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Theoretical considerations on the development of a selective radiation photothermogenerator using dichroic filters

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ABSTRACT:The article discusses the theoretical foundations of the dichroism effect and the possibility of using dichroic filters in the development of photothermogenerators of selective radiation. A schematic diagram of a photothermogenerator using photocells with different band gap zones, thermoelements and dichroic filters are presented.

KEY WORDS: photothermogenerator, solar spectrum, dichroic filter, selective radiation, protective block.

I. INTRODUCTION.

The problem of converting solar energy into electrical energy using photothermoelectric generators was first studied by scientists B.V. Tarnizhevsky, V.N. Malevsky, E.K. Iordanishvili, S.M. Gorodetsky and A.M. Kasymakhunova. Tarnizhevsky was engaged in the creation and theoretical and experimental research of the first photothermogenerators, and only one work was published in a scientific publication. However, it says that the results of the work are not very satisfactory. This is because as the light intensity increases, the temperature of the photovoltaic converter also rises, and the efficiency drops so quickly that the increase in thermocouple performance cannot compensate for this drop in performance. The author did not conduct a deep analysis of the reasons for this and associated physical processes, and also did not conduct any other research in this area. But, later, Professor A.M. Kasimakhunova proved the prospects for research in this direction. And to date, various models of photothermal generators with cascade elements, with two-way sensitivity and based on the selected radiation, have been developed and put into operation.

II. RELATED WORKS

Today, the interest of researchers in the creation and study of the energy potential of photothermal generators of various types is very high. The first work on the classification of hybrid energy devices by design and principle of operation was carried out by scientists E.S. Kern and M. Russell[1]. A group of Italian scientists led by F. Attivissimo [2] worked on calculating the economic efficiency of photo- and thermoelectric modules. R.M. Swanson [3] has created the first thermo-photovoltaic converter system with renewable heat motors and thermoelectric converters, designed to improve the efficiency of photovoltaic modules operating in concentrated light. Mexican and Russian scientists E.A. Chavez-Urbiola, Yu.V. Vorobiev and L.P. Bulat [4] proposed hybrid systems of four different designs without concentator and with concentator. Chinese scientists W. Pang, H.Yu, H. Yang, G. Lee, H. Chen [5] and others have constructed several samples of photothermogenerators arranged in a cascade of photo- and thermal elements.
As noted by E.K. Iordanishvili[6], there are two conceptual difficulties on the way of further development of this direction. The first difficulty is that the part of the solar spectrum that cannot be converted into electricity, especially in the presence of a concentrator, overheats the photoconverter. And this leads, despite the active heat removal, to a decrease in the efficiency of photoconversion due to thermal degradation of the photocell. The second difficulty lies in the fact that the heat flux coming from the chamber is not enough to create temperature differences at the thermoelement junctions, to achieve high values of thermoelectric efficiency. Taking into account the fact that the efficiency drops very noticeably when the photostructures are heated to 100-150 degrees, the real total efficiency of the photothermogenerator only slightly exceeds the efficiency of individual photocells.
As an alternative solution to the problem, the author proposed passing the light flux from a source, including from a concentrator, through a narrow-band light filter that cuts off the entire part of the spectrum that is not converted into

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electricity, and directs only that part that is optimally perceived by the photocell as the photosensitive surface of the photostructure. The rest of the luminous flux, actively heating the filter, is directed through the high-temperature "bridge" to the hot junction of the Seebeck thermoelement, where a heat flux is formed sufficient to create an optimal temperature difference between the junctions of the thermoelectric structure branches. But even in this version of the solution there are nuances that must be taken into account: when heat is transferred through the so-called "bridge", there is a loss of thermal energy.

III. THEORETICAL FOUNDATIONS

It is known that in optical physics there is the term dichroism, which refers to the absorption / transmission of light by anisotropic substances at different levels depending on its polarity and wavelength. This phenomenon was first discovered in 1809 by P. Kore in minerals and in 1816 by J.B. Bio and the German physicist T.I. Seebeck in tourmaline crystals. The diagram of the phenomenon of dichroism arising in them is shown in Figure 1.

