High Efficiency of a Photoelectric Converter in a Combined Design with a Thermoelectric Converter

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ABSTRACT

The paper analyzes 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 is described for eliminating heating of the PVC and increasing the value of its efficiency.

KEYWORDS: *photoconverters, sunlight, thermoelectric converter, photo holes and photoelectrons, integral sensitivity, spectral sensitivity, diffraction of monochromatic light.*

Introductions. Despite many years of research, the issue of increasing the efficiency of converting solar radiation into electrical radiation using semiconductor photoconverters (PCs) still remains relevant. In this regard, a lot of work has been done and 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 of manufacturing solar cells (solar cells), a number of works notify about the introduced impurities in the structure of starting materials [1-5], and there are certain positive results on combining solar cells with thermoelectric converters (TC) [6]. In addition, there are many publications on the creation of heterojunction and cascade solar cells, it is impossible to list everything.

There is, of course, a marked positive outcome in the results of these studies. However, due to the main reason, the meaning of which lies in 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 (efficiency) of the solar cell, there is the problem of temperature dependence. Although the latter is solved by adding additional coolers to the design of solar converters, eliminating the bulkiness of solar power sources is not only a weight and size problem, but also economically inexpedient.

In this regard, the present 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 referred to as a selective radiation photothermal converter (SRPTC) [8-9].

The purpose of creating SRPTC is to find possibilities for converting only the photoactive part of light radiation by a photoelectric converter, and the rest of the incident radiation by 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 nothing remains for heating the PTEC volume and, therefore, there will be no heating. For TEC, the composition of the light spectrum does not actually play any role. It absorbs all light energy from the side of the light-receiving surface. This can be achieved by painting the TEC surface with black paint. Further, due to the Seebeck effect, thermal energy is converted into electrical energy.

Brief theory of conversion of light into electricity and calculation of the main parameters of the photoconverter.

As you know, the basis of the PTEC is the process of interaction of sunlight with a semiconductor crystal; during which photons release electrons in crystals - carriers of electric charge. Areas with a strong electric field specially created in the bulk of the crystals (for example, the so-called p-n junctions) capture the generated electrons and separate them in such a way that a current begins to flow in the device circuit, and electric power is released on the payload.

According to the principle of operation, the existing types of FEP are divided into two classes:

➢ photocells based on external photoelectric effect (vacuum and gas-filled);

➢ semiconductor PVC with a blocking layer. The same photocells are called valve.

Valve photovoltaic cells compare favorably with all types of photovoltaic devices. This difference lies in the fact that under the action of 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 action of radiation valve photocells, thus directly transferring radiant energy into electrical energy. The emergence of a valve electromotive force. observed in the case when light generates charge carriers near the potential barrier, that is, when illuminating metal-semiconductor contacts and p-n-junctions. **The circuit for switching on the photocell is shown in Figure 1**. The photocell under consideration in this case is a converter of light energy into electrical energy.
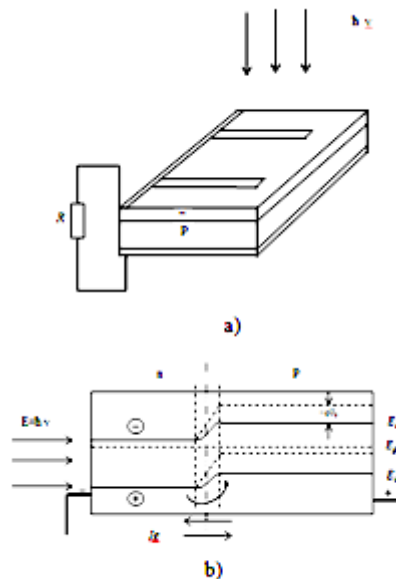

Figure 1. General view of the photocell (a) and its zone diagram (b)

The physical reason for the emergence of the valve photo emf. lies in the fact that the potential barrier of the p-n-junction separates the fluxes 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 photocell. Electrons and holes created by illumination will diffuse into the interior of the crystal, and some of their fraction, which did not have time to recombine (on the surface and in the bulk), reaches the pn junction [11-13]. Here, the effective operation of the photocell is expected when all the pairs created by the light have reached the contact layer. However, there is a potential barrier for the majority

carriers of electrons in the p-n-junction, and therefore practically 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 have reached the transition will be pulled by the transition field deep into the crystal, creating a current I equal in magnitude

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

where S is the rate of surface generation of pairs, β is the fraction of minority carrier photoholes that have reached the transition without recombinations, F is the illuminated area of the photocell.

