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Ultraviolet to visible light conversion - characterization of down-shifting layers

Streszczenie. *Pozyskiwanie energii elektrycznej z odnawialnych źródeł energii jest głównym celem światowej energetyki. Wiodącą rolę w tej dziedzinie energii odgrywa fotowoltaika, która wykorzystuje energię słoneczną bez emisji jakichkolwiek zanieczyszczeń. Jednak stosunek kosztów produkcji do wydajności ogniw słonecznych jest wysoki. Problem ten dotyczy ogniw, które w swojej strukturze wykorzystują jedno złącze P-N, czyli większość dostępnych na rynku paneli fotowoltaicznych. Możliwe jest przekroczenie tego limitu poprzez utworzenie dodatkowych połączeń półprzewodnikowych w strukturze komórki lub za pomocą światła ultrafioletowego lub podczerwonego. Istnieje sposób na zwiększenie wydajności poprzez wykorzystanie światła ultrafioletowego poprzez przesunięcie pewnego zakresu promieniowania UV do zakresu widzialnego. Przedstawione w artykule prace polegają na wytworzeniu i scharakteryzowaniu warstw przetwarzających promieniowanie UV na światło widzialne. Warstwy te składają się z kilku elementów: bazy, pigmentu konwertującego i rozpuszczalnika. W przedstawionej pracy zastosowano trzy różne metody osadzania warstw: • osadzanie natryskowe, • powlekanie wirowe, • sitodruk. Dla każdej metody osadzania roztwór został przygotowany w nieco inny sposób. Zwiększenie wydajności ogniw fotowoltaicznych przy niewielkich nakładach finansowych to niezwykły przełom w dziedzinie fotowoltaiki. Analiza wyników transmitancji warstw potwierdza również możliwość wykorzystania tych pigmentów do poprawy wydajności ogniw fotowoltaicznych.* ***(Konwersja światła ultrafioletowego na widzialne – charakteryzacja warstw typu down-shifting)***

Abstract*. Obtaining electricity from renewable energy sources is the main goal of the global energy industry. The leading role in this field of energy is photovoltaic that uses solar energy with no emissions of any pollutants However, the ratio of production costs to solar cell efficiencies is high. This problem concerns cells that use one P-N junction in their structure, all photovoltaic panels available on the market. It is possible to exceed this limit by creating additional semiconductor junctions in the cell structure or by using ultraviolet or infrared light. There is a way to increase efficiency by using ultraviolet light by shifting a certain range of UV radiation into the visible range. The work presented in this article is based on the production and characterization of layers converting UV radiation into visible light. These layers consist of several elements: a base, a converting pigment and a solvent. In the presented work three different methods were used for the deposition of converting layers: • spray-coating, spin-coating, • screen-printing. For each deposition method the solution has been prepared in a slightly different way. Increasing the efficiency of photovoltaic cells with a small financial outlay is a remarkable breakthrough in the field of photovoltaics. The analysis of the transmittance results of the layers also confirms the possibility of using these pigments to improve the efficiency of photovoltaic cells.*

Słowa kluczowe: down-conversion, spin-coating, spray-coating, screen-printing.
Keywords: down-conversion, spin-coating, spray-coating, screen-printing

Introduction

Obtaining electricity from renewable energy sources is the main goal of the global energy industry. The leading role in this field of energy is photovoltaics that uses solar energy with no emissions of any pollutants. However, the ratio of production costs to solar cell efficiencies is high. For this purpose, more and more innovative solutions are being developed.

The world's developing solar energy industry uses mainly traditional silicon cells. They are a good source of electricity obtained from solar radiation, but they have limitations. Their main limitation is the Shockley-Queasier limit, which determines the maximum efficiency of a photovoltaic cell. This limit depends mainly on the matching of the solar radiation spectrum to the absorption spectrum of the active material of the photovoltaic cell. This problem concerns cells that use one P-N junction in their structure, and all photovoltaic panels available on the market [1]. It is possible to exceed this limit by creating additional semiconductor junctions in the cell structure or by using ultraviolet or infrared light.