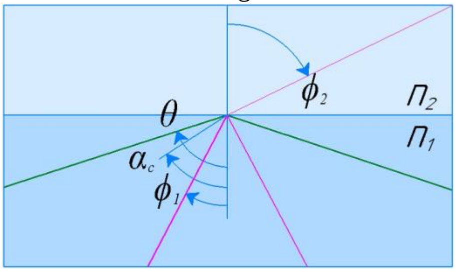

Figure 1. Schematic representation of the phenomenon of dichroism

In a schematic study of the process, two monochromatic beams were conventionally used as incident light. In this case, rays emanating from a medium with a relatively dark color, a refractive index n1, are directed into a second medium with a refractive index n2 and a lower density. As can be seen from the figure, the red rays fall at the angle $\phi_1 < \alpha_c = \Theta_c$, i.e. at the interface of two media, they are partially refracted at an angle ϕ_2 and partially reflected. Green light falls at an angle $\Theta > \alpha_c = \Theta_c$ and is fully reflected. By correctly choosing the stoichiometric composition and physical properties of the secondary medium, it is also possible to achieve a relatively lower or fully refraction of red light. This makes it possible to transmit beams with a wavelength of a certain range and reflect the rest.
Using dichroic mirrors and filters, it is possible to design a dichroic prism (Figure 2), that is, devices that separate the incident light into several streams with wavelengths in a certain range. Such devices typically include one or more glass prisms with a dichroic optical coating that absorbs and / or reflects light depending on the wavelength.

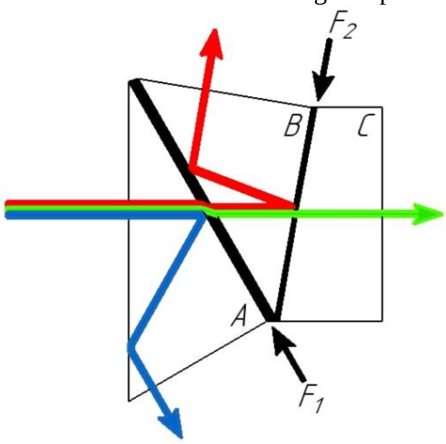

Figure 2. A trichroic prism assembly [7]

In Figure 2 shows the principle of operation of the device, in which the light rays falling on the prism A are split into rays with different wavelengths at the output and propagate in different directions. In this case, for example, the "blue" rays B are completely reflected from the filter surface and directed towards the lower surface of the prism. But, due to the fact that this filter is optically transparent to the relatively low frequency G- and R-beams, they are passed through.

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They are splits into two more as a result of hitting the second filter F2: red light is reflected, and green light is transmitted.
Based on this optical property of dichroic prisms, based on the scheme (Figure 3)proposed by Professor A.M. Kasimakhunova[8], it is possible to construct a device that uses selective beams, divided into two parts for directing to the surface of the photo and thermoelements located separately from each other. But in this case, there are a number of disadvantages and difficulties:

- To maintain the optimal temperature of the solar cells (cold junctions of the thermoelements legs and the photocell) that make up the photothermogenerator, needs using separated each other cooling systems;
- To prevent non-photoactive rays from reaching the surface, the photocell must be placed in a shell that protects it from the external environment;
- The exact direction of the split beams perpendicular to the surface of the solar cells requires complex physical and technical calculations;

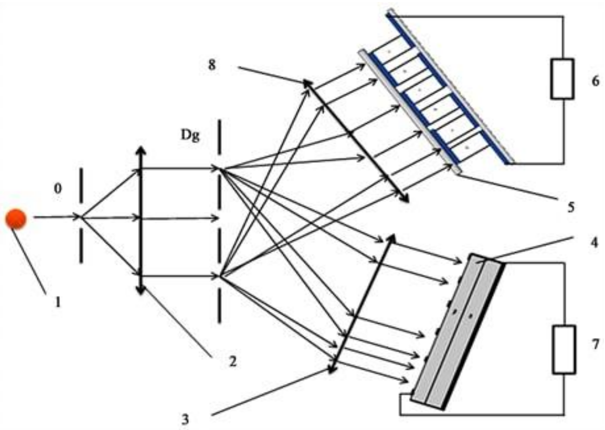

Figure 3. The scheme of distribution of light radiation on the surface of photoelectric and thermoelectric converters [8]. 1—light source, 2, 3, 8—set of optical glasses, 4—photo converter, the 5—front surface of thermo converter, 6—load of thermo converter, 7—load of photo converter, 0—enter hole, Dg—diffraction grating.

The wavelength range of the photoactive rays is not always optimal for the selected photocell sample. This is due to the fact that the spectral sensitivity of each sample of a photocell of the same type changes depending on the physical and technological properties of the semiconductor material. This requires redefining the optimal spectral content for each sample. Otherwise, the efficiency of the selected sample may not be as expected as a result of using not all the photocell potential due to overheating under the influence of non-photoactive rays on the sample surface or, conversely, due to narrowing of the spectra for a sample with a relatively wide range of photosensitivity.

IV. STRUCTURE OF THE DEVICE

In order to positively solve the above problems, which negatively affect the technical, economic and energy efficiency of the device, a design of a new model of photothermal generator was developed, based on the diagram shown below in Figure 4.

