SCIENCE AND INNOVATION
INTERNATIONAL SCIENTIFIC JOURNAL VOLUME 2 ISSUE 11 NOVEMBER 2023
UIF-2022: 8.2 | ISSN: 2181-3337 | SCIENTISTS.UZ

DESIGN FEATURES OF SELECTIVE RADIATION PHOTOTHERMOGENERATOR WITH A FIXED SLIT

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https://doi.org/10.5281/zenodo.10204306

Abstract. *The paper provides an analysis of the principle of combined conversion of light into electrical energy, a method for separating light radiation and the design of a highly efficient combined converter of light and thermal energy into electrical energy. A method for eliminating the heating of solar cells and increasing the efficiency value is described.*

Keywords: *radiation, manufacturing, technology, the efficiency of converting.*

Formulation of the problem

Despite many years of research, the issue of increasing the efficiency of converting solar radiation into electrical energy using semiconductor photoconverters (PVCs) still remains relevant. A lot of work has been done in this regard, the results of which are regularly published in periodical scientific and scientific-technical journals. A large number of works are devoted to improving the technology for manufacturing solar cells (SCs), a number of works report on the introduction of impurities into the structure of source materials [1-5], and there are certain positive results on combining SCs with thermoelectric converters (TECs) [6-7]. In addition, there are many publications on the creation of heterojunction and cascade SCs; it is impossible to list them all.

There are, of course, notable positives in the results of these studies. However, due to the main reason, the meaning of which is the strong spectral dependence of the conversion coefficient on the spectral composition of the incident radiation, the problem has not yet been fully solved. Along with the spectral dependence of the efficiency coefficient (efficiency) of the solar cell, there is the problem of temperature dependence. Although the latter can be solved by adding additional coolers to the design of solar converters, eliminating the bulkiness of solar sources of electrical energy is not only a weight and size problem, but also economically infeasible.

In this regard, this work is devoted to solving these last two problems. In our opinion, the creation and implementation of a photothermoelectric converter (PTEC) with a separate load and selected radiation gives a very positive result. Conventionally, such a converter is called a photothermal selective radiation converter (PSRC) [8-9].

The purpose of creating PSRC is to find the possibility of converting only the photoactive part of light radiation with a photoelectric converter, and the rest of the incident radiation with a thermoelectric converter. Moreover, in this case, since all light radiation with the corresponding spectral composition of light contributes to the creation of an electron-hole pair, then there is nothing left to heat the volume of the solar cell and, therefore, there will be no heating. For TECs, the composition of the light spectrum actually plays no role. It absorbs all light energy from the side of the light-receiving surface. This can be achieved by painting the surface of the TPE with black paint. Next, due to the Seebeck effect, thermal energy is converted into electrical energy.

A brief theory of converting light into electricity and calculating the main parameters of a photoconverter

As is known, the basis of the operation of solar cells is the process of interaction of sunlight with a semiconductor crystal; during which photons release electrons in crystals - electrical charge carriers. Regions with a strong electric field specially created in the volume of the crystals (for example, the so-called p-n junctions) trap the resulting electrons and separate them in such a way that current begins to flow in the device circuit, and electrical power is released to the payload.

According to the principle of operation, existing types of solar cells are divided into two classes: photocells based on the external photoelectric effect (vacuum and gas-filled), and semiconductor solar cells with a blocking layer. These same photocells are called valve cells.

Valve photocells compare favorably with all types of photovoltaic devices. This difference lies in the fact that when exposed to light they generate their own electromotive force (EmF). The value of this parameter in a number of cases in direct sunlight reaches up to one volt. By creating its own emf under the influence of radiation. valve photocells thus carry out a direct transition of radiant energy into electrical energy. The appearance of valve EmF. observed when light generates charge carriers near a potential barrier, that is, when illuminating metal-semiconductor contacts and *p-n* junctions. The photocell connection diagram is shown in Figure 1. The photocell under consideration in this case is a converter of light energy into electrical energy.

