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EXPERIMENTAL RESEARCH OF NEW GENERATION SOLAR CELLS

Abstract. Experimental work was done on a physical model of a solar photovoltaic battery with very high technical and economic efficiency due to the dispersion and focusing of solar radiation by wavelengths and due to the installation of various photocells at each wavelength.

Experimental data and their processing showed that the power of the proposed design of the solar cell in terms of photoconverters is 1.46-1.48 times higher compared to the use of gallium arsenide according to conventional technology, and 4.15-4.2 times higher than single-crystal silicon. Moreover, the proposed solar cells require much less photocells, which significantly increases economic efficiency.

Key words. Solar cell, holographic concentrator, photocells, technical and economic parameters of solar cells.

In world practice, the improvement of solar cells heads toward the increase in the efficiency of solar cells with silicon being the most widely used. For instance, at the world congress of scientists and engineers in the framework of EXPO-2017 held in 2017 in the city of Astana (Nur-Sultan), it was announced that in the coming years the efficiency value of about 25% will be achieved [1].

At the same time, increasing the conversion efficiency of solar radiation is possible not only as a result of increasing the efficiency of photocells, but also due to the increase in the efficiency of solar cells [2, 3] by means of dispersing rays by wavelengths, their separate concentration. A photocell is installed at each separately focused wavelength. In this case, thermal radiation does not hit the photocells, and the required number of photocells is many times reduced.

Figure 1 shows a process chart of one option of the solar cell with increased efficiency (in line with patent RK #31796 (2016) [4].

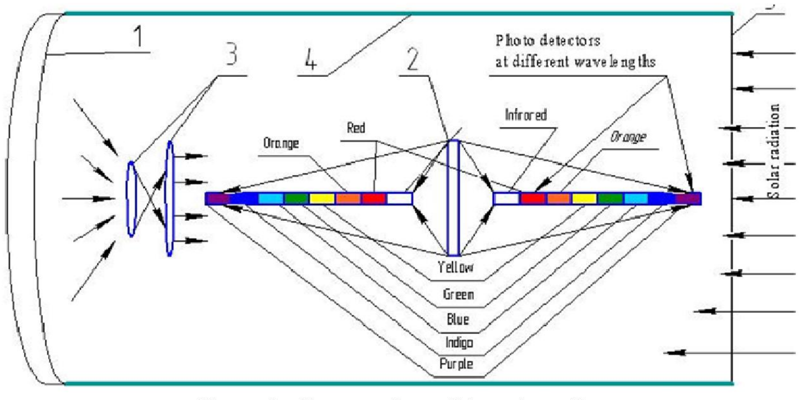

Figure 1 – Process chart of the solar cell

The mirror 1 with a radius of, for example, 30 cm concentrates sun rays, and the parallel rays through collimator lenses 3 hit the holographic concentrator 2 with a radius of 5 cm. The mirror area $S_з$ is 2,826 cm^2. The area of the concentrator $S_к$ = 78.5 cm. The concentration of solar stream K = $S_з/S_к$ = 2,826/78.5 = 36 times. Figure 1 shows that the photoelectric converters are located on both sides of the holographic concentrator, onto which sun rays come from two sides: single radiation of solar energy on the right, and thirty-six-fold one on the left. At ideal performance, the holographic concentrator reflects about 60% and transmits 40% of the sun rays.

Thus, 40% of single solar radiation and 60% of thirty-six-fold solar radiation hit the left photoreceivers, and 60% of single solar radiation and 40% of thirty-six-fold solar radiation fall onto the right photoreceivers:

$$\Phi_{лев} = 0{,}4 * \Phi + 0{,}6 * 36 * \Phi = 22\Phi \quad (1)$$

$$\Phi_{прав} = 0{,}6 * \Phi + 0{,}4 * 36 * \Phi = 15\Phi \quad (2)$$

where, Φ is single photoemission; $\Phi_{лев}$ is photoemission onto the left photoelectric converter; $\Phi_{прав}$ is photoemission onto the right photoelectric converter.

To examine the efficiency of conversion of solar radiation using a holographic concentrator and to measure the current-voltage characteristics of photoconverters, a physical model of the currently developed solar sell was produced. Figures 2, 3, 4 show photographs of a physical model without a mirror.

