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Antireflective and Hydrophobic Coated Lenses for Photovoltaic Moduls

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Abstract: An energy conversion efficiency of a solar cell, as well as a quality of a lens concentrator, are of great importance in modern photovoltaic (PV) modules. Lens concentrators must provide maximum energy through to solar cell and must be resistant against water and water vapor. To solve the first task we calculated and covered the outer and the inner surfaces of the lens with the following antireflective layers – SiO_2 with thickness of 85 nm (n = 1.47), ZrO_2 with thickness of 63 nm (n = 1.98), and SiO_2 with thickness of 85vnm (n =v1.47) – that achieved considerable increase (some wavelengths up to 10%) in energy of light passing through for wavelengths of 0.6 – 0.8 µm range. Multilayer antireflective coated polymer lens with high adhesion was proposed. Good adhesion was achieved by the formation of solid layer on the surface of the lens by means of sinking and removing the lens in the liquid polysiloxanevarnish basin before layering with antireflective coatings. To increase aquabhopy, the fluoroplast layer with thickness of 20 – 30 nm was formed above the antireflective layer of the concentrator. Aquaphoby has considerably increased when adding this layer. That has been confirmed when tested it in natural moistening, also measuring the edge angle moisture that has increased for its part in about 80°.

Keywords: Lens Concentrator, Antireflective Layers, Hydrophobic Layers

1. Introduction

High quality concentration (> 100) of solar energy in solar energy photovoltaic blocks that are produced on the basis of A^3B^5-type semiconductors can be achieved through the use of lens concentrators. This, for its part, reduces the area of the expensive material pro rata and, as a result, the photovoltaic block cost [1].

Nonetheless, the use of concentrators can result in the loss of the following ray energy:

1. Ray energy loss on reflection of the concentrator surface.
2. Ray energy loss on contamination of the concentrator surface by hygroscopic or dust particles.

The cause of the first issue is when sunlight falls on photoelectric inverter's lens concentrator.

During a passage from the air to the solid environment (through the lens) sunlight's large portion is refracted and reaches photoelectric inverter but some part, due to the big difference in refraction index between the air and the lens concentrator, is reflected from upper surface of the concentrator as well as the lower surface. Percentage value of the reflection depends on the concentrator material. The reflective loss value when using lens concentrators exceeds 10% on average. This means that quite large portion of the solar energy does not reach photoelectric inverter, thus reducing the effectiveness of the transformation of the solar energy into the electric energy.

In order to rectify the first issue, reflected light of the lens needs to be reduced using the spectral range that the photoelectric transformer of the solar energy is the maximally sensitive to. In modern optics this shortcoming is significantly reduced while producing lens with antireflective coating layers, which increases objective luminous sensitivity [2, 3]. We have not found any indications regarding luminous sensitivity increase in available materials (see e.g. [4, 5]). They only specify the increase of the photocell absorption / consumption coefficient. In our opinion, antireflective coating will significantly increase luminous sensitivity for both lens concentrators and lenses used in different types of optical systems and augment effectiveness of photovoltaic blocks.

The reason of the second issue is that photovoltaic blocks operate in a natural environment and are constantly exposed to climate. During rain the surface of the lens concentrator gets moistened, also additionally rain drops might get polluted by dust and as a result transparency of the lens will be reduced after the surface dries.

In order to rectify the second issue, the increasing the hydrophobicity of the lens concentrator is required. Aquaphobic layering including for optical components is widely used in various fields of technology. Hence these layers are rather thin (their width is nanometer scale) it cannot virtually have negative influence optical parameters of lens concentrator; on the contrary it will make its operation more stable. Besides aquaphobicity and resistance against dust particles, this layering protection from various mechanical impacts is possible to be achieved.

2. Materials and Methods

As mentioned above in order to increase lumineius sensitivity and aquaphobicity of the lens concentrators, formation of specific layering of both surfaces of the lens is required. Prior to the formation of these layers for the enhanced adhesion to the surface of the lens connecting-firming coating is needed. The whole structure of the layers on each side of the lens is shown on the Fig. 1.