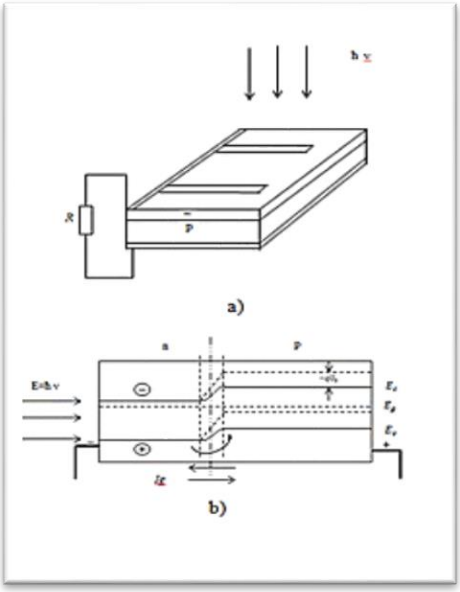

Figure. 1. General view of the photocell (a) and its zonal diagram (b)

The physical reason for the occurrence of valve photo emf. lies in the fact that the potential barrier of the p-n junction separates the flows of photoholes and photoelectrons.

Figure 1 shows the absorption of radiation by a crystal face parallel to the plane of the *n-p* junction. For definiteness, we will assume that the n-region is illuminated. In the first case, consider an open-circuit photocell. Electrons and holes created by illumination will diffuse deep into the crystal, and some of them, which did not have time to recombine (on the surface and in the bulk), reach the *p-n* junction. Here, effective operation of the photocell is expected when all the pairs created by the light reach the contact layer. However, for the majority electron carriers in the *p-n* junction there is a potential barrier, and therefore almost all of them will fall into the *p*-region. On the contrary, for minority carriers - holes - there is no potential barrier, and all holes that reach the transition will be drawn by the transition field deep into the crystal, creating a current I of equal magnitude

$$I = qS\beta F \tag{1}$$

where S – rate of surface vapor generation, β – fraction of minority carrier photoholes that reach the transition without recombination, F – illuminated area of the photocell.

The appearance of current I when the surface of the photocell is illuminated leads to negative charging of the *n*-region. The p-region in turn becomes positively charged. As a result, a potential difference arises between the electrodes of the element. This potential difference gives rise to a current I_∂ caused by the injection of holes into the *n*-region and electrons into the *p*-region. When there is no recombination in the *p-n* junction itself and the leakage currents are small, and also if the voltage drop in the thickness of the crystal is not taken into account, then this current can be described in the following form:

$$I_\partial = I_s(\exp(qU/kT)-1) \qquad (1)$$

Where $I_s = \frac{qD_p}{L_б} + \frac{qD_n\, n_p}{L_n}$ – saturation current; q – electron charge; k – Boltzmann constant; T – photocell temperature.

As a result of these currents, the following voltage will be established between the open electrodes of the photocell U_0, at which the total current $I_n = I - I_q = 0$. When the electrodes are shorted to an external load, the voltage between them decreases and the currents I and I_q will no longer compensate each other. As a result, a current arises in the circuit:

$$I_n'' = I - I_q = I - I_s(\exp(qU / kT)-1) \qquad (2)$$

Relation (2) is basic in the theory of valve photocells.

The main characterizing parameters of a photocell, such as integral sensitivity and spectral sensitivity, determine not only its properties, but also the limits of its application in a particular area. The *integral sensitivity of a photovoltaic cell is the value of the photocurrent* that flows in the short-circuited circuit of a photocell when a unit of radiant energy flux falls on it, consisting of waves of different lengths and corresponding in its spectral composition to the radiation of sunlight. This parameter is expressed by the formula:

$$K = \frac{I_\Phi}{\Phi} \qquad (3)$$

whre I_Φ - photocurrent; Φ- the total luminous flux incident on the PV.

At low luminous fluxes, the photocurrent and short-circuit current Is depend on the luminous flux. With increasing F, regardless of the inclusion of an external load on the PV, this linearity remains [10]. Spectral sensitivity Q_λ – characterizes the magnitude of the photocurrent from the action of a unit of radiant flux of a certain wavelength. In other words, to determine the spectral sensitivity of a photocell, the ratio of the short-circuit photocurrent is taken $I_{кз}^{\phi}$ to the flux of monochromatic radiation incident on the PV:

$$Q\lambda = \frac{I_{кз}^{\Phi}}{\Phi_\lambda} \qquad (4)$$

In all cases, when preparing photoelectric converters for operation, when it is necessary to have all optical data at hand, the value of the spectral sensitivity for any specific wavelength is not enough. Therefore, the spectral characteristic of a photovoltaic cell is most often used - the sensitivity distribution over the spectrum. And, as a consequence of this, the distribution of spectral sensitivity across the spectrum makes it possible to determine and calculate the current strength that flows in the photocell circuit when a light flux from any radiation source falls on it. Based on this, currently almost all photocells have their spectral characteristics depicted in graph form.