The holographic concentrator disperses solar radiation by wavelengths (by rainbow colors), focuses them separately, the area of each focused light (red, orange, etc.) is about 0.25 cm^2. To determine the efficiency of each wavelength, the photoconverters are mounted on a moveable bar (Figure 2). The moveable bar is installed inside the physical model of the solar sell (Figures 3, 4).

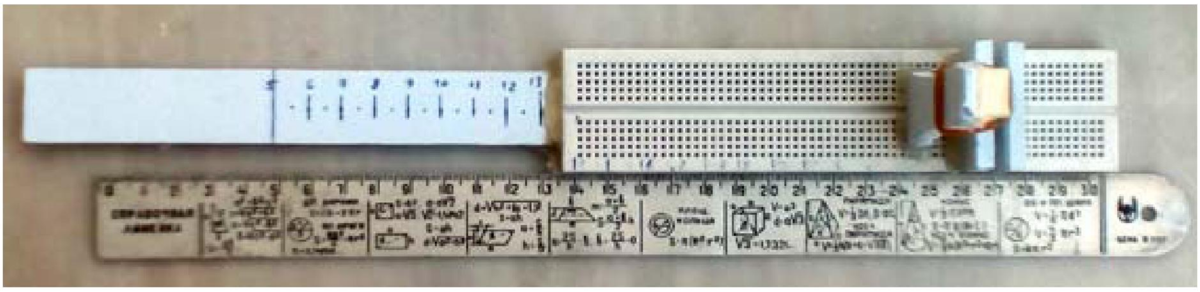

Figure 2 – Fixing a photoconverter onto a moveable bar

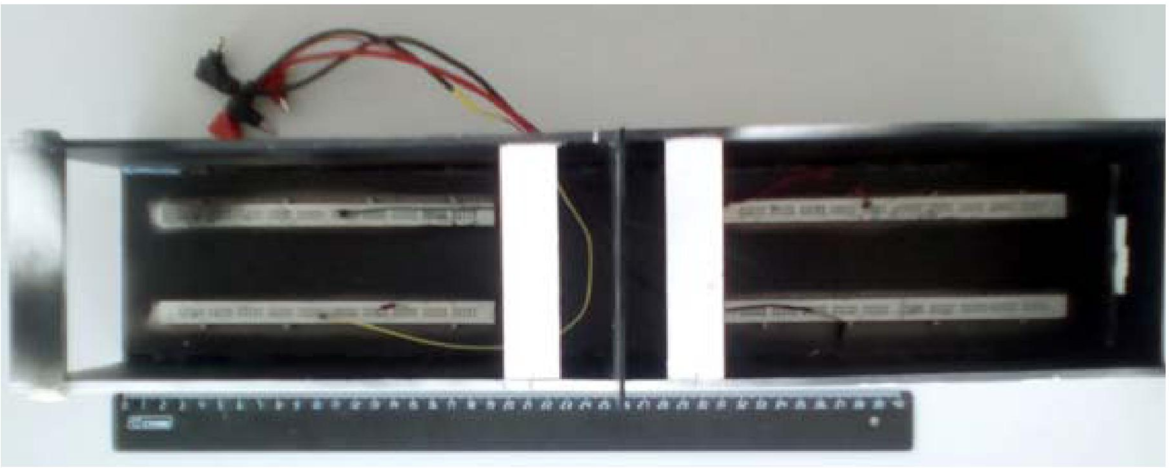

Figure 3 – Physical model of the solar sell (top view)

Figure 4 - Physical model of the assembled solar sell

To establish the photoconversion power of monocrystalline silicon (MonoSi) on an area of 0.25 cm^2, a 1 cm^2 panel was covered with a protective screen with a 0.25 cm^2 opening (Figure 5). The open circuit voltage V (*V*) and short circuit current I *(A*) were measured. Next, the output electric power P (*W*) was calculated. The measurements were made in 1 cm increments and the results are given in Table 1.

