Semiconductor Physics, Quantum Electronics & Optoelectronics. 2003. V. 6, N 3. P. 386-391.

PACS: 44.40.+a

Some properties of extremely restricted thermal radiation beams

E.A. Salkov, G.S. Svechnikov
Institute of Semiconductor Physics, NAS of Ukraine. 45 prospect Nauky, 03028 Kyiv, Ukraine

Abstract. Physical peculiarities of the equilibrium thermal radiation have been considered within the black body model for the case of ultimate restrained photon flows inside an ideal ("lossless") optical communication channel. Restrictions connected with the uncertainty relations have been used to determine critical interrelations between the thermal radiation parameters, sizes of thermal radiator and ideal photodetector. The effects conditioned by the "cutting" of the thermal radiation mode number in a small-size (but not quantum-size) radiator have been included into consideration. Spectral efficiency has been analysed in terms of the amount of information contents in spatially restricted beams of thermal radiation.

Keywords: blackbody thermal radiation, uncertainty relations, size-restrictions, photodetector, information content.

Paper received 23.04.03; accepted for publication 17.06.03.

1. Introduction

Current trends of the nonbiological vision technology (an electron vision [1], or photoelectronics) and optical information systems development are coloured by an aspiration to master the thermal radiation (TR) spectrum. This relates to a various areas of science and technology: astrophysics and space technology, biology and medicine, ecological monitoring, solid-state electronic technology, *etc*.

The main task of this paper is to analyze the ultimate physical restrictions of TR photon flows that emerge due to the size peculiarities of radiator and/or photodetector, which are acting in an ideal "lossless" optical communication channel (OCC).

The small-size radiators (SSR) occupy a specific niche in the above problem [2]. Thermodynamic aspects of TR inside the finite-dimensional black body (b.b.) cavity have been developed in [3]. Partly, the size-related problem in connection with spectral dependence of detectivity and noise equivalent temperature has been encompassed in [4].

Thermal radiation is accentuated in connection with actuality of the problem of detecting and processing TR information, and widely scaled application of corresponding technology. We believe that classic b.b. will preserve its tried-and-true physical model that will help to distinguish TR of SSR from b.b.TR [5]. We shall apply the phenomenological consideration in the maximum general approach to avoid the cumbrous calculations. The absence of any complicated optical apertures on the path between the SSR and PD is adopted. Specific optical aspects of the above problem have been discussed in [6]. These reservations permit us to carry on the discussion proceeding from the position of the fundamental principles. The meaning of "small system" imports that the system under consideration is really small in size but not quantum-size yet.

2. Fundamental restrictions

Below we shall use universally acknowledged photon characteristics [7, 8]:

photon energy – $h\nu = hC/\lambda$ (2.1)

where C – velocity of light; h = 6.62.10^{-27} erg·s – the Planck constant and $\hbar = h/2\pi$

photon momentum – $\vec{M} = \hbar\vec{k}; \left|\vec{M}\right| = h/\lambda$, (2.2)

and also the fundamental uncertainty relations between:

energy E and time t: $\Delta E \cdot \Delta t \geq h/2$ (2.3)

momentum M and coordinate x: $\Delta M \cdot \Delta x \geq h/2$ (2.4)

photon number N and photon phase φ: $\Delta N \cdot \Delta\varphi \geq 1/2$. (2.5)

The equilibrium in TR is determined by the Bose-Einstein statistics. The mean number of photons excited into the b.b.TR mode of frequency ν at a temperature T ^{0}K can be written as (Planck's formula is adopted):

$$\langle n \rangle = \left[\exp(h\nu / kT) - 1\right]^{-1} \quad (2.6)$$

2.1. Ultimate dimensions of radiator and PD in a "lossless" OCC

Equations (2.1)–(2.4) can be used to find out conditions of realization of the ideal "lossless" OCC that includes a TR SSR and an ideal photodetector (PD).

It is evident that for a free space OCC it is profitably to form the narrowest light beam if the distance between radiator and PD is long. This provides minimum losses of the TR power along the canal.