Method and method of dividing the light flux

Calculation of the light intensity distribution in the diffraction pattern can be carried out using the Huygens-Fresnel principle [11]. Based on the distribution of radiation in the spectrum, there is a device consisting of a set of lenses and prisms (Figure -2). The action of the prism is based on the phenomenon of dispersion, that is, the dependence of the refractive index φ of a substance on the wavelength of light λ. The radiation under study, which is subject to distribution over the spectrum, passing through the slit *S*, hits the lens $Л_{1.}$ the slit *S* on which the light falls is located at the focal point lens plane $Л_1$. This part of the device is called a collimator.

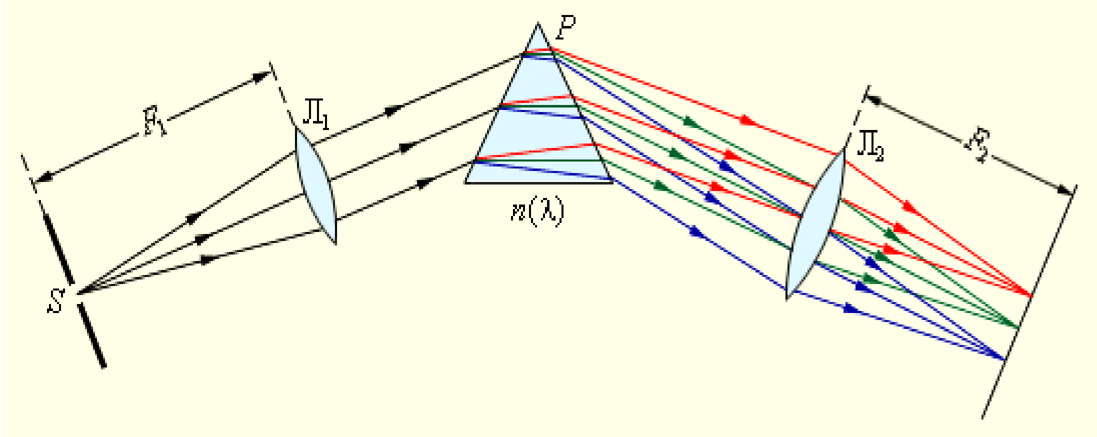

Figure 2. Scheme of decomposition of light radiation into a spectrum.

A parallel beam of light emerging from the lens falls on the prism *P*. Due to dispersion, light of different wavelengths leaves the prism at different angles. At the focal plane of the lens $Л_2$ there is a screen or photographic plate on which the radiation is focused. As a result, an image of the entrance slit S appears in different places on the screen in light of different wavelengths. For all transparent solids (glass, quartz) from which prisms are made, the refractive index n in the visible light range decreases with increasing wavelength λ, therefore, the prism deflects blue and violet rays most strongly from the original direction and red ones the least. Modern technology makes it possible to easily divide light fluxes into spectra. For this purpose, high-class spectral devices consisting of a diffraction grating can be successfully used.

In order for an interference maximum to be observed on the screen (or photographic plate) on which the radiation is focused, the path difference Δ between the waves emitted by adjacent slits must be equal to an integer number of wavelengths:

$$\Delta = d \sin \Theta_m = m\lambda \qquad (5)$$

Here d – lattice period, $m = 0, \pm 1, \pm 2, \ldots$ - order of the diffraction maximum. Lens focal plane distance y_m from the maximum of zero order (m = 0) to the maximum of mth order at small diffraction angles is equal to:

$$y_m = m\frac{\lambda}{\alpha}F, \qquad (6)$$

where F – focal length.

It should be noted that at each point of the focal plane of the lens, interference occurs between N waves arriving at this point from N grating slits. This is explained by multi-wave (or "multi-beam") interference. When moving from the main maximum to the adjacent minimum, the path difference $\Delta = d \sin \theta$ should change to λ / N. From this condition we can estimate the angular half-width $\delta\theta$ main maxima:

$$\Delta\delta = \delta(d \sin \Theta) = d \cos \Theta \delta\Theta \approx d * \delta\Theta = \frac{\lambda}{N} \qquad (7)$$

Here, for simplicity, it is assumed that the diffraction angles are sufficiently small. Hence,

$$\delta\Theta = \frac{\lambda}{Nd} \qquad (8)$$

where *Nd* – full grille size. This relationship is in full agreement with the theory of diffraction in parallel rays, according to which the diffraction divergence of a parallel beam of rays is equal to the ratio of the wavelength λ to the transverse size of the obstacle.