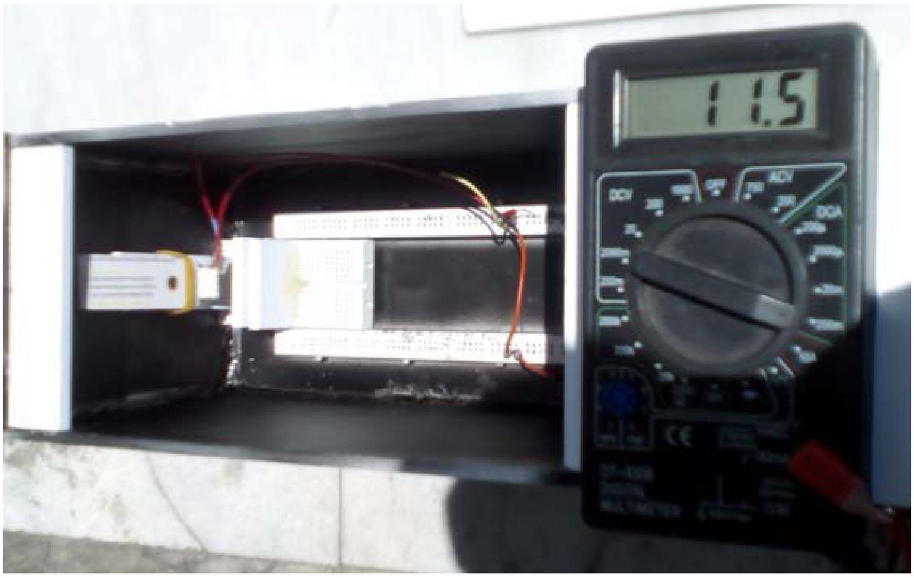

Figure 5 – Measuring current-voltage characteristics of photoconversion of single-crystal silicon (MonoSi) on the area of 0.25 cm^2

Table 1 - Variability of the photoconversion power of single-crystal silicon (MonoSi) over the area of 0.25 cm^2 depending on the wavelength of solar radiation

Colour	Red	Or	Yel	Green	Green	Light blue	Blue	Blue	Viol	Viol
Wavelength, nm	700	600	575	565	535	490	460	440	410	380
Distance from the concentrator, cm	13	14	15	16	17	18	19	20	21	22
V, V	1.87	1.85	1.83	1.81	1.79	1.77	1.75	1.73	1.71	1.69
I, A	0.077	0.076	0.075	0.074	0.074	0.073	0.072	0.071	0.070	0.069
P, W	**0.144**	**0.141**	**0.138**	**0.135**	**0.132**	**0.129**	**0.126**	**0.123**	**0.120**	**0.117**

The decomposition (dispersion) of solar energy begins at a distance of 13 cm from the holographic concentrator.

Figure 6 shows a curve of dependence of the photoconversion power of single-crystal silicon (MonoSi) over the area of 0.25 cm^2 (W) on the wavelength of solar radiation.

To examine the photoconversion power of amorphous silicon (AmSi) over the area of 0.25 cm^2, a 32 cm^2 panel was used and covered with a protective screen with a 0.25 cm^2 opening (Figures 7 and 8). The open circuit voltage V (*V*) and short circuit current I *(A*) were measured. Next, the output electric power P (*W*) was calculated. The measurements were made in 1 cm increments and the results are given in Table 2.

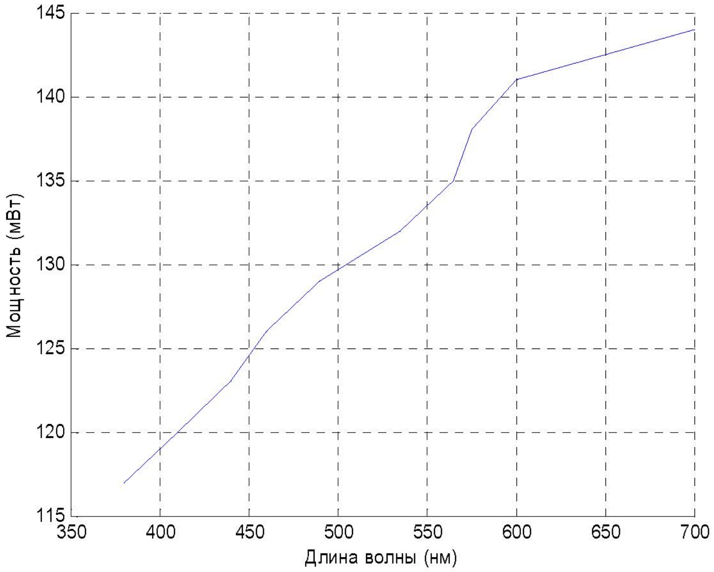

Figure 6 - The curve of dependence of the photoconversion power of single-crystal silicon (MonoSi) over the area of 0.25 cm^2 (W) on the wavelength

