Maryna MIKHALIEVA[1], Lubomyra ODOSII[2], Krzysztof PRZYSTUPA[3], Yuryi SHABATURA[4], Volodymyr ROMANCHUK[5], Lidiya PARASHCHUK[6]

Hetman Petro Sahaidachnyi National Army Academy: Lviv (1, 2, 4, 5), Lublin University of Technology (3), Lviv Polytechnic National University (6)

doi:10.15199/48.2024.03.51

Opportunities of electrical technologies for control of the quality parameters of light sensitive materials

Abstract. *Based on the obtained experimental results, an algorithm of the information and measurement system for operational control of the efficiency of photocells during their operation is proposed. The subject of the research was solar radiation energy converters into electric current energy - photocells from the wide-band semiconductor titanium oxide and polymethine dyes - sensitizers, which are sensitive to the action of light in the visible and near-infrared bands of the solar spectrum. Using the method of immittance spectroscopy, information on transport and recombination electronic processes was obtained, which was used to assess the potential for the construction and use of the investigated quality systems of solar cells. The object of the study is the dependence of the quality control parameter of the photocell - the titanium oxide content - on the value of the measured electrical parameter - admittance. Control of the efficiency of photocells is offered by the sign (positive or negative) of the value of the measured electrical parameter - complex conductivity.*

Streszczenie: *Na podstawie uzyskanych wyników eksperymentalnych zaproponowano algorytm układu sterująco-pomiarowego do operacyjnego zarządzania wydajnością fotokomórek podczas ich pracy. Przedmiotem badań były ogniwa zamieniające energii promieniowania słonecznego na energię prądu elektrycznego - wykonane z szerokopasmowego półprzewodnika z tlenkiem tytanu i barwnikami polimetinowymi pełniącymi rolę sensybilizatora, które są czułe na działanie światła w pasmach widzialnym i bliskiej podczerwieni widma słonecznego. Metodą spektroskopii immitancyjnej uzyskano informacje o zachodzących procesach elektronowych transportu i rekombinacji, które wykorzystano do oceny możliwości budowy i udoskonalenia ogniw słonecznych. Przedmiotem badań jest jakości fotokomórki skorelowana z zawartością tlenku tytanu i parametrem elektrycznym – admitancją. (**Możliwości technologii elektrycznych w kontroli parametrów jakościowych materiałów światłoczułych**)*

Keywords: photocatalitic activity, light-sensitive materials, immittanse, spectroscopy
Słowa kluczowe: aktywność fotokatalityczna, materiały światłoczułe, immitanza, spektroskopia.

Introduction

Modeling and creation of efficient photocatalytic systems is a priority area in scientific research using sunlight.

To improve the photosensitivity of semiconductor materials, a method based on the creation of new composite systems (heterostructures) is used, which is widely used in nanocatalysis.

Photosensitive systems include additional components - photocatalytic units [1-3]. It is most promising to use organic dyes in the role of photocatalytic blocks, which are able to undergo redox reactions. Due to their structure, these compounds are good sensitizers and are able to expand the zone of light absorption. Construction of such systems is carried out by direct deposition of a dye-sensitizer on the surface of a semiconductor.

Active solar radiation energy converters turned out to be polymethine dyes, which are of great importance when used in highly efficient dye-sensitized solar cells [1-3]. It is polymethines, having the largest assortment in the entire visible and near-IR range of the spectrum of photophysical and photochemical properties among organic dyes, that is promising for the creation of light-sensitive materials by introducing chromoform groups into them, which solved a number of practical issues related to the conversion of solar energy.

It is known that photocatalytic properties are affected by the concentration content of the dye, when it increases, internal filtration is observed, which interferes with the electronic transition to the semiconductor, which significantly affects its efficiency. Therefore, there is a need for studies of the concentration dependence of the content of dye and polymer material, which significantly affects the volume transport and recombination processes of photoinduced electronic transitions in heterostructures, which in turn affects the qualitative characteristics of photosensitive materials of solar cells.

Immittance studies on modern RLC-meters make it possible to establish the dependence of physical properties (complex conductivity of the measuring system) on the composition of the investigated substance [4-11].

Also, the efficiency of photoelectric conversion using immittance spectroscopy has been widely investigated [4]. We propose to use these two scientific facts to control the efficiency of the photocells we have improved and to monitor their quality.

The new concept of immittance quality control of light-sensitive materials is based on measurements of the parameters of the model that supplies the object in the alternating current circuit, as well as on the conditions and methods adopted in qualimetry, the observance of which allows realizing all the advantages of the electrical method of quality assessment.