An important conclusion can be drawn: when light is diffraction by a grating, the main maxima are extremely narrow. Figure 3 gives an idea of how the sharpness of the main maxima changes with increasing number of grating slits.

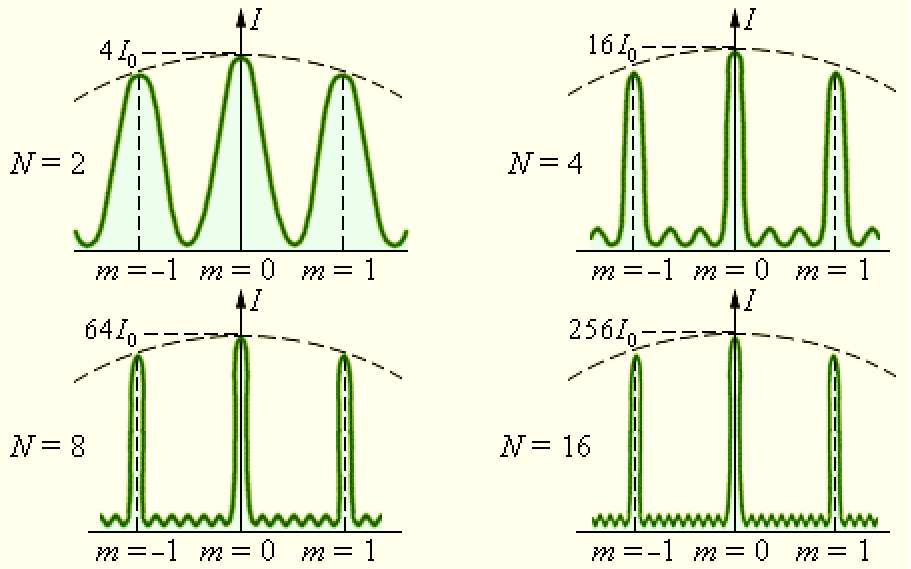

Figure 3. Intensity distribution during diffraction of monochromatic light on gratings with different numbers of slits. I_0 – intensity of vibrations during diffraction of light by one slit

As follows from the diffraction grating formula, the position of the main maxima depends on the wavelength λ. Therefore, the grating is capable of decomposing radiation into a spectrum, that is, it is a spectral device.

Methodology for designing and using a highly efficient combined converter

To obtain more detailed information about existing photothermoelectric converters, you can consult the previous works of these and other authors [6-7]. This development originally contributed to the overall efficiency as well as a simple photocell. significant, but not too much. The results of the study on the creation of photothermal converters (PCs) of a more advanced design led to the production of a sample (Figure 4), in which it is possible to solve two important problems: increasing the value of electrical efficiency. transformation and elimination of temperature deterioration of the electrical parameters of semiconductor materials.

This is achieved in the FTP design, in which the photo- and thermoelectric parts of the converters are exposed to light with light with different separated spectral characteristics. After all, overheating of the photoelectric converter occurred due to the non-photoactive part of solar radiation. Light passing into the FEC volume is not completely converted into electricity. Part of the radiation, absorbed in the volume, turns into heat. It has been known for a long time that an increase in the temperature of the solar cell has a negative effect on the conversion efficiency.

There are many works devoted to the temperature dependences of the electrophysical parameters of semiconductors.