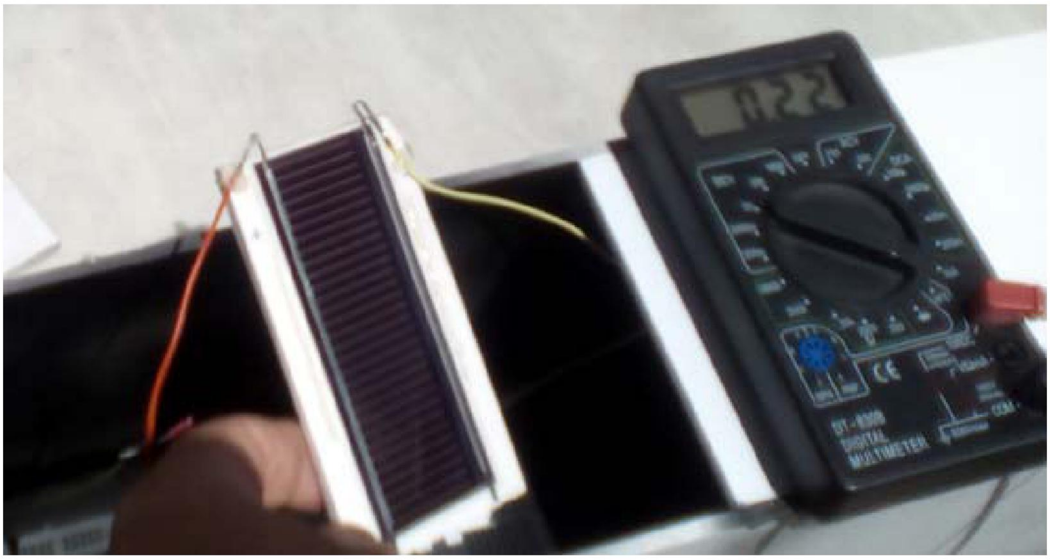

Figure 7 – Measuring the short circuit current of the amorphous silicon panel

Figure 8 – Measuring the photoconversion voltage and current over the area of 0.25 cm^2

Table 2 - Variability of the photoconversion power of amorphous silicon (AmSi) over the area of 0.25 cm^2 depending on the wavelength

Colour	Red	Or	Yel	Green	Green	Light blue	Blue	Blue	Viol	Viol
Wavelength, nm	700	600	575	565	535	490	460	440	410	380
Distance from the concentrator, cm	13	14	15	16	17	18	19	20	21	22
V, V	0.1	0.1	0.13	0.15	0.16	0.13	0.1	0.1	0.1	0.1
I, A	0.07	0.085	0.1	0.15	0.155	0.17	0.11	0.07	0.06	0.06
P, W	**0.007**	**0.0085**	**0.013**	**0.0225**	**0.0248**	**0.0221**	**0.011**	**0.007**	**0.006**	**0.006**

Figure 9 shows a curve of dependence of the photoconversion power of amorphous silicon (AmSi) over the area of 0.25 cm^2 (W) on the wavelength of solar radiation.

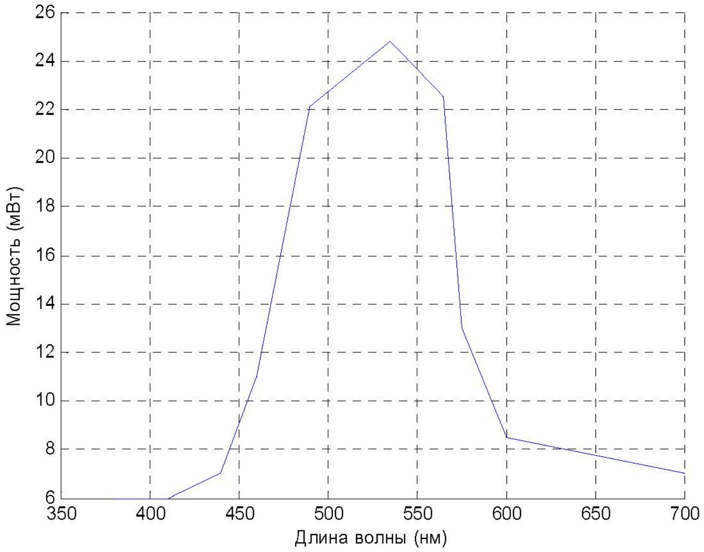

Figure 9 - The curve of dependence of the photoconversion power of amorphous silicon (AmSi) over the area of 0.25 cm^2 (W) on the wavelength

To establish the photoconversion power of gallium arsenide (GaAs), a 32 cm^2 panel was used valued at $575. The open circuit voltage V = 2.88 *V* and short circuit current I = 0.48*A* were measured (Figure 10). Next, the output electric power P = 2.88·0.48 = 1.3824 *W* was calculated.