The emergence of current I when illuminating the surface of the photocell leads to negative charging of the n-region. p-region, in turn, is positively charged. As a result, a potential difference arises between the electrodes of the cell. This potential difference leads to the appearance of a current Id 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 as follows:

$$I_\partial = I_s(exp\,(qU/kT)\text{-}1) \tag{2}$$

Where $I_s = \frac{qD_p}{L_\delta} + \frac{qD_n\,n_p}{L_n}$ - saturation current; q is the electron charge; k is the Boltzmann constant; T is the temperature of the photocell.

As a result of these currents, a voltage U0 will be established between the open electrodes of the photocell, at which the total current In = I - Iq = 0. When the electrodes are closed to an external load, the voltage between them decreases and the currents I and Iq will no longer compensate each other. As a result, a current arises in the circuit:

$$I_n^{''} = I - I_q = I - I_s(exp\,(qU\,/\,kT)\text{-}1) \tag{3}$$

Relation (2) is the main one 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 the PE K is the value of the photocurrent that flows in the short-circuited circuit of the photocell when a unit of the flux of radiant energy 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:

$$K = \frac{I_\phi}{\Phi} \tag{4}$$

where I_ϕ is the photocurrent; Φ is the total luminous flux incident on the PE.

At low luminous fluxes, the photocurrent and short-circuit current $I_{к3}$ depends on the luminous flux. With an increase in Φ, regardless of the inclusion of an external load on the PEC, this linearity remains [10]. Spectral sensitivity $Q\lambda$ - 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 the photocell, the ratio of the short-circuit photocurrent $I_{к3}^{\phi}$ to the monochromatic radiation flux incident on the PE is taken:

$$Q\lambda = \frac{I_{к3}^{\Phi}}{\Phi_\lambda} \tag{5}$$

In all cases, when preparing photovoltaic converters for work, when it is necessary to have all the optical data at hand, the value of the spectral sensitivity for any particular wavelength is not enough.

Therefore, the spectral characteristic of the PEC is most often used - the distribution of the sensitivity over the spectrum. And, as a consequence of this, the distribution of spectral sensitivity over the spectrum makes it possible to determine and calculate the strength of the current that flows in the photocell circuit when a light flux falls on it from any radiation source. Based on this, at present, almost all photocells have their own spectral characteristics shown in the form of a graph.

Technique and method of dividing the luminous flux

The calculation of the light intensity distribution in the diffraction pattern can be carried out using the Huygens-Fresnel principle [11]. The distribution of radiation in the spectrum is based on 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 investigated radiation, which is subjected to distribution over the spectrum, having passed through the slit S, falls on the lens L1. the slit S on which the light falls is in the focal one.
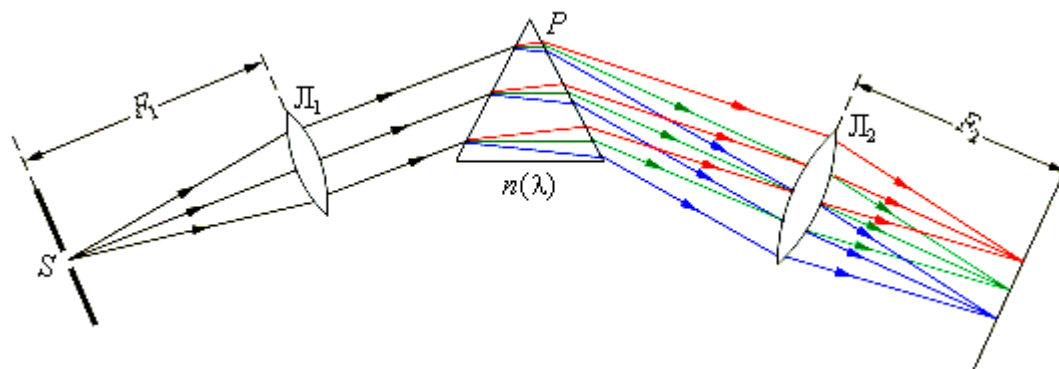