Since the immittance of the two-pole, which supplies the object of control, is characterized by several parameters, then such control is multidimensional or multiparametric. The first measurement transformation of immittance quality control is carried out by a primary converter (sensor), the informative parameter of which is a passive value. To turn it into an active one, it is necessary to apply the test signal to the object of control, in connection with which such control can be considered active. At the same time, there is an opportunity to actively influence unit quality indicators during the operation of the equipment.

The result of the measurement of multidimensional objects is determined based on the results of direct measurements of the informative parameter of the object, which connects the informative value with the parameters that determine it. The functional dependence of an informative quantity with such parameters (components of the measurement object model) can be:

linear $Y = \sum_{i=1}^{n} k_i A_i$,

non-linear $Y = \prod_{i=1}^{n} f(X_i)$

mixed type $Y = \sum_{j=1}^{m}\left[\prod_{i=1}^{n} f\left(X_i\right)\right]$, where

k_i – is the constant coefficient of the i-th parameter; A_i – informative parameter; $f(x_i)$– some functions.

The type of relationship between Y and Xi determines the methodology for calculating measurement errors.

The generalized quality indicator P of any type of product can be represented by the following functional dependence:

$$P = F_1\left(q_1, Q_1, q_2, Q_2, ..., q_n, Q_n\right), \tag{1}$$

where Q1, Q_2, ...Q_n – unit indicators of product quality; q_1, q_2, ...q_n – the weighting factor of a single indicator.

If the substance or material is supplied by a bipolar device, then its complex conductivity in the volume of the sensitive element of the sensor depends on the electrical parameters of the bipolar device. At constant values of the frequency, shape and amplitude of the test signal, without the influence of non-informative immittance, the conductivity

$$Y = F_2\left(X_1, X_2, ..., X_n\right), \tag{2}$$

where X_1, X_2, ...X_n – electrical parameters of the complex conductivity given by the known substitution scheme.

If the relationship between electrical parameters and unit parameters of products is known, then

$$\begin{aligned} X_1 &= F_1\left(Q_1\right); \\ X_2 &= F_2\left(Q_2\right); \\ X_n &= F_n\left(Q_n\right) \end{aligned} \quad , \tag{3}$$

and therefore can be written down

$$P = F\left(X_1, X_2, ..., X_n\right) \tag{4}$$

Thus, the product quality indicator can be determined by the set of electrical parameters of a two-pole, which gives grounds for the use of immittance control of product quality, which can be presented in the form of a two-pole. That is, to assess the level of quality, you can use measuring tools that implement immittance measurements [12].

Research conditions

We used light-sensitive chemical systems developed in laboratory conditions using a titanium dioxin P25 semiconductor photocatalyst. The special structure of this chemical system is formed by a polymethine-type dye, which is used as a sensitizer and fixed with a layer of the electron-conducting polymer material.

For the successful functioning of photocatalysts-heterostructures, it is necessary to select their components with certain optical, electrophysical, and electrochemical characteristics, which ensure thermodynamic gain of all possible electronic processes that lead to photocatalytic conversion under the conditions of a change in the required light spectral regime.

The electrical properties of photosensitive elements in a multi-frequency electromagnetic field depend on their composition [4-6]. For research, we used the admittance method, which is based on studies of the dependence of complex conductivity (admittance) on the composition of the substance. The negative value of this electrical indicator is explained by the inductive nature of the measuring system, and, in turn, the inefficiency of the photocells [4]. Therefore, we believe that the operational characteristic of controlling the photoefficiency of the material can be the negative or positive sign of the value of the reactive component of the complex conductivity of the measuring system, which has been repeatedly confirmed by works [4]. The inductance of the behavior of such systems (the negative reactive component of the conductivity) can be explained by the fact that the physical nature of the sharp non-monotonic frequency dependence of the real part of the complex impedance affects the processes of carrier capture - retention - release and coupling with them and the appearance of the physical inductive nature of conductivity. And the inductive nature of the conductivity of the system will indicate the photoinefficiency of the selected material, or the loss of this efficiency during operation. The novelty of the research conditions is the use of a new approach to the dielectric properties of objects of a non-electric nature and its use in the method of controlling the efficiency (composition) of photovoltaic cells, which affects their operational characteristics.

The main units of the measuring device are an impedance sensor, a communication line and a measuring circuit. A substance or material together with a sensitive element that is in direct contact with a physical quantity (its parameters) form an immittance sensor (primary transducer). Under the influence of the test signal parameters (level and frequency), it transforms a non-electrical physical quantity into an electrical quantity of a capacitive or inductive nature.

With the capacitive type, the reactive component of the admittance acquires a positive value, and with the inductive type, a negative value [7-9].

Discussion of research results

The laboratory experimental and measuring system consisted of a standard RLC-meter measuring device, a primary transducer with a capacity for the substances under investigation, and a computer with software for processing the measurement results. The computerized measuring system is designed for measuring electrical impedance in the frequency range of 0.5...100 MHz.