Figure 10 – Establishing the photoconversion power of gallium arsenide (GaAs)

To establish the photoconversion power of gallium arsenide (GaAs), a 0.25 cm^2 area of the panel was covered with a protective screen with a corresponding opening (Figure 11). The measurements were made in 1 cm increments and the results are given in Table 3.

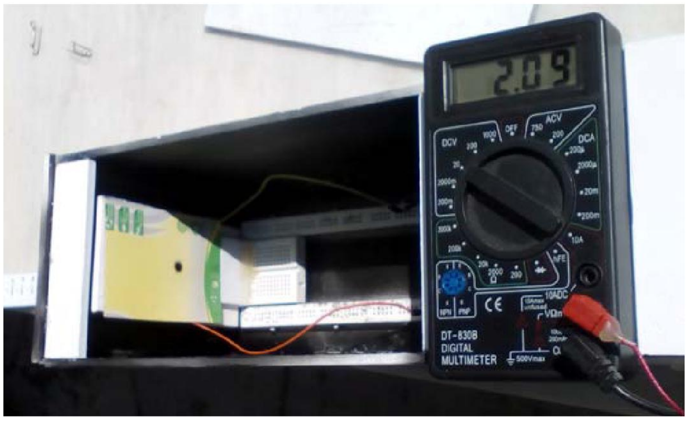

Figure 11 - Measuring current-voltage characteristics of photoconversion of gallium arsenide (GaAs) on the area of 0.25 cm^2

Table 3 – Variability of the photoconversion power of gallium arsenide (GaAs) over the area of 0.25 cm^2 depending on the wavelength

Colour	Red	Or	Yel	Green	Green	Light blue	Blue	Blue	Viol	Viol
Wavelength, nm	700	600	575	565	535	490	460	440	410	380
Distance from the concentrator, cm	13	14	15	16	17	18	19	20	21	22
V, V	2.04	2.027	2.016	2.006	1.998	1.992	1.988	1.984	1.98	1.977
I, A	0.508	0.499	0.492	0.487	0.484	0.481	0.480	0.478	0.476	0.474
P, W	**1.035**	**1.011**	**0.991**	**0.978**	**0.967**	**0.959**	**0.953**	**0.948**	**0.942**	**0.938**

Figure 12 shows a curve of dependence of the photoconversion power of gallium arsenide (GaAs) over the area of 0.25 cm^2 (W) on the wavelength of solar radiation.

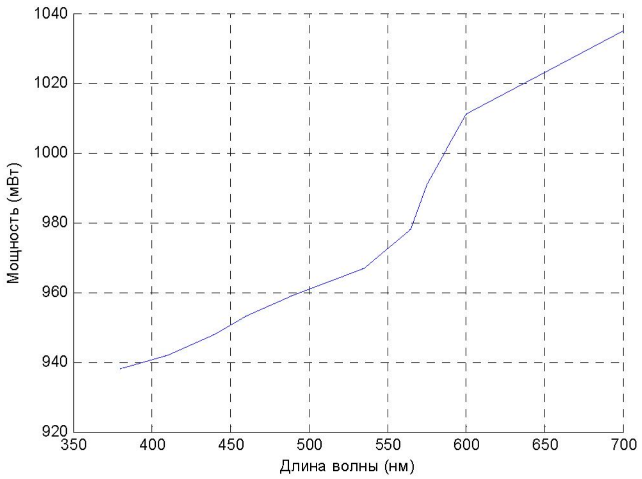

Figure 12 - The curve of dependence of the photoconversion power of gallium arsenide (GaAs) over the area of 0.25 cm^2 (W) on the wavelength

Figure 13 shows the dependence of intensity of photoconversion of solar energy on the wavelength of solar radiation using different photoconverters [5].

