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PHOTOCURRENT ANALYSIS IN SECURITY AND SAFETY SYSTEMS

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A new approach to using selectively sensitive sensors (photodiode) for detection and identification ofmixed substanceshas been studied. The studied application is the optical photocurrent analysis for identification and quantification of mixtures in natural objects with calculation capability of quantitative data (the spectral sensing range of 230…1000 *nm*). In this work, a new portable photospectrometer concept has been designed which is using a selectively sensitive sensor and makes the device to be low-cost and multipurpose.

Keywords: photocurrent**,** photodiode, photodetector, algorithm, spectral analysis, safety, drugs, explosives.

Introduction. Contactless photospectrometry of mixed substances means the identification and quantity measurement of the substance(s) in natural objects at a distance. Detection and assessment of dangerous substances is one of the important aspects of this study. Therefore, development of primary sensors allowing to provide a spectral analysis of the electromagnetic waves emitted from the object is of utmost importance today.

Especially important is the research and development of a selectively sensitive sensor capable of sensing in different environments [1, 2].

Currently, such analysis of the electromagnetic radiation spectral distribution is obtained using light filters, prisms with high precision mechanical devicesand diffraction grids [3]. The spectrophotometric systems that are available in the market using the listed methods are limited in flexibility of adding new features, as additional devices are required and external computer software modifications are needed. These factors are making the system expensive and limiting its use in the field.

Besides, these methods of analysis are accompanied bydata destruction, in quantitative and qualitative aspects. The credibility of the results depends directly on the parameters of the equipment used and requires improvements of measurement devices, and the development of rational methods for the analysis of experimental results. Moreover, the more information is received, the more complicated becomes the interpretation of measurement results, requiring the development of new signal processing methods and new algorithms for massive data processing [4].

An attractive way to solve this issues is to:

- Design a new silicon based sensor (semiconductor structure), capable of providing accurate spectral sensing of electromagnetic radiation;
- Design a data acquisition and signal processing unit;
- Develop a complex algorithm for data analysis and data visualization.

The existing investigations of multicolored photo detectors [5, 6] used cascade multi-layer structures with various thickness active layer bases. In these, different depths of penetration of the beam provides different sizes of photoconductivity. The mathematical processing of measurement results provides information on the spectral intensity distribution. Theregistration accuracy in such structures strictly depends on the absorption condition identity and necessity of developing nanoscale multilayer structures with numerous photodiodes. The obtained sophisticated technology and the impossibility to control the spectral sensitivity complicates their manufacturing and makes them non-usable for the multifunctional and multipurpose applications [7, 8].

Objectives. It is significantly important to design and develop new methods of identification of dangerous substances in distance. The primary goal of this study is aimed at developing a technology which could be used to create security and safety solution for the dangerous substances identification with high accuracy and high performance.

This solution should be able to solve the photocurrent analysis problems and be easily integrated in general and multipurpose monitoring systems, such as food or drug inspection, security check for the explosives, etc. The achieved spectral sensitivity should be in the range of 230…1000 *nm*.

This will allow the security or operational personnel to use the device to remotely identify, quantitatively analyze and mark the contaminants contained in this spectral range in natural objects, and classify the results by multiple patterns stored in the database.

This technology and method could be used and extended for other safety, security or inspection-related application.

Methods of research. This study proposes to research a remote explosive identification and monitoring system with a sensor that registers the information. The sensor is a semiconductor structure with two back-to-back p-n junctions (p + -n-p + -), in which the n – area is the base. The base is occupied by the p^+ - n andn - p^+depleted barrier layers (Fig. 1). By the manipulation of external voltage, the point of contact of the depleted layers xmcan be moved towards the photosensitive surface.

The electromagnetic wave absorption is depicted in Fig. 2.

The p^+ -n junction is biased positively, and the n- p+ junction - negatively. The photocurrent is generated in the base (d-x_m) segment of the structure. The photo charges generated in the range of 0 to x_m are reunified and because of that they are not moving to the external circuit and not creating photocurrent.