Figure 2. Scheme of the decomposition of light radiation into a spectrum

lens plane L1. This part of the instrument is called a collimator. A parallel beam of light emerging from the lens is incident on a prism P. Due to dispersion, light of different wavelengths exits the prism at different angles. In the focal plane of the lens L2 there is a screen or photographic plate on which the radiation is focused. As a result, in different places of the screen, an image of the entrance slit S appears in the light of different wavelengths. For all transparent solids (glass, quartz), from which prisms are made, the refractive index n in the range of visible light decreases with increasing wavelength λ, therefore the prism deviates most strongly from the original direction blue and violet rays and the least red. Modern technology allows you to easily split the light fluxes into spectra. For this, it is possible to successfully use high-class spectral devices consisting of a diffraction grating [13].

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:

$$\Delta = d \sin \Theta_m = m\lambda \qquad (6)$$

Here d is the grating period, m = 0, ± 1, ± 2, ... is the order of the diffraction maximum. In the focal plane of the lens, the distance ym from the zeroth order maximum (m = 0) to the mth order maximum at small diffraction angles is:

$$y_m = m\frac{\lambda}{\alpha}F, \qquad (7)$$

where F is the focal length.

It should be noted that at each point of the focal plane of the lens there is interference of N waves arriving at this point from N grating slits. This is due to multiwave (or "multibeam") interference. When passing from the main maximum to the neighboring minimum, the path difference $\Delta = d \sin \theta$ should change by λ / N. From this condition, it is possible to estimate the angular half-width $\delta\theta$ of the main maxima:

$$\Delta\delta = \delta(d \sin \Theta) = d \cos \Theta \delta\Theta \approx d * \delta\Theta = \frac{\lambda}{N} \tag{8}$$

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

$$\delta\Theta = \frac{\lambda}{Nd} \tag{9}$$

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

An important conclusion can be drawn: when light is diffracted by a grating, the main maxima are extremely narrow. Fig. 3. gives an idea of how the sharpness of the main maxima changes with an increase in the number of lattice slots.
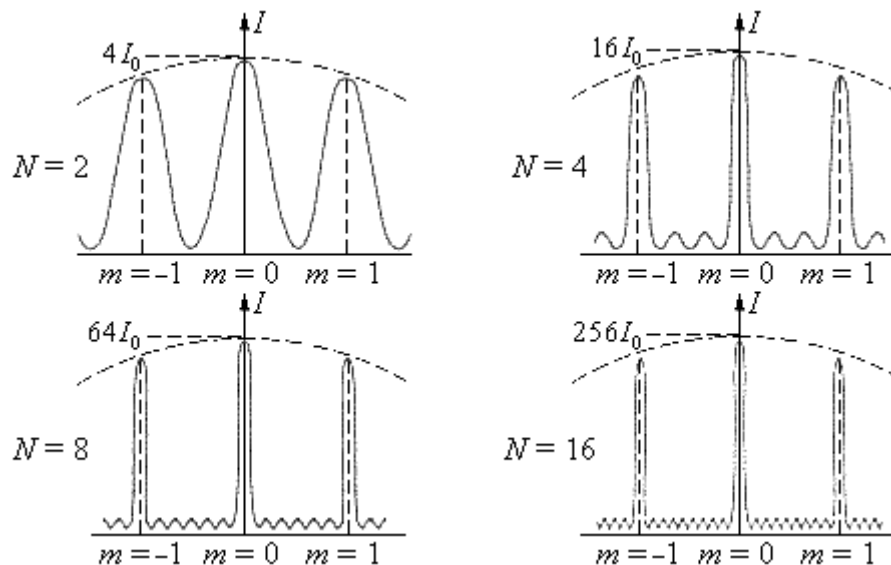

Figure 3. Intensity distribution for diffraction of monochromatic light on gratings with different numbers of slits. I_0 is the intensity of vibrations when light is diffracted by one slit

As follows from the formula of the diffraction grating, 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*.