Photons with high energy cause the thermal recombination of the cell and, consequently, the efficiency is lower of the entire device. The energy accompanying ultraviolet radiation is very high. Therefore, this range is not used to a large extent by a photovoltaic cell [2]. However, there is a way to increase efficiency by using ultraviolet light by shifting a certain range of UV radiation into the visible range. The implementation of this idea can take place using two methods: down-conversion and down-shifting. The first method involves the absorption of a photon in the UV range (higher energy) and the emission of two identical photons in the visible light range (lower energy). The down-shifting method is a variation of the down-conversion method, with the difference that one photon of lower energy is emitted instead of two. In other words, it can be concluded that both methods convert UV light into visible light [3]. The down-conversion and down-shifting phenomena are presented in Fig. 1.

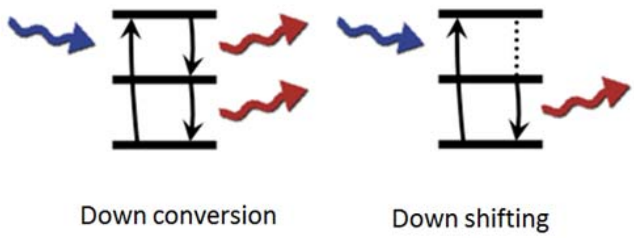

Fig. 1. Diagram of down-conversion and down-shifting methods

The effects of the presented light conversion methods can be achieved by creating an additional layer on the surface of the photovoltaic cell. The method of producing converting layers, the materials used and the characterization of the layers are presented in this article.

Materials and methods

The work presented in this article is based on the production and characterization of layers converting UV radiation into visible light. These layers consist of several elements: a base, a converting pigment and a solvent. The material responsible for the conversion of radiation is the luminescent pigment. Two types of pigment from Nemoto Lumi-materials CO., LTD with the product name BGL-300M and G-300M were used in the work. These are strontium alumina compounds doped with europium and dysprosium (Sr4Al14O25: Eu, Dy - BGL-300M; SrAl2O4: Eu, Dy - G-300M). According to the manufacturer's assurances, these compounds absorb UV radiation and emit radiation in the visible light range [4,5]. An example of the solution made for different pigments concentrations and their photoluminescent capabilities are shown in Fig. 2.

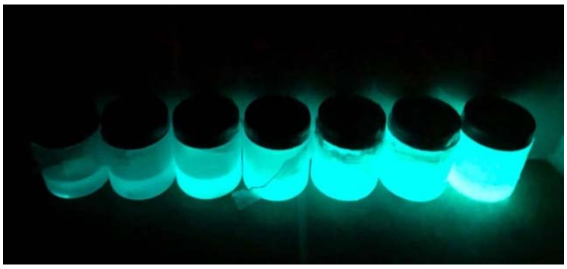

Fig. 2. Picture of prepared solutions with a photoluminescent effect

In the presented work three different methods were used for the deposition of converting layers:

- spray-coating,
- spin-coating,
- screen-printing.

For each deposition method the solution has been prepared in a slightly different way. All of them are described below.

Spin-coating method

Preparation of the layer by spin-coating method requires the preparation of a solution consisting of a matrix (base) in which BGL-300M and G-300M compounds are placed. The preparation of the base required the use of two components - polymethyl methacrylate (PMMA) with an average molecular weight of 350,000 according to GPC, and the solvent, which in this case was chlorobenzene. The PMMA granulate was dissolved in chlorobenzene (8% wt -PMMA, 92% wt - chlorobenzene). The compounds G-300M and BGL-300M were added to the prepared base in concentrations of 5%, 10% and 15%. All proportions were obtained using a laboratory balance. The prepared solution was mixed with a magnetic stirrer for 24 hours.. After the time has elapsed, the solution is ready to be applied to the surface of the glass (for the optical transmittance measurement), silicon (for the microscopic characterization) and the solar cell. Different deposition speeds which were used are as follows: 1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm, 5000 rpm, 6000 rpm. Acceleration 1000 rpms, deposition time 30s. The parameters were constant for all tested layers.