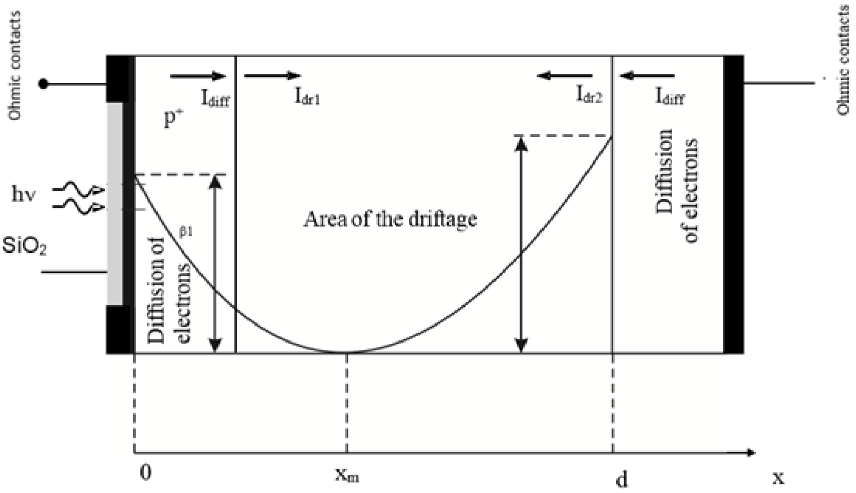

Fig. 1. p^+-n-p^+semiconductor structure

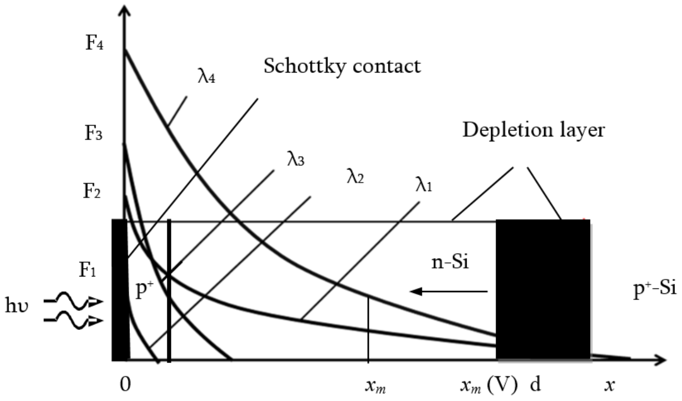

Fig. 2. The curves of different waves' absorption in semiconductor structure, F is the radiation intensity

By the application of external voltage, x_m is moved to the surface, in the direction of 0 (Fig. 2), thus the photocurrent range includes the absorption of new wavelengths, resulting in the change of photocurrent. It is known that, the shorter the wavelength, the smaller is the absorption depth. However, in an integral radiation flux, it is often possible that, for a given x_m, a high intensity short wavelength may have a higher intensity residual amplitude compared with lower intensity but longer wavelength.

In these conditions, there are multiple uncertainties at different depths, and because of this, the resulting photo signal is mainly due to the two high intensity wavelengths. Therefore, for two different close values of x_m, the corresponding total photo signal waveform correlation would be conditioned by that wavelength. Moreover, the bigger is the contribution of that Particular wavelength on the waveform photocurrent, and depending on how close these two x_m values are, it would be much more accurate [9].

Registration difficulties during the wave recognition could be easily managed if the objects are investigated under the radiation of Tungsten filament lamp. The intensities of wavelengths are increasing in parallel to the increase of wavelengths.

Thus, moving from the depth to the surface in photodetector's registration environment, the registration of the waves will be executed sequentially from long to short waves. This gives us an opportunity to develop an algorithm capable of differentiating the photocurrent of a particular wave from the total generated photocurrent and, based on that effect, to recognize the absorption material and the absorption portion, which will be the quantities value of the material.

The following equations contain parameter-specific relations for modeling the physical processes in researched structures. The specified parameters are correlated: the electron's potential energy minimum-point position in the base, photons full flow - F_0, base width - d, absorption ratio – α, deviation voltage – V, photocharges density [10].

P-zone, diffusion current,

$$I_{\text{diff}} = SqF_0 \frac{\alpha L_n}{1+\alpha w} e^{-\alpha d} . \tag{1}$$

In this work, the expressions for drift currents formed in the base of such structures are obtained:

$$I_{dr1} = qF_0 S\left(1 - e^{-\alpha x_m}\right), \tag{2}$$

$$I_{dr2} = qF_0 S\left(e^{-\alpha x_m} - e^{-\alpha d}\right). \tag{3}$$

Photocurrent produced by integral radiation is:

$$\begin{aligned} \sum_{i,j} I_{Ph\ i,j} &= \sum_{i,j} I_{dr\,1\ i,j} - \sum_{i,j} I_{dr\,2\ i,j} - \sum_{i,j} I_{dif\ i,j} = \\ &= S\,q \sum_{i,j} F(\lambda_i) \left(1 - 2e^{\alpha_i x_{mj}} + \frac{e^{-\alpha_i d}}{1+\alpha_i\ w} \right) . \end{aligned} \tag{4}$$