Technique for designing and using a high efficiency combined converter

To obtain more detailed information about the existing photothermoelectric converters, one can familiarize oneself with the previous works of the present and other authors [6-7]. This development, initially as well as a simple photocell, contributed to the overall efficiency. essential, but not too much. The results of a study on the creation of photothermal converters (PTEC) designs of a more advanced design led to the production of a sample (Fig. 4), in which it is possible to solve two

important problems: an increase in the value of the electric efficiency. transformation and elimination of temperature deterioration of the electrophysical parameters of semiconductor materials.

This is achieved in the design of the PTEC, in which the photo- and thermoelectric parts of the converters are exposed to illumination with light with different separated spectral characteristics. After all, the overheating of the photovoltaic converter occurred due to the non-photo of the active part of the solar radiation. The light passing into the PEC volume is not completely converted into electrical one. Part of the radiation, absorbed in the volume, turns into heat. The fact that an increase in the temperature of the PEC negatively affects the efficiency of the conversion has been known for a long time. There are many works devoted to the temperature dependences of the electrophysical parameters of semiconductors.
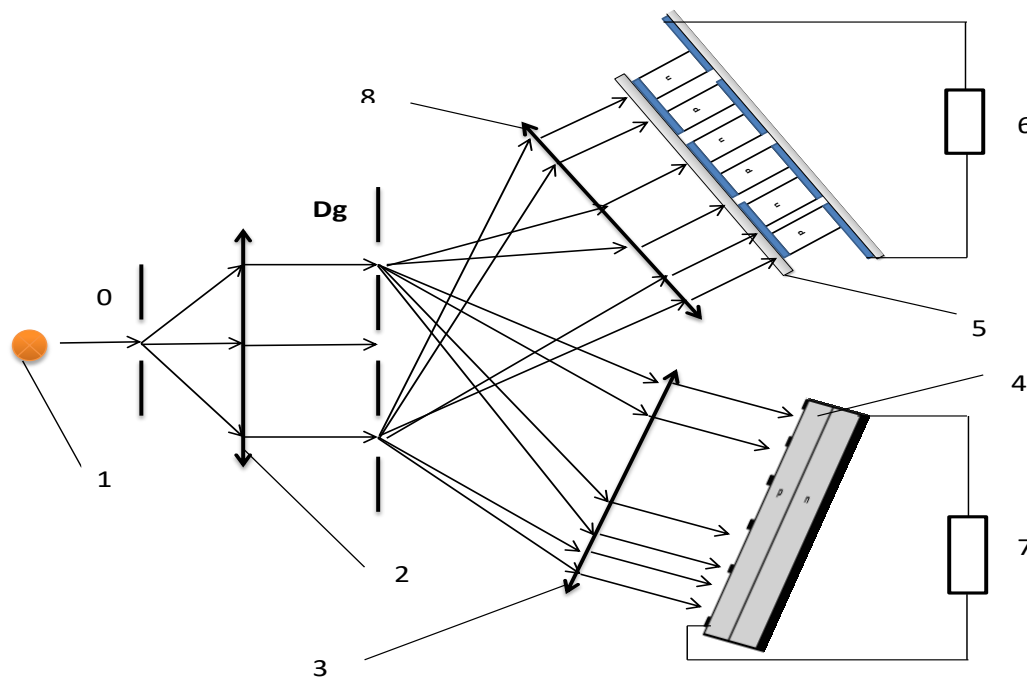

Figure 4. Scheme of distribution of light radiation on the surface of photoelectric and thermoelectric converters. 1-light source, 2, 3-set of optical glasses, 4-photoconverter, 5-front surface of the thermal converter, 6-load of the thermal converter, 7-load of the photoconverter.