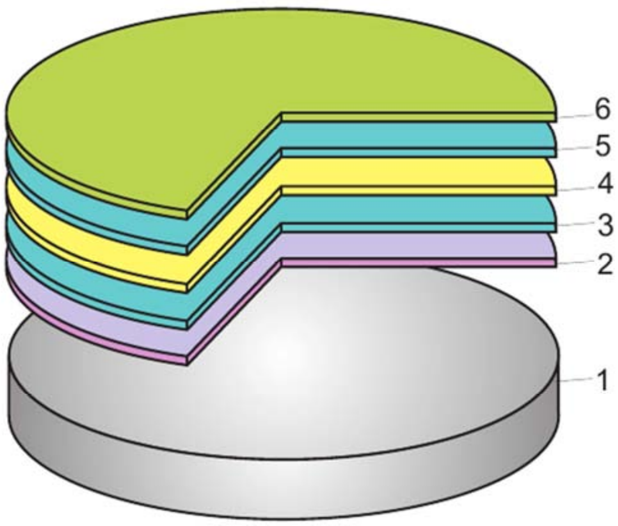

Figure 1. *Multilayer coating structure for the purpose of increased antireflection and hydrophobicity of polymer lens-concentrator.1 – lens, 2 – adhesive layers, 3 – 4 – 5 – antireflective layers, and 6 – firming layer.*

Luminous sensitivityand spectral transparency, important optical parameters of the lens-concentrator, are dependent on antireflective coatings.

Formation of antireflective layer on the lens implies coating its surface with thin film or several films. Depending on characteristics, their width and the quantity of materials of the film, the wavelength range of light can be selected where reflection (and, correspondingly, loss) will be minimal. At this point reduction of reflection of both surfaces of the lens is based on the event of interference. In case the width of the film is the fourth of the wavelength fallen on it, then the reflected light from the upper and middle surfaces will cancel each other due to interference (as they are in various phases) and their overall saturation will become zero.

As we can see efficiency of an antireflective layer at given wavelength is dependent on the thickness of the coating. So to cancel reflected light caused by interference, thickness must be selected in order to suffice the next condition of the phase differences of the landed and reflected light.

$$\Delta = \frac{(2m+1)\lambda}{2} = 2d \qquad (1)$$

where d is the thickness of the film, n is refrective rate. From this equation we get:

$$d = \frac{\lambda}{4} \qquad (2)$$

At this point the rate of the maximum efficieny of film refraction must be:

$$x = \sqrt{n_L}$$

where n_L is 5he lens refraction index.

Based on the above, for the given wavelength by forming the antireflective layers of pre-calculated parameters covering both sides of the lens-concentrator, it is possible to considerably reduce reflective losses of light. For the wade range of solar radiation wavelength on the basis of thin-layer dielectric materials of specific features, development of technology to produce multilayer antireflective cover represents the primary goal of our research.

As the solar radiation is not monochromatic and as photoelectric inverters have significantly high spectral sensitivity as well, given by formulas (1) and (2), ideal antireflective coating in entire spectral range is impossible. Therefore antireflective coating can be conducted considering maximum spectral range of a specific photocell. Our research has been conducted proceeding that maximum sensitivity of A^3B^5 photocell is located in the 0.6 – 0.8 μm range.

According to these data, the quantity and the materials of the thin films have been established and the thickness of the films has been calculated. As the spectral range is quite large, the quantity of the films should be at least three. Silicon dioxide and zirconium dioxide give good results in this range. According to our calculations, the entire structure of the layers must be composed of three thin films with the following sequence: SiO_2 – ZrO_2 – SiO_2. As a result of calculations the following widths have been set: 1 – SiO_2 with width of 85 nm (n = 1.47), 2 – ZrO_2 with width of 63 nm (n = 1,98), and 3 – SiO_2 with width of 85 nm (n = 1.47).

As we can see, the thickness of the films is very little and respectively coating technology must be quite accurate as the result depends on the precision. Thus we have eliminated simple techniques of the layering (chemical, pyrolytic and others) from the beginning and focused on the vacuum techniques.

To produce antireflective coating layers on the lens-concentrators, the VU – 1A-type vacuum device has been used that is designed to layer base-layers of plastic, glass, ceramic and other materials with protective and / or decorative purpose thin layers (titanium, zirconium, molybdenum, tantalum, vanadium, nitrides, carbides).

