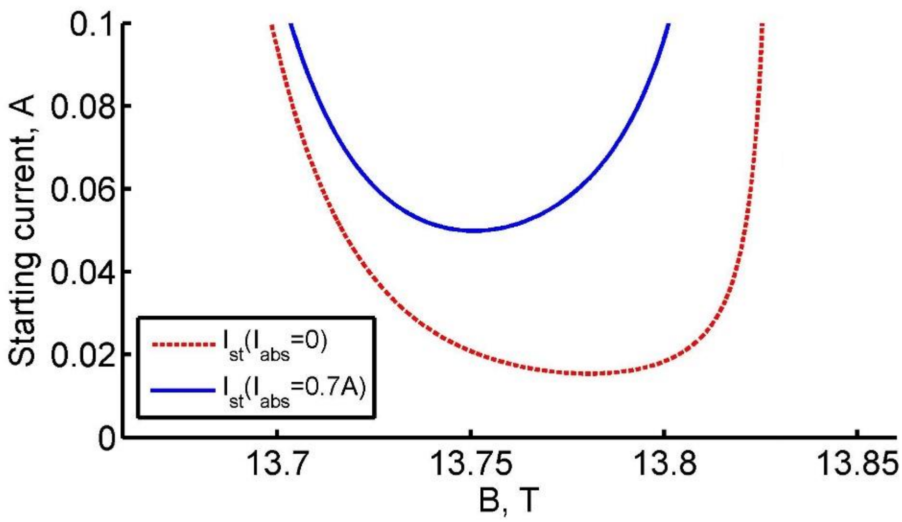

Fig.4 Starting current of $TE_{1,4}$ mode at the fundamental vs. magnetic field without absorbing beam and with an absorbing beam current I_2 = 0.7 A

IV. Conclusion

The influence of the additional rectilinear absorbing beam on the starting current of the spurious modes in gyrotrons has been investigated. The simple analytical estimates of the required $I_{absorbing}/I_{radiating}$ current ratio are given, as well as the results of the numerical simulation. In accordance with the previous works on the powerful gyrotrons with short resonators, the effectiveness of the absorbing beam as the mode selection tool is confirmed.

However, for the sub-THz and THz gyrotrons with weak electron-wave coupling and long cavities, the noticeable increase of the starting currents for the spurious modes at the fundamental cyclotron harmonic occurs only for large absorbing beam currents, proportional to $I_{radiating}*L/\lambda$. Therefore, for high-frequency gyrotrons, mode selection by an additional absorbing beam seems inefficient.

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Investigation of mode interaction for a gyrotron with a dense mode spectrum

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Abstract. Influence of the density of mode spectrum in the gyrotron cavity on the possibility of stable single mode excitation has been investigated for high-order modes. Interaction of the operating mode with its two neighbouring satellites symmetrically spaced in mode spectrum is analysed. Some threshold value of the mode spectrum density dependent on the beam current is found.

Keywords: vacuum electronics, gyrotrons, high-power microwave generation, millimeter wave devices, terahertz radiation

Introduction

Various applications of modern gyrotrons require high power (up to 1-2 MW) and high frequency (sub-THz to THz band) of radiation. To fulfill these requirements and to lower thermal loading on the cavity walls, it is essential to use high-order operating modes. However, it leads to the increase of the mode spectrum density of the cavity and strong mode competition, resulting in the possibility of spurious modes excitation during the turn-on process of the gyrotron. In particular, in such a cavity conditions of excitation of the triplet, formed by the operating mode with its two neighbouring equidistant satellites, may be fulfilled. Quite a number of the early researchers investigated the auto-modulation instability (4-photon decay) of a triplet in gyrotrons with a simplified Gaussian longitudinal field structure and pre-excited operating mode, not considering the question of the start-up scenario [1,2]. In several papers, the problem of turn-on scenario and its influence on the operating regime in a multimode gyrotron is investigated in detail [3, 4].

The aim of this paper is to find the limiting values of the current and the mode spectrum density parameters, where single-mode generation of the operating mode is still possible. We take into account two lateral satellites of the operating mode. We consider realistic field longitudinal structure in the cavity and realistic turn-on scenario, when initial amplitudes of all the modes are equally small and the beam voltage gradually increases from the initial to the operating value.

Model and equations

Let us consider a multimode gyrotron with a cavity similar to the one of the 170-GHz gyrotron, developed in IAP RAS [5]. The longitudinal field structure is assumed to be fixed and is the same as the cold structure of this cavity for the $TE_{28,12}$ operating mode (Fig.1). It is assumed that the density of the mode spectrum of the cavity can be varied by choosing different operating modes (the higher is the order of the operating mode, the denser is the spectrum), while keeping the field structure dependence on the dimensionless longitudinal coordinate.

Self-consistent equations, describing our model at the fundamental cyclotron resonance, can be written as

$$\frac{dF_s}{d\tau} + F_s = iI\frac{\tilde{I}_A}{I_A}\frac{\tilde{a}_\perp}{\tilde{a}_z}\int_0^{\varsigma_{ex}} f^*(\varsigma)\left\langle\left\langle p\right\rangle_\vartheta \exp(-i\Phi_s)\right\rangle_\psi d\varsigma \tag{1}$$

$$\frac{dp}{d\varsigma} + i\frac{\tilde{a}_\perp^{\ 2}}{\tilde{a}_z}\left(\tilde{\Delta} + |p|^2 - 1\right)p = i\frac{\gamma}{\tilde{\gamma}\tilde{a}_\perp\tilde{a}_z}\sum_s F_s f(\varsigma)\exp(i\Phi_s). \tag{2}$$

Both the corresponding initial and boundary conditions for the dimensionless mode amplitudes F_s and transverse electron momentum p are

$$F_s(\tau=0) = F_s^{(0)}\ ,\ p(\varsigma=0) = \exp(i\vartheta),\ 0 \le \vartheta < 2\pi\ . \tag{3}$$

Here we assume that all the considered three modes have equal Q-factors and dimensionless beam parameters I. In (1) and (2) ς is the dimensionless longitudinal coordinate within the interaction space; τ is dimensionless time, $\tilde{\Delta}$

is the dimensionless cyclotron frequency mismatch of the operating mode during the gyrotron turn-on process, and Δ – its value after this process. The phase mismatch between s-th mode and operating mode

$$\Phi_s = \Delta_s \varsigma - (m_s - m_0)\psi \qquad (4)$$

contains the parameter Δ_s, which characterizes the spectrum density. The tilted variables correspond to the values that vary during the turn-on process. For more detailed descriptions of these variables see [6].

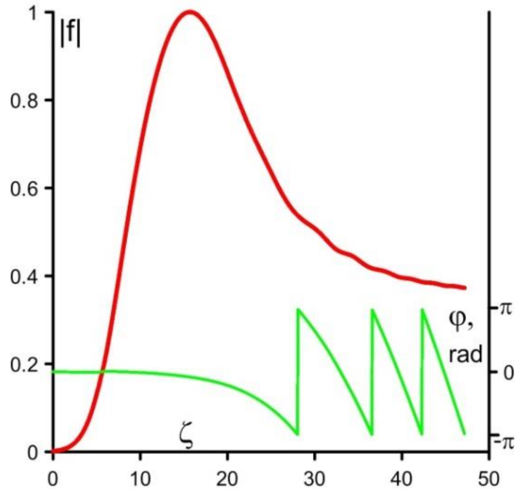

Fig. 1. Distribution of the module and field phase along the longitudinal coordinate ς in the cavity of 170 GHz TE28,12 gyrotron.