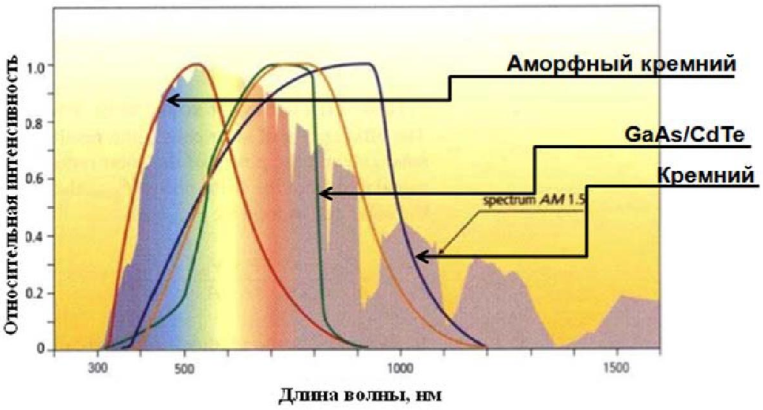

Figure 13 - Dependence of intensity of photoconversion of solar energy on the wavelength of solar radiation using different photoconverters
Относительная интенсивность – Relative intensity
Аморфный кремний – amorphous silicon
Кремний – Silicon
Длина волны – Wavelength, nm

By analyzing the curves in Figure 13 and the obtained experimental curves, it is possible to conclude that they are fully consistent. Moreover, the experimental data show that the photoconversion power of gallium arsenide (GaAs) is 7 times more than that of single-crystal silicon (MonoSi) and 42 times more than that of amorphous silicon (AmSi) on the area of 0.25 cm^2 after the holographic concentrator.

According to the invention protected by the RK patent No. 31796 (2016) [4], to produce electrical power using the physical model of the solar cell, ten 0.25 cm^2 gallium arsenide (GaAs) [6] photoreceivers valued at $8 each are used.

Figure 14 shows an electric circuit diagram of photoconverters.

Using formulas 1 and 2, the power of the photoconverters on the left of the holographic concentrator is multiplied by 22, and on the right, by 15. The obtained values are listed in Table 4. Here, the photocell was installed only at the focused wavelength of solar radiation, and not at regular intervals from the holographic concentrator as in the previous experiments.

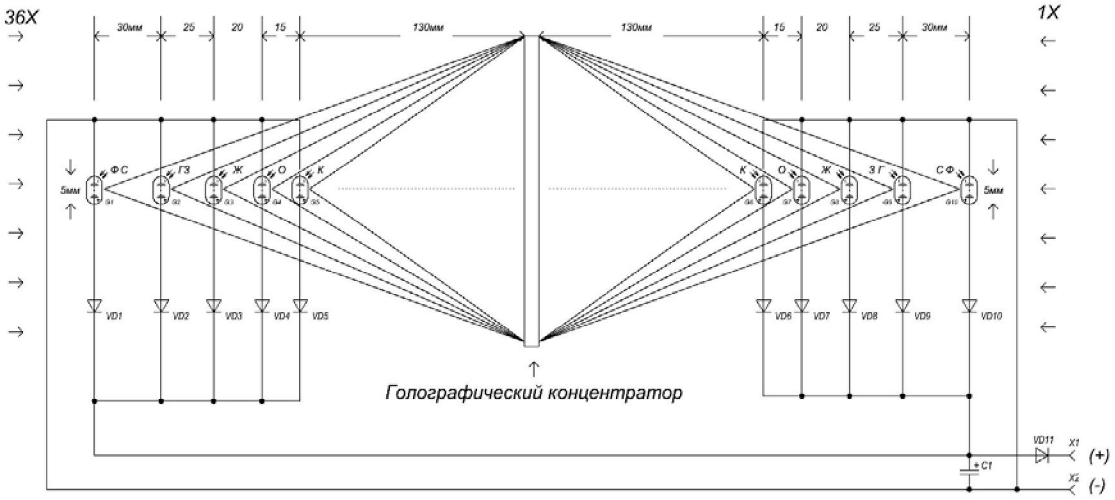

Figure 14 – The electric circuit diagram of photoconverters
Голографический концентратор - Holographic concentrator

Table 4 – Power of photoconverters of the entire solar cell

Color	Vio	Bl+Light bl	Gre	Yel+Or	Red	Red	Yel+Or	Gre	Bl+Light bl	Vio
Wavelength, nm	380	475	535	580	700	700	580	535	475	380
Distance from the concentrator, cm	22	19	16,5	14,5	13	13	14.5	16.5	19	22
P, W	0.938	0.953	0.972	1.000	1.035	1.035	1.000	0.972	0.953	0.938
Power on the right and left of the concentrator	20.636	20.966	21.384	22	22.77	15.525	15	14.58	14.295	14.07

The total power of the solar cell with ten 0.25 cm^2 gallium arsenide (GaAs) [6] photoconverters will be 181 W.

