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MEASUREMENT SYSTEM FOR IR ABSORPTION

Key words

Infrared radiation, infrared detector, measurement uncertainty.

Abstract

Radiation absorption measurement systems are widely used in the evaluation of different types of materials. They require a stable transceiver radiation measuring circuit. The article presents a transceiver infrared radiation system developed by the author, in which, apart from a stabilized power supply of transmitting and receiving subsystems, the dedicated software for temperature correction of output signals was also used. The system has two measuring circuits at wavelengths of 860 nm and 950 nm. The paper presents characteristics and measurement uncertainties of the system, determined by means of the reference material. This type of a system can be used in systems for IR transmission or reflection tests, and it can be of help in radiation absorbance studies.

Introduction

Infrared radiation (IR) is nowadays widely used in many areas, e.g. physico-chemical investigations, optics and materials engineering [1], as well as industrial applications [2]. In the studies, the infrared radiation is usually used in the form of a beam, which is transmitted through or reflected from a surface of the test object. Measurement systems using IR beam for the transmission through the test objects, employ the phenomenon of the spectral absorption in the infrared radiation of the test object [3], while the measuring systems using a reflected beam of IR, use the phenomenon of the emissivity of the test object [4].

The measurement using the phenomenon of the absorption is becoming more widely used, inter alia, in non-contact and non-destructive materials investigations, such as thin silicone materials research for medical applications [5], or the study on thickness and opacity of plastic specimens [6].

In the infrared absorption measurements transceiver circuits of radiation can be used, wherein, light emitting diodes (LED) are used as radiation sources. When the *p-n* semiconductor junction of the LED is polarised for the conduction, it emits radiation, when the electron loses energy, producing only the photon during the radiative recombination [7, 8]. An important feature of the diodes of this type is their linear characteristic in a wide range of the optical power to the current, which increases the use of the LED, e.g. for the systems of transmission of analogue information. Other advantages of LEDs include their long lifetime, durability, energy efficiency, wide range of colours, easy-dimming, design flexibility, environmental compatibility, and low-voltage power supply [9].

Power and control systems of diodes can be broadly divided into two systems for producing a continuous and a modulated beams of light [10, 11]. The system of modulated beam of light can be achieved by placing a pulse-width-modulated (PWM) function generator in the power supply circuit of the LED. Use of a PWM generator in the power supply circuit of diode, enables the *p-n* junction temperature stability and control of the optical power, radiated by the LED during the radiative recombination [12].

The semiconductor components are also used as photoconductive elements (photodetectors), in which photons cause the electron move from the valence band to the conduction band, due to the low energy of the gap between the bands. This phenomenon causes excitation and increases the conductivity of the semiconductor. Examples of such photoconductive elements can include photoresistors, photodiodes, phototransistors, or photothyristors. The phototransistors as photodetectors allow one to obtain an increased current signal by interaction of photons [13]. The increase in the intensity of light on the light-sensitive surface of a phototransistor causes an almost linear increase in its output current, at the constant voltage polarity of the *p-n* junction.

The article presents a system for the measurement of IR absorption, which uses two basic circuits, i.e. a radiation source and a photodetector circuit. As radiation sources IR LEDs are used, and in the photodetector circuit as photodetectors phototransistors are used. The developed system has two measuring channels in the infrared radiation with a radiation wavelength of 860 nm and 950 nm.

1. The power and control system

The developed measurement system for the IR absorption is composed of circuits of IR sources and photodetectors (Fig. 1). The system has two measurements channels, which enable research in the IR wavelengths between 860 nm and 950 nm.

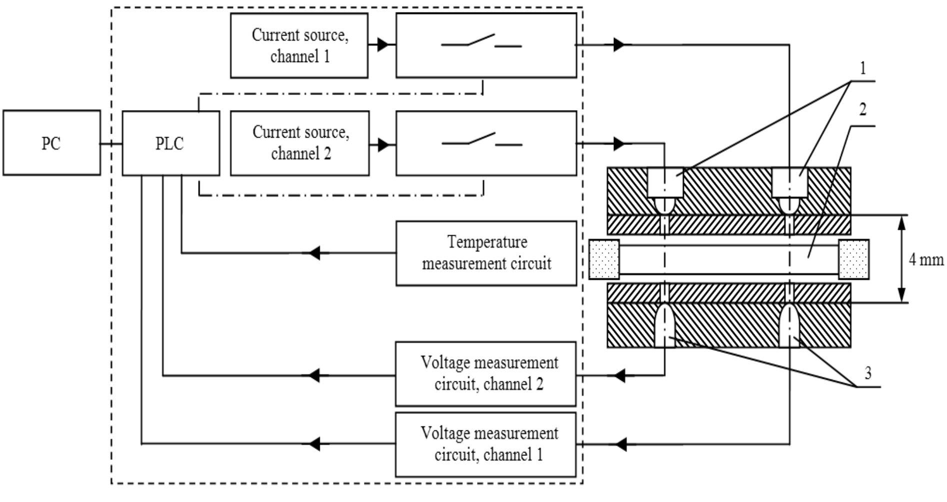

Fig. 1. Scheme of the two channel test stand for IR measurements. 1 – IR sources, 2 – test object, 3 – photodetectors