During the turn-on process the beam voltage gradually increases from its initial to the operating value. The beam current and the dimensionless cyclotron frequency mismatch $\tilde{\Delta}$ behave in a similar way, accordingly to the typical volt-ampere characteristic of the diode-type gun. Guns of that type are common in the modern gyrotrons which gives us freedom in varying of only one parameter: the beam voltage. Time-dependence of the startup scenario for I and $\tilde{\Delta}$ is shown in Fig.2.

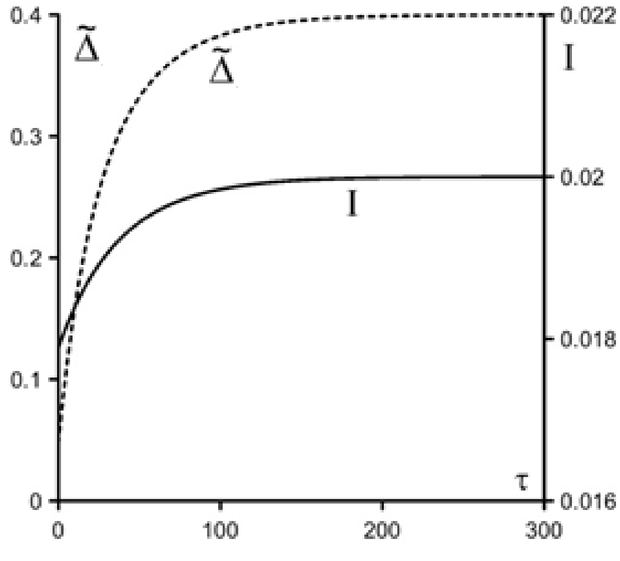

Fig. 2. Time-dependence of the cyclotron frequency mismatch $\tilde{\Delta}$ and dimensionless beam current I on the dimensionless time.

Simulations and discussion

To analyse the gyrotron regimes it is convenient to draw the starting current of the operating mode and its satellites along with the trajectory of the turn-on process (Fig. 3). Figure 3 represent the starting currents for the operating mode (O) and its left (L) and right (R) satellites as a function of the cyclotron frequency mismatch $\tilde{\Delta}$ (which varies together with the beam voltage), for several different values of the spectrum density parameters Δ_s: 0.05, 0.1 and 0.2. The trajectory of the turn-on process is shown by the black solid line with an arrow. Also shown are the boundaries of the zones of hard excitation for the operating mode and its right satellite. The areas of different regimes of oscillation are shown on the plane of the current *I* and mode density Δ_s parameters in Fig.4.

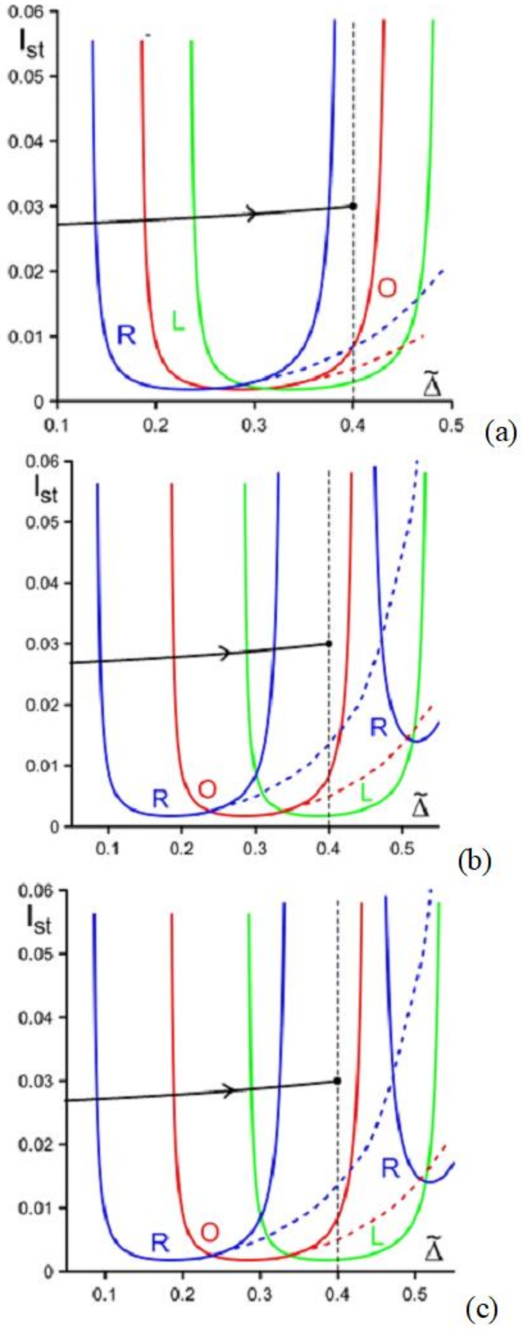

Fig. 3. Starting currents of the operating mode (O, red, solid), left (L, green, solid) and right (R, blue, solid) satellites and boundaries of hard excitation zones (dashed) for spectrum density parameter $\Delta_s = 0.05$ (a), 0.1 (b), 0.2 (c). Trajectories corresponding to the turn-on processes of the gyrotron with the final value of the parameter $\Delta = 0.4$ are shown by the black lines with an arrow. The second-tier branches of the starting current for the right satellite are also shown in (b), (c), though they are unreachable for this value of Δ_s.

One can easily see in Fig. 3 that during the initial stage of the turn-on process the gyrotron always passes through the zone of a soft-self-excitation of the R-mode, which then is driven into its hard-excitation zone, giving R-mode advantage over the other two modes. This is illustrated in the Fig.4, where one can see large domain of R. If the operating point lies within the hard-excitation R zone (Δ_s is not large enough, corresponding to a very dense spectrum), the R-mode mostly remains stable and the operating mode can't be excited (Fig. 5a). If both Δ_s and the beam current *I* are large enough, one can observe excitation of the left satellite (domain L in Fig. 4; Fig. 5b) and excitation of almost symmetrical triplet (domain T on Fig. 4; Fig. 5c). In the domain L, during the initial stage of the turn-on process the right satellite (R) is excited, then the oscillation switches to the left satellite (L) with a small fraction of the right satellite; operating mode (O) remains almost unexcited (Fig.5b). In the domain T (Fig. 4; Fig. 5c) during the initial stage of the turn-on process the right satellite (R) is excited, then oscillation switches to the almost symmetrical triplet of the operating mode (O) and its equidistant satellites (L,R). The possibility of excitation of the left satellite or the triplet can be explained by the fact that for these parameters (Δ_s and *I*) the right satellite may be on the verge of its hard-excitation zone and may lose the competition during the final stage of the turn-on process. In the regions O_1 during the initial stage of the turn-on process the right satellite (R) is excited, but the operating mode (O) wins the competition and the amplitude of the satellites become negligibly small (Fig.5d).

For every value of the beam current there is a threshold value of Δ_s, which delimits domain O_1 of the pure operating mode oscillation (Fig. 5d) and domains where one of the satellites or triplet are excited (Fig. 4). The other zone of O-oscillations O_2, located between the domains L and R, is very small and to the left of O_2 (with the decrease of Δ_s and corresponding densification of the spectrum) the R-domain continues.

The results of our simulations are in accordance with the results of the other researchers [2], which state that there is a limit of the spectrum density and beyond that limit a pure operating mode oscillation becomes impossible. Another efficient way to suppress the spurious modes excitation is frequency locking using as a driver a monochromatic external signal [6], which doesn't require any internal modification of the gyrotron. New techniques, developed in IAP RAS, allow very efficient injection of the external signal into the gyrotron cavity [5] and very high stability of the frequency of the driver [7].

