Visnyk NTUU KPI Seriia – Radiotekhnika Radioaparatobuduvannia, 2017, Iss. 69, pp. 62–65

УДК 535.24

Photometric Absorbance Spectrum Analyzer of Slightly Transparent Biomaterials

Yanenko O. P.[1], *Shevchenko K. L.*[1], *Shulha V. A.*[1], *Holovchanska O. D.*[2]

[1]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
[2]Bogomolets National Medical University

E-mail: *op291@meta.ua*

Introduction. The measurement of optical radiation, especially the intensity of the light flux passing through biological tissues or other slightly transparent (cloudy) materials and the environments is a challenging problem due to the extensive development of new light sources of different wavelengths and their use in various fields of human activity. Important is to provide high sensitivity and accuracy measurement of the output parameters of light fluxes passing through the studied material - the depth of penetration, attenuation coefficient or absorption. Known methods and devices do not provide the required sensitivity and accuracy of measuring parameters.
Main body. The aim of this study is to develop a photometric spectrum analyzer, in which, along with the simplification of the scheme and increasing sensitivity and measurement accuracy, the score of penetration depth of light flux into biological or other slightly transparent material, the determination of the attenuation coefficient and the spectrogram construction based on the analysis of two signals, separated by wavelength light sources, is ensured. One of the ways to increase the sensitivity and accuracy of the measurement devices is to use modulating method of the output signals transformation. Implementation of this method provides a significant reduction of the proper noises of the transformation signal path. Figure 1 shows a functional diagram of the developed by the authors device, based on modulating transformation of the optical signal. It provides the measurement of the slightly transparent materials absorbance, with increasing sensitivity and accuracy.
Conclusions. Considered possibilities greatly simplify the measurement process. The use of the modulating transformation of the light flux provides increase in sensitivity almost an order and in the measurement accuracy, because such transformation compensates the intrinsic noise level and noise of the measurement channel. As the light source semiconductor matrix is used. It provides accommodation of two crystals at one point of light diodes with the most spaced wavelengths, allowing them to be placed on the same axis with photocell and excludes collateral scattering of the light flux.

Key words: photometry; spectrum analyzer; biomaterials; absorption capacity; attenuating coefficient; modulating transformation

Introduction

Measurement of the optic irradiation parameters, first of all the intensity of the light flux passing through the biological tissue or other slightly transparent (cloudy) materials and environments is actual task due to the development of the new sources of the light with different wavelengths and their usage in different fields of human activity [1, 2].

Effectiveness of the laser and diode sources of the tanning signals used in the technologies of the practice medicine, food industry, in laboratory studies of the various solutions in medicine, chemistry is closely linked to the definition of the penetrating power of light fluxes into objects of study. It's important to provide the high sensitivity and measurement accuracy of the output parameters of the light fluxes passing through the studied materials — depth of penetration, coefficient of attenuation or absorption. Indicated in the [3] methods and devices don't provide the necessary sensitivity and measurement accuracy of the light fluxes parameters.

Photometric spectrum analyzers considered in [4–6] provide better metrological data, but the presence of the special optic means (photometric ball and light-measuring bench, the system of the protection from the extraneous light sources etc.) so as complicated optical mechanical communications and use the mechanical modulators of the light flux make the process of the measurement more complicated at all. Meanwhile, the necessary sensitivity and accuracy of measurement parameters of weak optical signals of different wavelengths is not provided.

Described at [7] photometer used modulation (electronic) method of converting the intensity of the light flux, somewhat simplifies and enhances the sensitivity of the measurement parameters of flux, but it lacks the ability to assess absorbance capacity of the materials and liquids, the penetration depth of the light flux through biological tissues and determine the attenuation coefficient. At the same time, measurement and assessment of these parameters can be used to predict, for example, the effectiveness of treatment with light therapy.

1 Statement of the Problem

The presence of the discussed disadvantages of the known photometers and photometric spectrum analyzers more or less hinder their practical use. The design of the simple construction but high metrological characteristics optic spectrum absorbance analyzer of slightly transparent materials and liquids would help its more widespread use in various fields of science and technology. Especially important parameter of measuring devices is increased sensitivity when light flux passing through slightly transparent analyzing material. This allows more deeply evaluate the interaction of light fluxes and biomaterials samples, for example, in biology and medicine, and to predict their impact on the level of the whole organism.