Spray-coating method

For the spray-coating method, three types of layers have been developed. The first one was based on the same preparation method as for the spin-coating. The difference was the reduction of the PMMA to solvent proportions to 2%. BGL-300M and G-300M pigments were added to the base in concentrations of 1%, 2%, 5%, 10%, 15%, 20%, 50%. The solutions were mixed with a magnetic stirrer for 24 hours then applied to the substrates (glass, silicon, PV cell) using the spray-coating method. The second and third types of the solvent preparation method required mixing the pigment with ethanol and isopropanol, in the proportions of 0.1 g; 0.2 g; 0.5 g; 1g per 30ml of used alcohol. The ingredients were mixed in an ultrasonic cleaner for 30 minutes. The solutions prepared in this way were placed on the substrates by spray-coating. After depositing the solution on the substrate, the samples were allowed to dry for 1 hour. The last step was the application of the PMMA base prepared in accordance with the recipe described in the first case, only without pigment. The base was spray-coated on the previously applied layer of pigment with alcohol in order to protect the pigment against external conditions.

Screen-printing method

For this method a base identical to that used in the spin-coating and spray-coating methods was used for the solution preparation. The pigment was mixed with the base solution (PMMA + chlorobenzene) in the proportions of 1%, 2%, 5%, 10%, 15%, 20% and 50% in relation to the mixture with the base. The PMMA concentration in the stock solution was 12%. The procedure of applying converting layers was the same as in the case of spin-coating. The solution was stirred for 24 hours with the magnetic stirrer. After this time, it was applied on the glass and silicon substrates. The obtained samples were left to dry for 24 hours.

The presented deposition technologies are commonly used in the full-scale production and therefore will allow to switch quickly from laboratory work to application in industry. Also, a clear and not too complicated procedure for the layers production enforce for the low costs associated with the implementation of such a solution for improving the efficiency of solar cells.

Results and Discussion

In order to confirm the manufacturer's assurances and to check the possibility of using these compounds as down-conversion or down-shifting agents , additional tests were performed to characterize the photoluminescence of the tested BGL-300M and G-300M materials. Characterization of the compound emission-excitation map was performed using the FLS980 fluorescence spectroscope (Edinburgh Instruments) with a 450 W xenon arc lamp and an R-928 photomultiplier detector. Figs 3 and 4 show the emission-excitation maps of BGL-300 M and G-300M compounds.

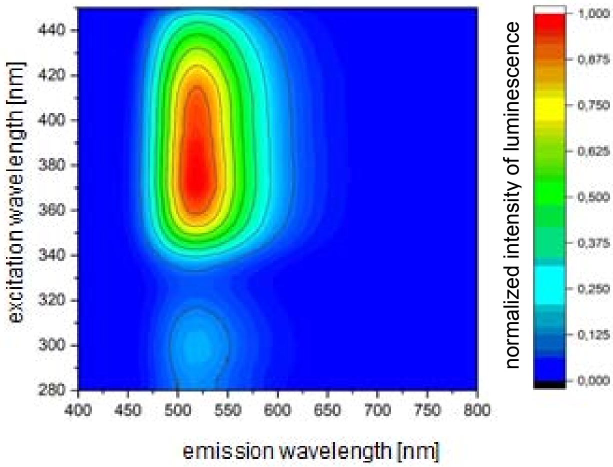

Fig. 3. Contour Emission Map of BGL-300M

The analysis of the obtained results presented in Fig. 3 shows that BGL-300M and G-300M compounds absorb UV radiation in the range from 340nm to 440nm, reaching the maximum at 370nm. These characteristics show the radiation emission of the tested materials in the visible light range. For BGL-300M, the emission range is 470nm to 500nm with a maximum of 490nm and for G-300M the emission range is 500nm to 540nm with a 520nm maximum. The obtained parameters are very promising, as they confirm the occurrence of the phenomenon of UV light conversion into visible light with the use of down-conversion and / or down-shifting methods. The confirmation of the assumption of light conversion allowed for the transition to the next stage of research, namely the production of a ready-made converting layer on the surface of the photovoltaic cell.

