

Temperature Measurement with Photodiode in Different Operating Modes

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Abstract - A method for contactless temperature measurement with photodetectors in different operating modes has been developed. It is based on the periodic change of the spectral sensitivity of the photodiode depending on the applied reverse voltage. This is accomplished by switching the photodiode within one measurement from photovoltaic to photoconductive mode. For this purpose, the scheme of the respective electronic key has been developed.

Keywords - contactless measuring of temperature, IR diapason, photovoltaic and photoconductive mode, spectral ratio pyrometer.

I. INTRODUCTION

Temperature is one of the main parameters of most modern production technologies. For this reason, its measurement and control is essential for the correct implementation of the respective technological process. This can be done both by traditional contact methods and by applying non-contact optical methods. The two main ways in which the method of optical pyrometry can be realized: energy and spectral ratio, are described in [4], [7], [10], [12], [14], [16]. For its part, the pyrometers of the spectral ratio can be realized in three variants: with two photodetectors, light-dividing device and narrow-band optical filters; with one tandem photodetector and with a matrix photodetector. It has been shown that in the pyrometers of the spectral ratio the uncertainty can be reduced when measuring the temperature, which arises as a result of:

- a) Different distance to the objects and their different shape;
- b) Different temperature of the environment;
- c) Presence of side background objects in the field of view of the device;

d) Presence of nearby high temperature sources and reflection of their radiation to the device;

e) Obscurity of the radiation coefficient of the objects and its dependence on the temperature and wavelength, i.e. $\varepsilon = f(\lambda, T)$.

All the mentioned pyrometers of the spectral ratio have a significant drawback. They correctly measure the temperature of only gray objects for which $\varepsilon = const$. If the objects are non-gray (selectively radiating), then for them the radiation coefficient will depend on the wavelength, i.e. $\varepsilon = f(\lambda)$. In this case, the ratio between the refractive indices in two narrow spectral ranges $\varepsilon_{\lambda_1} / \varepsilon_{\lambda_2}$ may change and lead to a measurement error. This error will be the greater the steeper the function $\varepsilon = f(\lambda)$ [1],[6]. For some metals it can reach up to 10%.

These disadvantages can be reduced with pyrometer with a single photodiode operating in series in different operating modes.

II. EXPOSITION

The goal of this publication is to develop a spectral ratio pyrometer using only one photodiode operating in two different modes to increase the accuracy and sensitivity of non-contact temperature measurement.

The set goal can be achieved by solving the following tasks:

- Development of a block functional scheme of the pyrometer;
- Development of a schematic electrical circuit diagram of the pyrometer;
- Development of the control program.

Online ISSN 2256-070X

<https://doi.org/10.17770/etr2021vol3.6556>

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A. Essence of the method

It is known that the photodiode can operate in two modes: photovoltaic and photoconductive. There is no external power supply in photovoltaic mode and the photodiode generates photo-EMF. The maximum voltage sensitivity in this mode is

$$S_{U_{\max}} = R_0 \left[\frac{S_i I_s}{S_i \Phi_{\max} + I_s} \right] \quad (1)$$

where: S_i - sensitivity by current; Φ_{\max} - falling optical flux; I_s - sum of the reverse drift currents of the non-core carriers; R_0 - resistance of $p-n$ junction.

Here

$$R_0 = \frac{kT}{eI_s}$$

where: e - electron charge; k - Boltzmann's constant; T - temperature of $p-n$ junction.

At room temperature $\frac{kT}{e} = 0.025V$ and expression (1) is as follows:

$$S_{U_{\max}} = 0.025 \left[\frac{S_i}{S_i \Phi_{\max} + I_s} \right]$$

In the photoconductive mode, a reverse voltage supply is connected in series with the photodiode. In this case, a reverse current flows through the photodiode, which is proportional to the optical flux falling on it. The voltage sensitivity in photoconductive mode is defined as

$$S_U = \frac{dU_n}{d\Phi} = S_i R_n$$

where: U_n - voltage drop across the electrical load; Φ - falling optical flux; R_n - load resistance.

Therefore, the voltage sensitivity can be increased if the load resistance increases. In order for the photodiode to operate in linear mode, the maximum load resistance $R_{n_{\max}}$ must be related to the falling optical flux by the expression

$$R_{n_{\max}} = \frac{U_p}{I_{\Phi} + I_s} = \frac{U_p}{S_i \Phi + I_s}$$

where: U_p is the supply voltage; I_{Φ} is the photocurrent of non-core carriers (current in the dark).

