Infrared Thermal Detectors Parameters: Semiconductor Bolometers Versus Pyroelectrics

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Abstract: - Semiconductor bolometric detectors parameters have been analyzed within the wavelength of 100μm up to 3mm and cryogenic temperatures. From analyses and results obtained, it is shown that the values of NEP have been found to be 16.4×10^{-15}W/Hz$^{-1/2}$ and 38.466×10^{-15}W/Hz$^{-1/2}$ for cryogenic temperatures 0.5K and 5K, respectively. For the wavelength 200 μm, the maximum value of the voltage responsivity R_V of the bolometer is 0.106×10^{-11} V/W, while for the wavelengths 1 mm, 2 mm and 3 mm, corresponding values of voltage responsivity R_V of the bolometer are 0.53×10^{-11} V/W, 0.58×10^{-11} V/W and 0.637×10^{-11} V/W, respectively. This paper also outlines analyzes of the temperature dependency of infrared pyroelectric detectors parameters at medium wavelength (MWIR). Certain pyroelectric materials such as TGS, $LiTaO_3$, $LiNbO_3$, $Li_2SO_4xH_2O$, $BaTiO_3$, $NaNO_2$, PVF_2, SBN and SbSi have been analyzed within the temperature range of 273K up to 343K. Analytically it is proven that thermal time constant decreases with increasing temperature and decreasing the thickness of the detector. Analyses have shown that the smallest response time for detector which operates at room temperature 300K was achieved for the material $Li_2SO_4\times H_2O$ with value of several milliseconds, but anyway much greater then that of photon detectors. It is also shown that NEP depends directly on circuit noises voltages. In the paper are analyzed three types of noises: thermal noise, dielectric noise, and amplifier noise. The maximum possible value of detectivity to be achieved for a MWIR infrared pyroelectric detector operates at room temperature 300K was 2.12×10^8 for $NaNO_2$.

Key-Words: - infrared, bolometers, pyroelectricity, pyroelectric detectors, responsivity, thermal time constant, NEP, detectivity.

1 Introduction

Every object radiates if its temperature is above absolute zero. This means that all real objects radiate. This radiation includes the spectrum of infrared waves (0.77-1000 μm), and if the radiant source temperature is quite high (above 1000 K), then a part of the emitted energy includes also visible light spectrum (0.39-0.77 μm). To detect radiation we use photodetectors. Photodetectors are optoelectronic devices that convert incident radiation, directly or indirectly, into equivalent electrical signals, and they are classified into two major classes: photon detectors and thermal detectors. In the photon detectors, absorbed energy of the incident radiation convert, through the process of photoelectric emission, directly into free charge carriers, namely electric current, which is proportional to the rate of absorption of light quanta (photons). In the thermal detectors, absorbed energy of the incident radiation increases the temperature of detector, which in turn causes the change of some temperature-dependent parameter, e.g. electrical conductivity (resistivity).

A problem that face photon detectors working in the infrared region of electromagnetic spectrum is that the absorbed photon energy of incident radiation is comparable with average thermal energies (≈ kT) of atoms in detector itself, which in turn cause generation of free charge carriers, which in fact are the source of noises. To overcome this problem the temperature of the detector must maintained low by using cooling system, which increases the system cost. Working principle of thermal infrared detectors can be explained as follows: incident infrared radiation is absorbed by active area of detector and increases the temperature of this area by ΔT, and this temperature change causes change of polarization, in the case of pyroelectric detectors, and change of the electrical resistance of sensing element, in the case of bolometers, respectively, in which case in the output a electrical signal is obtained. So, in other words, the temperature changes make optical energy to be

converted into electrical energy. Common types of thermal detectors are bolometers, thermocouples and pyroelectrics, and most of them are operated at room temperature. Each of these detectors has its way of detection and response to temperature changes. Bolometer is a detector built from a material (sensing element) having a large temperature coefficient of electrical resistance. Absorption of radiation produce temperature change which gives rise to a change in electrical resistance. According to sensing element, the bolometers are classified as thermistor bolometers, semiconductor bolometers, and superconductor bolometers. In this paper are analyzed semiconductor bolometers. In the thermistor bolometer, as the sensing element is used a blacked thin layer of metal, whose electrical resistance depends to a large extent by temperature. Sensitivity of a bolometer can be improved by using semiconductor or superconductor materials. More sophisticated are the low temperature Ge bolometers, which use as sensing element Ge crystal cooled to liquid helium temperatures (4.2 K). In general, semiconductor bolometers operate at cryogenic temperatures, i.e. under 4 K [1].
Thermal detectors convert optical energy into heat. This increases the temperature that is detected and transformed into electrical signal. Increased temperature is the sum of the heat sink temperature T_0 and the surface temperature of sensing element of bolometer T, i.e. $\Delta T = T_0 + T$. Usually the surface of sensing element of bolometer is covered with a black layer, in order to absorb as much as possible the incident radiation. The thermal mass of the detector should be small to increase sensitivity and to reduce its thermal time constant [2].
Pyroelectricity is a characteristic of some materials which stimulate generation of electric dipole moment due to changes in temperature, resulting the current which is proportional to the temperature changes. Such pyroelectric materials in which the crystals are spontaneously polarized are called pyroelectrics. This evidence enables the application of pyroelectrics for detection purposes - as thermal sensors. Full pyroelectric effect can be obtained in the cases where crystal temperature changes are homogeneous along entire crystal area, otherwise, a pseudo-effect can be caused. Perfect pyroelectric materials have a similar polar axis [3]. Pyroelectrics are high frequency thermal detectors, therefore in this paper we have analyzed pyroelectric parameters at medium wavelength MWIR, 3 – 5μm. Pyroelectric thermal detector crystal must be as thin as possible in order to ensure faster temperature changes. In this way, once the faster electric signal will be obtained, the thermal time constant value of the material will be smaller. This paper introduces the analyzes of frontal detector of 5μm thickness and 1.5 cm^2 area. Since pyroelectric crystals responds to the minimum excitations, two factors should be taken into consideration: medium temperature and incident radiation. This radiation may derive from different objects such as: warm objects, cold objects and different laser sources [4].