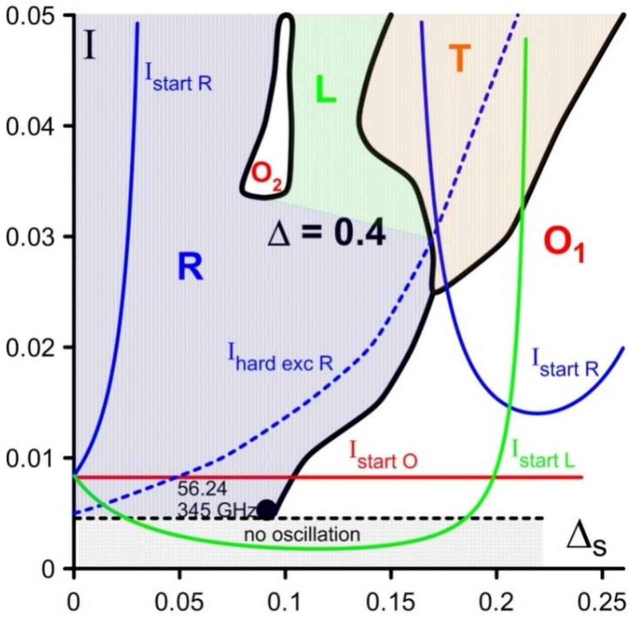

Fig. 4. Areas of different regimes on the plane of the dimensionless beam current *I* and mode density parameter Δ_s for the chosen value of the operating mode cyclotron frequency mismatch at the end of the turn-on process $\Delta = 0.4$. Regions of the pure operating mode oscillations (O_1, O_2, white), triplet excitation (T, orange), left (L, green) and right (R, blue) satellite excitation; lines of the starting currents for the operating mode (red, solid), the left (green, solid) and the right (blue solid) satellites and boundary of hard excitation regions of the right satellite (blue, dashed) are shown. Grey rectangle zone in the bottom of the plane corresponds to the absence of oscillations at any mode. Black point corresponds to the oscillations at very-high-order operating mode $TE5_{6,24}$.

Results of our recent simulations show an optimistic forecast about the possibility of single-mode single-frequency operation at the very-high-order operating mode $TE_{56,24}$ with a very high spectrum density ($\Delta_s \approx 0.1$) [8] by the help of the frequency locking. Considering Fig. 4, one can expect that with the use of a frequency locking, the threshold value of Δ_s may be significantly lowered. For example, the black point corresponding to $TE_{56,24}$ moves from the area R into the area O_1. We are going to investigate the possibility of the single-mode operation in the gyrotron with a very high spectrum density also by using the reflected signal [9, 10].

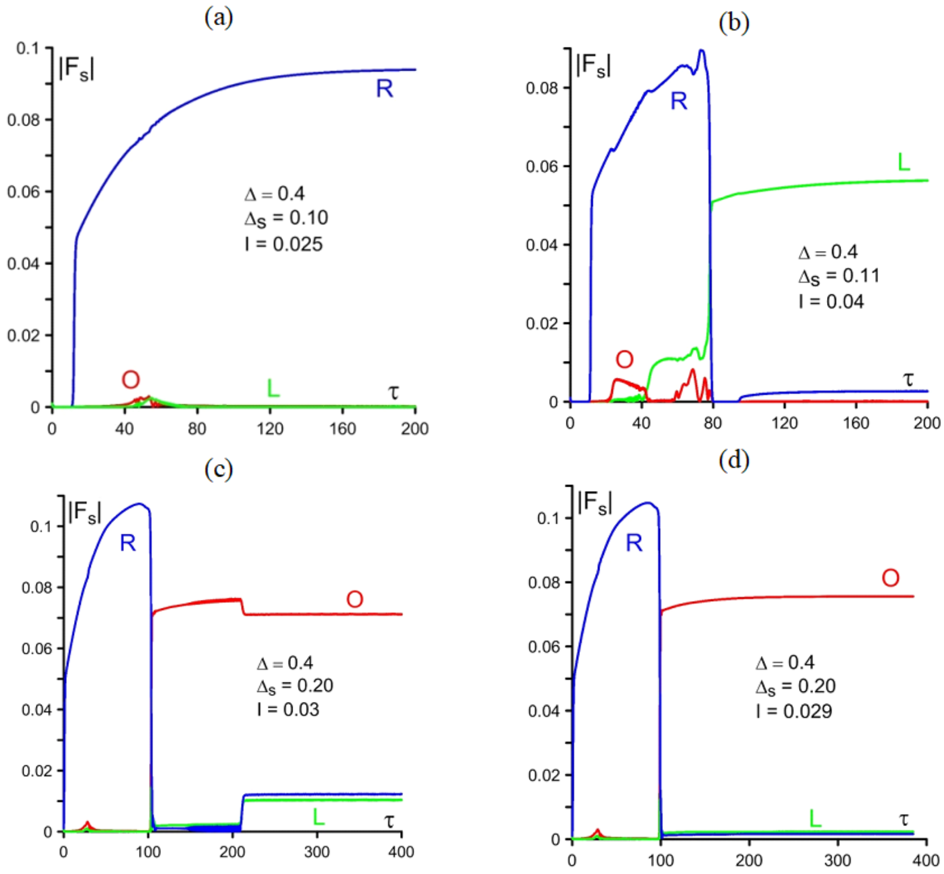

Fig. 5. Typical scenarios in the region R (a), L (b), T(c), O1(d).

Conclusion

In the modern gyrotrons with a dense mode spectrum there is a threshold value of the spectrum density parameter, which is dependent on the beam current and delimits domains of the stable operating mode oscillation and domains of oscillation at spurious modes. For a density higher than the critical, a pure operating mode oscillation becomes impossible at common startup scenarios. Penetration into the region of higher densities may be possible using phase- and frequency locking by external signal or reflected signal.

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Analysis of the possibilities to control diffraction quality factors of the cavities of sub-terahertz gyrotrons

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Abstract: Manufacturing of cylindrical cavities for short-wavelength gyrotrons is usually performed with a micron-scale precision. In the sub-terahertz (sub-THz) and terahertz (THz) gyrotrons, this often results in the fabrication of slightly up-tapered cavities instead of cavities having central parts of a constant radius. Correspondingly, the diffractive quality factors (Q_D-factors) of such slightly conical cavities may differ from those calculated for the cavities with regular central parts of a constant radius. We show that the sensitivity of Q_D-factors to the cavity fabrication can be mitigated by introducing some local nonuniformities at the end of a slightly conical up-tapered section of the cavities. The proposed approach is illustrated with an example of a gyrotron designed for spectroscopic applications and having an output radiation power of tens of watts at the frequency of 0.527 THz. The paper presents some numerical modeling results, which show how the proposed local nonuniformities reduce the sensitivity of the Q_D-factors on the fabrication defects.
Index Terms: gyrotron, cavity, tapering, Q-factor, efficiency, mode transformation, terahertz radiation.

1. Introduction

Nowadays, the gyrotrons [1, 2] demonstrate a record level of the continuous-wave (CW) power in the sub-terahertz and terahertz range [3, 4]. A number of tubes for spectroscopy, diagnostic and medical applications are capable of generating tens [5–9] or hundreds of watts [10] at the frequencies up to 0.8 THz in the CW regime. Since the capabilities of cryomagnets to produce strong magnetic fields are limited, for the wavelength (λ) shortening, it is necessary to operate at higher harmonics of the gyro-frequency. As a rule, for realizing stable harmonic excitation (see, for example [11]), "long" cavities (where the length of the uniform section is about 20-30 λ) of a relatively small radius (2-5 λ) are used. In such cavities, the processes of mode interaction are susceptible to the accuracy of manufacturing.