In each of the measurement channels, in the IR source circuit, the following elements can be found: a current source, an IR LED, a subsystem of transistor and a subsystem of PWM generator. The output signals of the PWM generators are programmable on the platform level of the PLC. The purpose of this circuit is to obtain the modulated IR signals at the optical outputs. The IR LEDs with the emission surfaces from materials such as *GaAlAs* (VSLY3850) and *GaAs* (CQY37N) are used as the IR sources [14]. The IR source circuit developed enables to maintain the desired constant level of radiation intensity source at the nominal level of operating parameters specified by the manufacturer.

The photodetector circuit, on the other hand, is composed of the following subsystems and components: stabilised power sources, voltage sources, phototransistors and voltage measurement subsystems. The task of this circuit is to measure the intensity of infrared radiation, by the current measurement in the phototransistor circuit, with its maximum sensitivity at 900 nm (Fig. 2). The current measurement in the circuit is perform using the indirect method, by voltage measurement across a resistor with a constant and known value of resistance.

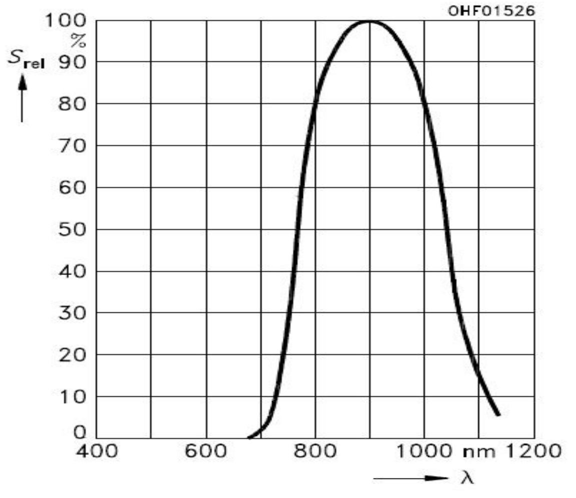

Fig. 2. Relative spectral sensitivity (S_{rel}) of a phototransistor type SFH309FA [15]

A measurement signal received from the phototransistor circuit is forwarded to a twelve-bit A/D converter of the PLC, where the signal is processed and analysed. Then measurement data via the Ethernet interface are transmitted and stored in a database of the PC.

2. Measurement method

The measurement method developed for IR absorption enables investigations for two parallel measurement channels in the infrared radiation wavelength between 860 nm and 950 nm. During the test, the IR LED sources are supplied by a PWM modulated current with defined parameters of the frequency and the duty cycle by the manufacturer recommended. The generated optical output signals from the IR LEDs have the optical power higher than 5 mW, and the signals are transmitted through a test object onto the photodetectors, which have the maximum sensitivity at the wavelength of 900 nm. Then, in the photodetector circuits, the current values are measured using the indirect method of voltage measurement. The developed measurement method gives a possibility of implementation to the measuring system of programmed temperature compensation. The temperature is measured concurrently to the current, in the work environment of the elements of the measurement system. The programmed temperature compensation of the current value is accomplished in the PLC, according to the developed algorithm presented in Figure 3.

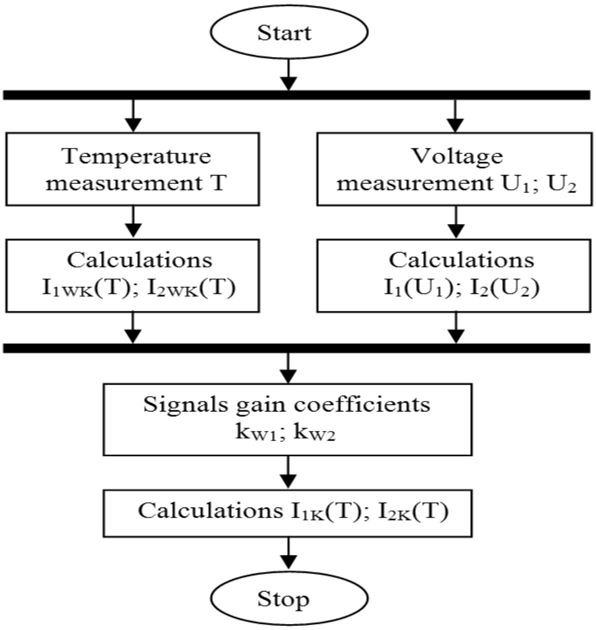

Fig. 3. Algorithm of determining the current value in the two channel circuits of the IR photodetector