2 Infrared Semiconductor Bolometers Detectors Parameters

Bolometers are the best choice in modern astronomy for detection of electromagnetic radiation at wavelengths between 200 μm and 3 mm [5]. At shorter wavelengths, direct detection is used, in which detector respond to the square of the small signal amplitude, which causes direct excitation of charge carriers. At longer wavelengths heterodyne detection is used, in which detector respond to the product of the signal amplitude with a much larger local oscillator amplitude.
The electrical resistance of a bolometer varies with temperature as [6][7]:

$$R(G) = R_0(1 + \alpha\Delta T) \qquad (1)$$

where R_0 is the strip resistance of sensing element when $\Delta T = 0$ and α is the temperature coefficient of resistance. In metals α is positive, while in semiconductors it is negative. Raising the temperature of sensing element, as a result of the incident radiation, can be expressed by following relation: [6]

$$C\frac{dT}{dt} + G(T - T_0) = I^2 R_0 + \Phi_c^b + \eta\Delta\Phi_c \qquad (2)$$

where: C – thermal capacity of the element; G – average thermal conductance from element to the heat sink at initial temperature T_0; T_d – detector temperature; I – bias current; Φ_c^b – background radiant energy; $\Delta\Phi_c$ – signal radiant energy; η – emissivity; T_0 – initial temperature of the detector and the temperature of the heat sink.
In Figure 1 is presented a simple bolometer model. It consists of a bolometer weakly coupled to a heat sink by a thermal link. The bolometer is composed of an absorber attached to a thermistor of resistance R and at a temperature $T \geq T_0$, where T_0 is the heat sink temperature, which, in generally, is referred to as the stage temperature.

Fig. 1. Schematic diagram of a typical bolometer detector system

The bolometer is a device with very high sensitivity. The change of the temperature of absorbent material of bolometer, as a result of absorbed radiation, cause change in electrical resistance of the sensing element of bolometer. This sensing element of detector consists of a thin layer of semiconductor, in our case, from germanium, which is placed between two electrical parts, which plays the role of thermal contact. Usually, the sensing element is covered with a thin black layer in order to absorb as much as possible the incident radiation.

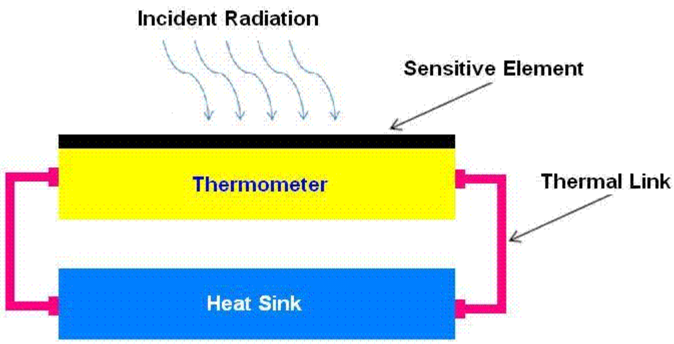

Fig. 2. Bolometric Detector

In this paper ideal bolometer detector is analyzed. It is built from semiconductor material, germanium, as this material finds most viability in infrared radiation. Germanium bolometers are used at wavelengths between 5 μm and 10 μm. Most important parameters of infrared (IR) bolometers are: detektivity (D^*), thermal responsivity (R_V) and thermal time constant τ. Thermal time constant shows how quickly responds IR bolometer, as a result of the incident IR radiation, and is given as:

$$\tau = \frac{C}{G} \qquad (3)$$

where C is thermal capacity of sensing element, and G is thermal conductivity. In order to obtain as smaller response time, the active area of sensing element needs to be as small as possible, but in this case, this small area will receive less incident radiation energy and thus detection of optical power incident will be reduced greatly. IR sensing areas of bolometer can be fabricated very small (typically 10^{-5} cm^2) with thermal mass of sensing surface of order 10^{-9} J/K. If thermal conductivity of sensing area is 10^{-7} W/K, thermal time constant will be of the order of 10 ms. [8]

Thermopile is an array of thermocouples each produces a small voltage when there is a temperature difference between the two junctions of two different metals. With the use of semiconductor materials, the sensitivity of thermopiles has been improved in comparison with common metal thermocouples. Main parameters of a bolometric detector are: noise equivalent power *NEP*, voltage responsivity R_V, specific detectivity D^* and thermal time constant τ.