Then the maximum voltage sensitivity in photoconductive mode is

$$S_{U_{\max}} = \frac{S_i U_p}{S_i \Phi + I_s} \quad (2)$$

From expressions (1) and (2) the ratio between the sensitivities of the photodiode in photoconductive mode $S_{U_{\max FC}}$ and in photovoltaic mode $S_{U_{\max FV}}$ can be determined

$$\frac{S_{U_{\max FC}}}{S_{U_{\max FV}}} = \frac{U_p}{kT/e}$$

It is clear that the maximum sensitivity in photoconductive mode is higher than in photovoltaic mode.

Graphs of the spectral sensitivity of the Hamamatsu S2386 photodiode $S_{FC}(\lambda)$ in photoconductive mode and $S_{FV}(\lambda)$ in photovoltaic mode are shown in Fig.1.

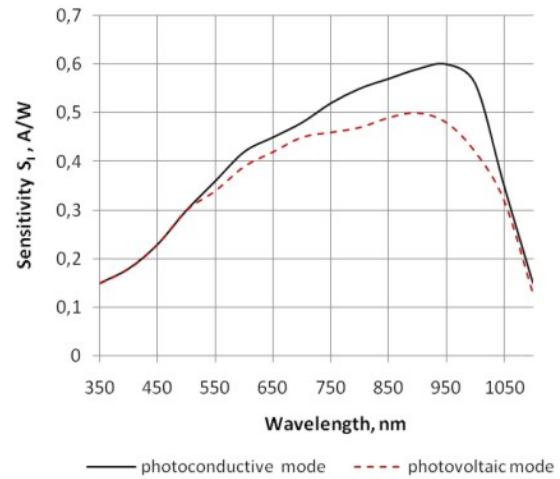


Fig. 1. Spectral sensitivity of the Hamamatsu S2386 photodiode in photoconductive and photovoltaic mode

The spectral sensitivity of the photodiode depends mainly on the properties of the semiconductor material from which it is made [8], [17]. As the reverse voltage increases (switching from photovoltaic to photoconductive mode) the volume charge, the potential barrier height and the $p-n$ junction width increase. All this leads to an increase in the collection coefficient of non-core charge carriers. As a consequence, there is an increase in the maximum of the spectral sensitivity of the photodiode and its displacement in the long-wavelength region [9], [16]. These properties of the photodiode can be used in a pyrometer in order to simplify its design and increase the accuracy and sensitivity of pyrometric measurements [11], [13].

The proposed method consists in the use of one photodiode and in the sequential switching within one measurement of its modes from photovoltaic to photoconductive, whereby its sensitivity and, consequently, the photocurrent flowing through it will be successively changed. In goal to minimize the

methodological error, the operating spectral range will be relatively wide.

The electric current at the output of the photodiode is determined by the expression

$$I(T) = A \int_{\Delta\lambda} M(\lambda, T) S(\lambda) d\lambda \quad (3)$$

where: $M(\lambda, T)$ - the spectral exitance of the studied object; $S(\lambda)$ - the spectral sensitivity of the photodiode; $\Delta\lambda$ the operating spectral range of the pyrometer; A - coefficient depending on the parameters of the lens, the photodiode and the distance between them.

According to the proposed method, the output signal of the pyrometer K_I will be the ratio of the individual signals received in the two modes of operation of the photodiode

$$K_I(T) = \frac{I_{FC}}{I_{FV}} \quad (4)$$

where: I_{FC} - photocurrent in photoconductive mode;

I_{FV} - photocurrent in photovoltaic mode.

The pyrometer is graduated according to a reference blackbody radiation source (bb). In this case, according to (3) and (4) it can be written

$$K_I(T) = \frac{\int_{\Delta\lambda_{FC}} M_{bb}(\lambda, T) S_{FD}(\lambda) d\lambda}{\int_{\Delta\lambda_{FV}} M_{bb}(\lambda, T) S_{FV}(\lambda) d\lambda} \quad (5)$$

where: $M_{bb}(\lambda, T)$ - spectral exitance of the reference.