Due to some limitations on the precision of manufacturing, the uniform section of the cavity can take the form of a truncated cone (see Fig. 1a) instead of a section of a constant radius. It should be noted that the existing ultra-precision manufacturing technique permits fabricating such cavities with a 0.05-micron accuracy [12], but the precision of conventional means used for cavity manufacturing is about 0.5-1 microns. Such accuracy strongly affects (10-15%) the diffractive quality factor (Q_D-factor) of the cavity modes [13]. In the case of a cavity up-tapering towards the collector, the diffraction losses increase and, correspondingly, Q_D of the cavity decrease, that leads to an increase in the starting current of the cavity modes. Since, as a rule, the sub-THz gyrotrons under consideration operate with relatively low currents, which slightly exceed the starting current of the cylindrical cavities, this effect leads to a dramatic drop in the generated power and, in some cases, even to the absence of generation. In the case of a reverse situation, where the output radius is less than the input one, Q_D increases, but the output radiation power decreases due to an increase in the share of the Ohmic losses in the cavity walls. With an increase in Q_D, this share can reach 90% that may lead to a substantial drop in the generated microwave power.

It is well known that a local non-uniformity of the cavity wall affects the Q_D and field distribution [14] that makes it possible to compensate for the change of Q_D caused by slight tapering of the cavity. Some studies of this effect in gyrotron cavities are described in [16, 17. In the present paper, we analyze requirements to the shape and dimensions of such local non-uniformities shown in Fig.1, which allow one to obtain efficient and pure mode generation in slightly up-tapered cavities. The analysis is performed using as an example the second harmonic gyrotron for spectroscopic applications developed at the Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS).

2. Numerical investigation of the influence of the cavity profile on the generation efficiency and mode purity

For studying how the sensitivity of the gyrotron operation to the cavity tapering can be mitigated by the local non-uniformities of the cavity wall, we used as an example a 0.527 THz gyrotron operating at the second harmonic of the gyro-frequency on the $TE_{6,5}$ mode [18]. The operating frequency is determined by the intended application of the tube as a radiation source for experiments on dynamic nuclear polarization (DNP) in nuclear magnetic resonance (NMR) spectrometer. The gyrotron was designed to operate with an accelerating voltage of 15 kV, an electron beam current of 0.4 A, and a pitch factor (orbital-to-axial electron velocity ratio) of 1.2. Earlier, the electron-optical system for this device was tested in a gyrotron at the fundamental resonance with an operating frequency of 0.263 THz [19]. The experimental test results of the 0.263 THz gyrotron are in agreement with the numerical simulations [5, 19] that gave us the reason to believe that the designed parameters of the electron beam are obtained. The radius and length of the cavity section were selected to be 1.988 mm and 20 mm correspondently. The angles of the input and output tapers are equal to 4 and 1 degree. The calculated efficiency is about 2.5%, which results in microwave power of 150 W.

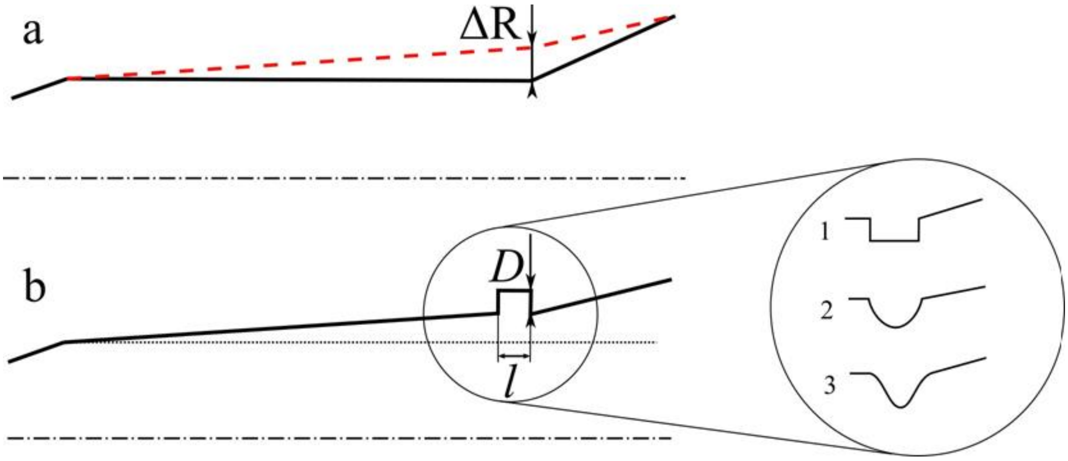

Fig. 1. Cavity with a taper (a) and with a local non-uniformity (b). The inset shows the considered non-uniformity shapes.

Figure 2 shows the influence of the cavity tapering on the starting current and generation efficiency of the $TE_{6,5}$ mode. The calculations were made using the self-consistent single-mode model described in [20]. The electron velocity spread (the RMS value of the relative transverse velocities spread is about 10%), and the Ohmic losses (the ohmic Q-factor Q_{ohm} is equal to 10460) were taken into account. As follows from Fig. 2, the efficiency dramatically drops if the difference between the cavity radius at the input and output of the regular section exceeds 1 micron. So, this is minimal accuracy of manufacturing for the investigated tube.

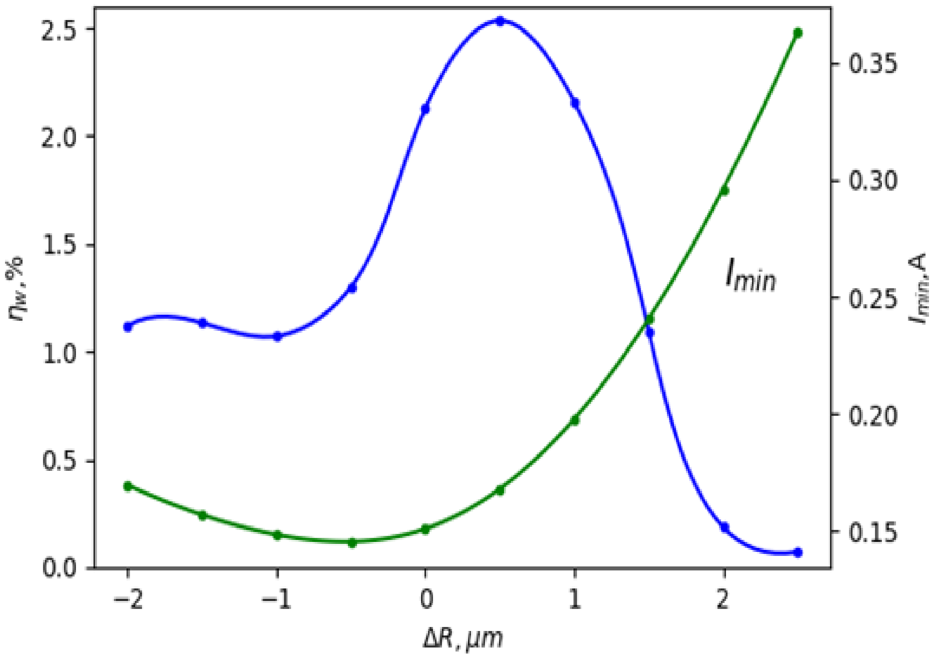

Fig. 2.The efficiency and the minimum starting current as functions of the cavity taper ΔR.

For the first test of a 0.527 GHz gyrotron, the cavity was made using a traditional tool, namely lathe. Unfortunately, the microwave power at the level of 5-10 watts only was obtained. This discrepancy between the theoretical and experimental results can be explained by the influence of a possible cavity tapering of about ΔR = 2 microns, which dramatically reduces Q_D of the operating mode.

