AD-A098 432 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 17/5

INFLUENCE OF THE FEATURES OF INFRARED DETECTORS ON THEIR USEFUL--ETC(U)

MAR 81 T PIOTROWSKI

UNCLASSIFIED FTD-ID(RS)T-0062-81 NL

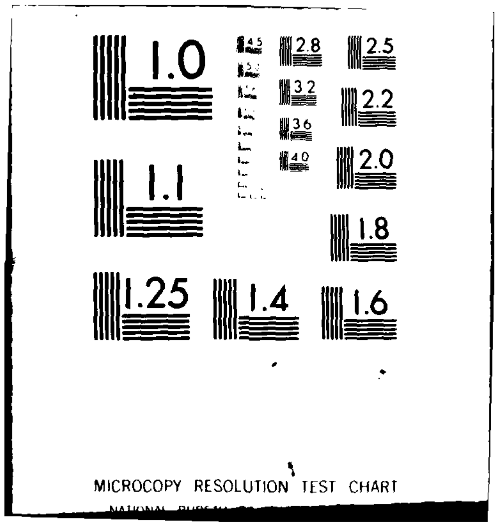
1 of 1

END

DATE FILMED

5-81

DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART

FTD-ID(RS)T-0062-81

FOREIGN TECHNOLOGY DIVISION

INFLUENCE OF THE FEATURES OF INFRARED DETECTORS ON THEIR USEFULNESS IN THERMOGRAPHY

by

Tadeusz Piotrowski

Approved for public release;
distribution unlimited.

EDITED TRANSLATION

(12) 23

(14) FTD-ID(RS)T-0062-81 (11) 13 Mar [redacted] 81

MICROFICHE NR: FTD-81-C-000212L

INFLUENCE OF THE FEATURES OF INFRARED DETECTORS ON THEIR USEFULNESS IN THERMOGRAPHY,

By (10) Tadeusz Piotrowski

English pages: 21

(21) Edited trans. of

Source: Rozprawy Elektrotechniczne, Vol. 21,
(Poland) v21 No. 2 [redacted] p391-403 1975.

Country of origin: Poland
Translated by: SCITRAN
F33657-78-D-0619
Requester: FTD/TQTR
Approved for public release; distribution unlimited.

Accession For		
NTIS GRA&I		☒
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A		

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP.AFB, OHIO.

141600

INFLUENCE OF THE FEATURES OF INFRARED DETECTORS ON THEIR USEFULNESS IN THERMOGRAPHY

Tadeusz Piotrowski (Warsaw)
Institute of Electronic Technology, Warsaw Technical University

Fast progress of thermographic technology in the world creates new problems, among them evaluation of the usefulness of IR detectors in thermography. This article analyzes the influence of characteristic features of IR detectors on their application in thermographic installations. NEP, D*, sensitivity, time constant, and spectral range of the detector are considered. An example of a detector whose spectral sensitivity range is well matched to the second atmospheric window (8 - 13 μm) and to human body emittance is CdHgTe detector. Comparison between CdHgTe and PbTe photoconductive detectors shows that the latter are better suited for work at higher object temperatures. Formulas for thermal and angular resolutions of thermographic assembly as a function of the parameters of detector are discussed. Commonly used thermographs and detectors with which they are equipped are mentioned. Finally, parameters of PbTe detectors, used in a 15-71-03 thermograph developed at the Institute of Electronic Technology at Warsaw Technical University, are described.

1. INTRODUCTION

Recent years have seen a fast progress in thermographic technology in the world. In Poland several prototype installations have been made, and simultaneously some basic research was initiated in several scientific centers. One of the problems which appeared in the course of these investigations is evaluation of the usefulness of IR detectors in thermographic technology.

Two types of the detectors of infrared radiation have found use in thermography. The first type are thermal detectors, in which the radiation absorbed in a thin blackened surface layer causes an increase in the temperature of the sensitive material of detector. This is the group of nonselective detectors, whose spectral range of work reaches submillimeter waves. Changes of temperature of sensitive material in these detectors are found by measurements of thermoelectric potential (in thermoelectric junctions), of changes in resistance (in thermistors), of the expansion of gas (in Golay detectors) or in spontaneous polarization (in pyroelectric detectors). The second type are photon detectors, in which the effect of absorbed quanta of radiation energy upon the properties of semiconductive material may be registered as a result of appearance of photoelectric phenomena (photoconductivity, photovoltaic and photomagnetoelectric effects).

