Silicon photodiode as the two-color detector

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Abstract. This paper describes a silicon photodiode as the two-color photodetector. The work of one photodiode in two spectral ranges is achieved due to the changes of the spectral sensitivity of the photodiodes in the transition from photodiode mode for photovoltaic in the short circuit mode. On the basis of silicon photodiode FD-256 the layout of the spectral ratio pyrometer was assembled and the results of theoretical calculations was confirmed experimentally. The calculated dependences of the coefficient of error of the spectral ratio pyrometer from temperature reverse voltage 10 and 100 V was presented. The calculated dependence of the instrumental error and the assessment of methodological errors of the proposed photodetector spectral ratio was done. According to the results of the presented research was set the task of development photodiode detectors which change the spectral sensitivity depending on the applied voltage.

1. Introduction

Currently, the spectral relations pyrometry is used "tandem" and mosaic receivers radiation with a broad band of spectral sensitivity. "Tandem" photodiodes have a two-layer structure, wherein the allocated plots of spectral sensitivity are negligible spectral overlap of the intervals, which determines the methodical error of measurement associated, primarily, with the changes of spectral and integral emissivity $\varepsilon(T,\lambda)$ of the measurement object. When mosaic detectors using spectral selection is performed at the expense of the photosensitive elements with different spectral sensitivities, secured or optical filters or the use of radiation detectors with different spectral sensitivities. The photodetectors are arranged in one plane. Reduction of truncation error in the latter case is possible due to the convergence and spectral overlapping working ranges [1].

In this paper we propose to implement a radiation sensitive element for spectral pyrometer relationship on one photodiode without the use of emit spectral plots of optical filters [2].

The work of one photodiode in two spectral ranges is achieved due to the changes of the spectral sensitivity of the photodiodes in the transition from photodiode mode with applied reverse voltage to the photovoltaic in the short circuit mode. According to the physics of the operation of p-n junction photodiode [3] with the increase of the reverse voltage applied to the p-n transition in photodiode mode, grow the width of the space charge region, the height of the potential barrier and increases the width of the p-n junction. This leads to an increase of the coefficient of collecting minority charge carriers and, consequently, to increase the maximum spectral sensitivity and its shift in the long wavelength region. The change in the characteristic of the spectral sensitivity of the silicon photodiode on the applied voltage, according to [3], is presented in Fig. 1.

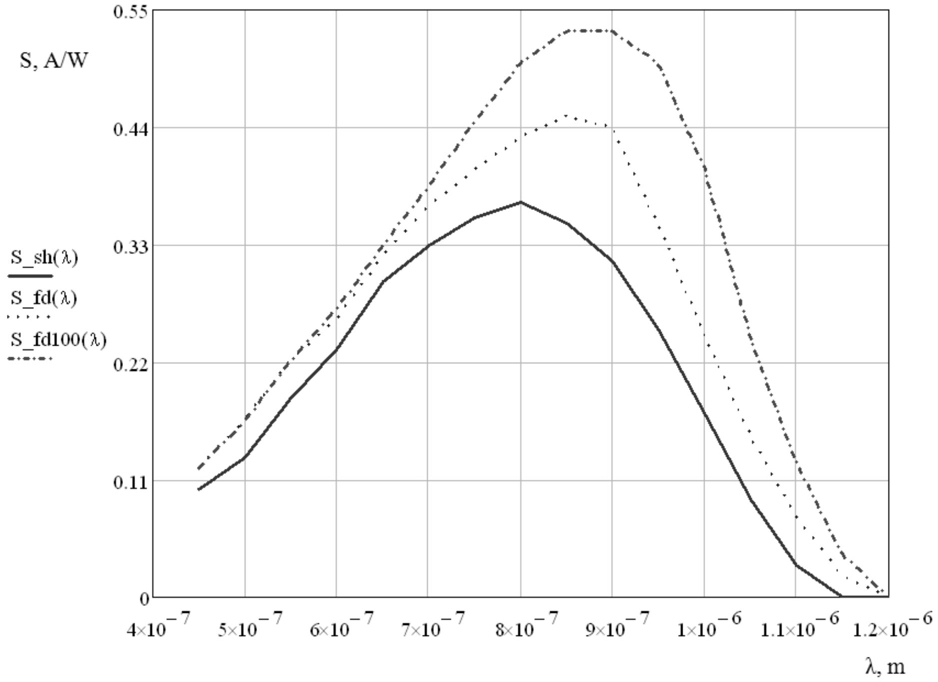

Figure 1. Changes of the spectral sensitivity of the silicon photodiode FD-256: S_sh - when the voltage on the photodiode Upn=0; S_fd - when Upn= 10 V, S_fd100 - when Upn= 100 V.