As already mentioned before, in order to minimize such effect, a local non-uniformity near the end of the regular cavity section can be used. This inhomogeneity is shown in Fig.1 and can be made with D < 0 (as described in [15]) or D > 0. The introduction of a groove in the middle part of the cavity was considered for suppressing the low-frequency oscillations at the fundamental cyclotron resonance in a gyrotron at a high cyclotron harmonic [21].

The dependence of the Q_D on the dimensions of the rectangular inhomogeneity (length l and depth D) is presented in Fig. 3 for the taper with ΔR = 2 microns. Based on the data of Fig.3, the reasonable area of inhomogeneity dimensions, which result in high enough Q_D, can be defined. The several periodically located areas with high Q_D at D> 0 are caused by the resonant nature of the reflection from inhomogeneity. The calculated efficiency (for optimal frequency mismatch) is given in Fig.4. In contrast with Fig. 2, where ΔR = 2 microns results in a doubling of the starting current and zero efficiency, the introduction of the nonuniformity leads to an efficiency of about 1%, which is approximately two times less than the maximum one in a gyrotron with an ideal cavity. Such efficiency, however, takes place for a wide area of the tapering value.

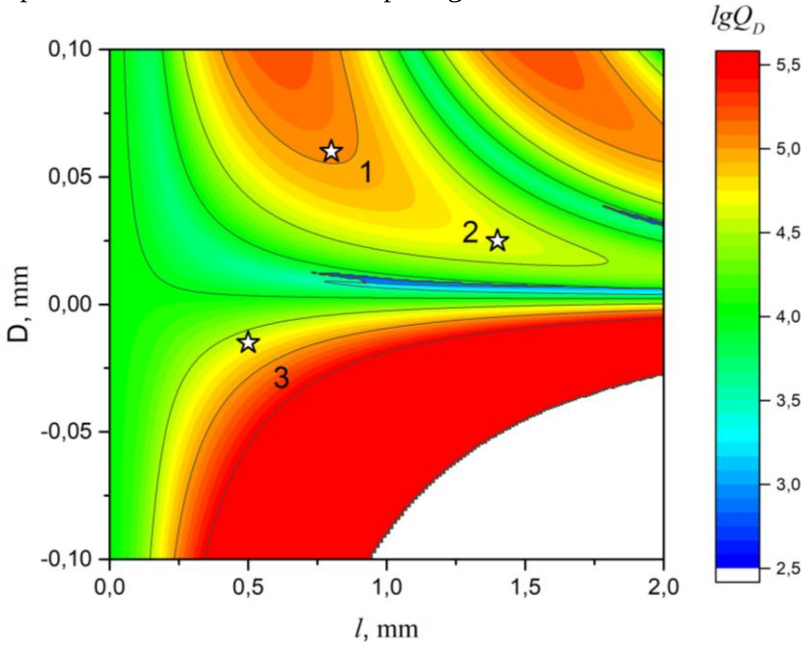

Fig. 3. Isolines of the diffraction Q-factor on a logarithmic scale in the plane of the nonuniformity length l and the depth D for the cavity with a taper with ΔR = 2 μm.

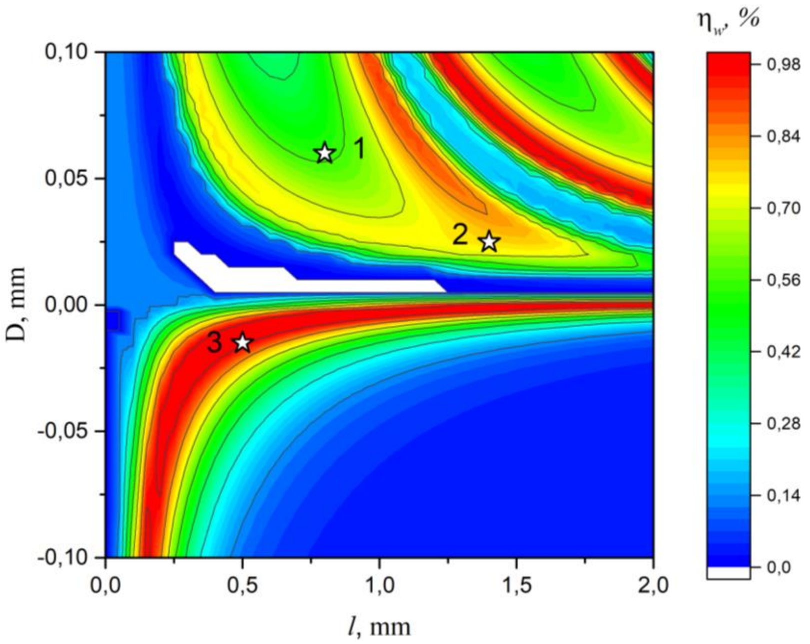

Fig. 4. Isolines of the efficiency in the plane of the non-uniformity length l and depth D for the taper ΔR = 2 μm. The considered non-uniformity configurations are marked by asterisks.

For the gyrotrons, however, not only the efficiency is important – we must take care also about the mode purity. The effects of mode transformation on the non-uniform section of a waveguide were analyzed based on the method of plane cross-sections (PCS) [22, 23]. The transverse electric and magnetic fields are decomposed according to the system of TE and TM modes in regular reference waveguides. Since the nonuniformity under consideration has axial symmetry, the azimuthal index *m* was assumed to be identical for all modes in the analysis. Figure 5 presents the data of mode content for a rectangular inhomogeneity with the length *l* = 0.5 mm and the depth *D* = -15 microns (point 3 in figures 3 and 4).

The next step is defining the inhomogeneity size, which yields high enough efficiency and high purity of the operating mode. The efficiency was calculated within the single-mode approximation and not include mode transformation effects. The mode conversion occurs only near the cavity output, where the interaction between the electron beam and the parasitic modes has no strong effect on the mode excitation, so the efficiency calculations are quick and accurate enough. Figure 6 presents efficiency for different inhomogeneities marked by stars in the figures 3 and 4 as a function of the initial tapering. The use of profile No. 1 (*l* = 0.8 mm, *D* = 60 microns) results in the widest and flat curve, but too low mode purity (82%) and efficiency. The profile No. 2 (*l* = 1.4 mm, *D* = 25 microns) gives mode purity equal to 97%. The profile No. 3 (*l* = 0.5 mm, *D* = -15 microns) has good mode purity (94.3%) and efficiency and appears to be the most appropriate.

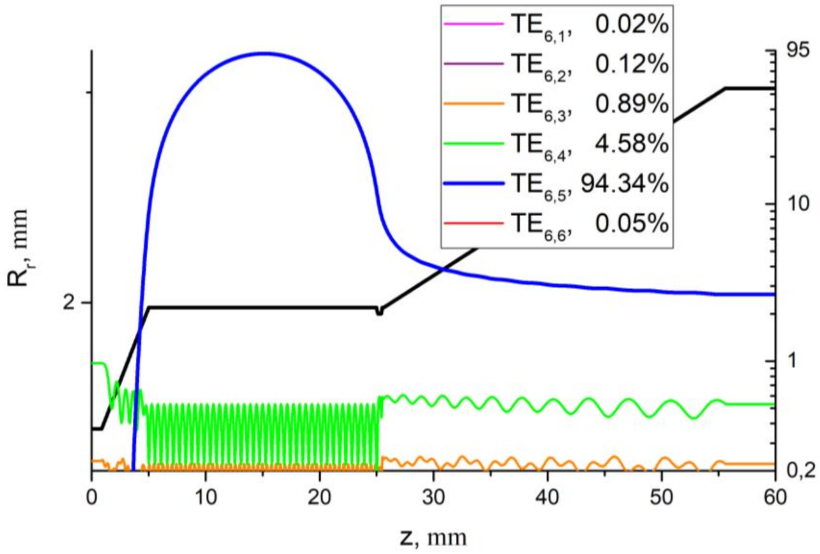

Fig. 5. Axial profiles of the operating $TE_{6,5}$ mode and spurious modes (on the logarithmic scale), and the content of the modes in the output wave beam.