The cost of 10 photoconverters will be $80, therefore the cost of 1W of electric energy converted by the proposed solar cell will be $0.44/W.

The application of gallium arsenide (GaAs) [6] photoconverters in traditional solar cells to convert solar energy over the area of 2,826 cm^2 will require $S_З/S_{фпAmSi}$ = 2,826 cm^2/ 32 cm^2 = 88 photoconverters worth $575 each. Therefore, the total cost will be $50,600 with an output power of $P_з$ = 1.3824 W·88 = 122 W. Consequently, the cost of 1W of electric energy converted by 88 gallium arsenide (GaAs) panels in traditional solar cells will be $414.75/W.

It is evident that the use of gallium arsenide in traditional solar cells is not acceptable, while the proposed design of the solar cell ensures the use of gallium arsenide with high economic efficiency compared to even widely used single-crystal silicon.

So, the use of single-crystal silicon (MonoCrSi) [7] photoconverters to convert solar energy over the area of 2,826 cm^2 will require $S_з/S_{фпAmSi}$ = 26826 cm^2/132 cm^2 = 21 photoconverters worth $55 each at an output power of $P_з$ = 42 W. In this case, the cost of 1W of electrical energy converted by 21 single-crystal silicon panels will be $1.3/W.

It is evident that the economic efficiency of the proposed solar cell using gallium arsenide 2.95 times exceeds the traditional cells with single-crystal photocells over the 2,826 cm^2 solar radiation area.

The cost reduction of the proposed solar cell can be achieved by using single-crystal silicon, for example, in red and orange lights. At the same time, the efficiency of converting solar radiation into electrical radiation will somewhat decrease.

Table 5 shows the parameters of the proposed solar cell and that of a traditional ones. It does not account for the cost of mirrors, collimator lenses and the holographic concentrator. Accounting for these parameters will only insignificantly reduce the value of the proposed design of solar cells. Moreover, the table does not include other costs, namely: the cost of accumulators, charge controllers, inverters, etc., which are similar for all compared solar cells.

In addition to the above-mentioned technical and economic advantages, the proposed design of solar cells occupies a much smaller area of land allotment.

Table 5 – Performance parameters of the proposed and traditional solar cells

The proposed solar cell				Traditional solar cells based on			
				Gallium arsenide		single-crystal silicon	
Mirror radius, cm	Total P, W	Cost of 1W, $/W	Mirror area, sq. cm	Total P, W	Cost of 1W, $/W	Total P, W	Cost of 1W, $/W
30	181	0.44	2,826	122	416	43	1.3
40	318	0.25	5,024	217	416	76	1.3
50	495	0.16	7,850	339	416	119	1.3

The results of powers of solar cells obtained in experiments and given in Table 5 show that the power efficiency of the proposed design in terms of photoconverters is 1.46-1.48 times higher than that of gallium arsenide using traditional technology, and 4.15-4.2 times higher than single-crystal silicon. This is because infrared radiation does not hit a photocell, and the visible spectrum is dispersed (decomposed) by wavelengths and only one wavelength hits a photocell.

Moreover, the proposed solar cells require much less photocells. For example, the considered physical model of the solar cell requires ten 0.25 cm^2 photocells, regardless of the cross-sectional area of solar radiation, i.e. in this case regardless of the mirror area. Whereas the traditional design requires photocells with an area equal to the cross-sectional area of solar radiation, which in this case equals to the mirror area. In this connection, regardless of the cross-sectional area of the utilized solar radiation, the cost of conversion of light energy of the sun into electrical energy remains constant, while in the proposed design of the solar cell it is sharply reduced (Figure 15).