Noise Equivalent Power (NEP) - is the main indicator of performance of a detector. The NEP is defined as absorbing input power which produces in output the signal to noise ratio (SNR) equal to the unity (e.g S/N = 1), normalized to frequency bandwidth of 1 Hz. For this reason, it is desirable to have the NEP as small as possible, because the smaller NEP is, the greater will be the signal to noise ratio (SNR). Alternatively, NEP can be defined as the ratio between the minimum detectable power and square root of frequency. In this case, the unit of NEP appears to be (W/Hz$^{-1/2}$). The NEP of an ideal detector consists of various noises, like Johnson noise, photon noise, amplifier noise etc. In order to analyze the NEP of the bolometric detector, we consider following bolometer's parameters: resistance R = 10 kΩ, bias current I_B = 20 μA, output voltage V_o = 0.2 V, input RF power P_{in} = 4 μW, modulation frequency f_m = 10 kHz, empirical $1/f$ parameter $n = 10^{-13}$, thermal conductance G = 10^{-7} W/K, thermal capacitance C = 10^{-9} J/K and transmission efficiency ρ_a= 0.8. To draw the NEP, we need to measure two parameters: the detector voltage responsivity for a given frequency and detector noise voltage for the same frequency. Noise equivalent power (NEP) of the bolometric detector can be calculated by the following expression:[7]-[9]

$$NEP = \frac{V_n}{R_V} \qquad (4)$$

where V_n is noise voltage and R_V is voltage responsivity. As in a bolometric circuit a considerable number of noises are present, in general, the noise voltage V_n can be expressed as the quadratic sum of the squares of different voltage noises:

$$V_n^2 = V_J^2 + V_{Ph}^2 + V_{1/f}^2 + \ldots \qquad (5)$$

where V_J is Johnson noise voltage, V_{Ph} is photon noise voltage, and $V_{1/f}$ is $1/f$ noise voltage. On the other hand, voltage responsivity R_V can be expressed as: [9]

$$R_V = \frac{V_0}{P_{in}} \qquad (6)$$

where V_0 is output voltage, and P_{in} is input RF power. Here are considered the three main noises: Johnson noise voltage V_J, photon noise voltage V_{Ph} and $1/f$ noise voltage $V_{1/f}$. Replacing expressions (5) and (6) into (4), we obtain the final expression for calculation of the NEP of bolometric detectors:

$$NEP = \frac{P_{in}\sqrt{V_J^2 + V_{Ph}^2 + V_{1/f}^2}}{V_0} \qquad (7)$$

The NEP of the bolometer was analyzed for the case of cryogenic temperatures, 0.5 K to 5 K. From the results obtained, we can see that for cryogenic temperatures T = 0.5 K, the maximum value of the NEP of the bolometer is 16.4 × 10^{-15} W/$Hz^{-1/2}$, while for T = 5 K, the value of the NEP of the bolometer is 38.466 × 10^{-15} W/$Hz^{-1/2}$.

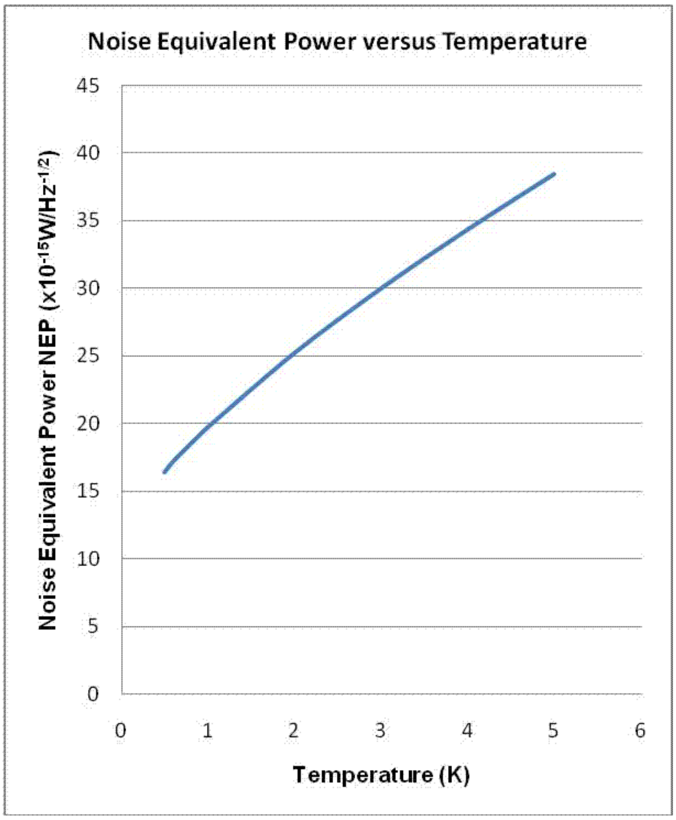

Fig. 3. Noise Equivalent Power versus Temperature

*Specific Detecticvity D** - Detectivity *D* of a detector is defined as reciprocal value of noise equivalent power. Since most of the parameters used to calculate the NEP depend on the detector area, in most cases it is preferable that instead of detectivity D, to be used specific detectivity D*, which is given as the ratio between square root of detector area and noise equivalent power (NEP).

$$D^* = \frac{\sqrt{A}}{NEP} \qquad (8)$$

Here is analyzed the detector with sensitive layer area of $10^{-6}cm^2$. From analyses made and results obtained, it is shown that maximum and minimum values of specific detectivity D^* for cryogenic temperatures from 0.5 K to 5 K are 0.0609 × 10^{12} cm$Hz^{1/2}W^{-1}$ and 0.0259 × 10^{12} cm$Hz^{1/2}W^{-1}$, respectively.

