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Thermal detector for measuring radiation parameters of pulsed lasers and generators of submillimetre and millimetre ranges

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Abstract. **A theoretical formula is derived that makes it possible to establish a relationship between the speed and sensitivity of bolometers with geometric and thermophysical parameters of the receiving element and substrate. The result is confirmed by a preliminary (evaluation) experiment. The proposed thermal detectors can record and measure the radiation power of lasers and generators of the submillimetre (SMM) and millimetre (MM) ranges.**

Keywords: *bolometers, thin-film bismuth.*

1. Introduction

Thermal detectors are widely used to register IR radiation [1]. In continuation of the studies published in [2, 3], we have investigated experimentally bolometers with a receiving element (RE) in the form of a thin bismuth film on a substrate, which showed the possibility of expanding the spectral range of such bolometers up to millimetre (MM) and submillimetre (SMM) wavelength ranges. A formula and evaluation relations are proposed that relate the speed τ and sensitivity of the bolometer with geometric and thermophysical parameters of its components. Conditions are formulated for undistorted recording of the signal shape of pulsed radiation from lasers and generators in the MM and SMM regions by the bolometers.

2. Theoretical basis of the receivers' operation

Without prejudice to generality, let us analyse a model bolometer (Fig. 1), which consists of a thin-film rectangular receiving element (RE) with an area $S = 2a2b$, where $2a$ and $2b$ are the lengths of the sides of the rectangle. The RE is located on a thin membrane with thermal conductivity K_1 and thermal diffusivity χ_1. The membrane, in turn, is on a massive substrate (for example, silicon) with thermal conductivity K and thermal diffusivity χ. If the silicon is etched away from under the membrane, then air plays the role of a massive substrate, and the rest of the silicon plays the role of mechanical fastening of the membrane with the RE to the substrate. The RE with an area S combines the functions of an absorber with an absorption coefficient A and a thermosensitive element (TSE).

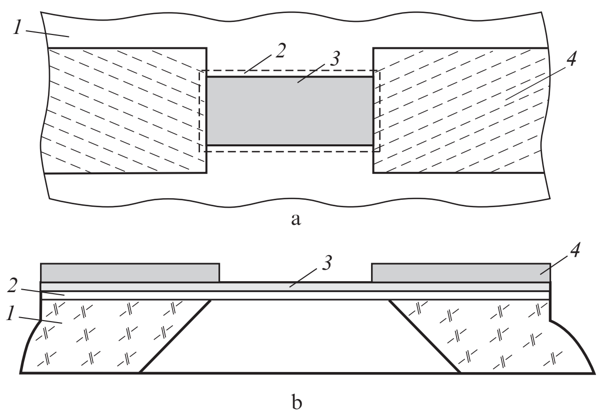

Figure 1. Schematic of a bolometer [(a) side view and (b) top view]: (*1*) silicon substrate; (*2*) bearing membrane; (*3*) thermosensitive element; (*4*) contacts (MEMS technology [1]).

It is necessary to find the time dependence of the temperature response $T(t)$ [$T(t)$ is the temperature $T(x, y; t)$ averaged over an area S, taking into account the heat propagation from the TSE into the entire three-dimensional space], when radiation with the flux density is incident on the RE

$$P(t) = \begin{cases} 0, t < 0 \\ P_0, t \geq 0 \end{cases}, \qquad T(t) = \frac{A}{S}\int\int_s T(x, y; t)\,\mathrm{d}x\mathrm{d}y. \tag{1}$$

After solving the three-dimensional equation of thermal conductivity [3] and omitting simple but cumbersome calculations, we obtain

$$T(x, y; t) = P_0\frac{A}{2\pi K}\int_{-a}^{a}\mathrm{d}\eta\int_{-b}^{b}\mathrm{d}\xi\left\{\left(\frac{1}{r}\right)\left[1 - F\left(\frac{r}{2\sqrt{\chi t}}\right)\right]\right\}, \qquad T(t) \approx P_0\frac{AL}{2\pi K}\left(1 - \sqrt{\frac{\tau_0}{t}}\right), \tag{2}$$

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Table 1. The results of measuring RE-1 characteristics in the MM and SMM ranges.