Thus, considering the identified deficiencies of these devices for measurement light fluxes — the complexity, lack of sensitivity and precision, the aim of this study is to develop photometric spectrum analyzer, in which, along with the simplification of the scheme and increasing sensitivity and measurement accuracy, the score of penetration depth of light flux into biological or other slightly transparent material, the determination of the attenuation coefficient and the spectrogram construction on the analysis of two signals, separated by wavelength light sources, is ensured.

2 Hardware providing

One of the directions to increase the sensitivity and accuracy of the measurement devices is use the modulating method of the output signals transformation [7,8]. Realization of this method use provides significant reducing of the proper noises of the transformation signal path. It fully concerns to optical measurements of the slightly transparent substances and materials properties [9].

Figure 1 shows a functional diagram to realize the measurement of the absorbance ability of the slightly transparent materials with use of the modulating transformation of the optic signal.

Explication: 1 — microcontroller, whose outputs are connected under the control inputs of the modulator 2, key 3 and synchronous detector 11; 4, 5 — emitting diodes, which are connected to the inputs outputs key 3, and outputs irradiate object of study 6; 7 — moving carriage with a photocell 8, its outputs connected to an amplifier 9 and through selective switching frequency filter 10 connected with the alarm input synchronous detector 11. The output of the synchronous detector 11 through a low frequencies filter 12 and analog-to-digital converter 13 is connected to the computer input 14 and the output of a computer connected to the input of the microcontroller.

Figure 2 shows a block conversion spectrum analyzer.

Photometric measuring device of the materials absorbance properties works in several stages as follows.

Under the program, which is installed in the computer 14, the device calibration is conducted in the beginning of the work.

For this the work signal mode is fed from the computer 14 to microcontroller 1 and on its outputs are set: on the first output — voltage of the emitting diodes, on the second — pulse voltage switching frequency Ω.

On the third entry is set the key position, such as ab and to the pulsed power is connected, for example, light diode 4 with a wavelength λ_1.

The carriage 7 with photocell 8 is installed at a distance corresponding to the thickness of the studying material. Under the influence of a switching rectangular signal type:

$$U_1(t) = F_1(t) + F_2(t) \tag{1}$$

where

$$F_1(t) = \left[\frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\sin(2n-1)\Omega t}{2n-1}\right]; \tag{2}$$

and

$$F_2(t) = \left[\frac{1}{2} - \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\sin(2n-1)\Omega t}{2n-1}\right], \tag{3}$$

by modulator 2 is held periodically (with a frequency Ω) power supply for light diode 4. Accordingly, the alternate light flux emission with power F_1 is carried. It should be noted that the power supply to the light emitting diodes is provided by feeding the modulator with the positive half-wave modulating signal $F_1(t)$. On the output of the photocell 8, by the periodical work of the modulator 2, the pulse voltage, which amplitude is proportional to the power of light flux $Uf_1 \equiv F_1$, is formed. The received pulse voltage is increased to the desired value with the amplifier 9 and, as a result, on the output of the frequency selective filter 10 the switching signal is released

$$U_2(t) = U_1 S_1 K_1 K_2 F_1(t) = \\ = U_1 S_1 K_1 K_2 sign \sin\Omega t, \tag{4}$$

where S_1 – slope conversion of the photocell 8; – K_2 transmission coefficient of the selective filter 10; – $F_1(t) = sign \sin\Omega t$ syhnum function (bypass of the periodic process sign).