Taking into account that photons do not interact with each other [9], a minimal emission solid angle ($\theta_{\min}$) at low occupation $\langle n \rangle$ of TR modes can be determined through the uncertainty of a single photon momentum (ΔM_1) as $\theta_{\min} = \Delta M_1 / M_1$. From Eq. (2.4) it is found, that at a fixed wavelength λ and radiator size $R \cong \Delta x$, one can not expect for the angle to be less than

$$\theta_{\min} \geq \lambda/2R \quad (2.1.1)$$

Obviously, geometrical correlation between size D of PD and maximum length $L_{\max}$ of the "lossless" OCC is given by

$$\theta_{\min} \cong D/2L_{\max} \quad (2.1.1^*)$$

as it is seen in Fig. 1, where size D exactly overcovers the open side of the $\theta_{\min}$. In this case, for example, at fixed $\lambda = 10$ µm, $R = 1$ cm and $D = 10$ cm, the maximum length of the "lossless" information transmission will be equal only to $L_{\max} = RD/\lambda = 100$ m. This enough trivial evaluation shows that principle restrictions of optical information transmitting in visible (0.4–0.7 µm) and IR spectra occurred within the real space scales, and they have to be accounted in practice.

On grounds of the reversibility principle [10] for the case of TR detecting and using Eq. (2.4), the restriction for the detector size D as a function of operating wavelength λ and $\Delta\lambda$ appears as:

a) $D_{\min}\Delta\lambda \geq \lambda^2/2$, or b) $\Delta\nu \geq C/2D_{\min}$, (2.1.2)

were $D_{\min}$ is the least size of PD. Expressions (2.1.2) are analogues to the diffraction restrictions [11]. The deviation from (2.1.2) results in the decreasing photon probability to fall within the PD area that, in its turn, inevitably leads to a losses of the TR received. Thus, size restriction of PD, acting within a "lossless" OCC, results in the inequality

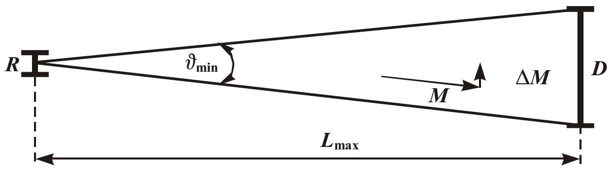

Fig. 1. Space link model.

$$D_{\min} \geq \lambda L_{\max}/R. \quad (2.1.2^*)$$

Two elementary operations with (2.1.2*) enable us to obtain important physical results.

1. Inverting the inequality symbol in (2.1.2*), we obtain a condition for the interference fringes in the classic Young interference experiment [10-12]. Consequently, Eq. (2.1.2*) requires a minimum linear PD size $D_{\min}$ to exceed certain "interference length" L_{coh}. The latter corresponds to the distance between the slits on the first screen in mentioned Young's experiment. Thus, the minimum size of PD has to exceed the coherence length of the detecting radiation.

2. Having squared Eq. (2.1.2*), we obtain the next inequality

$$D^2\Omega \geq \lambda^2, \quad (2.1.3)$$

that is equivalent to Sigman's antenna theorem for the heterodyne optical detecting [13].

Therefore, Eqs (2.1.1), (2.1.2*) and (2.1.3) allow us to conclude that both criteria for the "lossless" transmitting with the direct detecting and with the most efficient heterodyne detection boils down to a problem of "parallelism" of the radiation beams. Simple combination of Eqs (2.1.1), (2.1.1*) and (2.1.2) results in "global" expression, which determines acceptable relations between the sizes R, D and parameters of TR – λ, $\Delta\lambda$, as well as the geometry of the "lossless" optical communication channel – $\theta_{\min}$ (or $L_{\max}$):

$$2\theta_{\min} R \cdot D \cdot \Delta\lambda = \frac{R \cdot D^2 \cdot \Delta\lambda}{L_{\max}} \geq \lambda^3 \quad (2.1.4)$$

As defined by Eq. (2.1.4), a wide variety of choices design optoelectronic information systems with "limiting high efficiency" exists, but each of them is restricted by the classic criterion [11], the "photon volume" $V_{ph} = \lambda^3$.