There is a large choice of the types of IR detectors which can be actually used in thermography. So far, the most frequently applied detectors are photoconductive and photovoltaic detectors made from InSb, CdHgTe, PbTe and from admixed germanium. More recently tests are being made with pyroelectric detectors. Detectors working in known models of thermographs are listed in Table 1.

Table 1. Detectors used in thermographs.

Typ termografu	Detektor rodzaj detektora	temperatury pracy (K)	zakres widmowy (μm)	Czas analizy obrazu (s)
AGA 680/102B AGA 750 Szwecja	InSb	77	2÷5,6	1/16 1/25
Barnes T-4 USA	termistor	otoczenia	2÷1000	6 min
Barnes T-6 USA	piroelek-tryczny	otoczenia	2÷1000	30
Barnes RM-50 USA	InSb	77	2÷5,6	1
Bofors T-101 Szwecja	InSb (CdHgTe)	77 (77)	2÷5,6 (8÷15)	0,25
Bofors T-102 Szwecja	InSb (CdHgTe)	77 (77)	2÷5,6 (8÷15)	0,5
LEP Francja	Ge:Hg (InSb)	30 (77)	8÷14 2÷5,6	0,5
Politechnika Warszawska 15-71-03 Polska	PbTe	77	1,1÷5,7	1 min

Columns: Type of thermograph; Detector: type of detector, working temperature (K), spectral range (μm); Time of picture analysis (sec). Szwecja = Sweden, Francja = France, Polska = Poland, Politechnika Warszawska = Warsaw Technical University, otoczenia = ambient

2. PARAMETERS OF DETECTOR AND THEIR INFLUENCE UPON CHARACTERISTICS OF THERMOGRAPH

A detector, as an element sensitive to infrared radiation sent by an object, exerts decisive influence upon parameters of thermograph and the spectral range of its work. For this reason, detector has to be always chosen from the point of view of usefulness in a thermograph with defined application and assumed values of parameters. Often during the planned work it is found that no detector is available which would fulfill all the requirements, since favorable factors are not always going in pairs and have to be replaced by others.

a) Time constant

For most of the detectors the dependence of sensitivity on the frequency of modulation can be described by the formula

$$C = \frac{C_0}{\sqrt{1+(2\pi f\tau)^2}}, \quad (1.1)$$

where:

τ - time constant

C_0 - sensitivity at small frequencies.

If f_1 is a frequency at which sensitivity of the detector decreases by 3 dB in relation to the sensitivity at small frequencies then the time constant is defined by the expression

$$\tau = \frac{1}{2\pi f_1}. \quad (1.2)$$

The speed of response of the detector to a signal, determined by the time constant, has influence upon the time of analysis of the temperature distribution of an object. The dependence of the minimum time of the duration of analysis of a picture upon the time constant of detector, using the standard 150 lines x 150 points, is shown in Figure 1.

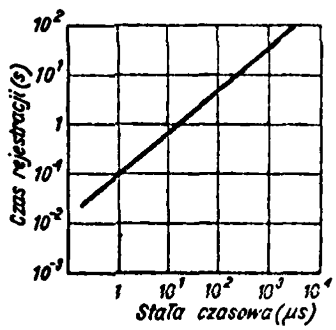


Figure 1. Dependence of the minimal analysis time on the time constant of detector (at the standard 150 lines x 150 points). Ordinate: Recording time (sec). Abscissa: Time constant (μsec).