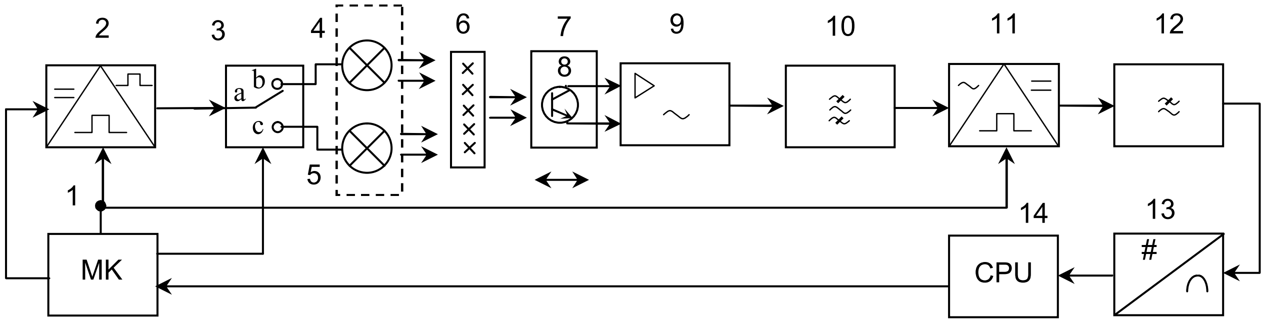

Fig. 1. Functional diagram of the photometric absorbance spectrum analyzer of the slightly transparent biomaterials

Power (4) is fed to the signal input of the synchronous detector 11, on its managing input the rectangular reference voltage of the same frequency $F_{1opor}(t)$ is fed. As a result of multiplying the measuring $U_2(t)$ and reference signals $U_1(t)$, for each of the half switching period, taking into account the properties of switching functions, that $F_{1opor}(t) = F_1(t)$, and the $F_1(t)2 = F_1(t)$, receive signal

$$U_3(t) = U_1 U S_1 S_2 K_1 K_2 F_1(t) = \\ = U_1 U K_1 K_2 S_1 S_2 \left[\frac{1}{2} + \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{\sin(2n-1)\Omega t}{2n-1} \right] \quad (5)$$

where S_2 – slope conversion of the synchronous detector, U_{opor} – reference voltage amplitude.

On the output of the low frequences filter 12 the constant component of voltage equation (5) is released, and the variable is delayed

$$U_4 = \frac{U_1 U}{2} S_1 S_2 K_1 K_2 K_3 = \frac{U_1 U}{2} K_\Sigma \quad (6)$$

where K_3 — transfer coefficient of the low frequencies filter, and $K_\Sigma = S_1 S_2 K_1 K_2 K_3$.

Power (6) turns by ADC in the calibration code N_1 for light diode 4 and computer 14 remember it.

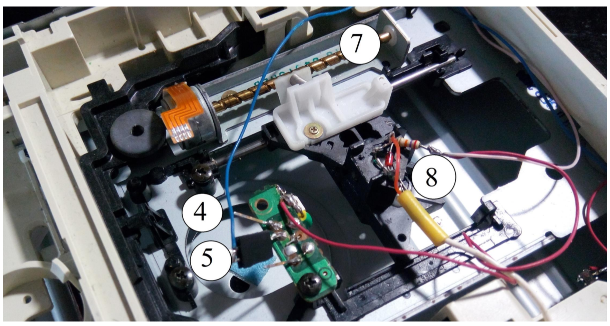

Fig. 2. The design of optoelectronic transducer and measure channel spectrum analyzer (designation according to Fig. 1)

A similar transformation algorithm implemented with the second light diode 5 signal, with the wavelength λ_2, at the key position ac to receive the code value N_2. After calibration completion they place studied material and carry out the same algorithm for measuring the level of the sample output signal receiving the code for light diode 4 — N_3, and the light diode 5 — N_4.

Correlation $\alpha_1 = N_3/N_1$ characterizes the ability of the material to absorb the light flux from emitting diode 4 with a wavelength λ_1, and $\alpha_2 = N_4/N_2$ — the same data for light diode 5 with a wavelength λ_2. Observed values defined parameters, for example, of separated light diodes ($\lambda_1 = 400$ nm — purple and $\lambda_2 = 700$ nm — red) allow to construct with computer program predicted diagram of the absorption of other wavelengths light fluxes.

Correlation $\beta_1 = (N_1 - N_3)/d_1$ provides a definition of the linear absorption values, which allow to count the weakening for similar material of other thickness dx without additional measurements.

3 Conclusions

Considered possibilities greatly simplify the measurement process. The use of the modulating transformation of the light flux provides increase in sensitivity almost an order and provides increase the measurement accuracy, because such transformation compensates the intrinsic noise level and noise of the measurement channel. As the light source semiconductor matrix is used. It provides accommodation of two crystals at one point of light diodes with the most spaced wavelengths, allowing them to be placed on the same axis with photocell and excludes collateral scattering of the light flux.