It will be in point to underline that commonly known Eqs (2.1.1)–(2.1.3) can be simply obtained with no resort of complicated mathematics but proceeding from only two points: 1. Applicability of the uncertainty relations, and 2. Requirement for the OCC to be lossless. The transcript of the second point can be obtained from Eqs (2.1.1), (2.1.1*) and (2.1.2) in the form of the expression

$$\theta_{\min} \geq \frac{\lambda}{2R} \cong \frac{D}{2L} . \qquad (2.1.5)$$

Thus the "lossless" OCC is realizable in case when limited angle of the TR light beam $\theta_{\min}$ is overlapped "exactly" by the PD size D. Hence, when measuring the spectrum of "lossless" OCC efficiency, the ratio λ/D is required to be constant.

3. Distinctive features of TR from radiator restricted by size

3.1. Density of modes and TR of SSR

Let us suppose that the main size-factor that restricts equilibrium between the ideal b.b. TR and SSR is the "cutting" effect of the longwave TR modes. Total number of TR modes with wavenumbers from k to $k + dk$ (where $k = 2\pi/\lambda = 2\pi\nu/C = \omega/C$) inside a b.b. cavity of volume $V >> \lambda^3$ is equal to [7, 8]

$$\Delta Z = \frac{V}{(2\pi)^3} \cdot 4\pi k^2 \cdot \Delta k = V \frac{4\pi \cdot \Delta\lambda}{\lambda^4} \qquad (3.1.1)$$

The full number of TR modes inside SSR cavity of the restricted volume $V = R^3$ at thermodynamic equilibrium cannot contain modes with wavenumbers less than k_R which is determined as

$$| k_R | = \pi/R \qquad (3.1.2)$$

Formally, critical values of size-restricted parameters of the TR radiation corresponding to Eq. (3.1.2) are

$$\lambda_R = 2R;\ \nu_R = C/2R;\ E_R = hC/2R \qquad (3.1.3)$$

where λ_R, ν_R and E_R are wavelength, frequency and energy of the lowest mode, respectively. This lowest mode in some way is an analogue to the zeroth oscillation of quantum oscillator: the energy of $E_R = hC/2R$ can not be realised outside the b.b. cavity.

As the size-correction to the spectral density of modes for SSR (of a cubic form with side R) the following expression has been cited in [3]

$$z_R \cong \frac{4\pi \cdot \nu^2}{C^3} \left(1 - \frac{C^2}{4 \cdot R^2 \cdot \nu^2} \right). \qquad (3.1.4)$$

The adequate to Eq. (3.1.4) result for number of modes can be obtained by deducting $\pi \cong 3$ lowest modes from the total number of allowed modes within a SSR cavity [4,5]

$$Z_R \cong V \cdot \frac{4\pi \cdot \nu^2 \Delta\nu}{C^3} - 3 . \qquad (3.1.4^*)$$

In case when $\Delta\nu \cong \nu_R - 0$, the Eq. (3.1.4*) matches the strict formula from [3].

Spectral distribution of a "b.b." TR energy density $\varepsilon_R(\lambda)$ as applied to the SSR TR can be expressed (for better comparison between λ and R this is done in terms of wavelengths) as

$$\varepsilon_R(\lambda) \cong 8\pi \frac{hC}{\lambda^4} \left[1 - \frac{\lambda^2}{4R^2} \right] \left(\frac{\Delta\lambda}{\lambda} \right) < n > \qquad (3.1.5)$$

It is essential that the above spectral distribution being "measured" at a fixed ratio $\left(\frac{\Delta\lambda}{\lambda}\right) = \left(\frac{\Delta\nu}{\nu}\right)$, results in mutually equal positions of specific points (for example the Wien maximum) both in the scale of "λ" as well as in "ν" scale. Initial value of $\left(\frac{\Delta\lambda}{\lambda}\right)$ in Eq. (3.1.5) can not be identified with the same form as in Eq. (2.1.2) as the latter is determined by the radiator size while the value of $\left(\frac{\Delta\lambda}{\lambda}\right)$ is arbitrary selected by the observer.

When $2R >> \lambda$, Eq.(3.1.5) is transformed into the classic form and in case when $2R \to \lambda$ the SSR drops out of the "b.b.-model". Increase in the SSR temperature does not change the situation : the "invisibility" effect of SSR in its own TR always takes place, even when a great number of SSRs (i.e., SSR within a dense cloud like dusty object) have been observed within a PD aperture, assuming that they provide enough TR energy for detection. A few aspects of the SSR TR "truncated" spectra have been considered in Ref. [4, 5].