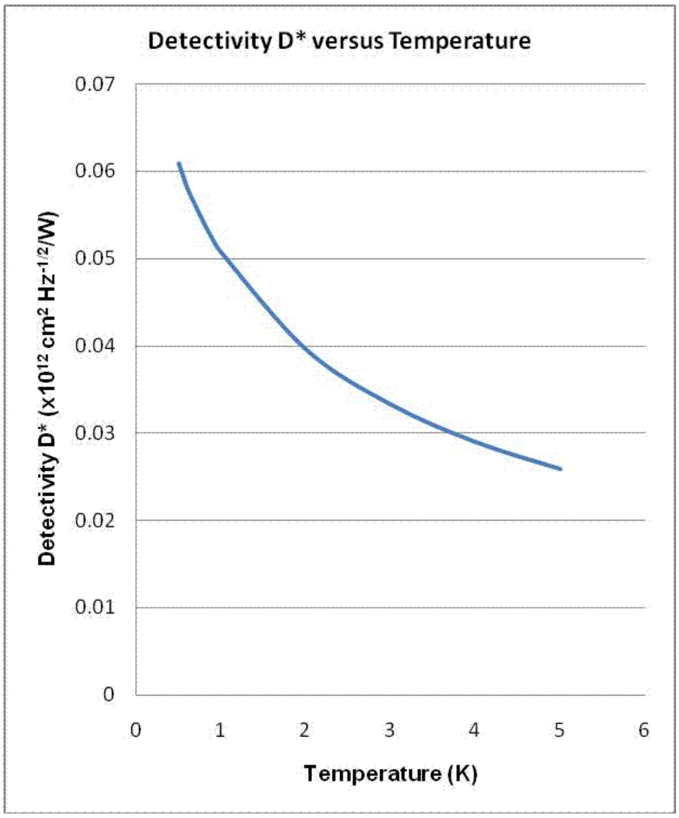

Fig. 4. Detectivity versus Temperature

Voltage Responsivity (R_V) - As discussed by Rogalski et al. [10], voltage responsivity R_V of bolometric detectors can be expressed as follows:

$$R_V = \frac{I_B \cdot R \cdot \alpha \cdot R_{th} \cdot \varepsilon}{\left(1 + \omega^2 \tau_{th}^2\right)^{1/2}} \qquad (9)$$

where: I_B – bias current, R – electrical resistance, α – temperature coefficient of resistance, R_{th} – thermal resistivity, ε – emissivity of the material, and τ_{th} – thermal time constant. For analysis of semiconductor bolometer parameters, the germanium bolometer is used. Since semiconductor materials have negative temperature coefficient, then the absolute value of the temperature coefficient of germanium is assumed 0.5, while emissivity of material is assumed to be unity, e.g. ε = 1. Specific heat and density of germanium are c = 0.31 J/gm°C and ρ = 5.323 gm/cm^3, respectively. The thickness of the bolometer sensitive layer is assumed to be 5 μm. The voltage responsivity R_V of the bolometer was analyzed in wavelength band from 100 μm to 3 mm. From the results obtained, it is shown that for the wavelength 200 μm, the maximum value of the voltage responsivity R_V of the bolometer is 0.106×10^{-11} V/W, while for the wavelengths 1 mm, 2 mm and 3 mm, corresponding values of voltage responsivity R_V of the bolometer are 053×10^{-11} V/W, 0.58×10^{-11} V/W and 0.637×10^{-11} V/W, respectively.

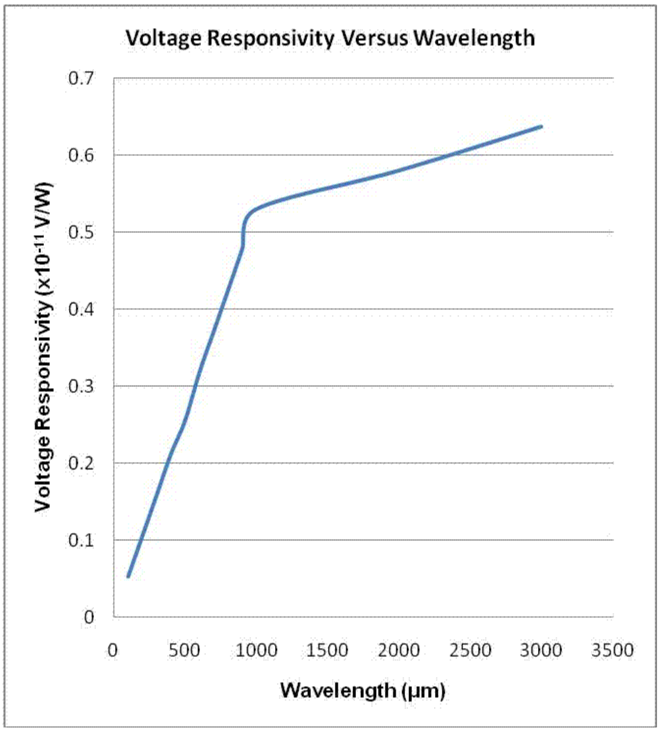

Fig. 5. Voltage Responsivity versus Wavelength for Germanium

3 Infrared Pyroelectric Detectors Parameters

Pyroelectric detectors are thermal detectors which crystal internal temperature changes when the detector is exposed to a radiation. This change in temperature affects directly the change in polarization, thus changing the parameters of this detector as well.

