Previously, we provided preliminary results from an investigation of composite polyethylene film-ceramics based on ferrous oxide with three-layer cascade conversion of sunlight and its efficiency in solar air heaters, as well as their spectral characteristics in the visual and near-IR spectral range [1]. It was shown that this composite has an ability to stabilize the temperature to some extent, which can be useful not only in greenhouse facilities, but also in cases when strong heating in high solar radiation is unacceptable.

This work deals with a study of the possible use of film-ceramic composites based on functional ceramics to increase the efficiency of silicon solar photoconverters (PCs).

The maximum efficiency of PCs based on silicon conversions was achieved in laboratory samples, ~24%, and in industrial samples, from ~16 to 18%.

The optimal range of solar energy conversion for silicon PCs falls within the infrared spectrum with a low intensity of solar radiation flow; the absorption of more intense short electromagnetic waves of solar spectrum causes a change of the entropy of the silica scale [2, 3].

Thus, the problem of increasing the effectiveness of silicon-based PCs for mass production of electrical energy from solar energy depends on the spectral content and the intensity of the converting subspersetum of solar radiation. However, there are many open questions. It is necessary to develop not only the process design of the PC itself based on new scientific approaches, ideas, and mechanisms [4], but also of the systems that convert the unused high-energy shortwave part of the solar radiation into the range where photoelements have their maximum efficiency. As well, one of the main problems is temperature reduction in solar cells in order to prevent losses of electromotive force, which not only decrease the real efficiency, but also require the use of additional elements to compensate for similar losses. In order to charge the majority of 12-volt batteries in the optimal mode, 14.2 to 14.4 V are required. At the same time, due to overheating, the electromotive force of a PC can be reduced by 18% and more.

In this case it is necessary to compensate for these losses with additional in-series elements. Then, in contrast, at normal temperatures the voltage delivered to the battery will increase significantly, resulting in a decrease of its lifetime. Thus, it is necessary to find means of temperature stabilization for PCs in order to provide high-efficiency operation of not only conversion of the intensity of the solar spectrum into a photo current, but also the prolongation of battery lifetime. In any case, we will use batteries, as PCs cannot be used during night; thus, it is necessary to save energy for this time period.

Taking all of the above into account, we have developed a number of film-ceramic composites based on polyethylene film and functional ceramics, which solve this problem.

Particularly, we have developed a number of film-ceramic composites for PCs, which stabilize their temperature within definite limits.

As is known, a temperature increase of photo batteries by 3–4°C, depending on their quality, results in a decrease in the efficiency of solar energy conversion by 1%.

As an example, we can take the results of the investigation of temperature peculiarities for a three-layer cascade composite. The measurements were done via a unit that consisted of two similar bodies with dimensions of 750 × 750 × 350 mm². One body was fully covered by a three-layered film, where the first layer was a polyethylene film with additives, which convert the ultraviolet range into the visual range. This allows one not only to use sunlight energy more effectively, but also protects the film itself from photodegradation and...
extends its lifetime. The second body was covered the same polyethylene film, but the bottom layer contained two types of functional ceramics. The total content of ceramics in the composite was 2.5 wt % in relation to polyethylene. The first type of ceramics absorbs solar energy in a wide range and converts it into IR radiation with a maximum of 3.3 $\mu$m. This allows one to maintain higher temperatures due to additional heating, for example, in greenhouses. The second type of ceramics converts the solar energy in farther-IR radiation with a maximum of 9.7 $\mu$m. The temperature of the obvious start of the transformation is from +15 to –20°C on the film.

These investigations showed that the use of the composite with cascade conversion at low environmental temperatures provides higher temperatures in comparison with ordinary film by 5–11°C. At relatively high environmental temperature values, in contrast, it provides lower temperature by 9–14°C (Table 1, Fig. 1).

$$\Delta T = T_1 - T_2,$$
where $T_1$ is the temperature with an ordinary film and $T_2$ is the temperature with a film-ceramic composite.