It is found that a detector with the time constant about 0.5 μsec enables to obtain the analysis time of 1/25 sec (standard T.V.). It seems that at present time this is a sensible limit for applications in thermography.

b) NEP, normalized detectability, sensitivity

These parameters are defined analytically in the following way:

- NEP (noise equivalent power) is determined from the relation

$$NEP = \frac{P}{S\sqrt{\Delta f}} \left(\frac{W}{Hz^{1/2}}\right), \qquad (1.3)$$

where:

$S = \frac{U_s}{U_n}$ - ratio of the potential of signal to potential of noise,

P - effective value of radiation power falling on the detector,

Δf - equivalent noise beam;

- normalized detectability (Jones's) is defined as follows

$$D^* = \frac{\sqrt{A}}{NEP} \left(\frac{cm\, Hz^{1/2}}{W}\right), \qquad (1.4)$$

in which A - sensitive surface of the detector;

- sensitivity is the ratio of the potential of output signal to the power of radiation falling, which causes this signal, measured under matching conditions

$$C = \frac{U_s}{P} \left(\frac{V}{W}\right). \qquad (1.5)$$

Quite often we use concepts of normalized spectral detectability D^*_λ of detector, and of spectral sensitivity C_λ , given for a specific defined wavelength of radiation.

These listed parameters are used to determine detection capabilities of detectors. Here, NEP, D* and D^*_λ serve to describe detector properties for small signals, at which the effect of noise is considerable. The limiting curves (graphs) arising from the noise potential are usually given in descriptions of the characteristics of detectors; they define the range of work. As an illustration, Figure 2 shows the effect of photon noise, dependent on the temperature of background, on the normalized spectral detectability D^*_λ.

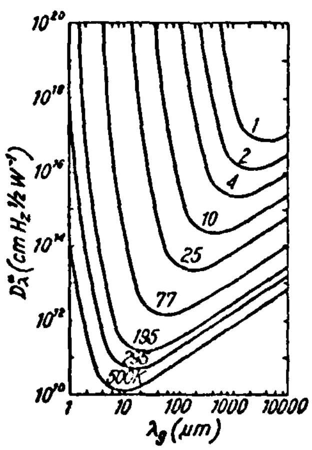


Figure 2. Theoretical dependence of the normalized spectral detectability of detector $D^*_\lambda(\lambda, f, \Delta f)$ on the long-wave radiation limit λ_g at various temperatures of background and considering only photon noise /6/.

The photon noise has a white spectrum and does not depend on polarization of the detector. It defines the limiting detection characteristics in cases where other types of noise can be neglected.

The comparison of detectors by means of NEP, D* and D^*_λ is often inaccurate. It happens that these parameters depend on the angle of vision of detector and on dimensions of the sensitive layer /13/. Large discrepancies may occur for detectors with long and narrow layers. It was found on the basis of observation that sensitivity plays large role in the evaluation of usefulness of a detector for thermography. Sensitivity does not depend on size of the sensitive surface of detector (in the range of linear dependence of signal potential on the incident power), nor does it depend on characteristics of radiation source. The sensitivity is, therefore, the decisive parameter, since it defines the potential of signal at the detector outlet, and the large value of this potential allows to level off the worse noise properties of the thermograph. This is particularly important for universal systems, in which it is difficult to avoid external disturbances.

When giving sensitivity of a detector, it is necessary also to give the signal-to-noise ratio.

c) Spectral sensitivity range

The basic factor affecting the usefulness of a detector for a given thermographic assembly is its spectral sensitivity range. This follows from dependence of the spectral distribution of power of IR radiation falling on the detector on the temperature of object and on absorption of the center.

In thermographs which are intended for measurements of radiation passing through the earth atmosphere we utilize only the clear windows through the atmosphere: 3.5 - 5 μm and 8 - 13 μm (Figure 3). On the other hand, in medical thermography where the source of radiation is human body at the temperature about 310 K we can utilize a broader spectral range, for instance from 3 μm to 13 μm. An example of a detector whose spectral range is well matched to both the mentioned applications is CdHgTe detector. CdHgTe detectors cover the range of the second atmospheric window and are also sensitive in the region of of the highest emittance of human body (Figure 4).