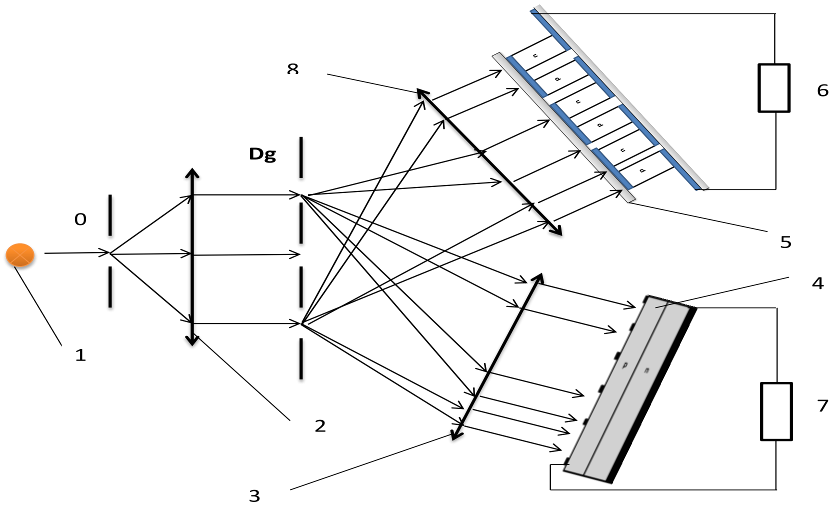

Figure-4. Scheme of distribution of light radiation on the surface of photoelectric and thermoelectric converters.
1-light source, 2, 3-set of optical glasses, 4-photoconverter,
5-front surface of the thermal converter, 6-load of the thermal converter, 7-load of the photoconverter.

Thus, a photothermal converter with light radiation separated by spectrum (Figure 4) is illuminated so that the radiation that creates electron-hole pairs hits the front surface of the photoelectric converter. This is achieved by using a set of lenses and prisms 2 and 3, operating according to the Huygens-Fresnel principle. A set of optical filters, repeatedly refracting the radiation, distributes it into two parts. The main - the first part of the radiation mainly consists of short-wave and partly from the visible regions of the spectrum. It is directed to the front surface of the photoconverter 4. The other, longer-wave part ("warm") of the radiation, entering the upper hot switching plates 5 of the thermal converter (TEC), is additionally converted into electrical energy. As is known, for TEC the spectral composition of light is not significant. Conversion into heat is important to him. The thermal energy of the hot junction contributes to the generation of electricity in addition to the electricity of the photoelectric conversion method.

The presented version of a photothermal converter operating on specially distributed light is included for separate loads. The FEP load is 7 and the TEP load is 6. However, based on the results of theoretical calculations, it was established that they can be included in the total load. To do this, it is necessary to select the number and geometric dimensions of the thermoelement branches, and the number of fuel elements.

The advantage of this design of selective converters is that in this case the heating of photoelectric converters is eliminated. As a result, it is possible to practically maintain the efficiency values of solar cells at the highest light intensities.

And formula

$$\eta_{\text{фэп}} = \frac{W_{\text{пол}}^{\text{макс.фэп}}}{W_{\text{пад}}^{1}} \qquad (9)$$

shows that this parameter becomes significantly higher than it was before, that is, the same solar cell without any design changes gives greater values of η solar cell. This is explained by the following: in formula (9), the expression in the denominator, in contrast to traditional calculations,

$$\eta_{фэп}=\frac{W_{пол}^{макс.фэп}}{W_{пад}} \qquad (10)$$

is a quantity equal to $W_{пад}^{1} = (1-k)W_{пад} – Q$, where $W_{пол}^{макс.фэп}$ – useful maximum electrical power released at the PV load, $W_{пад}^{1}$ - the photoactive part of the light radiation arriving at the surface of the solar cell, $W_{пад}$ – integral light power directed from the light source to the photothermal converter, k is the coefficient of light reflection from the front surface of the photoconverter. For calculation it was taken equal to 20%. Accordingly, efficiency thermal converter

$$\eta_{тэп}=\frac{W_{пол}^{макс.тэп}}{(1-k)W_{пад}-W_{пад}^{1}}=\frac{W_{пол}^{макс.тэп}}{Q_{тэп}} \qquad (11)$$

In the last formula $W_{пол}^{макс.тэп}$ – useful electrical power generated at the load of the thermal converter when its front surface is illuminated. $Q_{тэп} = W_{пад}^{"}$ – light power incident on the ceramic plate on the surface of the thermal converter. It is actually equal to the heat flux entering the hot junctions of the TEC, since the front surface of the TEC is painted black, which corresponds to a 100% black body absorption coefficient.

Conclusion

In conclusion, it should be noted that the proposed method of combining and converting light radiation gives high efficiency values. without significant economic and constructive costs. In addition, it is an original way to eliminate the parasitic thermal effect in the volume of the solar cell. Aiming at the fact that there are still prospects for the development of research and development work in finding ways to increase the efficiency of the photoelectric method of converting light into electricity, it can be assumed that there is a method for utilizing non-photoactive light from photoelectric conversion using solar collectors. Modern solar collectors, if the optimal design option is found, can work quite successfully in combination with solar cells. And in this case there is a gain - it is saving heat energy, which is not an unimportant factor in our time!

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