In practice, heat conversion into electric signal is not ideal, so the signal must be amplified. Better part of systems generates different kinds of noises, so that, when the signal is amplified, the noises will be amplified at the same time. This fact should be taken into consideration too. There are three types of noises in the pyroelectric detection system: thermal, dielectric and amplifier noises [3][11]. Thermal noises shown up due to crystal temperature changes. Dielectric materials have a resistance, therefore dielectric noises results from this resistance. We have analyzed these types of noises and introduced relevant analytical expressions.

In general, typical pyroelectric detector system consists of four basic elements [13], which are: sensor or detector, amplifier, window comparator and coupler. The schematic diagram of a typical pyroelectric detector system is shown in Fig.6.

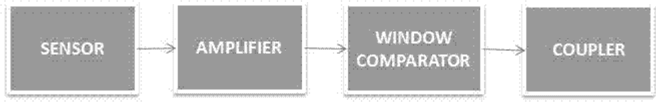

Fig. 6. Schematic diagram of a typical pyroelectric detector system

The properties of some pyroelectric materials have been shown in Table 1 [3][4][11].

Table 1.

Material	Volume specific heat c' [J/cm^3 K]	Pyroelectric coefficient p [C/cm^{2}K]	Dielectric constant ε_r
TGS	1.70	3.5×10^{-8}	35
$LiTaO_3$	3.19	1.9×10^{-8}	58
$LiNbO_3$	2.32	4.0×10^{-9}	75
$Li_2SO_4xH_2O$	0.82	1.0×10^{-8}	10
$BaTiO_3$	3.01	2.0×10^{-8}	4100
$NaNO_2$	2.016	1.2×10^{-8}	8
PVF_2	2.40	3.0×10^{-9}	11
SBN	2.34	6.0×10^{-8}	400
SbSi	2.378	2.6×10^{-7}	10^4

3.1 Thermal Time Constant

Thermal time constant of pyroelectric detector is the time for which incident radiation power on its input surface responds with electric signal at its output. Compared with other thermal detectors, pyroelectric detector response time is much smaller because the pyroelectric crystal does not have to reach the thermal equilibrium as in cases of thermocouples and thermistors [4]. Let C_{th} and G_{th} be the thermal capacity and conductance, respectively. Response time of the detector is given as the ratio of these two quantities named above [3][4][11][12]:

$$\tau = \frac{C_{th}}{G_{th}} = \frac{c'Ab}{G_R A} = \frac{c\rho b}{4\eta\sigma T^3} \tag{10}$$

where: c' – volume specific heat (J/cm^{3}K); c – specific heat of material (J/gmK); ρ – density (gm/cm^3); b – sensor thickness (μm); G_R – irradiative conductance (W/cmK); A – detector area (cm^2); η – emissivity of the crystal; σ – Stefan-Boltzmann constant (5.67×10^{-12} W/cm^{2}K^4); T – temperature (K).

Equation (10) indicates that thermal time constant is dependent of thickness and temperature of the detector. The Fig. 7 shows the temperature dependency of thermal time constant for some pyroelectric materials.

3.2 Responsivity

As discussed by [3], electrical responsivity of detector depends on two factors: thermal responsivity of detector due to incident radiation and responsivity of pyroelectric material due to temperature changes. Also thermal response depends on two factors: the radiation absorption capacity of the detector, and temperature changes due to absorbed radiation [3]. This paper provides analyzes on current responsivity R_I, and voltage responsivity R_V.

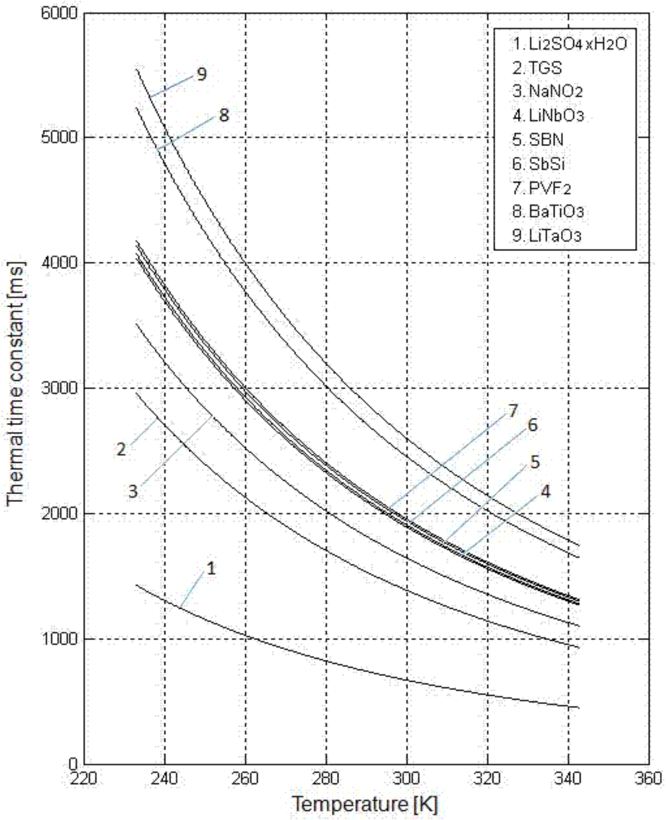

Fig. 7. Thermal time constant for some pyroelectric materials.