The algorithm describes the concurrent measurement and processing of the temperature (T) and the voltages (U_1) and (U_2), which are measured in the two circuits of phototransistors. The resistance values in each photodetector circuit are known, while the values of voltages (U_1) and (U_2) are read, and using the Ohm's law the values of currents (I_1) and (I_2) are calculated. Then, knowing the time characteristics of the currents (I_1) and (I_2), and temperature (T), characteristics of the currents as functions of the temperature are determined (Fig. 4). After approximation of the measurement data of the I_1 and I_2 currents, their functions of average values were determined as functions $\bar{I}_1(T)$ and $\bar{I}_2(T)$, and for them the temperature compensation functions $I_{1WK}(T)$ and $I_{2WK}(T)$ were calculated. Variables I_1 and I_2, and functions $I_{1WK}(T)$ and $I_{2WK}(T)$ implemented to matrix arrays to receive the equation (1) of functions $I_{1K}(T)$ and $I_{2K}(T)$.

$$\begin{bmatrix} I_1 & I_{1WK}(T) & 0 & 0 \\ 0 & 0 & I_2 & I_{2WK}(T) \end{bmatrix} \cdot \begin{bmatrix} k_{W1} \\ k_{W1} \\ k_{W2} \\ k_{W2} \end{bmatrix} = \begin{bmatrix} I_{1K}(T) \\ I_{2K}(T) \end{bmatrix} \quad (1)$$

In the developed method, the equation (1) was defined by the following parameters of: boundary conditions (T ≥ 0ºC), and amplification coefficients of output signals k_{W1} and k_{W2}. The use of the amplification coefficients allows one to shape the output signals of the measurement system using the software of the PLC.

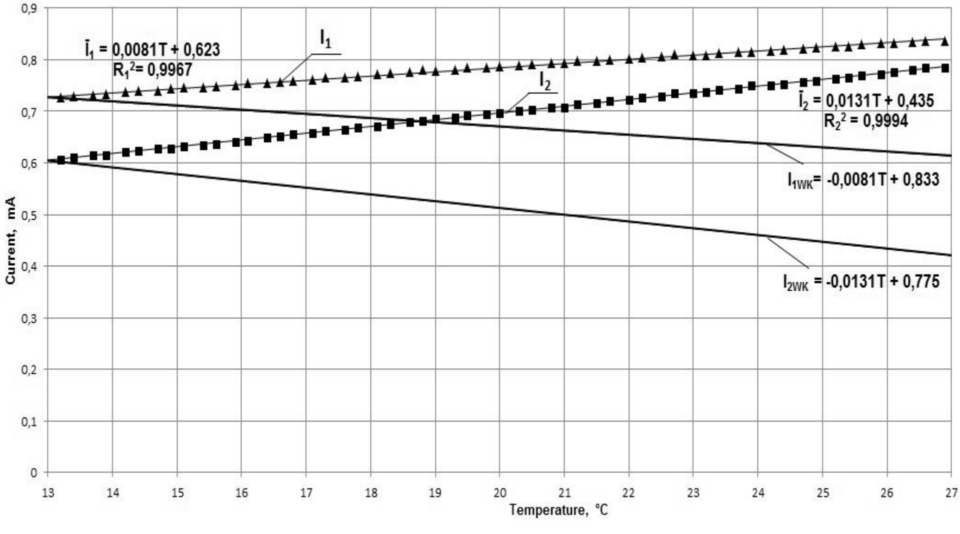

Fig. 4. Characteristics of measurement signals of currents as functions of temperature and their temperature compensation functions. I_1, I_2 – current values measured on the channels 1 and 2; I_{1WK}, I_{2WK} – temperature compensation functions of currents for channels 1 and 2

3. Verification of the system

The developed system for the measurement of the IR absorption was installed in the mechanical housing (Fig. 5), to protect the IR transceiver circuit from ambient light radiation.

The system was subjected to long-term investigations under various thermal conditions. As a test object, a certified test material (Densitometric Screen S/N012, Eclipse Laboratories Inc.) was used.