Let us compare, for instance, photoconductive detectors made of CdHgTe and of PbTe. Figure 5 shows the temperature dependence of the power radiated through black body, in ranges corresponding to those of the utilization of detectors CdHgTe (8 - 13 μm) and PbTe (1.1 - 5.7 μm). Calculations were made utilizing the distribution of radiation power of a black body (Figure 4). It follows from the graph shown in Figure 5 that above the temperature 530 K (257°C) a larger radiation power falls on the PbTe detector than on the CdHgTe detector (in the range of their sensitivities). In this connection the PbTe detector is more suited for work at higher temperatures. Moreover, the PbTe detectors cover the range of the first window of atmospheric transmission, hence they can be

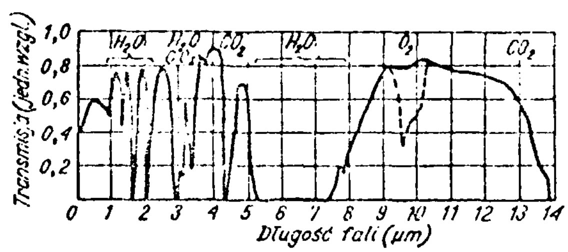


Figure 3. Spectral transmission of earth atmosphere at the distance 2000 m at sea level /3/.
Ordinate: Transmission (arbitrary units); Abscissa: Wavelength

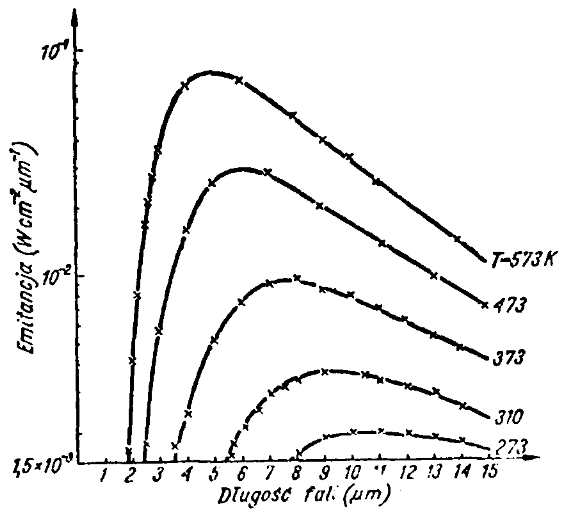


Figure 4. Spectral distribution of the emittance of back body at its various temperatures (310 K - temperature of human body).
Ordinate: Emittance; abscissa: Wavelength.

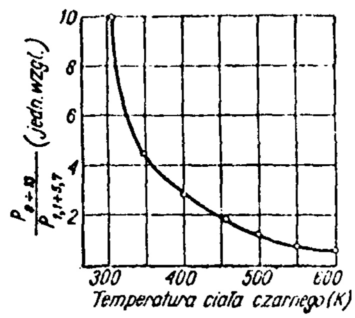


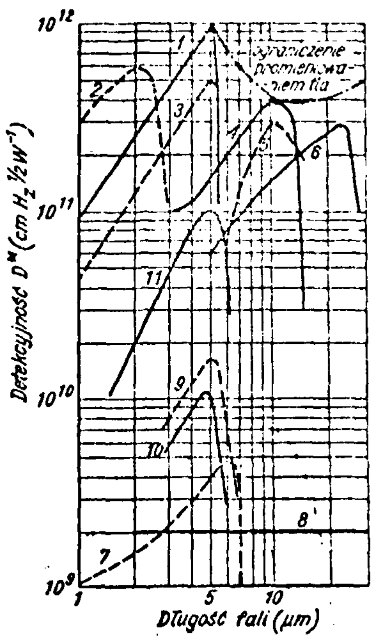
Figure 5. Dependence of the ratio of emittance of black body on the temperature (range λ = 8-13 µm - typical for CdHgTe detectors, range λ = 1.1-5.7 µm - typical for PbTe detectors).
Ordinate: $P_{8-13}/P_{1.1-5.7}$ (arbitrary units)
Abscissa: Black body temperature (K).

also applied in thermographs serving for measurements at long distances. In practice, the PbTe detectors are very universal (versatile) and, despite the fact that their spectral characteristic is moved to the side of shorter wavelengths, they probably could be utilized successfully in medical studies.

Figure 6 shows spectral characteristics of the most often used detectors of IR radiation.

d) Working temperature of detector

The working temperature of sensitive layer of a photon detector exerts important influence on its properties. On the whole, photon detectors made of the same material have the long-wave threshold moved towards shorter waves (among others lead halogens make an exception) and have a better detectability, when they are



1 — InSb (kąt widzenia 60°)	T = 77 K	Mullard
2 — PbS	T = 300 K	,,
3 — InSb (kąt widzenia 2π)	T = 77 K	,,
4 — CdHgTe	T = 77 K	,,
5 — Ge:Hg	T = 35 K	,,
6 — Ge:Cu	T = 4,2 K	,,
7 — InSb	T = 300 K	,,
8 — Bolometr piroelektryczny	T = 320 K	,,
9 — CdHgTe	T = 193 K	,,
10 — CdHgTe	T = 295 K	,,
11 — PbTe	T = 77 K	ITL P.W.