The laboratory experimental and measuring system shown in Fig. 1

Fig. 1. Experimental measurement using a laboratory RLC-meter

Samples of photocells with sufficient efficiency and photocells that partially lost their operational properties (after long-term use) were studied. Therefore, the value of the admittance of the latter from a certain value of the frequency of the electromagnetic field acquires a negative value.

On the basis of the obtained results and conclusions, we developed a computerized charter for operational control of solar cells according to admittance parameters. The measuring system consists of an impedance meter, a high-frequency generator, a computer, as well as hardware (coupling) nodes of a high-frequency generator and an impedance meter with a computer. The operation of the complex is carried out under the control of a computer program that coordinates the interaction of all hardware, the input of control signals to external devices, the input of data, their initial processing and measurement of the parameters of the object under study. The software part of the charter runs on the Microsoft Windows operating system.

During such studies, parameters are established according to which it is possible to determine the efficiency of the system for their evaluation and quality control. Such studies contribute to the theoretical and practical development of the design and creation of effective photocatalytically active light-sensitive materials, the samples of which are made on the basis of crystalline or amorphous semiconductor materials, and to determine their quantitative composition with the help of direct measurement. Fast (within a few seconds) control of solar cells takes place according to the impedance sign and precedes the following test algorithms or replaces them.

We used light-sensitive chemical systems developed in laboratory conditions using a titanium dioxin P25 semiconductor photocatalyst. The special structure of this chemical system is formed by a polymethine-type dye, which is used as a sensitizer and fixed with a layer of the electron-conducting polymer material polyepoxypropylcarbazole.

The electrical properties of photosensitive elements in a multi-frequency electromagnetic field depend on their composition.[4-5]

For research, we used the admittance method, which is based on studies of the dependence of complex conductivity (admittance) on the composition of the substance. The negative value of this electrical indicator is explained by the inductive nature of the measuring system, and, in turn, the inefficiency of the photocells. Therefore, we believe that the operational characteristic of controlling the photoefficiency of the material can be the negative or positive sign of the value of the reactive component of the complex conductivity of the measuring system, which has been repeatedly confirmed by works. The inductance of the behavior of such systems (the negative reactive component of the conductivity) can be explained by the fact that the physical nature of the sharp non-monotonic frequency dependence of the real part of the complex impedance affects the processes of carrier capture - retention - release and coupling with them and the appearance of the physical inductive nature of conductivity. And the inductive nature of the conductivity of the system will indicate the photoinefficiency of the selected material, or the loss of this efficiency during operation.The novelty of the research conditions is the use of a new approach to the dielectric properties of objects of a non-electric nature and its use in the method of controlling the efficiency (composition) of photovoltaic cells, which affects their operational characteristics. The value of the electrical parameter measured for the photosensitive material with the content of polymethine dye C (g/l) is shown in Figure 2.

Based on the obtained experimental results, an algorithm of the information and measurement system for operational control of the efficiency of photocells during their operation is proposed (Figure 3).

Using the method of immittance spectroscopy, information on transport and recombination electronic processes was obtained, which was used to assess the potential for the construction and use of the investigated quality systems of solar cells.

Control of the efficiency of photocells is offered by the sign (positive or negative) of the value of the measured electrical parameter - complex conductivity.

Research refers to direct measurements of the composition of multi-component material, which allows to improve quality control and efficiency of photo materials through automation.

B (Cm)	C (g/l)
0,00678	0,034
0,00504	0,048
0,0033	0,062
0,00156	0,076
-0,00018	0,09
-0,00192	0,104
-0,00366	0,118
-0,0054	0,132
-0,00714	0,146
-0,00888	0,16
-0,01062	0,174
-0,01236	0,188
-0,0141	0,202
-0,01584	0,216
-0,01758	0,23
-0,01932	0,244
-0,02106	0,258
-0,0228	0,272
-0,02454	0,286
-0,02628	0,3
-0,02802	0,314
-0,09276	0,328

Fig 2. The value of the electrical parameter measured for the light-sensitive material with the content of polymethine dye C (g/l).

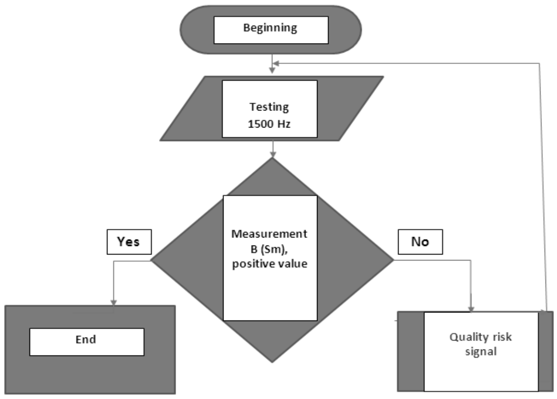

Fig 3. The algorithm of practical application of the electrical method to control the quality of photo materials according to experimentally established electrical parameters.