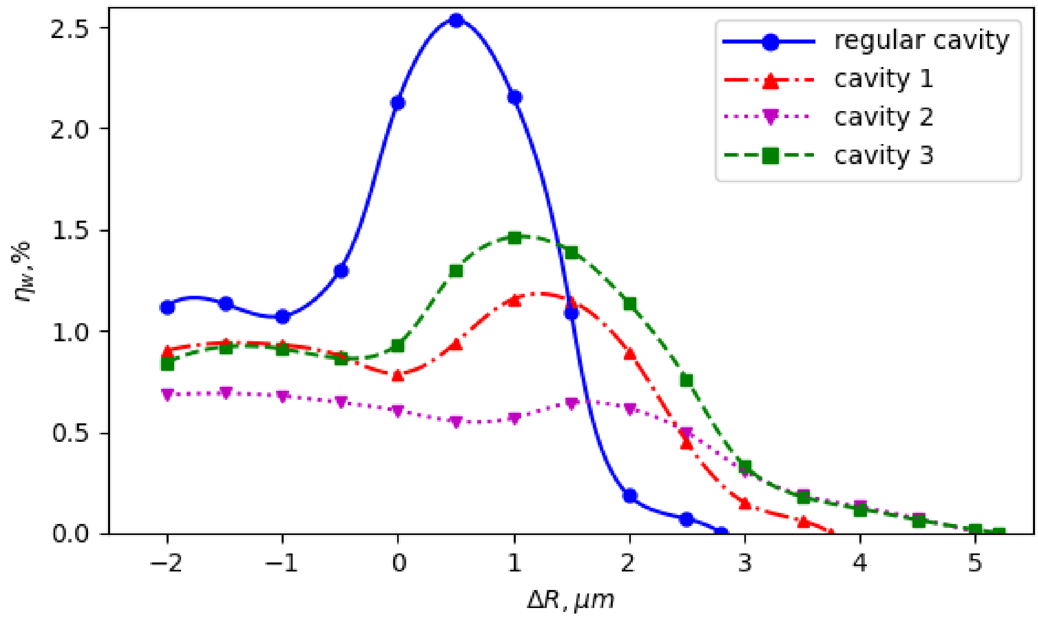

Fig. 6. The efficiency as a function of the taper for the regular cavity and three considered inhomogeneity profiles.

The frequency tuning, necessary for spectroscopy applications, can be increased in the case of excitation of modes with longitudinal indexes q>1. The data of Fig.7 demonstrate that in the case of additional nonuniformity, the positive influence on mode excitation takes place also for modes with q>1. Without non-uniformity, the efficiency for modes with q>1 is equal to zero.

The mode purity can be increased by optimization of the inhomogeneity form. For example, the change of the rectangular inhomogeneity to the $sin(z)|_0^\pi$ shape or $sin^2(z)|_0^\pi$ (see the inset in Fig. 1) with the same Q_D, mode purity reaches 95.9% and 96.8%, respectively, in contrast with 94.5%. However, in practice, the most suitable technology is assembling the structure as a number of cylinders. That is why in the above calculations, the shape of the inhomogeneity was specified as a rectangular.

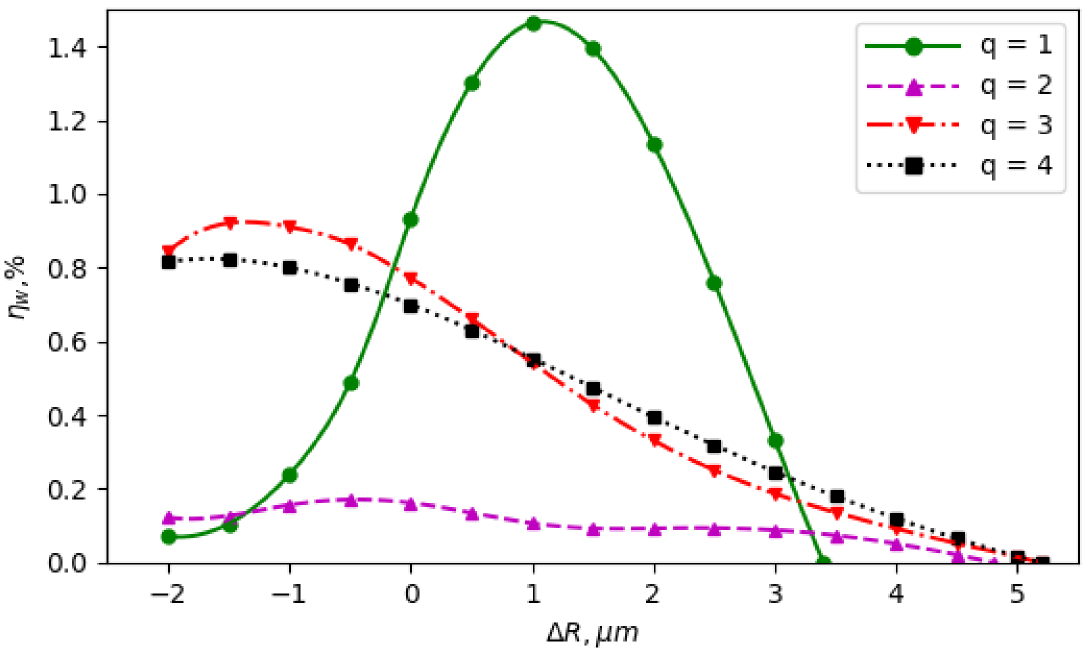

Fig. 7. The efficiency of mode interaction with a different number of axial variations as a function of the cavity taper for the iris type of the nonuniformity (l = 0.5 mm, D = -15 μm).

3. Conclusion

The influence of a local inhomogeneity on the interaction efficiency and mode purity is studied for a 0.527 THz gyrotron with a tapered cavity. Based on numerical simulation, the requirements for the optimal form of the inhomogeneity can be formulated for a wide range of initial tapering.

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FORTHCOMING EVENTS (UPDATED ANNOUNCEMENTS)

IW-FIRT2021

The 8th International Workshop on Far-Infrared Technologies
(IW-FIRT 2021)
March 8-9, 2021 (Online Conference)

The first International Workshop on Far-Infrared Technologies (IW-FIRT) was held in 1999 as a celebration event for establishing FIR FU, and the second IW-FIRT was held in 2002 as a part of the Fukui University International Congress to celebrate the 50th anniversary of our university. The third IW-FIRT was held in 2010, eight years after the second IW-FIRT, to commemorate the 10th anniversary of the foundation of FIR UF. The fourth, fifth, and sixth IW-FIRT were held in 2012, 2014, 2017, and 2019, successively, every few years. In these workshops it was aimed to discuss the recent developments and future directions of far-infrared and terahertz science and technologies with a special emphasis on high power radiation sources in this frequency region and their applications. We feel that it is the time to organize the next IW-FIRT to update our knowledge and understanding in this rapidly developing field. Therefore, we organize the 8th International Workshop on Far-Infrared Technologies (IW-FIRT 2021).