Figure 6. Spectral characteristics of detectors. Ordinate: Detectability; Abscissa: Wavelength. Ograniczenie promieniowaniem tla = Limit caused by background radiation; kat widzenia = viewing angle.

[8] Pyroelectric Bolometer

used at lower temperatures. Thermal detectors work usually at an ambient temperature (of surroundings) and their parameters do not depend on this temperature (an exception are pyroelectric detectors which work normally at the Curie temperature).

At present, cooled photon detectors are used most frequently in thermography. Cooling of detectors to the temperature of liquid nitrogen does not cause any problems under laboratory conditions. Detectors cooled to 77 K are generally used in thermographs for laboratory measurements, for industrial purposes and in the majority of instruments used on the surface of Earth. However, for certain special measurements, for instance performed with the aid of flying objects, it is more convenient to use noncooled detectors.

The users of thermographic instruments pay attention to the period of time through which the sensitive layer of detector maintains its working temperature. For detectors cooled with liquid nitrogen, and having a vacuum insulation, this period of time may last from 1 hour to 1 day, depending on size of the reactor and on actual needs. For detectors cooled to the temperature of liquid helium (4.2 K) the time of work is several hours. For instance, the all-metal insulation of a detector of Mullard company, with outside dimensions 400x200 mm, the nitrogen space capacity 1 l and helium capacity 700 ml, enables the continuous work for the time of at least 7 hours.

In some types of detectors the inlet aperture is cooled to reduce the background radiation.

3. THERMOGRAPH PARAMETERS DEPENDENT ON PROPERTIES OF DETECTOR

In addition to the thermograph parameters already discussed - - time of the analysis of picture and spectral range of work - we can distinguish two more parameters dependent on characteristics of the utilized detector.

a) Thermal resolving capacity

The thermal resolving (resolution) capacity of a thermograph ΔT_m is defined as the smallest difference between temperatures which can be observed. It is described as a difference of temperatures between two black bodies at temperatures T and $T+\Delta T_m$, recorded by means of a thermograph with mechanical selection and a point detector.

The value of ΔT_m can be found from the relation /4/:

$$\Delta T_m = \sqrt{\frac{\Delta f}{A}} \cdot \frac{1}{\Omega t_1} \cdot \frac{T}{4 t_2 D^* \int\limits_{\lambda_1}^{\lambda_2} \left(\frac{dW_\lambda}{d\lambda} \right)_T d\lambda}, \qquad (3.1)$$

where:

- A - sensitive surface area of detector,
- Ω - aperture angle of the optics-detector system,
- Δf - beam width of selective amplifier,
- t_1 - transmission coefficient of the optical system,
- t_2 - transmission coefficient of the atmosphere on the path of source-detector,

D^* - normalized detectability of detector,

$\left(\frac{dW_\lambda}{d\lambda}\right)_T$ - monochromatic emittance of black body at temperature T,

λ_1, λ_2 - limit values of spectral sensitivity range of detector.

The relation (3.1) may be presented in the form

$$\Delta T_m = \alpha \cdot \beta, \tag{3.2}$$

where α is a factor determined by parameters of the detector--optics-amplifier system, whereas β characterizes the influence of spectral power distribution of radiation source and detectability of the detector.

The value of ΔT_m is the lower, the steeper is the course (curve) of the radiation power of source in a given spectral range, and the higher is the value of the normalized detectability of detector D^*. An increase of the sensitive surface of detector A, as well as a higher transmission of medium t_2, also improve the thermal resolving capacity.

b) Angular resolving capacity

The angular resolving capacity (resolution) is defined by means of the relation /6/:

$$R_\varphi = \frac{2}{d}\sqrt{\frac{S\sqrt{A}}{E \cdot \Delta T_m D^*}}\sqrt{\frac{n \cdot p}{2}}, \tag{3.3}$$

where:

d - inlet diameter of optical system,

A - sensitive surface of detector,

D^* - normalized detectability of detector,

S - signal-to-noise ratio,

E - density of radiation power sent out by surface unit of the object at the difference of temperatures $\Delta T = 1$ K.