Therefore, it is proposed in the pyrometric device during one measurement consistently use the inclusion of a photodiode with a maximum reverse voltage and the voltage is zero (short circuit). Thus the output signal of the pyrometer to form as the ratio of the output signals obtained at different modes of inclusion.

2. Calculation justification

Theoretical calculations of the flow characteristics of the pyrometer for each of the modes of the photodiode based on the Planck equation and experimental functions changes the spectral sensitivity of the photodetector shown in Fig.1.

For two spectral intervals λ1 - λ2 and λ3 - λ4 functions of the spectral sensitivities of the photodetectors output signal of the pyrometer in accordance with the Planck function is represented as

$$K = \frac{I_{f1}(T)}{I_{f2}(T)} = \frac{\int_{\lambda 1}^{\lambda 2} S_1(\lambda) r(\lambda, T) d\lambda}{\int_{\lambda 3}^{\lambda 4} S_2(\lambda) r(\lambda, T) d\lambda}, \quad (1)$$

where $r(\lambda,T)$ is the Planck function; $I_{f1}(T)$ and $I_{f2}(T)$ is the photocurrent for different inclusions photodiode; $S_1(\lambda)$ and $S_2(\lambda)$ is a function of the spectral sensitivity of the photodetector.

The share of total energy luminosity converted by a photodetector into an electrical signal photocurrent in the photodiode modes and short-circuited, can be calculated using the product of

$$I_{fi}(T) = A \cdot \int_{0.45 \cdot 10^{-6}}^{1.2 \cdot 10^{-6}} S_i(\lambda) \cdot r(\lambda, T) d\lambda, \quad (2)$$

where A is the aperture coefficient taking into account the ratio of the geometric parameters between the receiver and the emitter.

In accordance with the expression (2) were obtained by calculation of the dependence of the photocurrent on the temperature of the radiating blackbody cavity for silicon photodiode FD-256. The calculated dependence of the ratio of the output signals obtained as

$$K(T) = \frac{I_{sh}(T)}{I_{fd}(T)} \quad (3)$$

is shown in Fig. 2, where *Ish(T)* is the photocurrent in the short circuit mode; *Ifd(T)* is the photocurrent in the photodiode mode.

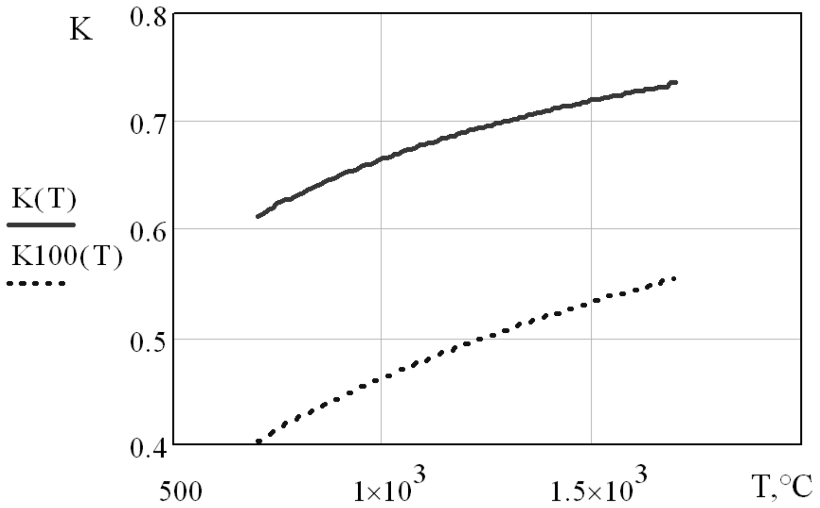

Figure 2. The calculated function according to the relationship of the output signals of the pyrometer from the temperature of the blackbody cavity: K(T) - Upn= 10 V, K100(T) - Upn= 100 V.

3. The results of experimental studies

On the basis of the photodiode FD-256 the layout of the pyrometer was assembled and produced experimental studies of the dependency of K functions on T. In Fig. 3 shows the experimental dependence of the normalized output signal of the pyrometer on the basis of silicon photodiode FD-256 from the cavity temperature emitter type blackbody model. When the experiment was used model of a black body MTP-2M-50-500 manufactured by the "Etalon" (Omsk). The output signal of the pyrometer was measured in accordance with the expression (3). Thus the experimental value of the reverse voltage in the photodiode mode Upn was 10 V.