List of the invited speakers (in alphabetical order of family names):

Mitsuru Akaki (Kobe Univ., Japan)
Mikhail Yu. Glyavin (Institute of Applied Physics, RAS, Russia)
Masahiko Harata (Tohoku Univ., Japan)
Masaki Horitani (Saga Univ., Japan)
Iwao Hosako (NICT, Japan)
John Jelonnek (Karlsruhe Institute of Technology, Germany)
Takayasu Kawasaki (Tokyo Univ. of Science, Japan)
Setsuko Komatsu (Fukui Univ. of Technology, Japan)
Alexei Kuleshov (O. Ya. Usikov Institute for Radiophysics and Electronics of NAS of Ukraine, Ukraine)
Sergey Morozov (Institute of Applied Physics, RAS, Russia)
Yukihiro Ozaki (Kwansei Gakuin Univ., Japan)
Svilen Sabchevski (Institute of Electronics of BAS, Bulgaria)
Harumi Sato (Kobe Univ., Japan)
Hideyuki Takahashi (Kobe Univ., Japan)
Keisuke Tominaga (Kobe Univ., Japan)
Inna Tupaeva (Southern Federal Univ., Russia)
Shota Yamazaki (RIKEN, Japan)
Takeshi Yasui (Tokushima Univ., Japan)
Irina Zotova (Institute of Applied Physics, RAS, Russia)

In view of the pandemic of COVID-19 the Workshop will be held on 8 and 9 March 2021 online via Zoom. For more detail please visit the website of the Workshop.

Announcement by the organizers: “We regret to inform you that because of the significant health risks and transportation disruptions associated with the COVID-19 pandemic we are forced to **postpone the 11th International Workshop “Strong Microwaves and Terahertz Waves: Sources and Applications” until summer 2021**.

We will inform you about the planned dates for the Workshop as soon as they are available. Please visit the website of the Workshop.

Thank you for your interest in our Workshop and hope to see all of you in Nizhny Novgorod next summer.”

The twenty-second International Vacuum Electronics Conference, IVEC 2021

The twenty-second International Vacuum Electronics Conference, IVEC 2021, organized and sponsored by the European Space Agency (ESA) with the technical co-sponsorship of the IEEE Electron Devices Society (EDS). The conference will be held virtually on 27 to 30 April 2021. For up-to-date information, please visit the conference website.

ICHPMT 2021: 15. International Conference on High Power Microwave Technologies
April 22-23, 2021 in Tokyo, Japan

For up-to-date information, please visit the conference website.

46th International Conference on Infrared, Millimeter and Terahertz Waves
Date: Aug 29 –Sep 3 2021
VENUE: INTERCONTINENTAL CENTURY CITY，CHENGDU，SICHUAN，CHINA P. R.

For up-to-date information, please visit the conference website.

CMTT 2021: 15. International Conference on Microwave and Terahertz Technology
June 03-04, 2021 in New York, United States

For up-to-date information, please visit the conference website.

SPECIAL JOURNAL ISSUES IN THE FIELD OF THZ SCIENCE

Special Issue "Design, Technologies and Applications of High Power Vacuum Electronic Devices from Microwave to THz Band". For more detail, please follow the link.

electronics

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IMPACT FACTOR 2.412

Design, Technologies and Applications of High Power Vacuum Electronic Devices from Microwave to THz Band

Guest Editor:

Prof. Dr. Mikhail Glyavin
Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia

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Deadline for manuscript submissions:
31 January 2021

Message from the Guest Editor

The last decade has contributed to the rapid progress in the development of high-power microwave sources, in particular of gyrotrons. This Special Issue aims to bring together information about the most striking theoretical and experimental results, new trends in development, modern remarkable applications, new demands in parameter enhancement, and future goals. Therefore, researchers are invited to submit their manuscripts to this Special Issue and contribute their models, proposals, reviews, and studies.

Special Issue "Terahertz Optical Elements: Science and Technology". For more detail, please follow the link.

applied sciences

an Open Access Journal by MDPI

IMPACT FACTOR 2.474

Terahertz Optical Elements: Science and Technology

Guest Editor:

Prof. Svilen Petrov Sabchevski
Laboratory "Plasma Physics and Engineering", Institute of Electronics, Bulgarian Academy of Sciences, 1784-Sofia, Bulgaria

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Deadline for manuscript submissions:
28 February 2021

Message from the Guest Editor

In any system utilizing THz waves, the optical elements for shaping and manipulating the THz wave beam are indispensable components. This Special Issue is devoted to their fundamental principles and the current state-of-the-art in their development, investigation, manufacturing, and usage.

Areas of interest include (but are not limited to) the following main topics:

- Fundamentals and physical principles of the THz optics
- Terahertz sources and detectors
- Focusing lenses for THz waves
- Diffractive THz optical elements (e.g., beam homogenizers), collimators, beam splitters, reflectors, polarizers, attenuators, filters
- Computational design of THz optical and quasi-optical elements
- Materials (including metamaterials) and advanced technologies (e.g. 3D-printing technology, laser treatment, etc.) for precise fabrication of THz optical components
- Production of optical elements for THz systems (scanners, cameras, imaging, and inspection devices)

LIST OF SELECTED RECENT PUBLICATIONS

Bibliography and links to selected recent publications on topics related to the research field of the International Consortium and published after October 2020, i.e. after issuing the previous Newsletter #16. This cumulative list is in chronological order as collected from various bibliographical and alert services

A. Publications by authors from the institutions participating in the International Consortium

M. Glyavin, V. Manuilov, E. Taradaev, G. Sominskii, A. Fokin, A. Sedov, “Design of a pulsed 0.5 THz gyrotron and preliminary test of its electron gun with field emitter,” Infrared Physics & Technology, vol. 111 (2020) 103480. DOI:10.1016/j.infrared.2020.103480.
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C Patents

Magnetic coupler for launching and receiving electromagnetic waves and methods thereof
Inventors: Bennett, Robert (Southold, NY, US); Vannucci, Giovanni (Middletown, NJ, US); Wolniansky, Peter (Ocean Grove, NJ, US); Willis III, Thomas M. (Tinton Falls, NJ, US); Barzegar, Farhad (Branchburg, NJ, US; Gerszberg, Irwin (Kendall Park, NJ, US); Barnickel, Donald J. (Flemington, NJ, US); Henry, Paul Shala (Holmdel, NJ, US)
US Patent: 10812123
Date of publication: 10/20/2020
https://www.freepatentsonline.com/10812123.html

Microwave generation
Inventors: Mark ISKANDER, David Rowlands
US Patent: US20200358418A1
Date of publication: 11/12/2020
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High-frequency structure of broadband gyrotron traveling wave tube
Inventors: 罗勇赵歌歌鄢然姚叶雷王建勋刘国王丽蒲友雷蒋伟吴泽威徐勇马春光
Chinese Patent: CN111755300A
Date of publication: 09/10/2020
https://patents.google.com/patent/CN111755300A/en?q=gyrotron&oq=gyrotron&sort=new&page=1

Integrated EPR NMR with frequency agile gyrotron
Inventors: Barnes, Alexander B. (St. Louis, MO, US)
United States Patent 10712298
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NEW BOOKS

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NEWS FROM THE NET (OUR BROADER HORIZONS)

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The Inaugural Issue, which includes 500+ pages of quality content covering a broad swath of the microwave field, can be accessed from IEEE Xplore now. You also can sign up for a free print copy to be direct mailed to you on our web site. The source of this great news - *MHz to THz Community* (published on 12 Jan 2021) announces that with the release of this Inaugural Issue of the IEEE Journal of Microwaves, *“we christen the first fully-open access technical journal focused exclusively on microwaves and spanning the entire field – from science to invention; from theory to applications; from astronomy, chemistry, biology and physics to engineering and technology; from nanowatt to gigawatt; and from MHz to THz. In this, and future volumes, we will be publishing high quality technical articles covering all aspects of microwave science, technology, and applications in sub-disciplines both within, and occasionally beyond traditional engineering. We plan to broaden our appeal and our readership by including both overview and review articles on a wide variety of subtopics. These will both consolidate current knowledge, making it convenient for expert referrals, and serve as a learning tool for individuals just starting out in the microwave field.”*

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Journal of Microwaves is a model for, rather than simply a participant in, our changing future. (ISSN: 2692-8388, OCLC: 1163785784)."