Conclusions

During laboratory studies, parameters are established according to which it is possible to determine the efficiency of the system for their evaluation and quality control. Such studies contribute to the theoretical and practical development of the design and creation of effective photocatalytically active light-sensitive materials, the samples of which are made on the basis of crystalline or amorphous semiconductor materials, and to determine their quantitative composition with the help of direct measurement. Fast (within a few seconds) control of solar cells takes place according to the impedance sign and precedes the following test algorithms or replaces them.

Authors: *Maryna Mikhalieva, PhD, Hetman Petro Sahaidachnyi National Army Academy: Lviv, UA,* galmih@ukr.net, *ORCID:0000-0001-5612-3737;*
Lubomyra Odosii, Ph.D, Hetman Petro Sahaidachnyi National Army Academy: Lviv, UA, odosiu@ukr.net*, ORCID:0000-0003-2438-7759;*

Krzysztof Przystupa, Ph.D, Lublin University of Technology, Lublin, Poland, k.przystupa@pollub.pl, ORCID:0000-0003-4361-2763
Yuryi Shabatura, Dr.Sc, Hetman Petro Sahaidachnyi National Army Academy: Lviv, UA, shabaturayuriy@gmail.com, *ORCID:0000-0002-9961-1244;*
Volodymyr ROMANCHUK, Hetman Petro Sahaidachnyi National Army Academy: Lviv, UA, vovaroman80@gmail.com, *ORCID:0000-0002-8284-0657;*
Lidiya PARASHCHUK, PhD, Hetman Petro Sahaidachnyi National Army Academy: Lviv, UA, lidadmy@ukr.net, *ORCID:0000-0002-4049-2033*

REFERENCES

1 Kobasa I.M., Odosiy L.I., Kurdyukov I.V., Ishchenko A.A., Kurek S.S.. Electrochemical and Energetic characteritics of new dye-sensitizers for photovoltaic cells // J. Funct. Mater. Lett. Vol. 8, No. 6. – P. (5).
2 Kobasa I.M., Gusyak N.B., Odosii L.I. Titanium dioxide sensitization with a biscyanine dye in the photocatalytic reduction of methylene blue. Kinetics and Catalysisthis link is disabled, 2015, 56(2), pp. 158-163.
3 Kobasa I.M., Kondratyeve I.V., Odosiy L.I., Kropelnytska Y.V., Sensitization of TiO2 by a symmetric anionic polymethin dye with three conjugated chromophones. Research on Chemical intermediates 2019, 45(6) pp 4043-4052
4 Grigorchak I., Monday G. Impedance Spectroscopy. Lviv: Publishing House of Lviv Polytechnic, 2011.- 352p.
5 Hixson E/S/ Mechanical impedaance. In Harris C.M. Shok and vibration. - New York Mc Grew – Hill, 1988, chapter 10.
6 Imnpedance spectroscopy. Theory, experiment and application/Ed. Barsoukov E. and Macdonald J.R.- Wiley interscience (Canada).- 2005. -585p.
7 Mikhalieva M., Odosii L., Przystupa K., Shabatura Y., Hots N., Hrubel M. Improvement of electrical methods of control and evaluation of impact of military activity on surface waters | Poprawa elektrycznych metod kontroli i oceny wpływu działań wojskowych na wody powierzchniowe. Przeglad Elektrotechniczny, 2023, 99(2), pp. 230–233.
8 Mikhalieva M., Parakuda V., Shabatura Y., Odosii L., Przystupa K. Electrical method for a water control after an osmosis process for the standard unit of ultrasound power in the aquatic environment | Elektryczna metoda kontroli wody po procesie osmozy w środowisku wodnym. Przeglad Elektrotechniczny, 2021, 1(1), pp. 104–106.
9 Mikhalieva M., Odosii L., Seredyuk B., Parashchuk L., Lunkova H. An electrical method for intelligent cooling liquid control Systems. Acta IMEKO, 2020, 9(1), pp. 56–60.
10 Mikhalieva M., Odosii L., Shabatura Y., Przystupa K., Atamaniuk V. Electrical method for the cyberphysical control system of non-electrical objects. Przeglad Elektrotechniczny, 2019, 95(12), pp. 200–203.
11 Mączka, M. Effective Simulations of Electronic Transport in 2D Structures Based on Semiconductor Superlattice Infinite Model. Electronics 2020, 9, 1845. https://doi.org/10.3390/electronics91118
12 Vanko V.V., Pokhodylo E.V. Measurement of dielectric parameters by capacitive methods // Second International Conference "Structural and Functional Materials" (KFM'97). October 14-16, Lviv, 1997. – P167.