Herein below, we use conventional simplified approach for systems without losses and aberrations [14]. The photon flow F_D which strikes PD at square with the radiating area R^2 throughout a small cone of a solid angle $\Omega_D = D^2/4L^2$ with reference to [15] may be written as

$$< F_D > \cong \left(8\pi / \lambda^3\right) \cdot \left(1 - \frac{\lambda^2}{4R^2} \right) \left(\frac{\Delta\lambda}{\lambda} \right) < n > \times \frac{C}{2} \times R^2 \times \frac{D^2}{4L^2} \qquad (3.1.6)$$

It is quite in order to admit an assumption that SSR's radiating area can be equated to R^2, i.e. to the SSR cross-sectional area itself.

3.2. Size-restriction of the detecting time

The number of photons $\langle N_{th}(\lambda) \rangle$ which is larger than the sensitivity threshold of PD can be expressed via the photon flow $\langle F_D(\lambda) \rangle$ as $\langle N_{th}(\lambda) \rangle = \langle F_D(\lambda) \rangle \cdot T_D$ where, usually, T_D is the time needed to accumulate an electric charge larger than the PD noise within the certain bandwidth $\Delta f_D = 1/2T_D$ [16]. Here we define the time T_D through the well known concept of signal-to-noise ratio, for the sake of simplicity assuming condition of noise-limited-detection (SL) [15]. Hence, taking into account Eq. (3.1.6), the total photocurrent includes:

– signal current

$$< i_s >= e \cdot \eta \cdot \langle F_D \rangle = e \cdot \eta \cdot \left(4\pi C/\lambda^3\right)\times$$
$$\times\left(1-\frac{\lambda^2}{4R^2}\right)\left(\frac{\Delta\lambda}{\lambda}\right)< n > \cdot R^2 \cdot \Omega_D,$$

and

– mean-square shot-noise current due to the signal current $i_{sn}^2 = 2e\cdot < i_s > \cdot \Delta f_D = \frac{e\cdot < i_s >}{T_D}$.

The signal-to-noise ratio being equal to that defines the sensitivity threshold. Using the above formulae the expression for T_D can be found as follows:

$$T_D = \left[\pi \cdot \Omega_D \cdot \left(\frac{4R^2}{\lambda^2} - 1\right) \cdot \Delta\nu \cdot < n >\right]^{-1} \quad (3.2.1)$$

It is seen that when $(2R/\lambda)^2$ => 1, the detecting time of SSR increases dramatically. It cannot be emphasised enough that increase in number of SSRs and/or their temperature, as well as expansion of the frequency interval $\Delta\nu$, do not change the "value" of the correction factor $\left[\frac{4R^2}{\lambda^2} - 1\right]$. It is obvious fact that the increase of time detecting at $\lambda \to 2R$ cannot be passed over as a physical fact.

4. Informative qualities of restricted TR

4.1. Transfer of information through the OCC by means of TR

Statistical analysis shows [17] that the maximum of information transmitting by light can be achieved by using such a method of light modulation that imparts a statistical properties of TR into the light**.** This fact induces us to discuss the principal aspects of restrictions of the information transmission through an OCC that includes TR radiator and PD. For the reason of simplicity, we will deal with photon beams only, exclude the electrical circuit part.

In a simple analysis lets consider that information has been coded by amplitude of TR light pulses only (duration – Δt; frequency – $\nu = C/\lambda$, and within a bandwidth of $\Delta\nu$). The source is a b.b. radiator of an area A or the SSR of volume $V \cong R^3$ and radiative area $\approx R^2$.