So, a photothermal converter with a spectrum-separated light radiation (Figure-4) is illuminated so that the radiation that creates electron-hole pairs hits the front surface of the photoelectric converter. This is achieved using a set of lenses and prisms 2 and 3, working according to the Huygens-Fresnel principle. A set of optical filters, repeatedly refracting radiation, distributes it into two parts. The main - the first part of the radiation mainly consists of short-wave and partly of the visible spectral regions. It is directed to the front surface of the photoconverter 4. The other, the longer-wavelength ("warm") part of the radiation, arriving at the upper hot switching plates 5 of the thermal converter (TEC) is additionally converted into an electrical one. As is known, for TEC, the spectral composition of light is not essential [12]. For him, transformation into heat is important. The thermal energy of the hot junction contributes to the production of electricity in addition to the electricity of the photovoltaic conversion method.

The above version of a photothermal converter operating on specially distributed light is included for separate loads. The load of the PEC is 7 and the load of TEC-6. However, as a result of a theoretical calculation, it was found that they can be included in the total load. For this, it is necessary to select

the number and geometrical dimensions of thermoelement legs, and the number of TEs.

The advantage of the present design of selective converters is that in this case the heating of the photovoltaic converters is eliminated. As a consequence of this, it is possible to practically maintain the values of the efficiency of the photovoltaic transformer at the highest light intensities. And the formula

$$\eta_{\text{фэп}} = \frac{W_{\text{пол}}^{\text{макс.фэп}}}{W_{\text{пад}}^{1}} \qquad (10)$$

shows that this parameter becomes significantly higher than it was before, that is, one and the same PEC without any design changes gives a larger value of $\eta_{\text{ФЭП}}$. This is explained by the following: in formula (9), the expression in the denominator, in contrast to traditional calculations,

$$\eta_{\text{фэп}} = \frac{W_{\text{пол}}^{\text{макс.фэп}}}{W_{\text{пад}}} \qquad (11)$$

there is a value equal to $W_{\text{пад}}{}^{1} = (1\text{-}k)W_{\text{пад}} - Q$, where $W_{\text{пол}}^{\text{макс.фэп}}$ is the maximum useful electrical power released at the PEC load, $W_{\text{пад}}^{1}$ is the photoactive part of the light radiation arriving at the surface of the PEC, $W_{\text{пад}}$ is the integrated 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 the calculation, it was taken equal to 20%. Accordingly, efficiency thermal converter

$$\eta_{\text{тэп}} = \frac{W_{\text{пол}}^{\text{макс.тэп}}}{(1-k)W_{\text{пад}} - W_{\text{пад}}^{1}} = \frac{W_{\text{пол}}^{\text{макс.тэп}}}{Q_{\text{тэп}}} \qquad (12)$$

In the last formula, $W_{\text{пол}}^{\text{макс.тэп}}$ is the useful electrical power generated at the load of the thermal converter when its front surface is illuminated. $Q_{\text{тэп}} = W_{\text{пад}}^{''}$ is the light power falling 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 one hundred percent absorption coefficient of the black body.

Conclusion

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

References:

1. Mamadilieva L. K., Zokirov S. I. Automation problems of finding the optimal coordinates of a photocell in a selective radiation photothermogenerator. – 2019.

2. Kasimakhunova A. M. et al. Research of AHV-effect in films and crystals with the effect of the double luxurification //Computational nanotechnology. – 2018. – №. 3. – С. 44-48.

3. Касимахунова А. М. и др. Исследования некоторых явлений в АФН-структурах с изовалентными примесями для разработки приборов и устройств неразрушающего

контроля и измерения //Computational nanotechnology. – 2018. – №. 2.

4. Abduqaxxorovich O. S. et al. Development and research of heterostructures with an internal thin layer based on p-type silicon //European science review. – 2018. – №. 9-10-1.

5. Мамадалиева Л. К., Набиев М. Б., Усмонов Я. Легирование термоэлектрических материалов на основе Bi2Te3-Sb2Te3 для фототермопреобразователей солнечного излучения //Янги материаллар ва гелиотехнологиялар. – 2030. – С. 90.