ΔT_m - thermal resolving ability,

p - number of points in the picture,

n - number of pictures per second.

It is assumed here that the time constant of the detector is so small that it does not affect the value of the angular resolving capacity. Also, we neglect here the effect of the wavelength.

The largest influence on the angular resolving ability is exerted by the inlet diameter of optical system. Apart from effects of the parameters of detector and source, it is found that the resolving capability becomes worse when the analysis of picture is fast. In general, slower systems ensure a better angular resolving ability.

4. CONCLUSIONS REGARDING THE USEFULNESS OF PARTICULAR TYPES OF DETECTORS IN THERMOGRAPHY

Discussions carried out in Part 1 indicate the necessity of matching spectral characteristics of detector to the spectral range of radiation emanating from the object. It is necessary to choose detectors with possibly broad spectral range of sensitivity to be able to utilize the largest part of power radiated by the object. However, in practice such an idealized situation cannot be realized because, with an increase of wavelength, detection parameters of detectors become worse, the costs increase as well as the labor to prepare the detector to work (the necessity of use of special transmission materials in infrared, the necessity of cooling the sensitive layer in photon detectors). The angular resolving ability also decreases. The angular resolving capability becomes worse with an increase in wavelength, as a consequence of the wave nature of radiation. For instance, the angular resolving ability of photographic equipment working in the visible range is better than in the infrared region.

It seems that the upper limit of the spectral range of a detector used in thermography is λ = 11-13 μm; 13 μm is the limit for thermographs measuring the radiation passing through the earth atmosphere, and 11 μm - for the remaining thermographs.

In practice, the conditions of matching the spectral range of detector to the temperature of measured object are very often not observed. As an example may serve thermographs of AGA company used for medical purpose, which employ InSb detector cooled to the temperature of liquid nitrogen. Often, thermographs are used where the conditions of measurement force us to give up the spectral matching. This takes place in microscopic thermographic arrangements and also in systems requiring an extremely high resolution.

An essential role in thermographic applications is played by the fast speed of reaction of detector. For thermographs with a short time of picture analysis of less than one second, working in broad-band system, we need fast detectors, whose frequency characteristic of sensitivity in the working range has a steady course, and the value of time constant amounts to a few microseconds at the most. We use then the detectors of InSb, CdHgTe, ZnHgTe, or admixed germanium. It is difficult in these systems to avoid deformations caused by nonuniform distribution of angular and thermal resolution ability.

The system of selective modulation provides the possibility of avoiding the mentioned deformations; moreover, it enables to employ detectors with larger time constants.

In thermographs type 15-71-03, developed in the Institute of Electronic Technology, at the Warsaw Technical University, working at modulation frequency f = 500 Hz, we employ PbTe photoconductive detectors with time constants of the order of ten or so microseconds, and with sensitivity equal to at least ten thousand volts per watt (Table 2). High sensitivity of these detectors should enable to use them at a modulation frequency higher than it follows from the value of the time constant. Moreover, this high sensitivity enables to use the PbTe detectors for recording thermograms in the presence of external disturbing fields.

When detectors are used for thermography of objects with large radiation power, for instance lasers, the value of permissible power W_{dop} falling on the surface of sensitive layer is important. For instance, the company Laser Precision Corporation /14/ produced for this purpose a pyroelectric detector KT-2000 intended for cooperation with a CO_2 laser. This detector has the value W_{dop} = 100 W/cm^2.