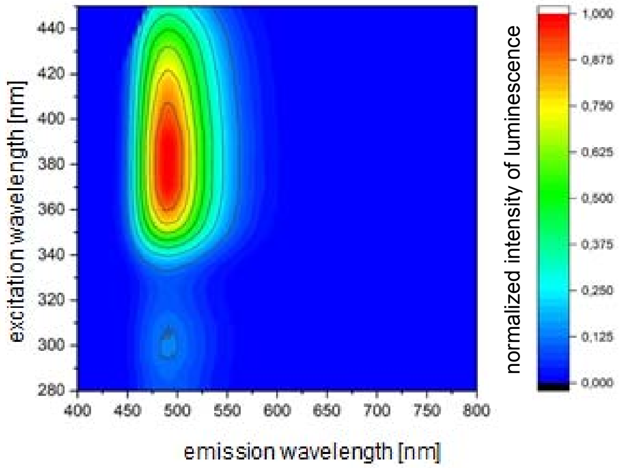

Fig. 4. Contour Emission Map of G-300M

Spin-Coating method

The produced samples with converting layers were tested and the obtained result was analyzed and included in this chapter of this article. Increasing the concentration increases the amount of pigment particles in the applied layer and a denser distribution of the pigment particles in the layer. Examples of photos showing the distribution of pigment in the layer are shown in Fig. 5.

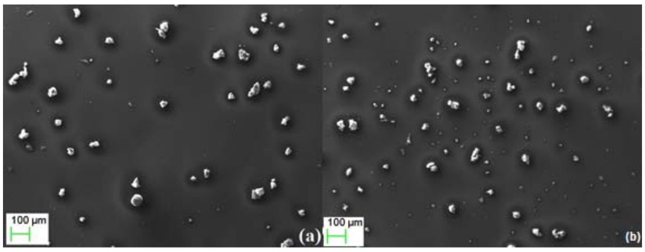

Fig. 5. Pictures obtained with scanning electron microscope (SEM) for the layers: BGL-300M pigment in a concentration of 5% (a) and 15% (b) applied by centrifugation

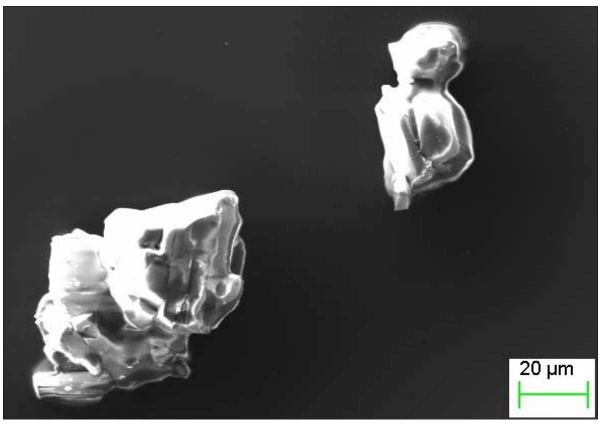

Fig. 6. Sample SEM photo for the layer of BGL-300M with a concentration of 5% with the formed agglomerates

The scanning electron microscope (SEM) photos presented in Fig. 5 and 6 show how the pigment particles are dispersed in the layer. When analyzing the presented photos, one can notice different sizes of the particles (agglomerates) formed. The formation of agglomerates results from the aggregation of pigment particles. Also, the distribution of particles is chaotic, resulting in areas where the number of particles is small and areas where there are many particles. Increasing the concentration of pigments in the solution favors the formation of agglomerates and the chaotic distribution of particles in the layer. The consequence of this is the deterioration of the optical transmittance parameter.

Spray-coating method

The samples obtained using the spray-coating method were tested and analyzed in the same way as for the spin-coating methods. The obtained results of optical transmittance are shown in Figs 7 and 8.

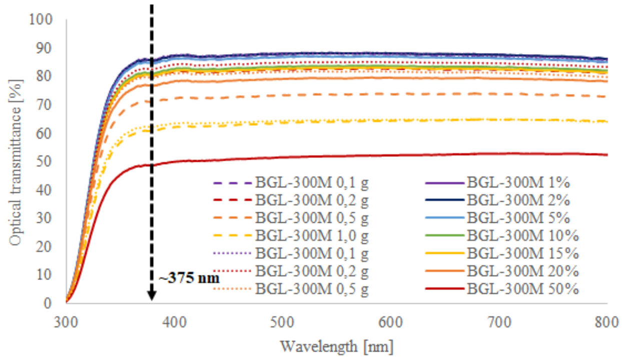

Fig. 7. Optical transmittance results for layers made with the spray-coating method in all variants for the BGL-300M pigment