6. Мамадалиева Л. К. Анализ и выбор монохроматоров для фототермогенератора селективного излучения //Universum: технические науки. – 2020. – №. 6-1 (75). – С. 74-77.

7. Mamadalieva L. K. Development of photothermoelectric converters and research of their design and operational features //Euroasian Journal of Semiconductors Science and Engineering. – 2019. – Т. 1. – №. 6. – С. 3.

8. Мамадалиева Л. К. и др. Энергосберегающий частотноуправляемый асинхронный электропривод с вентиляторной нагрузкой //Вестник науки и образования. – 2019. – №. 13-2 (67).

9. Paizullakhanov MS, Kholmatov AA, Sobirov MM, Khamdamov B. Wear-Resistant Materials Synthesized in A Solar Furnace. // Journal of Material Sciences & Manufacturing Research. 2020.

10. Muhammad-Sultanhan, Paizullahanov, Sobirov Muslimjon Mukhsinjonugli, Xolmatov Abdurashid Abdurakhimugli. "Materials processing in the solar furnace." ACADEMICIA: An International Multidisciplinary Research Journal. 10.10 (2020): 1233-1237.

11. Payzullakhanov Mukhammad-Sultan Saidvalikhanovich, Xolmatov Abdurashid Abdurakhim ugli, Sobirov Muslim Muhsinjon ugli. Magnetic materials synthesized in the sun furnace // International Journal of Advanced Research in Science, Engineering and Technology. 2020. Vol. 7, Issue 4, pp.1499-13505.

12. A.A Xolmatov, J.X Karimov, A.M Xayitov. Effect of crystallizer catalyst on properties of glass-crystalline materials. // EPRA International Journal of Research and Development (IJRD). 2021, pp.273-275.

13. Пайзуллаханов Мухаммаде-Султанхан Саидивалиханович, Холматов Абдурашид Абдурахим Угли, Собиров Муслимбек Мухсинжон Угли Титанаты бария и стронция, синтезированные на солнечной печи // Universum: технические науки. 2020. №6-1 (75).

14. Paizullakhanov MS, Kholmatov AA, Sobirov MM, Khamdamov B. Wear-Resistant Materials Synthesized in A Solar Furnace. // Journal of Material Sciences & Manufacturing Research. 2020.

15. Muhammad-Sultanhan, Paizullahanov, Sobirov Muslimjon Mukhsinjonugli, Xolmatov Abdurashid Abdurakhimugli. "Materials processing in the solar furnace." ACADEMICIA: An International Multidisciplinary Research Journal. 10.10 (2020): 1233-1237.

16. Okhunov, M., & Minamatov, Y. (2021). Application of Innovative Projects in Information Systems. European Journal of Life Safety and Stability (2660-9630), 11, 167-168.

17. Kuchkarov A. A., Muminov S. A., Abdurakhmanov A. A. Combined Energy Supply for Sixty-Two Heliostats of the Big Solar Furnace //Journal of Siberian Federal University. Engineering & Technologies. – 2020. – Т. 13. – №. 4. – С. 449-454.

18. Кучкаров А. А., Муминов Ш. А. У. Моделирование и создание плоского френелевского

линейного зеркального солнечного концентратора //Universum: технические науки. – 2020. – №. 3-2 (72). – С. 80-85.

19. Kasimakhunova A. M. et al. Photo Thermal Generator of Selective Radiation Structural and Energetic Features //Journal of Applied Mathematics and Physics. – 2019. – Т. 7. – №. 06. – С. 1263.

20. Axmadaliyevich K. A. et al. Possibilities of getting electricity with the help of a small solar furnace //EPRA International Journal of Research & Development. – 2021. – Т. 6. – №. 6. – С. 147-151.

21. A. M. Kasimaxunova, Maxsudjon Norbutaev, and Madinaxon Baratova. Thermoelectric generator for rural conditions. Scientific progress, vol. 2, no. 6, 2021, pp. 302-308.