4. Estimation of errors

According to [1] the accuracy of the pyrometer spectral ratio increases with the decrease of the slope of the conversion. The steepness of the conversion is determined by private derivative with respect to T relationship pyrometric signal $K(T) = I_{f1}(T)/I_{f2}(T)$. The increase in error can be evaluated using the coefficient kp. When measuring the temperature of grey bodies, this coefficient is calculated as:

$$kp(T) = \frac{K(T)}{T \cdot \left(\frac{d}{dT} K(T) \right)} \quad (4)$$

The coefficient kp shows how many times the measurement error in the spectral ratio pyrometer. In Fig. 4 shows the calculated dependences of the coefficient kp of the temperature of the blackbody for spectral pyrometer relations on the basis of a silicon photodiode FD-256, calculated in accordance with expression 4.

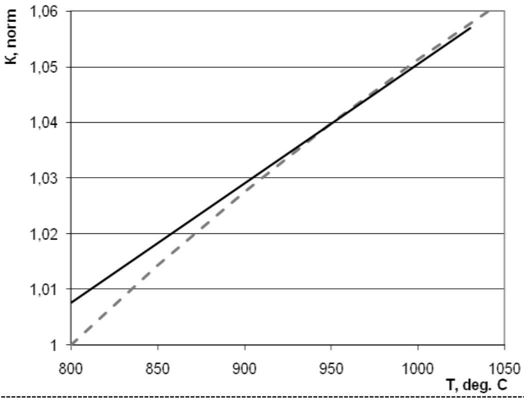

Figure 3. Dependence of the output signal of the pyrometer on the basis of silicon photodiode FD-256 temperature: calculate (- - -), experiment (—).

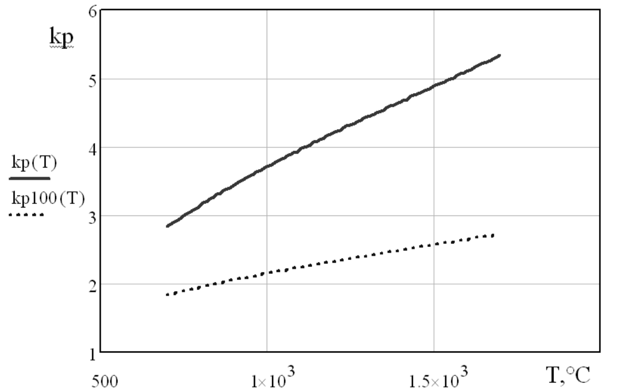

Figure 4. The calculated function of the dependency of the coefficient kp of the temperature of the blackbody cavity: kp(T) - Upn= 10 V, kp100(T) - Upn= 100 V.

Relative instrumental error δTi determining the temperature of the pyrometer spectral ratio in accordance with [1] can be found by the expression:

$$\delta Ti = kp \cdot \sqrt{(\delta Tr)^2 + \left[\frac{\Delta I_{1\text{H}}}{\text{I}_1}\right]^2 + \left[\frac{\Delta I_{2\text{H}}}{\text{I}_2}\right]^2} \tag{5}$$

where δTr is the relative error caused by radiation noise of the received radiation, the intrinsic noise of the photodetector and the dependence of the dark current of the photodetector temperature. The calculation of this error for a silicon photodiode FD-256 gives a small amount $\delta Tr = 3\cdot10^{-5}$. The instability of amplification channels $\Delta I_H/I$ is determined by the circuit parameters of gain, bit ADC conversion and the error function linearization. For modern solutions in the industry $\Delta I_H/I = 10^{-4}$. While the relative instrumental error, respectively δTi = kp·0,000141. The calculated dependence of the instrumental error on the temperature is shown in Fig. 5.

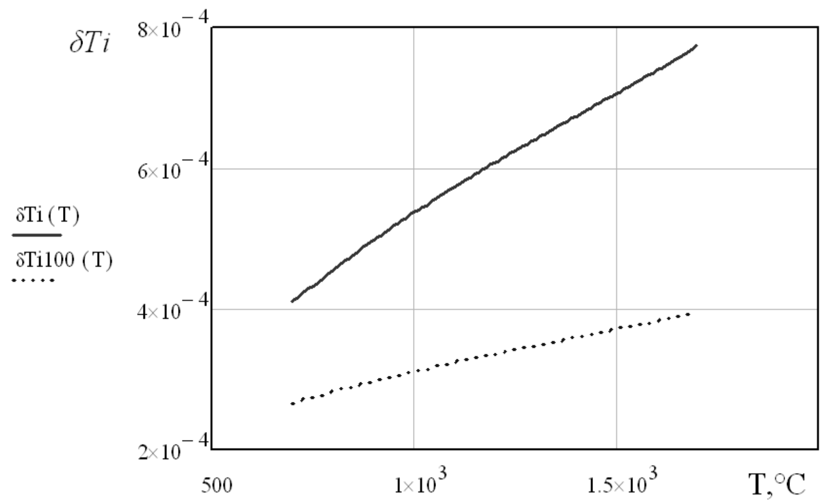

Figure 5. The calculated feature dependencies relative instrumental error δTi from the temperature of the blackbody cavity: δTi (T) - Upn= 10 V, δTi100(T) - Upn= 100 V.