***Editor's pick*:** We are glad that the Inaugural Issue of the Journal includes the following paper authored by members of our International Consortium:

A.G. Litvak, G.G. Denisov and M.Y. Glyavin, "**Russian Gyrotrons: Achievements and Trends**," in IEEE Journal of Microwaves, vol. 1, n. 1 (2021) 260-268. DOI:10.1109/JMW.2020.3030917.
https://ieeexplore.ieee.org/document/9318737

Wakefield undulator for the generation of powerful electromagnetic radiation

Recently, Ilya Sheinman, Associate Professor of the Department of Physics of St. Petersburg Electrotechnical University "LETI presented the project of a wakefield undulator for the generation of powerful electromagnetic radiation in the terahertz, ultraviolet, and X-ray regions of the electromagnetic spectrum. The technology will utilize the deviation of the particle beam from the waveguide axis, which is a negative effect in the wakefield accelerators, arising from the interaction of the charged beam with the electromagnetic wave created by it. "The principle of operation of traditional accelerators is that charged particles, moving in a circle, pass through a special interval in which they increase energy. Over the past 10-20 years, several fundamentally new solutions have emerged for the design of accelerators. One of them is to place the particles in a tube filled with plasma or in a dielectric tube in a metal shell," the researcher says. "A beam of charged particles interacts with the filling of the waveguide and creates an electromagnetic field, which is a variant of Cherenkov radiation, in which the speed is close to the speed of light. If a small charged beam is placed in this wakefield wave, it will accelerate. The primary beam that creates the field will lose its energy, and the secondary beam will accelerate to very high values."

A significant disadvantage of this approach is the shift of the beam relative to the axis of the waveguide. As a result of that, particles are attracted to the wall of a tube, which with huge energy can burn a hole in it. Ilya Sheinman proposed to use this parasitic effect to create a wakefield undulator, a waveguide in the form of a sinusoid, in which the tail of the main beam or a secondary beam of charged particles, attracted to one wall or another, will oscillate in a transverse direction. Due to such oscillations, the electrons of the beam will move with acceleration and generate electromagnetic waves, which is a necessary condition for creating a free-electron laser.

Experts of the European X-Ray Free-Electron Laser Facility (European XFEL), a complex of experimental facilities located in Hamburg, have already expressed their interest in the joint implementation of the researcher's project.

For more information and detail, follow the source of this information on the website of ETU "LETI"

CORE: The world's largest collection of open access research papers that offers (among others) great collection of publications in the fields of THz science and technology that are of interest to the members of the International Consortium.

See for example the following two Editor's picks:

Roger Lewis, "Materials for Terahertz Engineering," In: Springer Handbook of Electronic and Photonic Materials DOI: 10.1007/978-3-319-48933-9_55. Link to the book chapter.

Stefano Alberti, et al., "High-efficiency, long-pulse operation of MW-level dual-frequency gyrotron, 84/126GHz, for the TCV Tokamak," DOI: 10.5445/IR/1000100042. Follow the link to the paper (post-print).

New material system to convert and generate terahertz waves

An article published recently at *PhysOrg* reports that a German-Spanish research team with the participation of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) has now developed a material system to generate terahertz pulses much more effectively than before. It is based on graphene, i.e., a super-thin carbon sheet, coated with a metallic lamellar structure. Some time ago, a team of experts working on the HZDR accelerator ELBE were able to show that graphene can act as a frequency multiplier: When the two-dimensional carbon is irradiated with light pulses in the low terahertz frequency range, these are converted to higher frequencies. Until now, the problem has been that extremely strong input signals, which in turn could only be produced by a full-scale particle accelerator, were required to generate such terahertz pulses efficiently. "This is obviously impractical for future technical applications," explains the study's primary author Jan-Christoph Deinert of the Institute of Radiation Physics at HZDR. "So, we looked for a material system that also works with a much less violent input, i.e., with lower field strengths." For this purpose, HZDR scientists, together with colleagues from the Catalan Institute of Nanoscience and Nanotechnology (ICN2), the Institute of Photonic Sciences (ICFO), the University of Bielefeld, TU Berlin and the Mainz-based Max Planck Institute for Polymer Research, came up with a new idea: the frequency conversion could be enhanced enormously by coating the graphene with tiny gold lamellae, which possess a fascinating property: "They act like antennas that significantly amplify the incoming terahertz radiation in graphene," explains project coordinator Klaas-Jan Tielrooij from ICN2. "As a result, we get very strong fields where the graphene is exposed between the lamellae. This allows us to generate terahertz pulses very efficiently." To test the idea, team members from ICN2 in Barcelona produced samples: First, they applied a single graphene layer to a glass carrier. On top, they vapor-deposited an ultra-thin insulating layer of aluminum oxide, followed by a lattice of gold strips. The samples were then taken to the TELBE terahertz facility in Dresden-Rossendorf, where they were hit with light pulses in the low terahertz range (0.3 to 0.7 THz). During this process, the experts used special detectors to analyze how effectively the graphene coated with gold lamellae can multiply the frequency of the incident radiation.

For more details, please visit the source of this information following the link.

Journal Reference: Jan-Christoph Deinert, David Alcaraz Iranzo, Raúl Pérez, Xiaoyu Jia, Hassan A. Hafez, Igor Ilyakov, Nilesh Awari, Min Chen, Mohammed Bawatna, Alexey N. Ponomaryov, Semyon Germanskiy, Mischa Bonn, Frank H.L. Koppens, Dmitry Turchinovich, Michael Gensch, Sergey Kovalev, Klaas-Jan Tielrooij, "Grating-Graphene Metamaterial as a Platform for Terahertz Nonlinear Photonics," ACS Nano, 2020; DOI: 10.1021/acsnano.0c08106.

Multiple-beam and double-mode staggered double vane travelling wave tube with ultra-wide band

In a paper under the above title, published on 19 November 2020 in *Scientific Reports* (Open Access) the authors present design, fabrication and cold test of an ultra-wide band travelling wave tube (TWT) with planar alignment multiple pencil beams. The fundamental double-mode of staggered double vane slow wave structure (SDV-SWS) rather than the only one mode are put forward and adopted to match with the same electron beam to increase the bandwidth greatly. Simultaneous planar alignment multiple pencil beam tunnels are designed to improve interaction impedance and then to enhance the output power, gain, efficiency, and growth rate. The transmission performance of a two-stage 51-period SDV-TWT in G-band with structure attenuator between two sections shows that it indeed has an ultra-wideband performance from 81 to 110 GHz. By using computer numerical control machining, the SDV-SWS was manufactured and a detailed cold test was conducted. Good agreement is found at the wide band, where S_{21} is above − 5 dB and S_{11} is below − 10 dB. 3D PIC simulations with double-mode multiple-beam SDV-TWT within total length of 70 mm show that it can get a nearly 2120 W peak output power, a 42.5 dB corresponding gain and a 10.7% electron efficiency at 94 GHz with a 22.1 kV beam voltage and a 3×0.15 A beam current. The 3 dB bandwidth of our double-mode SDV-TWT can achieve about 29 GHz.

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Kenneth J Button Award for 2020

The recipient of the Button Prize for 2020 is Prof. Dr. Alfred Leitenstorfer, University of Konstanz, Germany

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