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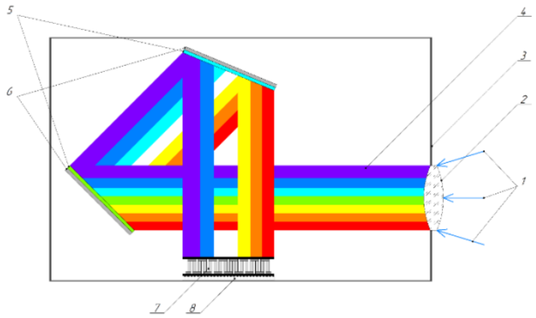

Figure 4. Schematic diagram of a multi-photo element photothermogenerator using dichroic filters
1-sunlight, 2- collimation system, 3- protective block, 4- parallel rays, 5-photocells, 6- dichroic filters,

As can be seen from the figure, sunlight 1, collected by the concentrator, with the help of the collimation system 2 is introduced into the protective block 3 in the form of parallel rays 4. The incoming light flux is completely directed to the surface of the first photocell 5. But the rays do not hit directly on the surface of the photocell. This is due to the fact that the dichroic filter 6, located on its surface and transmitting photoactive rays for this photocell, reflects all rays, except for spectra with a wavelength corresponding to a certain interval. As a result, only photoactive rays fall on the surface of the photocell for a given sample, and almost all of them contribute to the formation of a photocurrent. This in turn keeps the cell temperature low. The reflected light using the first dichroic filter is directed to the second photocell, which differs in spectral sensitivity from the first sample. The process of refraction and reflection of light is exactly the same for the second filter and photocell. All light energy, with the exception of those transmitted by the filters, is absorbed by the receiving surfaces of the thermocouple 7, and electricity is additionally generated. It is necessary to achieve their complete absorption by the thermocouple so that the rays directed to the thermocouple do not negatively affect the efficiency of the photocells when reflected from its surface. For this, the receiving surface is covered with a black layer. The cold end 8 of the thermocouple is cooled using streams of cold air or liquid (water).
An ideal photocell would be capable of converting all incident photons into electrical energy and would have perfectly linear characteristics depending on the light intensity, since the amount of current generated would be directly proportional to the number of photons falling into the photocell. But the spectral sensitivity of a real photocell is limited to a rather small region of the spectrum, as shown in Figure 5. For example, the spectral sensitivity of a silicon photocell is observed in the UV and visible regions of the spectrum. But they are insensitive above 1100 nm, while germanium photocells are insensitive to UV light, but can be effective at longer wavelengths up to 1800 nm. Photocells based on compounds such as InGaAs are also sensitive at longer wavelengths and are more efficient than germanium photocells. But at the same time they are inferior in terms of technical and economic indicators in production.

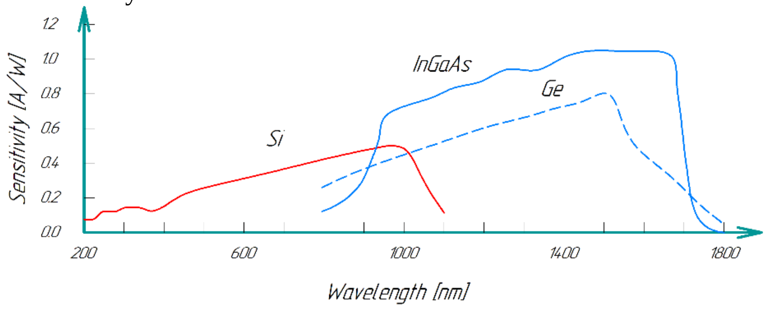

Figure 5. Spectral sensitivity of a real photocell

Based on the foregoing, the correct choice and location of photovoltaic cells in the device is one of the most important technical and physical aspects for the optimal conversion of solar energy, mainly with the help of photovoltaic cells. Since selective light transmission allows parasitic temperatures to be dissipated and thereby allows the potential of the photocells to be used as consistently as possible, improper sampling of dichroic filters or improper placement of photocells will result in lower output values than the optimum expected.

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V. CONCLUSION

Suboptimal separation of light beams for the photocell results in more light energy going to the thermocouple, which in turn causes the thermocouple to generate more electricity. But the increase in electrical energy produced by thermocouples cannot compensate for the energy losses that could be obtained from a photocell with an optimal design of the device. Because even the most efficient thermoelement with its low efficiency cannot produce more than 6-7% electricity. Because this value is the limit for thermoelements at full direction of light energies. Therefore, the overall efficiency of the photothermal generator is determined by the maximum using of the photoelectric conversion capability.

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