A mean number of TR photons per single light pulse is $<N_{imp}> = <F_D>\Delta t$. Thus, the information contains in a pulse amplitude only. According to the definition adopted in the theory of information [18, 19], a mean information content within a single light pulse can be approximately expressed by Shannon's formula

$$\langle \Phi_{imp} \rangle \cong \log_2\left(1 + \frac{F_D \cdot \Delta t}{\Delta N_{th}}\right). \quad (4.1.1)$$

where ΔN_{th} is a distinguishablility threshold of individual pulses amplitude by the photon number. Fluctuation of the TR photon flow at PD input will be given by

$$\langle \Delta F_D^2 \rangle = \left(\frac{C}{\lambda^3}\right) \cdot \left(1 - \frac{\lambda^2}{4R^2}\right)\left(\frac{\Delta\lambda}{\lambda}\right) \cdot \langle n \rangle \times$$
$$\times R^2 \cdot \frac{D^2}{L^2} \cdot \left(\left(1 + < n > \frac{C}{2R}\right)\right) \quad (4.1.2)$$

where for SSR using Eq. (3.1.3), $\Delta\nu_R = \nu_R - 0 \approx C/2R$. The bandwidth $\Delta\nu_R$ is a minimum feasible frequency bandwidth for a single mode of equilibrium TR. In other words, this is, effectively, the intrinsic frequency of the lowest mode of a b.b. equilibrium TR inside a cavity of volume $V = R^3$ (in more detail see ref. [5,20]).

4.2. Efficiency of "lossless" OCC at a limiting restriction

Cases under consideration are related to the signal-to-noise-limited (SL) detection regime [15]. The latter allows to uncover the fundamental restrictions of TR efficiency in OCC. One must remember that Eq. (2.4) leads to an angular-limiting condition (2.1.2*) that provides the "lossless" regime. Being squared Eq. (2.1.2*) leads to extremely limiting solid angle, i.e. equality

$$D_{min}^2 / L_{max}^2 = \lambda^2 / R^2 , \quad (4.2.1)$$

that fixes physical (λ) and geometrical (Ω) parameters of the OCC. This means that when measuring a spectra of extremely restrained TR beams in a "lossless" OCC one has also to "move" the D_{min}^2 / L_{max}^2 ratio following the Eq. (4.2.1). In that way, one measures the physical properties of the TR spectrum but not a "spectral losses" of the TR**.**

From (4.2.1) and (3.1.6) $<F_D>$ becomes

$$< F_D > \cong \pi(C/\lambda) \cdot \left(1 - \frac{\lambda^2}{4R^2}\right)\left(\frac{\Delta\lambda}{\lambda}\right) < n > \quad (4.2.1^*)$$

It can readily be seen from Eq. (4.2.1*) that the restrictions being introduced for the lossless OCC (Eq. (2.4) results in a single mode operation even within a wide bandwidth $\Delta\lambda$.

Below four different regimes have been considered**:**

1. No principal restrictions on photon flow; ΔN_{th} is determined by the dispersion of F_D

Because the value of ΔN_{th} is given by the fluctuation of TR photon number F_D at the PD input (4.1.2)*,* consequently, we can rewrite ΔN_{th}

$$\Delta N_{th} \cong \left\langle (\Delta F_D)^2 \right\rangle^{1/2} \Delta t .$$

Then, substituting Eqs (3.1.6) and (4.1.2) into Eq. (4.1.1) for a single large radiator, Φ_{imp} becomes

$$\langle \Phi_{imp} \rangle_1 = = \log_2 \left[1 + \left[\left(2\pi R \lambda^3\right) \cdot \left(\frac{\Delta\lambda}{\pi}\right) \times A \times \frac{D^2}{L^2} \cdot \exp\left(-\frac{hc}{\lambda \cdot kT}\right) \right]^{1/2} \right] \quad (4.2.2)$$

2. SSR has been included in to the OCC; ΔN_{th} is determined by the dispersion of F_D

In case of a single SSR ($A \cong R^2$ *i.e.* $R_{SSR} = 10^{-3}$ cm) the information content corresponds to Eq. (4.2.2). With a single mode regime in the mind, the solid angle $\Omega_D = D^2/L^2$ must be replaced by the λ^2/R^2 ratio in agreement with Eqs (2.1.1) and (2.1.1*). This replacement is essential because the radiator of a given size ($R_{SSR} = 10^{-3}$ cm) can not provide an adequate filling with TR a solid angle of $\Omega_D = 10^{-6}$ within the chosen range of wavelength. Hence the information spectrum for this case can be presented as

$$\langle \Phi_{imp} \rangle_2 = \log_2 \Big[1 + \left(\left(\frac{2\pi R}{\lambda}\right) \cdot \left(1 - \frac{\lambda^2}{4R^2}\right) \cdot \left(\frac{\Delta\lambda}{\lambda}\right) \cdot \exp\left(-hC/\lambda kT\right) \right)^{1/2} \Big] \quad (4.2.2^*)$$

A spectral dependence of information content in a single pulse that arrives from large radiator (R = 50 cm, A = 25 cm^2 (curve 1), and from SSR ($R_{SSR} = 10^{-3}$ cm, $A = (R_{SSR})^2 = 10^{-6}$ cm^2 (curve 2)) are shown in Fig. 2.