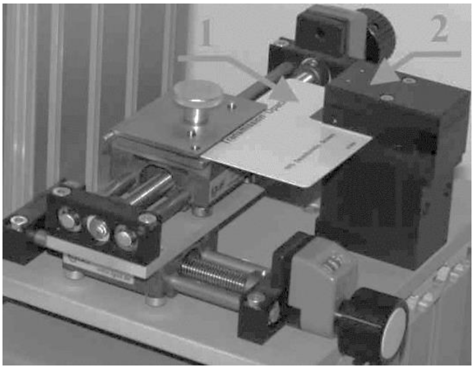

Fig. 5. View of test object (1) and the IR measuring head of the system (2)

Investigation results were obtained in the PC using an original programme, developed in the LabVIEW environment. The received data are presented as a function of time in Figure 6.

The expanded uncertainties of the results of current measurements with the programmed temperature compensation in both measurement channels 1 and 2 were determined for a 99% level of confidence and the coefficient of expansion k_p = 2.576, using calculation methods type A and B [16]. The received expanded uncertainties for the two measurement channels I_{1K}, and I_{2K} have the same value of 0.036 mA [17].

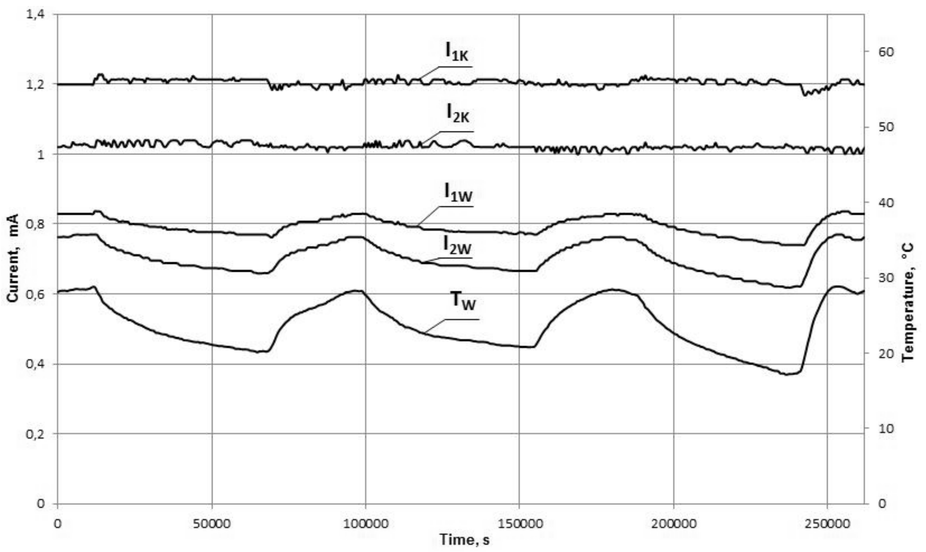

Fig. 6. Examples of characteristics of programmed temperature compensation of measured currents and temperature as functions of time. I_{1W}, I_{2W} – measuring current on the channels 1 and 2; I_{1K}, I_{2K} – current measurements with programmed temperature compensation on the channels 1 and 2; T_W – temperature measurement

Summary

The system for the measurement of IR absorption was developed. The system retains the thermal stability of optical signals. The measurement method of test objects in the infrared radiation in two wavelengths 860 nm and 950 nm was described. A verification of the developed system was conducted, using the certified test material and by subjecting the system to long-term investigations under different temperature conditions. As a result of the performed investigations received the positive evaluation of verification for the measuring channels of the system. For the developed system estimated the expanded uncertainty at a 99% confidence level.

The developed measuring system can operate independently or can be used as a submodule of other systems, such as e.g. network control system (NCS) [18], or systems using mathematical modelling of processes and advanced procedures of control [19].

Other examples of application of the measuring system can include systems for investigation of transmission or reflection of infrared light such as a non-destructive infrared inspection of foils [20], the study on specimens of biological and chemical installations [21, 22], or the identification and detection of objects in industrial applications [23].

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References

1. Rydzkowski T.: Metods of research on polymers sturkture. Crystallinity. Teka Kom. Bud. Ekspl. Masz. Elektrotech. Bud. – OL PAN. 2008, pp. 143–148.
2. Seshadri A., Pagilla P. R.: Optimal web guiding. Journal of Dynamic Systems, Measurement, and Control. Vol. 132, no 1/2010, pp. 011006-1––011006-10.
3. Rocha W.R.M., Pilling S.: Determination of optical constants *n* and *k* of thin films from absorbance data using Kramers–Kronig relationship. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 123 (2014), pp. 436–446.
4. Herve P., Cedelle J., Negreanu I.: Infrared technique for simultaneous determination of temperature and emissivity. Infrared Physics & Technology. 55 (2012), pp. 1–10.
5. Park I.S., Ha J.S.: Thickness measurement of silicon thin film coated on metal mold by analyzing infrared thermal image. International Communications in Heat and Mass Transfer. 36 (2009), pp. 462–466.