(500 K, 500 Hz, 1 Hz)

Symbol detektora	Czułość $\frac{V}{W}$	NEP $\frac{W}{Hz^{1/2}}$	D* $\frac{Hz^{1/2} cm}{W}$	τ μs	R MΩ
DP-245-41	16 000	$1,8 \cdot 10^{-11}$	$3,5 \cdot 10^{9}$	20	20
DP-255-65	17 800	$1,63 \cdot 10^{-12}$	$3,68 \cdot 10^{10}$	15	0,35
DP-255-70	10 700	$2,7 \cdot 10^{-12}$	$2,22 \cdot 10^{9}$	40	4,5
DP-445-126	77 000	$6 \cdot 10^{-13}$	$1 \cdot 10^{11}$	—	0,65

Table 2. Parameters of photoconductive PbTe detectors cooled with liquid nitrogen, employed in thermographs of the Institute of Electronic Technology, Warsaw Technical University (500 K, 500 Hz, 1 Hz)

Columns: Detector symbol, Sensitivity, NEP, D*, τ R.

τ - time constant of detector; R - resistance of sensitive layer.

Recently produced pyroelectric detectors represent progress in research. They are quite universal (versatile), but their parameters are not much different from parameters of detectors used at present.

Summary

Recently great progress in thermography technologies has been made. Because of it a new problem appeared: usefulness of I.R. detectors to these applications. The author analyses the influence of an I.R. detector parameters on its application in thermography. *NEP*, *D**, sensitivity, time constant and spectral range of the detector are taken into account. An example of a detector whose spectral range is well matched to the second atmospheric window (8—13 μm) and to human body emittance is detector CdHgTe. Comparison between CdHgTe and PbTe photoconductive detectors shows that those latter are better suited to higher target temperatures. Formulas for thermal and angular resolutions of thermographic assembly as a function of detector parameters are discussed. Commonly used thermographs and detectors, with which they are equipped are mentioned. Parameters of I.R. detectors used in thermograph 15-71-03 made in Institute of Electron Technology, Warsaw Technical University, are described.

REFERENCES

1. P. Kruse, L. Mc Glauchlin, R. Mc Quistan, *Elements of Infrared Technology*, London 1963.
2. M. R. Holter, S. Nudelman, G. M. Smits, W. L. Wolfe, G. J. Zissis, *Fundamentals of Infrared Technology*, Mc Millan, New York 1963.
3. I. Simon, *Promieniowanie podczerwone*, PWN, Warszawa 1968.
4. M. Jatteau, *Infrared Thermography Equipment for Medical Application*, Philips Technical Review, 8, 1969, 278--289.
5. M. Jatteau, *Thermographe fonctionnant à 4 ou 10 microns et permettant le tracé précis des isothermes*, Acta Electronica, 12. 1, 1969, 21--62.
6. C. M. Cade, B. V. Barlow, *Fundamental Design Principles for Thermographic Scannners*, Sci. Prog. Oxf., 55, 1967, 167—185.
7. S. F. Jacobs, M. Sargent, *Photon Noise Limited D* for Low Temperature Backgrounds and Long Wavelengts*, Infrared Physics, 10, 1970, 233--235.
8. *AGA Thermovision System 680/102B* — Operating Manual.
9. K. Stahl, *Infrarot Detektorren*, Optik, 1, 1968, 11—30.
10. M. Smollett, *The Properties and Performance of Some Modern Infrared Radiation Detectors*, Infrared Physics, 1, 1968, 3—7.
11. Y. Ueda, H. Yamashita, T. Yamaoka, H. Sei, *Infrared Detectors Using Semiconductors*, Fujitsu, 1, 1971, 53—83.
12. *Półprzewodnikowe Detektory Promieniowania*, Materiały z Konferencji, Warszawa 7--8.II.1972.
13. *Mullard Infrared Detectors* — Cataloque of Mullard Limited, 1970.
14. *Laser Precision Corporation Cataloque*, 1972.
15. H. B. Beerman, *Pyroelectric Infrared Radiation Detector*, Am. Ceramic Society Bull., 8, 1967, 737—740.
16. W. M. Doyle, *Pyroelectric Detectors*, Laser Focus Magazine, 7, 1970, 34—37.
17. A. M. Glass, *Investigation of Electrical Properties of SBN with Special Reference to Pyroelectric Detection*, Journal of Applied Physics, 12, 1969, 4699--4713.
18. B. C. McIntosh, D. W. Sypek, *Pyroelectric Detector Arrays*, Laser Focus Magazine, 12, 1972, 38--40.

3. Simon - Infrared radiation; 9 - Infrared detectors;

12. Semiconductive Radiation Detectors, Proceedings of a Conference

DATE
ILME