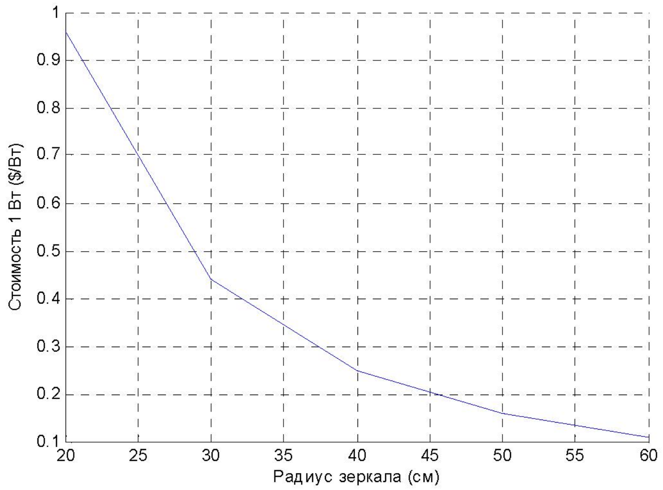

Figure 15 – Dependence of electricity cost on the cross-sectional area of solar radiation (mirror radius) in the proposed design of the solar cell
Стоимость 1 Вт ($/Вт) – Cost of 1W (($/W). Радиус зеркала - Mirror radius

As Figure 15 demonstrates, there is a sharp decrease in the cost of energy as the cross-sectional area of solar radiation increases. As already noted, this ensues from the fact that the number of photocells in the proposed design of the solar cell does not change, it remains constant.

Table 5 shows that the economic efficiency of the proposed design of the solar cell with the use gallium arsenide photoconverters will be 2.95 to 8.12 times compared with the use of single-crystal silicon in traditional cells, and 945.45 – 2,600 times compared with the use of gallium arsenide in traditional cells.

Table 5 does not account for additional costs for the mirror and collimator lenses as well as the cost of the holographic concentrator. When taken into account, their effectiveness will slightly decrease, but not significantly, since the cost of collimator lenses and the holographic concentrator is much less than the cost of photocells, it remains constant, and only the cost of the mirror depends on its size.

Thus, the obtained experimental results and their processing convincingly demonstrate the efficiency of the proposed design of solar cells.

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ЖАҢА БУЫН КҮН БАТАРЕЯЛАРЫНЫҢ ТИІМДІЛІГІН ЭКСПЕРИМЕНТТІК ЗЕРТТЕУ

Аннотация. Толқын ұзындығы бойынша күн сәулесін диспергирлеу және фокустау және толқынның әр бір ұзындығына әр түрлі фотоэлементтер орнату есебінен өте жоғары техникалық-экономикалық тиімділігі бар күн фотоэлектрлік батареяның физикалық үлгісімен тәжірибелік жұмыстар жүргізілді.

Тәжірибелік мәліметтер және оларды өңдеу күн батареялары құрылымының фототүрлендіргіш деңгейін-дегі қуаты дәстүрлі технология бойынша галлий арсенийдің пайдалануымен салыстырғанда 1,46–1,48 есе, ал монокристалды кремний 4,15–4,2 есе жоғары екенін көрсетті. Бұл ретте ұсынылған күн батареялары үшін көрсетілген фотоэлементтерден бірнеше есе аз талап етіледі, бұл экономикалық тиімділікті айтарлықтай арттырады.

Түйін сөздер. Күн батареясы, голографиялық концентратор, фотоэлементтер, күн батареяларының техника-лық-экономикалық көрсеткіштері.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ЭФФЕКТИВНОСТИ СОЛНЕЧНЫХ БАТАРЕЙ НОВОГО ПОКОЛЕНИЯ

Аннотация. Проведены экспериментальные работы с физической моделью солнечной фотоэлектрической батареи с весьма высокой технико-экономической эффективностью за счет диспергирования и фокусировки солнечного излучения по длинам волн и установки на каждую длину волны различные фотоэлементы.

Экспериментальные данные и их обработка показала, что мощность предлагаемой конструкции солнечной батареи на уровне фотопреобразователей выше по сравнению с использованием арсенида галлия по традиционной технологии в 1,46 – 1,48 раза, а монокристаллического кремния – в 4,15-4,2 раза. При этом для предлагаемых солнечных батарей требуется многократно меньше указанных фотоэлементов, что существенно повышает экономическую эффективность.

Ключевые слова: солнечная батарея, голографический концентратор, фотоэлементы, технико-экономичес-кие показатели солнечных батарей.

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