For bodies with emissivity ε(λ) depend on the wavelength of the relative truncation error δTε according to [1] can be described by the expression:

$$\delta T\varepsilon = \left| kp \cdot \left(\frac{\varepsilon_1^{эф}}{\varepsilon_2^{эф}} - 1 \right) \right|$$

where $\varepsilon_1^{ef}(\lambda)$, $\varepsilon_2^{ef}(\lambda)$ is the effective emissivity [4], defined by the expression:

$$\varepsilon_i^{эф} = \frac{\int_{\lambda 1}^{\lambda 2} \varepsilon(\lambda) S_i(\lambda) r(\lambda, T) d\lambda}{\int_{\lambda 3}^{\lambda 4} S_i(\lambda) r(\lambda, T) d\lambda}$$

Figure 6 according to [5] shows an example of the spectral dependence of the emissivity ε(λ) for iron. The calculated dependence of the relative methodical error δTε(T) for iron are shown in figure 7. For both cases Upn= 10 In and Upn= 100 In it matches.

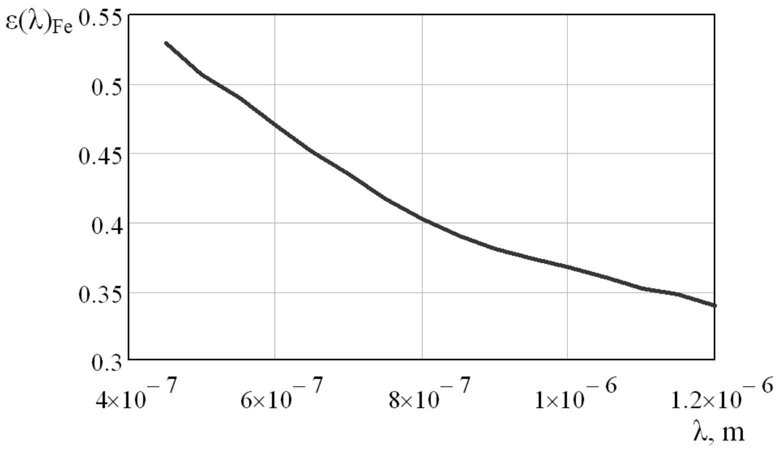

Figure 6. The spectral dependence of the emissivity ε(λ) iron.

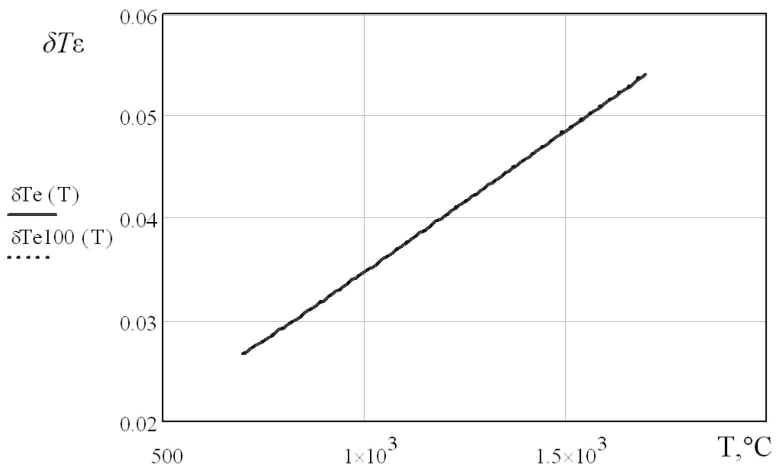

Figure 7. The calculated function according to the relative systematic error δTi from the temperature of the iron.

5. Conclusions

It should be noted that thanks to the work of silicon photodiode in a wide spectral sensitivity plots for different modes of inclusion decreases the relative systematic error of measurement. This instrument accuracy comparable with thermometers that use narrowband optical filters or detectors with different spectral sensitivity ranges "tandem" and mosaic types.

The results are a prerequisite for developers not only a new type of thermometers, but also outlines the challenges for developers of photodiodes to create specialized photodetectors providing maximum difference of the spectral sensitivity functions with changes applied to p-n - transition voltages, for tasks spectral pyrometry relations. Such detectors will allow in accordance with expressions (4) and (5) to reduce the sampling error when a small reverse voltage in the photodiode mode.

References

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