3.2.1 Current Responsivity R_I

Current responsivity R_I is the ratio of the output current flow ΔI to the input radiation power incident to detector surface P_i. The current responsivity can be calculated as [4][13]:

$$R_I = \frac{\Delta I}{P_i} \tag{11}$$

Pyroelectric charge ΔQ is given by:

$$\Delta Q = \Delta I = pA\Delta T = AP_S \tag{12}$$

where p – pyroelectric coefficient of material and P_S – polarization.

Let we suppose that radiation power is sinusoidal function, therefore, temperature changes of whatever detector due to irradiation flux is given by steady-state equation as [4]:

$$\Delta T = \frac{\eta P_i}{c' bA} \frac{\tau}{\left(1+\omega^2\tau^2\right)^{1/2}} \tag{13}$$

Substituting (12) and (13) into (11), the final expression for the current responsivity becomes:

$$R_I = \frac{p\eta\tau}{c' b\left(1+\omega^2\tau^2\right)^{1/2}} \tag{14}$$

3.3 Voltage Responsivity R_V

Voltage responsivity R_V is determined as a ratio of the voltage generated in the detector ΔV and radiation power incident to detector surface P_i. From this definition, we have [4][13][14]:

$$R_V = \frac{\Delta V}{P_i} \tag{15}$$

Generated detector voltage is given by:

$$\Delta V = \frac{\Delta Q}{C_d} \tag{16}$$

where $\Delta Q = pA\Delta T$ is electric charge and $C_d = \varepsilon_r\varepsilon_0 A/b$ is detector capacitance.

When substituting (12), (13) and (16) into (15), we will get the final expression for the voltage responsivity:

$$R_V = \frac{p\eta\tau}{c'\varepsilon_r\varepsilon_0 A\left(1+\omega^2\tau^2\right)^{1/2}} \tag{17}$$

In Fig. 8 it is shown the wavelength dependency of the voltage responsivity for the different pyroelectric materials.

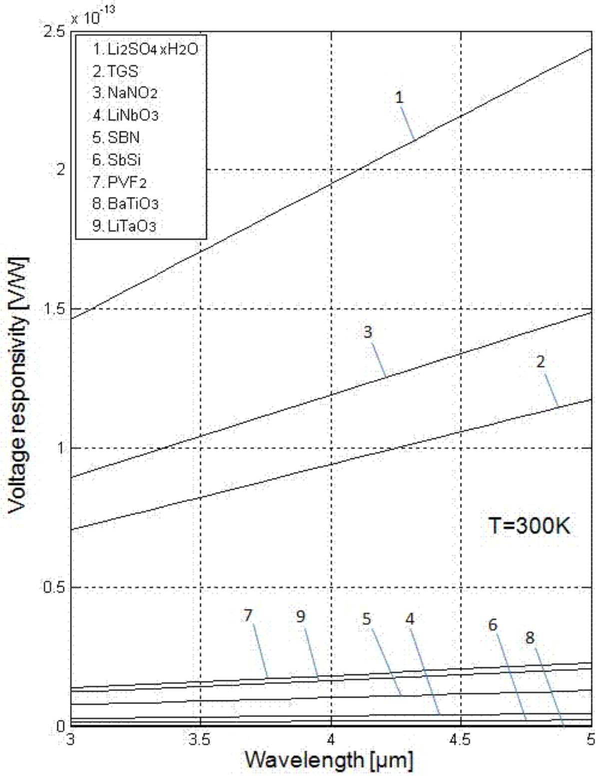

Fig. 8. Voltage responsivity for the different pyroelectric materials at room temperature 300 K.

3.4 Noise Equivalent Power (*NEP*)

Noise is characterized by the signal to noise ratio *SNR*, which is determined as the ratio between signal power and noise power. For detecting a signal, signal to noise ratio should be greater than unity. *S/N* ratio of the pyroelectric detector is given by the expression below: [4]

$$\frac{S}{N} = \frac{P_i}{\left(4kT^2AB\right)^{1/2}} \tag{18}$$

where P_i - incident radiation power, k – Boltzmann constant, B – bandwidth.

Noise equivalent power (*NEP*) is the incident detector radiation power for which signal to noise ratio is equivalent to the unity, for the specific wavelength, thus minimum detectable power. Usually, *NEP* is specified for the given value of the wavelength, modulation frequency, bandwidth of the detector frequencies, temperature, and cut-off frequency. In most of the cases, infrared sensors are described by their *NEP*, using as a reference a black body at the temperature of 500 K, for cut-off frequency of 90 Hz, and for frequency bandwidth of 1 Hz, and so, *NEP* can be written as NEP(500,90,1) [15].

Noise equivalent power for the pyroelectric detector is given as a ratio of total noise voltage V_{noise} and voltage responsivity R_V:

$$NEP = \frac{V_{Noise}}{R_V} \tag{19}$$

Now, we need to determine the total noise voltage Vnoise.