Naturally, the information contents are radically differ in appearance. An important feature can be discerned from this figure: within a narrow frequency band at the maximum of the spectral distribution the information contents $\langle \Phi_{imp} \rangle_1$ and $\langle \Phi_{imp} \rangle_2$ are differ by about of

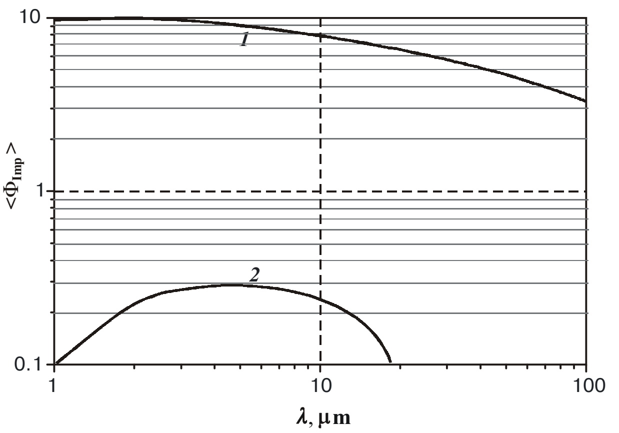

Fig. 2. Spectral dependence of information content in a single pulse from: *1* – large size radiator, R = 50 cm, A = 25 cm^2; *2* – SSR, $R = 10^{-3}$ cm, $A = 10^{-6}$ cm^2.

thirty times only, whereas emitting areas are differ dramatically by $25/10^{-6}$ times. This takes place because the losses along the optical pathway (L) have been excluded from $\langle \Phi_{imp} \rangle_2$ (λ^2/R^2 => D^2/L^2). The latter means that the spectrum $\langle \Phi_{imp} \rangle_2$ was measured for the "lossless" OCC. In practice this regime requires the ratio λ^2/D^2 to be constant during the spectral measurements.

3. No principal restrictions on photon flow; ΔN_{th} is determined by the uncertainty of "photon number-phase" type (2.5)

Distinctive feature of this restriction is that the ΔN_{th} is formed by the phase fluctuation $\Delta\varphi = \nu\Delta t$. Using the quadratic form of Eq. (2.3) [21] one can obtain required inequality, adequate to Eq. (2.5)

$$< \Delta N_D^2 >^{1/2} \cdot (\nu \cdot \Delta t) \geq \frac{1}{2} \quad (4.2.5)$$

Then, extremely low threshold can be defined via the light pulse duration Δt as $\Delta N_{th} = <\Delta N_D{}^2>^{1/2} = (2\nu\Delta t)^{-1}$. Thus, substituting ΔN_{th} with $(2\nu\Delta t)^{-1}$ and Eq. (4.1.1) can be rewritten as

$$\langle \Phi_{imp} \rangle_3 = \log_2 \left[1 + \left(\frac{8\pi C}{\lambda^4}\right) \left(1 - \frac{\lambda^2}{4R^2}\right) \left(\frac{\Delta\lambda}{\lambda}\right) \times \times < n > \left(\frac{C}{2}\right) \cdot A \cdot \frac{D^2}{4L^2} (\Delta t)^2 \right] \quad (4.2.6)$$

4. Photon flow is restricted by Eq. (2.1.1); ΔN_{th} is determined by the uncertainty of "photon number-phase" type (2.5)

For this double-restricted signal (i.e. by Eqs (2.1.1) and (4.2.5)) similarly we get

$$\langle \Phi_{imp} \rangle_4 = = \log_2 \left[1 + 2\pi \left(\frac{C}{\lambda}\right)^2 \left(1 - \frac{\lambda^2}{4R^2}\right) \left(\frac{\Delta\lambda}{\lambda}\right) < n > (\Delta t)^2 \right] \quad (4.2.6^*)$$