The above data (Fig. 1) show that at the beginning a higher temperature occurs with the composite film; an inflection then occurs at 15°C. At temperatures of 25–27°C, the temperatures with the composite film and control film become leveled. If the temperature increases further, a lower temperature occurs with the composite film. Thus, the composite film based on functional ceramics can stabilize the temperature to some degree.

To study the impact of film–ceramic composites on the effectiveness of conversion of solar energy into electrical energy, a PC based on silicon produced by SPA $Kvant$ was used (its effective area was 66 cm$^2$; it consisted of 20 series of cells and the electromotive force at 35°C was 11 V). The measurements were done in various modes, which differ in the operating surface of the PCs, which were covered either with standard glass or polymer-ceramic composite films.

Mode 1 is covering by standard glass.
Mode 2 is the covering by a three-layered film-ceramic composite with a ceramic content equal to 2.5 wt % in the bottom layer with respect to the polymer.
Mode 3 is covering by a one-layered film-ceramic composite with a ceramic content equal to 1.0 wt %.
Mode 4 is covering by one-layered film-ceramic composite with a ceramic content equal to 1.5 wt %.
Mode 5 is the covering by a one-layered film-ceramic composite with a low content of rare earth metals in ceramics; the ceramic content equaled 0.5 wt % compared to the polymer.
Mode 6 is the same as mode 6, but the ceramic content compared to the polymer equaled 1.0 wt %.
Mode 7 is the same as mode 6, but the ceramic content compared to the polymer equaled 2.0 wt %.
Mode 8 is the same as mode 6, but the ceramic content compared to the polymer equaled 5.0 wt %.

The measurements were done at a temperature of 35°C.

The results are summarized in Table 2.

The temperature was measured using an IR-350 optical infrared thermometer produced by Voltcraft

Table 1. Temperature difference in chambers made from clear polyethylene film and a three-layer composite

<table>
<thead>
<tr>
<th>$T_{\text{aver.}}, ^\circ\text{C}$</th>
<th>–5</th>
<th>+5</th>
<th>+15</th>
<th>+20</th>
<th>+25</th>
<th>+30</th>
<th>+35</th>
<th>+38</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T$</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td>–6</td>
<td>–10</td>
<td>–14</td>
</tr>
</tbody>
</table>

Table 2. The dependence of the main parameters of a photovoltaic cell on the mode of measurement

<table>
<thead>
<tr>
<th>Mode of measurement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current, mA***</td>
<td>68</td>
<td>74/1.09</td>
<td>75/1.11</td>
<td>79/1.16</td>
<td>80/1.18</td>
<td>78/1.16</td>
<td>77/1.13</td>
<td>78/1.15</td>
</tr>
<tr>
<td>$T$, °C</td>
<td>62</td>
<td>49</td>
<td>55</td>
<td>53</td>
<td>54</td>
<td>49</td>
<td>47</td>
<td>49</td>
</tr>
<tr>
<td>Electromotive force, V****</td>
<td>9.3</td>
<td>10.7/1.08</td>
<td>9.7/1.03</td>
<td>9.8/1.04</td>
<td>9.8/1.04</td>
<td>10.1/1.08</td>
<td>10.2/1.09</td>
<td>10.1/1.08</td>
</tr>
<tr>
<td>$P$</td>
<td>1.00</td>
<td>1.18</td>
<td>1.14</td>
<td>1.21</td>
<td>1.23</td>
<td>1.25</td>
<td>1.23</td>
<td>1.24</td>
</tr>
</tbody>
</table>

Notes: *** The numerator is the current at a given mode, denominator is the relationship between the current at the given mode and the current of the cell covered by standard glass.
**** The numerator is the electromotive force at a given mode, the denominator is the relationship of the electromotive force at a given mode to the electromotive force of the cell covered by the standard glass.