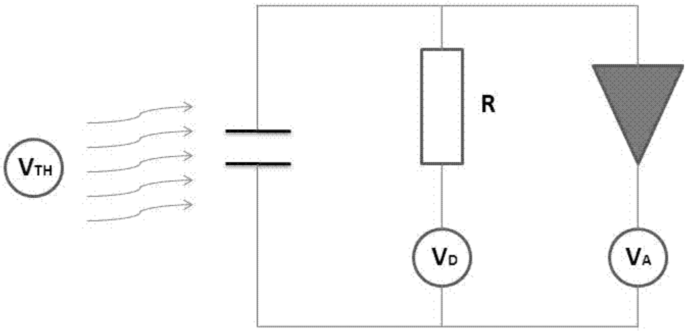

Fig. 9. Noise sources in the common detector circuit.

The major noise sources in a common detector circuit, as shown In Fig. 9, are: Thermal noise, V_{Th}; Dielectric noise, V_D, and; Amplifier noise, V_A.

Thermal noise V_{Th} is generated as a result of temperature changes in pyroelectric crystal. These thermal changes are consequence of incident radiation. This noise is very small, and the smallest of three noises mentioned above. Incident radiation power that falls into detector area is given by [11]:

$$P_i = \left(4kT^2G_{th}\right)^{1/2} \tag{20}$$

Finally, thermal noise, as a voltage, is calculated by the expression below [11][14]:

$$V_{Th} = R_V \frac{P_i}{\eta^{1/2}} \tag{21}$$

Dielectric materials also have a resistance. Due to the thermal motion of electrons, in this resistance occurs a so-called dielectric noise, or Johnson noise. From Fig. 9 we can see that dielectric noise voltage is in series with a resistance, at a bandwidth of 1 Hz. Referred to the amplifier input (Fig. 9) the corresponding voltage will be [12][16][17]:

$$V_D = \left(\frac{4kTR}{1+\omega^2\tau^2}\right)^{1/2} \tag{22}$$

Amplifier noise V_A is the noise produced by electronic amplifier used in the detection system. According to the type of amplifier that is used, we can derive the specific amplifier noise equation. Amplifier noise can be calculated as [13][18]:

$$V_A = \left(\frac{4kb \tan \delta T}{\omega \varepsilon_r A} \right)^{1/2} \quad (23)$$

where *tanδ* – loss tangent. The values for loss tangent of the material and load resistor are 0.003 and $10^{12}\Omega$, respectively. Typical values for some types of proper amplifiers that can be used in pyroelectric sensor system are shown in Table 2 [11].

Table 2.

Amplifier	Frequency (Hz)	Voltage Noise (V/Hz$^{1/2}$)	Current Noise (A/Hz$^{1/2}$)
BFW II	10^{14}, 10^{15} and 10^{16}	10^{-9}	10^{-14}
XE 5886 Triode Connected	10^{14}, 10^{15} and 10^{16}	10^{-8}	10^{-15}
XE 5886 Pentode Connected	10^{14}, 10^{15} and 10^{16}	10^{-7}	10^{-16}

Now, although we found analytical expressions for the three types of noises, we can easy calculate total noise voltage V_{noise}, which is given as the square sum of the three noise generators:

$$V_{Noise}^2 = V_{Th}^2 + V_D^2 + V_A^2 \quad (24)$$

Finally, noise equivalent power is given with the expression below:

$$NEP = \frac{\sqrt{V_{Th}^2 + V_D^2 + V_A^2}}{R_V} \quad (25)$$

In Figure 10 it is shown temperature dependency of noise equivalent power for some pyroelectric materials.

3.5 Detectivity *D**

Another pyroelectric sensor parameter of great importance is detectivity *D**. Value of sensor detectivity is denoted as *D*(T,f,1)*, where *T* is the temperature in degrees Kelvin, *f* is the frequency and 1 stands for bandwidth of 1 Hz. The unit of detectivity is cmHz$^{1/2}$W^{-1}. The maximum possible value of *D** to be achieved for a thermal sensor operates at room temperature 300K and viewing backgrounds at room temperature is 1.98×10^{10} cmHz$^{1/2}$W^{-1} [16]. At a given frequency for a constant sensor thickness, *D** is given as a ratio between the square root of sensor area *A* and noise equivalent power *NEP*, which is given in (25). Thus, *D** can be calculated by expression below [3][4]:

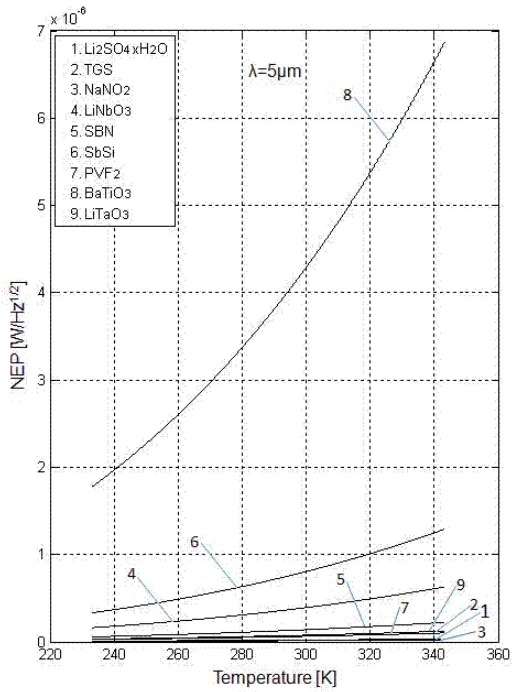

Fig. 10. Noise equivalent power (NEP) for different pyroelectric materials.

$$D^* = \frac{A^{1/2}}{NEP} \quad (26)$$

In Fig. 11 it is shown temperature dependency of detectivity *D** for different pyroelectric materials at the wavelength of 5µm. Generally, pyroelectric sensors parameters values for some pyroelectric materials in the room temperature 300 K are shown in Table 3.