Range	Absorption coefficient (%)	Noise voltage (in 1-Hz band)/nV	Sensitivity/V W^{-1}	Threshold sensitivity (NEP)/W $Hz^{-1/2}$	Speed/ms
MM*	67	2–3	3–5	$\sim 0.5 \times 10^{-9}$	100
SMM**	40	2–3	3	$\sim 10^{-9}$	30

Note: * frequency 146 GHz; ** wavelength $\lambda = 220$ μm [4].

where $r^2 = (x - \xi)^2 + (y - \eta)^2 + z^2$, $z \to 0$; F is the error function; and

$$L = \frac{4}{ab}\left\{b^2 a \ln\left(\frac{a}{b} + \sqrt{1 + \frac{a^2}{b^2}}\right) + a^2 b \ln\left(\frac{b}{a} + \sqrt{1 + \frac{b^2}{a^2}}\right) + \frac{1}{3}\left[a^3 + b^3 - \sqrt{(a^2 + b^2)^3}\right]\right\}.$$

The parameter $\tau_0 = (1/\pi\chi)(S/L)^2$ determines the speed τ of the receiver, and the parameter L characterises the average size of the heat spot in the plane (x, y).

In deriving (2), we neglected the influence of the membrane thickness l. This is possible if the inequality $(\chi/\chi_1)(l/L)^2 \ll 1$ is met, which follows from the condition that the heating time of a thin membrane is $\tau_1 \ll \tau_0$. Relation (2) is valid at $S/4\chi t \ll 1$; if $S > 4\chi t$, then $T(t) = AP_0(2/K)\sqrt{\chi t/\pi}$ [2].

Figure 2 shows an oscillogram of the response of a RE-1 bolometer, the RE of which was made in accordance with the scheme in Fig. 1 by thermal sputtering of bismuth in a vacuum, when it is exposed to a radiation pulse from a G4-161 generator with a generation frequency of ~146 GHz and a pulse duration of ~0.7 s (the duration pulse front is $\tau \sim 0.1$ s, and the RE area is $S = 1 \times 0.5$ cm^2). To carry out measurements in the SMM range, we used the radiation of a water vapour laser [4]; in this case, the RE area was 0.15×0.07 cm^2.

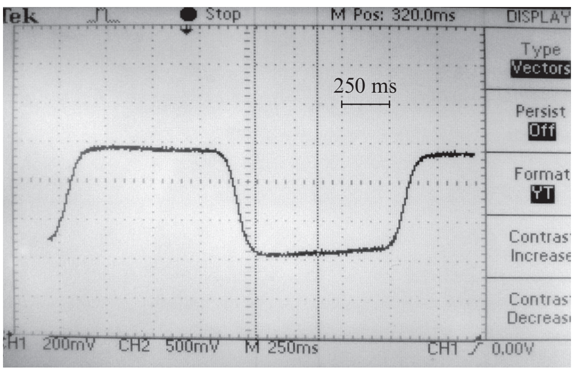

Figure 2. Oscillogram of the RE-1 response to modulated (meander) radiation from a microwave generator with a generation frequency of 146 GHz.

Other preliminary-estimated measurements of the characteristics of the RE-1 receiver for the MM and SMM ranges at the general values of the bolometer parameters, including resistance $R_0 = 245–247$ Ω, bias voltage $U_0 = 0.3$ V, operating temperature $T_0 = 275$ K, and temperature coefficient of resistance of 0.5%, are presented in Table 1.

3. Conclusions

The obtained theoretical formula, which establishes a relationship between the speed and sensitivity of bolometers with geometric and thermophysical parameters of the receiving element and the substrate, has been confirmed experimentally. The performed calculations and modelling can also find application in the development of a number of bolometric converters of pulsed radiation in an extended spectral range. The possibility of their use for registration and measurement of radiation parameters of pulsed generators and lasers of MM and SMM ranges is demonstrated.

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