Assume, the informative signal to be the photocurrent. By the external voltage, we can obtain the largest values of $x_m - x_{m1}$ and $x_{m2}$with the difference of 1nm, and the corresponding photocurrents I_1 and I_2. From Lambert's law of the radiation absorption in the homogeneous environment, we will have the coefficient of the wave absorption,

$$\alpha_i = \frac{1}{\Delta x} ln \frac{I_2}{I_1}, \tag{5}$$

where $\Delta x_m = x_{m2} - x_{m1}$.

Then, with the help of $\alpha = f(\lambda_i)$and with the corresponding program we can determine the length of the wave for the initial material of the photodetector, e.g. for silicon.By means of the formula for the photocurrent (1), we will obtain the intensities of separate waves in the absorbed radiation,

$$F_{0i} = \frac{I_i}{qS\left(1 - 2e^{-\alpha_i x_{m_j}} + \frac{e^{-\alpha_i d}}{1 + \alpha_i L_n}\right)}. \tag{6}$$

The object under investigation for safety and security reasons. There are three main factors which are feasible for remote (~3*m*) identificationof explosives using the phenomenon of molecular substance fluorescence of the Nitrogen oxide (NO) caused by photolysis of the vapor concentrated on the surface of the natural object which somehow had a contact with explosive [11].

1. The Nitrogen oxide (NO) nitro group is the widely used chemical component in most explosives.
2. ($C–NO_2$, $N–NO_2$, $O–NO_2$) functional groups have the minimum connection energy and during the photolysis process the Nitrogen oxide (NO) portion is separating and producing the fluorescence (236 *nm*).

   This allows to use the spectral analysis of the fluorescence wave and identify the explosive chemicals.
3. The molecules of explosives exhibit a wide absorption spectrum specific for Nitrogen oxide (NO) molecules. Therefore, in many cases, we can use the same radiation sourcefor absorption which is used for the emission spectra.

When irradiated by a Krypton (Kr) laser beam (310 *nm* wavelength), the vapors of explosive materials undergo photolysis and, as a result, electronically excited molecules of Nitrogen oxide (NO), Nitrogen (N2) and Oxygen (O2) are formed. This excitation is accompanied by fluorescence at corresponding wavelengths (Fig. 3).

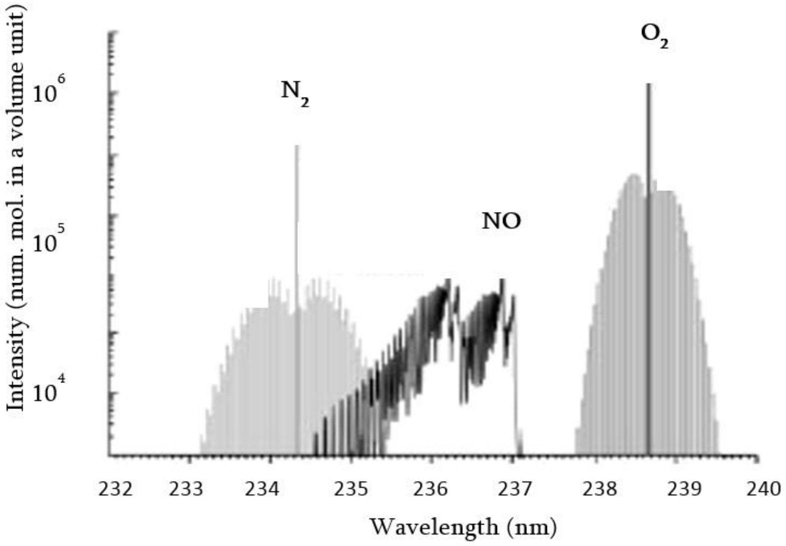

Fig. 3. The dependence of the intensity of the fluorescence wavelength from the Spector

During the modeling of the photodiode we used a corresponding range of solar spectrum [12, 13] (Fig. 4). Using the software developed based on our algorithm, we obtained spectral distribution of the intensity for 13 selected wavelengths. The red dots signify the lack of adsorption, and the blue dotsrepresent adsorption