References

[1] Zelenkov I. A. (2003) *Fotometriia* [Photometry], Kyiv, NAU, 211 p.

[2] Kotyuk A. F. (2003) *Osnovy opticheskoi radiometrii* [Fundamentals of optical radiometry]. Moskow, Fizmatlit, 552 p.

[3] Gurevich M. M. (1983) *Fotometriya (Teoriya, metody i pribory)* [Photometry (Theory, Methods and Devices)], Leningrad, Energoatomizdat, 272 p.

[4] Kul'chitskii A.P. and Obrinskii L.U. (1989) *Polevoi spektrofotometr* [Field spectrophotometer], Patent SU1511603.

[5] Bunyak A. M. (2001) *Fotometr* [Photometer], Patent UA38107.

[6] Gerasimov S. Yu. (1989) *Spektrofotometr* [Spectrophotometer]. Patent SU1511602.

[7] Yanenko, A. P., Mikhailenko, S. V., Lisnichuk, A. S. (2014) Radiometric modulation measuring device of intensity of optical radiation. *Visn. NTUU KPI, Ser. Radioteh. radioaparatobuduv.*, no. 56, pp. 96-101. (in Ukrainian)

[8] Skrypnyk Yu. A., Manoilov V.P. and Yanenko O.P. (2001) *Moduliatsiini radiometrychni prystroi ta systemy NVCh diapazonu* [Microwave modulating radiometric devices and systems], ZhITI, 373 p.

[9] Ivanov B. C., Kotyuk A.F., Sapritskii V.I. and Stolyarevskaya R.I. (2002) *Fotometriya i radiometriya opticheskogo izlucheniya (obshchii kurs)* [Photometry and radiometry of optical radiation (general course)]. Moskva, Poligraf servis, 264 p.

Фотометричний спектроаналізатор поглинальної здатності слабко прозорих біоматеріалів

Яненко О. П., Шевченко К. Л., Шульга В. А., Головчанська О. Д.

Авторами запропонована функціональна схема фотометричного спектроаналізатора та алгоритм перетворення вимірювальних сигналів, які дозволяють оцінити поглинальну здатність слабко прозорих біоматеріалів, рідин та інших фізичних і біологічних об'єктів, що тією чи іншою мірою пропускають та поглинають світлові потоки. Поряд зі спрощенням схеми та одночасним підвищенням чутливості практично на порядок і точності вимірювання забезпечується оцінка глибини проникнення світлового потоку в біоматеріал, визначення коефіцієнта згасання та побудова спектрограми за результатом аналізу сигналів двох рознесених за довжиною хвилі джерел світла. Використання максимально рознесених за довжиною хвилі світлодіодів (синього та червоного), мікроконтролера та персонального комп'ютера забезпечує можливість побудови спектрограми для всіх потоків видимого світла за результатами тільки двох вимірювань.

Ключові слова: фотометрія; спектроаналізатор; біоматеріали; поглинальна здатність; коефіцієнт затухання; модуляційне перетворення

Фотометрический спектроанализатор поглощающей способности слабо прозрачных биоматериалов

Яненко А. Ф., Шевченко К. Л., Шульга В. А., Головчанская А. Д.

Авторами предложена функциональная схема фотометрического спектроанализатора и алгоритм преобразования измерительных сигналов, которые позволяют оценить поглощающую способность слабо прозрачных биоматериалов, жидкостей и других физических и биологических объектов, в той или иной степени пропускающих и поглощающих световые потоки. Наряду с упрощением схемы и одновременным повышением чувствительности практически на порядок и точности измерения обеспечивается оценка глубины проникновения светового потока в биоматериал, определение коэффициента затухания и построение спектрограммы по результатам анализа сигналов двух разнесенных по длине волны источников света. Использование максимально разнесенных по длине волны светодиодов (синего и красного), микроконтроллера и персонального компьютера обеспечивает возможность построения спектрограммы для всех потоков видимого света по результатам только двух измерений.

Ключевые слова: фотометрия; спектроанализатор; биоматериалы; поглощающая способность; коэффициент затухання; модуляционное преобразование