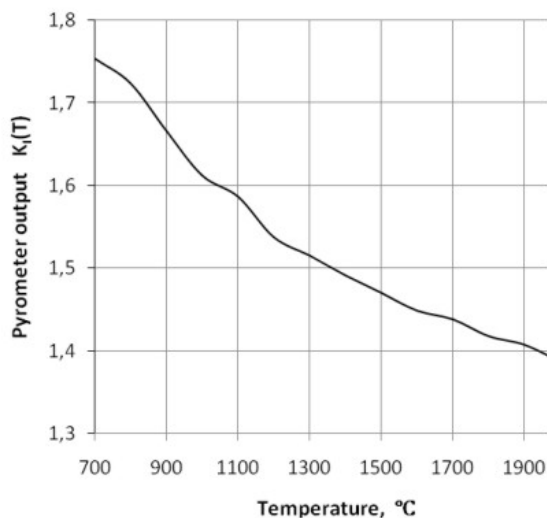


Fig. 2. The dependence $K_I(T)$

According to expression (5) the dependence $K_I(T)$ is drawn, which is shown in Fig. 2.

The total error in the pyrometer of the spectral ratio is determined by the instrumental error, the error of calibration of the pyrometer on a black body, the presence of parasitic reflections and the methodological error caused by the uncertainty of the emission coefficient. The methodological error has the greatest influence. It is shown in [2], [3], [5], [15] that when using wide spectral ranges and near the maxima of the spectral sensitivity of the two photodetectors, the methodological error decreases to 3.5%. The instrumental error is comparable to that of spectral ratio pyrometers using two photodetectors and narrow spectral ranges, as well as tandem and matrix photodetectors.

B. Block functional diagram of the pyrometer

The block functional scheme of the pyrometer is shown in Fig. 3. The lens forms an image of the object under study on the photodiode (Hamamatsu S2386). A light filter is situated between the lens and the photodiode that absorbs the radiation in the visible range of the spectrum. The function of the light filter is to eliminate the influence of visible light on the measurement. FEL070 was selected as a filter from the Thorlabs catalog. This is a long-wave cut-off filter that transmits radiation with a wavelength of $\lambda > 750$ nm. The scheme works in two cycles. In the first cycle, the electronic switch S, according to the instructions from the microcontroller, switches the anode of the photodiode to ground. In this case, the photodiode operates in photovoltaic mode. The output current from the photodiode is converted into voltage by an operational measuring amplifier OA. The voltage from the output of the amplifier is converted into digital form by a 10-bit ADC of the microcontroller and stored.

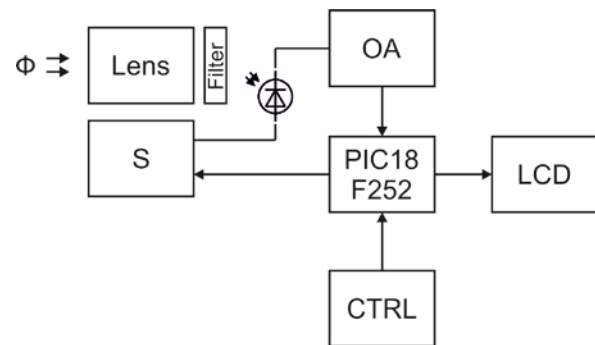


Fig. 3. Block chart of an optoelectronic device for measuring the power of laser radiation

In the second cycle, the electronic switch under the instruction of the microcontroller supplies a negative voltage of $-14V$ to the anode of the photodiode. Then the photodiode operates in photoconductive mode. The output current from the photodiode is similarly converted to voltage, then digitally and stored. After the end of the second cycle, the microcontroller calculates the ratio of the output signals of the photodiode in the two operating

microcontroller's RD0, RD1, RD2, RD3, RD4, RD5, RD6, RD7 ports which are initialized as outputs. At the beginning of the program, initialization of the display takes place, which selects the following:

- a) 8-bit interface;
- b) two-line mode;
- c) character format 5x8 dots;
- d) incrementing the address counter by one unit when in read/record mode.

III. CONCLUSION

A two-spectrum pyrometer using only one photodiode has been developed. The device can be used to measure temperature in a wide range from 700°C to 2000°C. The spectral ratio is obtained by switching the photodiode from photovoltaic mode to photoconductive mode. The device operates in two wide spectral ranges and the corresponding two maxima of the spectral sensitivity of the photodetector are close. The use of the proposed scheme leads to an increase in the accuracy and sensitivity of the measurements.

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