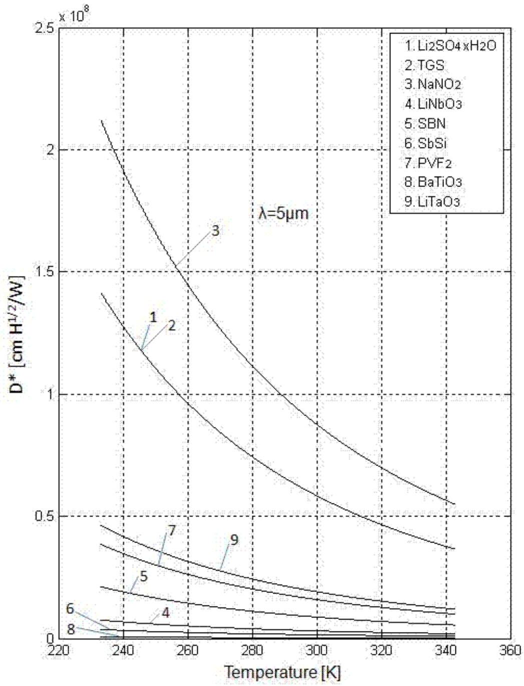

Fig. 11. Detectivity as a function of temperature for constant sensors area of 1.5 cm^2.

Table 3. Pyroelectric sensors parameters values in 300K

Material	τ [ms]	R_V [V/W]	NEP [W/Hz$^{1/2}$]	D* [cmHz$^{1/2}$/W]
TGS	1390	7.05×10^{-14}	8.658×10^{-9}	1.41×10^{8}
$LiTaO_3$	2600	1.23×10^{-14}	2.643×10^{-8}	4.63×10^{7}
$LiNbO_3$	1890	2.76×10^{-15}	1.623×10^{-7}	7.54×10^{6}
$Li_2SO_4 \times H_2O$	670	1.46×10^{-13}	8.658×10^{-9}	1.41×10^{8}
$BaTiO_3$	2460	1.94×10^{-16}	1.774×10^{-6}	6.9×10^{5}
$NaNO_2$	1650	8.92×10^{-14}	5.773×10^{-9}	2.12×10^{8}
PVF_2	1960	1.36×10^{-14}	3.175×10^{-8}	3.86×10^{7}
SBN	1910	7.69×10^{-15}	5.771×10^{-8}	2.13×10^{7}
SbSi	1940	1.31×10^{-15}	3.329×10^{-7}	3.68×10^{6}

4 Conclusion

In this paper we have analyzed bolometric detectors parameters for the cryogenic temperatures and wavelength 100µm up to 3mm. The NEP of the bolometer was analyzed for the case of cryogenic temperatures, 0.5 K to 5 K. From the results obtained (Fig. 3) we can see that for cryogenic temperatures T = 0.5 K, the maximum value of the NEP of the bolometer is 16.4×10^{-15} W/Hz$^{-1/2}$, while for T = 5 K, the value of the NEP of the bolometer is 38.466×10^{-15} W/Hz$^{-1/2}$. It is shown that maximum and minimum values of specific detectivity D^* for cryogenic temperatures from 0.5 K to 5 K are 0.0609×10^{12} cmHz$^{1/2}$W^{-1} and 0.0259×10^{12} cmHz$^{1/2}$W^{-1}, respectively (see Fig. 4). The voltage responsivity R_V of the bolometer was analyzed in wavelength band from 100 µm up to 3 mm. For the wavelength 200 µm, the maximum value of the voltage responsivity R_V of the bolometer is 0.106×10^{-11} V/W, while for the wavelengths 1 mm, 2 mm and 3 mm, corresponding values of voltage responsivity R_V of the bolometer are 0.53×10^{-11} V/W, 0.58×10^{-11} V/W and 0.637×10^{-11} V/W, respectively (Fig. 5). In this paper we have also analyzed four major pyroelectric sensors parameters for some different pyroelectric materials. Based on results obtained, as shown in Figures (7, 8, 10, 11) and Table 3, we see the impact of temperature and wavelength on the sensor parameters. Therefore, we can conclude that thermal time constant decreases by increasing temperature and decreasing the thickness of sensor. Now, briefly we will discuss the results obtained for the four parameters, for the pyroelectric sensors which operate at room temperature 300 K. The smallest response time was achieved for the material $Li_2SO_4 \times H_2O$ with the value of 670 ms and the largest response time was for $LiTaO_3$, 2600 ms. It is shown that voltage responsivity depends on wavelength, thickness and detector area. Voltage responsivity maximum and minimum values operate at room temperature 300K, are $1.46\times10\text{-}^{13}$V/W for $Li_2SO_4 \times H_2O$ and 1.94×10^{-16} V/W for $BaTiO_3$. It was shown that *NEP* depends directly on circuit noises voltages. The maximum possible value of D^* to be achieved for a MWIR infrared pyroelectric detector which operates at room temperature 300K is 2.12×10^{8} cmHz$^{1/2}$W^{-1} for $NaNO_2$.

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