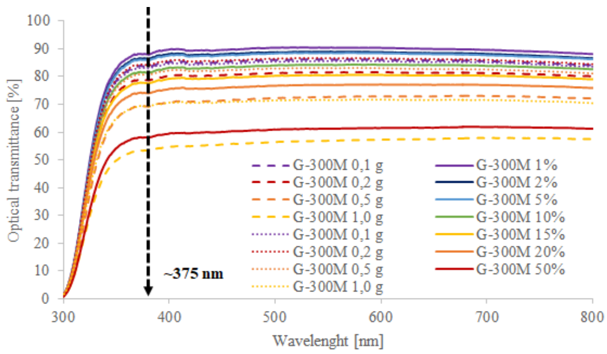

Fig. 8. Optical transmittance results for layers made with the spray-coating method in all variants for the pigment G-300M.

Analyzing the obtained transmittance results presented in Figs 7 and 8, one can notice the analogy between the results obtained with the spin-coating method and the spray-coating method. By increasing the amount of pigment in the layers, a decrease in the optical transmittance value is achieved. A more detailed analysis of the results brought an additional conclusion. There was a decrease in transmittance below a wavelength of about 375 nm for both pigments. The explanation for such a decrease is that the pigments obtain the maximum excitation for this wavelength. This means that the layer absorbed a significant part of the radiation with a wavelength of about 375 nm. Observations of the decrease in transmittance allow to assume the occurrence of the phenomenon of UV light conversion into visible light.

Screen-printing method

In the screen-printing method, as in the previous methods, the samples were examined for optical transmittance. The results are presented in Figs 9 and 10.

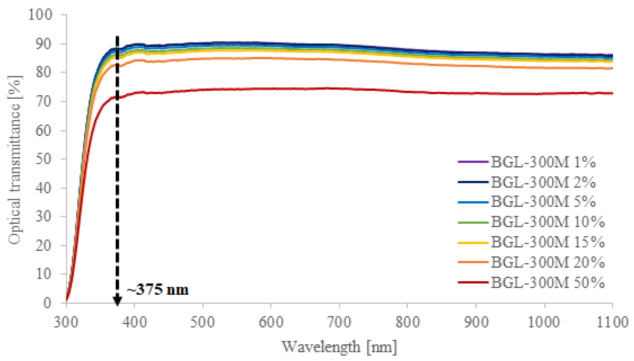

Fig. 9. Optical transmittance results for layers made by screen-printing in the PMMA variant for BGL-300M pigment.

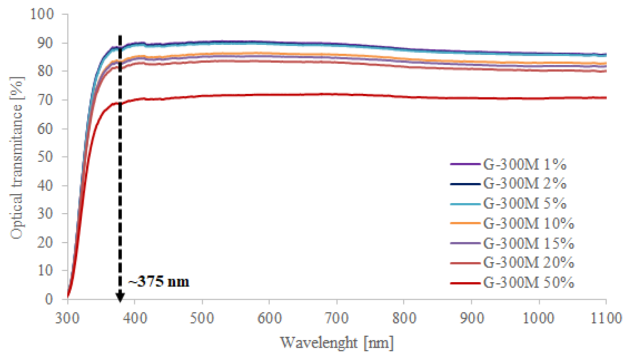

Fig. 10. Optical transmittance results for layers made by screen-printing in the PMMA variant for G-300M pigment.

The analysis of the presented characteristics in Figs 9 and 10 allows for similar conclusions as in the case of the spray-coating method. Similarly to the previously-mentioned methods, also in this case there is a visible decrease in optical transmittance for the wave below about 375 nm.

Conclusions

Increasing the efficiency of photovoltaic cells with a small financial outlay is a remarkable breakthrough in the field of photovoltaics. The first step in this direction is the use of layers that convert UV radiation into visible light. The layers presented in this article use photoluminescent pigments that enable the down-conversion and / or down-shifting methods. The suitability of BGL-300M and G-300M pigments was confirmed and presented in this article (Figure 3). The analysis of the transmittance results of the layers also confirms the possibility of using these pigments to improve the efficiency of photovoltaic cells. The tested layers do not significantly deteriorate the transmittance of waves in the visible light range, as evidenced by the transmittance graphs presented in this article. The BGL-300M and G-300M pigments proposed in the article will make it possible to increase the efficiency of photovoltaic cells.

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