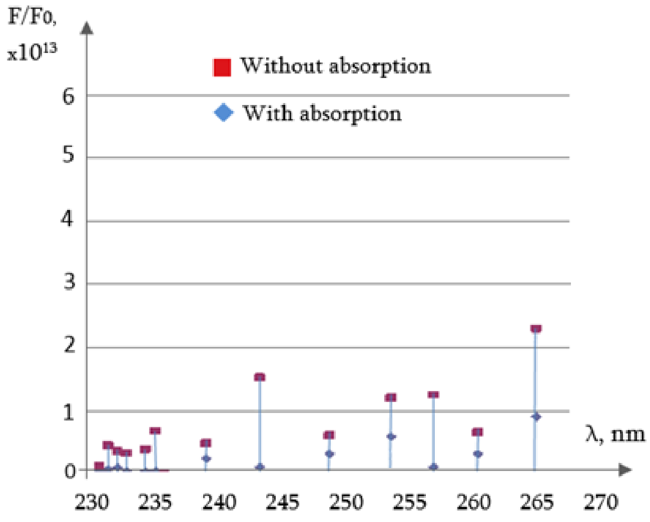

Fig.4. The spectral distribution of radiation relative intensity in the visible radiation range

Conclusion. The new studied model of the selectively sensitive sensor (photodiode) developed for contactless detection of optical information, and the identification and quantitative analysis of mixed substances in natural objects are investigated. In the radiation spectrum, the waves have different absorption depths, and the process of the selection of these waves is carried out via widening the registering volume by means of gradual change of the external voltage applied to the sensor. The developed complex algorithm allowed to perform spectral analysis without preliminary calibration. The usability of this sensor and the developed algorithm could be a best fit in the security and safety related applications where contactless detection of the explosives or harmful substances is required.

This study could provide a significant development in the production of sensors that are used in the new knowledge-based and multi-purpose devices applicable for economic, security and defense applications. The low-cost advantage of the technology is opening a new horizon for the natural objects investigation in wide areas where high volume of sensors is required.

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ՖՈՏՈՀՈՍԱՆՔԻ ՎԵՐԼՈՒԾՈՒԹՅՈՒՆԸ ԱՆՎՏԱՆԳՈՒԹՅԱՆ ԵՎ ԱՊԱՀՈՎՈՒԹՅԱՆ ՀԱՄԱԿԱՐԳԵՐՈՒՄ

Ս.Հ. Ծատուրյան

Նոր մոտեցմամբ ուսումնասիրվել է ընտրողական զգայնությամբ տվիչ (ֆոտոդիոդ), որն ունակ է զգալու և հայտնաբերելու տարբեր խառնուրդային նյութեր բնական օբյեկտներում: Կիրառված մեթոդով օպտիկական ֆոտոհոսանքի վերլուծության միջոցով հայտնաբերվում են խառնուրդային նյութերը, և մշակված ալգորիթմով կատարվում է քանակական հաշվարկ՝ առանձին նյութերի պարունակության արտացոլմամբ (230…1000 *նմ* սպեկտրային զգայնության միջակայքում): Ամփոփված է նաև նոր մոտեցմամբ ստեղծված ֆոտոսպեկտրամետրային, շարժական սարքի կոնցեպտը, որի հիմքում օգտագործված է ընտրողական զգայնությամբ դյուրակիր տվիչը: Այս մոտեցումը զգալիորեն էժանացնում է բազմանշանակ ֆոտոսպեկտրամետրային սարքերի արտադրությունը:

Առանցքային բառեր. ֆոտոհոսանք, ֆոտոդիոդ, ֆոտոդետեկտոր, ալգորիթմ, սպեկտըրային վերլուծություն, անվտանգություն, թմրանյութեր, պայթուցիկ նյութեր:

АНАЛИЗ ФОТОТОКА В СИСТЕМАХ БЕЗОПАСНОСТИ И ОХРАНЫ

С.У. Цатурян

Исследуется новый подход к использованию датчиков с селективной чувствительностью (фотодиодов) для обнаружения и идентификации различных химических веществ. Изучены возможные случаи применения оптического анализа фототока для идентификации и качественного обнаружения различных смесей химических веществ в природных объектах с возможностью расчета количественных показателей (в спектральном диапазоне 230…1000 *нм*). Предлагается концепция портативного фотоспектрометра на базе датчика с селективной чувствительностью, позволяющая создать недорогое устройство для множества различных применений.

Ключевые слова: фототок, фотодиод, фотодетектор, алгоритм, спектральный анализ, безопасность, наркотические вещества, взрывчатые вещества.