6. Shams Nateri A., Hajipour A.: Measuring thickness of translucent plastic by scanner. Optik. 125 (2014), pp. 452– 456.
7. Scajev P., Karaliunas M., Kuokstis E., Jarasiunas K.: Radiative and nonradiative recombination rates in cubic SiC. Journal of Luminescence. 134 (2013), pp. 588–593.
8. Dodd P., Stellwag T., Melloch M., Lundstrom M.: Surface and perimeter recombination in GaAs diodes: an experimental and theoretical investigation. IEEE Transactions on Electron Devices. 38 (1991), pp. 1253–1261.
9. Choi J.H., Shin M.W.: Thermal investigation of LED lighting module. Microelectronics Reliability. 52 (2012), pp. 830–835.
10. Żagan W.: Podstawy techniki świetlnej. Wydawnictwo Politechniki Warszawskiej. Warsaw 2005 (in Polish).
11. Czajka P.: The determination of characteristics of highly-efficient LED diodes impulse work. Maintenance Problems. 2 (2008), pp. 33–44 (in Polish).
12. Ohyama S., Iizuka J., Takayama J., Kobayashi A.: Position measurement using an enclosed signal field with pulse-width-modulated function. Sensors and Actuators A. 113 (2004), pp. 54–59.
13. Shih N.F., Pai F.J., Chuang W.J., Hong J.W.: Current gain control of near infrared c-Si phototransistors. Solid-State Electronics. 44 (2000), pp. 1399–1404.
14. Information on http://www.vishay.com.
15. Information on http://www.osram-os.com.
16. Evaluation of measurement data – Guide to the expression of uncertainty in measurement. JCGM 100:2008.
17. Neska M., Majcher A.: Estimation of the uncertainty of measurement in a two-channel system for tests on the intensity of infrared radiation. Maintenance Problems. 3 (2014), pp. 45–55.
18. Majcher A.: Model of the event driver networked control system for the diagnostics use. 10th International Science and Technology Conference: Diagnostics of Processes and Systems. Zamość 2011. Maintenance Problems. 2 (2011), pp. 131–140.
19. Mazurkiewicz A.: Innovative technological solutions for sustainable development. Published by Institute for Sustainable Technologies-National Research Institute, Radom (Poland) – Shanghai (China), 2010, ISBN 978-83-7204-955-1, pp. 29–61.
20. Just P., Ebert L., Echelmeyer T., Roscher M.A.: Infrared particle detection for battery electrode foils. Infrared Physics & Technology. 61 (2013), pp. 254–258.
21. Skowroński J., Bojarska M., Neska M.: The concept of the system for parameterization of functionalized membranes. Solid State Phenomena. Vol. 223 (2015), pp. 3–10.

22. Kato K., Omoto H., Tomioka T., Takamatsu A.: Visible and near infrared light absorbance of Ag thin films deposited on ZnO under layers by magnetron sputtering. Solar Energy Materials & Solar Cells. 95 (2011), pp. 2352–2356.
23. Zbrowski A., Samborski T., Kozioł S.: The model of the system for prototype production of the RFID identifiers. Maintenance Problems. 3 (2011), pp. 251–263 (in Polish).

Układ pomiaru tłumienia promieniowania podczerwonego

Słowa kluczowe

Promieniowanie podczerwone, detektor podczerwieni, niepewność pomiaru.

Streszczenie

Układy pomiaru tłumienia promieniowania znajdują szerokie zastosowanie w ocenie różnych typów materiałów. Wymagają one stabilnego toru nadawczo-odbiorczego promieniowania. W artykule przedstawiono opracowany układ nadawczo-odbiorczy promieniowania podczerwonego, w którym obok stabilizowanych źródeł zasilania podukładów, nadawczego i odbiorczego, zastosowano programową korekcję temperaturową sygnałów wyjściowych. Układ posiada dwa tory pomiarowe o długościach fal 860 i 950 nm. W artykule zaprezentowano charakterystyki i niepewności pomiarowe układu wyznaczone przy wykorzystaniu referencyjnego materiału.

Układ tego typu może być zastosowany w systemach badania przepuszczalności lub odbicia światła podczerwonego, czy badaniach absorbancji promieniowania.