Fig. 3 shows the information content spectra for above two cases (3 and 4). First, it has to be underlined a significant increase of information contain versus previous case depicted in Fig. 2. Moreover, this "exotic" way of TR information transfer contains not incurious fact. Regime of doubly restricted TR beam (Eq. (4.2.6*)) terns out to be more effective within a long wavelength region (λ > 20 μm) versus one-fold restricted case Eq. (4.2.6). Physically, this can be explained by more intense random processes in the multi-mode regime (Eq. (4.2.6)), whereas the single-mode case (Eq. (4.2.6*)) is characterised by the higher population of the single acting mode

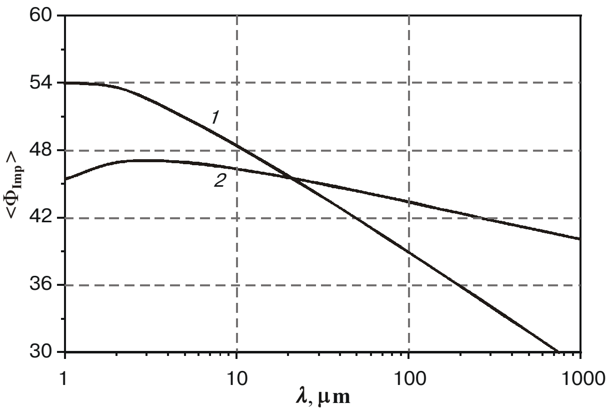

Fig. 3. Spectral distribution of the information content in the b.b.TR (T = 3000 K) pulse (Δt = 10^{-6} s) for the large radiator (R = 1 cm). *1* – $\Omega_D = D^2/L^2 = 10^{-6}$, $(\Delta\lambda/\lambda) = 10^{-2}$. Noise is determined by the uncertainty relation (2.5); i.e. $\Delta N_D = (2\nu\Delta t)^{-1}$; *2* – Ω_D is extremely restricted by uncertainty relation (2.4). $\Delta N_D =$ $= (2\nu\Delta t)^{-1}$.

(the crossing of curves in Fig. 4 occur at $<n> \approx 3.7$) and thus results in more stable time and phase fluctuations. This result shows that spatially ($\theta \geq \lambda/2R$) and "time" ($\Delta t \geq (2\Delta N\nu)^{-1}$) restricted photon flow behaves as a "noise-proof". Realisation aspects of this temping way of information transfer by TR will be discussed in the next paper.

5. Conclusions

It is essential to underline the universal character of the (λ/2R)-factor. The latter exposes itself in classic processes (restriction of TR modes number and solid angles) as well as in quantum (uncertainty relations) phenomena. (See, e.g. Eqs (2.1.1), (3.1.5), (4.2.2*), etc.).

1. Restriction of the angular parameter of the TR beam within a "lossless" OCC by the uncertainty relation (2.4), leads to a single-mode regime of observation. The restriction criteria can be connected with sizes of radiator (R), and detector PD (D) as well as with the TR parameters. In a whole set of parameters, the "total" restricting factor can be reduced to the "photon volume" = λ^3 (Eq. (2.1.4)).

2. It is well known that 75 % of the b.b. TR energy falls onto the spectrum region of $\lambda > \lambda_m$ (λ_m – is the Wien's maximum wavelength). In case of the SSR just from this region the model of the b.b. starts to "dissolve"**.** Thus the total TR energy of the *SSR* has to be calculated by integrating of Eq. (3.1.5) within the limits from ν_R to ∞ .

3. Using a scanning system for detecting TR from the *SSR* or from fine-dispersed objects (aggregation) requires special tools for the scanning rate control to take into account possibility of the detecting time increase at $2R \to \lambda$ Eq. (3.2.1)**.**

4. Measurements of the spectral distribution of the information content in extremely restrained beams of the "lossless" OCC makes sense only when the ratio D^2_{min}/L^2_{max} is kept in accordance with Eq. (4.2.1). In this way one automatically gets above mentioned physical spectral properties of TR information content but not a "spectral losses" of the information on its pathway because of the predetermined solid angle.

5. The restriction of the F_D fluctuations that follows from the uncertainty relations (2.3), and (2.5), i.e. $\Delta N_{th} = <\Delta F_D{}^2>^{1/2}\Delta t = (2\nu\Delta t)^{-1}$, leads to a virtual possibility of drastic increase of the information content $\langle\Phi_{imp}\rangle_3$ and $\langle\Phi_{imp}\rangle_4$ (Fig. 3).

The practical realisation of this tempting regime requires a special study.

References

1. Albert Rose, *Concepts in Photoconductivity and Allied Problems,* John Wiley and Sons, New York–London, 1963.
2. Salisbury J.W., Glaser P.E., *The Lunar Surface Layer*, Academic. Press, New York, 1964;
3. a) A.A. Kolokolov, G.V. Skrotchki, Ravnovesnoe izluchenie v polosti konechnogo razmera. // *Optics and Spectroscopy*, **36**, N.2, pp.217-221 (1974).
   b) A.A. Kolokolov, G.V. Skrotchki, Fluktuacii ravnovestnogo elektromagnitnogo izlucheniya // *Optics and Spectroscopy*, **35**, N.3, pp.393-395 (1973).
4. E.A. Salkov, G.S. Svechnikov, Size-restrictions of radiation detecting using semiconductor photodetectors. // *Proc.SPIE*, **2894**, pp. 66-73 (1996).
5. E.A. Salkov, G.S. Svechnikov, N.M. Krolevets. // Peculiarities of detecting of radiation from small radiators. // *Proc.SPIE*, **3182**, pp. 134-141 (1997).
6. V.L. Bakumenko, A.N. Sviridov, I.I. Taubkin. Analiz predelnih vozmoznostei idealnih teplovizorov pri nabludenii tochechnih izluchatelei. // *Appl. Phys.***1**, pp. 63-70 (2002).
7. P. Loudon, *The Quantum Theory of Light*, Clarendon Press, Oxford,1973.
8. L.D. Landau, E.M. Lifshic, *Statisticheskaya fizika* (Teoreticheskaya fizika **5**), Moskva, Nauka,1964.
9. P. Dirak, *Principi kvantovoi mehaniki*. Moskva, Nauka, 1979.
10. G.S. Landsberg, *Optika*, Moskva, Nauka, 1976.
11. E. Volf, L. Mandel,
   a) Kogerentnie svoistva opticheskih polei-I // *Ukrainsk. Fizicheski Zh.*, **87**, N.3, pp. 491-520 (1965).
   b) Kogerentnie svoistva opticheskih polei-III // *Ukrainsk. Fizicheski Zh.*, **88**, N.4, pp. 619-673 (1966).
12. M. Born, E. Volf, *Osnovi optiki*, Moskva, Nauka, 1970.
13. A.E.Sigman. The Antenna Properties of Optical Heterodyne Receivers*,* // *Appl. Optics*., **5**, N.10, p. 1588 (1966).
14. U. Volf, *Radiometriya, v sborn. Proektirovanie opticheskih system*, ch.5, Moskva, Mir, 1983.
15. R.H. Kingston, *Detection of 0ptical and Infrared Radiation*. In Springer Series in Optical Science, **10,** Springer-Verlag, Berlin-Heidelberg-New York, 1978.
16. Bracewell R. N.: *The Fourier Transform and Its Applications*, McGraw-Hill, New York, 1965.
17. V.V. Mitugov, *Fizicheskie osnovi teorii informacii*, Moskva, Sov.Radio, 1976
18. A.M. Yaglom, I.M. Yaglom, *Veroyatnost i informaciya*, Moskva, Nauka, p. 512, 1973.
19. H. Viner, *Kibernetika,* Moskva, Nauka, 1983.
20. E.A. Salkov Microscopic Parameters of Stochastic System and Variance of Physical Quantity (ideal gas, electric currents, thermal black body radiatio. // *Semicond. phys.,quant. electronics & optoelectronics*. **1**, pp. 116-120 (1998).
21. A.S. Davidov, *Kvantovaya mehanika*. Moskva, Fizmatgiz, 1963.