Device beneath the lid of production of type VU – 1A vacuum equipment, that is resistant and one electronic-radial vaporisation systems, which cannot comply with the modern requirements, specifically for the production of the high quality optical layers – antireflective layers. Therefore modernization of the device was required and thus improving its technical and technological settings (Fig. 2).

Within the framework of the VU – 1A-type vacuum equipment modernization project [6] were conducted:

- Installation of the magnetron sputtering device (2 sets) under the lid;
- Installation of quadrupolar mass spectrometer on the upper part of the lid;
- Construction, production and installation of the gas system, geometrical adhesion of AALBORG (2 sets), gas flow regulator to the gas system and to the argon and oxygen containers separately; and
- RFDC ("PlasmaSwitch").

Figure 2. Device beneath the lid of VU – 1A-type vacuum machine with two modernized magnetron sputteringsets. 1 – disk-shaped horizontal carouse, 2 – magnetron sputtering device with Si and Zr targets, 3 – lens concentrator cleaning device, and 4 – O_2 and Ar individual gas flow system, directly connected to magnetron sputtering device.

Antireflective layer must have good adhesion to the surface of the lens. For this formation of the pre-fixing layer, what is necessary, the method of sinking the lens in liquid polysiloxane varnish tab is used for this purpose. Experimental device (Fig. 3) was made for this reason that has a possibility to control immersion and eventration speeds of the lens in the liquid. Chemically processed polymer lens is sunk in the tub that has polysiloxane varnish solution in it. The thickness of the fixing layer is regulated by the selection of the viscosity of the polysiloxane varnish and removal speed of the lens from the tub. After removing from the tub thermal treatment of the lens is carried out for the polymerization of the polysiloxane varnish. Polysiloxane varnish is high in elasticity; produced surface does not get damaged in contact with the environment and is resistant to scratches. To define the width of the fixing layer of the lens we used the existing literature data [7, 8], according to which it must not exceed 40 – 50 nm.

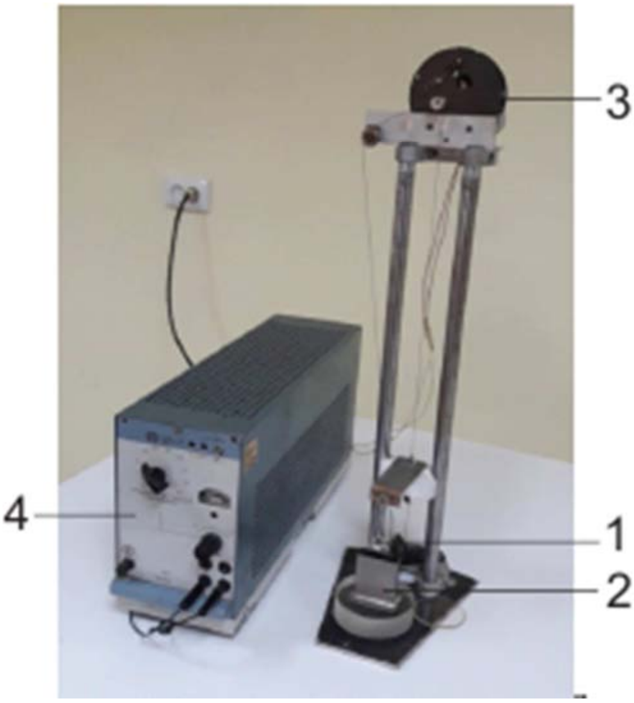

Figure 3. Device for producing fixing and aquaphobic layers. 1 – lens, 2 – tube with coating liquid, 3 – lens immersion mechanism in liquid, and 4 – electro-power supply unit to regulate lens immersion and eventration speeds in liquid.

Formation of hydrophobic layers above the antireflective layers was conducted with the similar method and the same experimental device. In this event the solution in the tub was made P – 32LN powder of fluoroplast solution of a specific viscosity. As the thickness of a layer must be less, the velocity rate of removal of the lens compared with the previous processes is higher and the concentration of the solution is fewer. Drying process of the hydrophobic layer of the lens-concentrator is done in thermostat at 60 – 70 °C temperature. To define the thickness of the hydrophobic layer we used the existing literature data [7, 8] as well, according to which it must not exceed 20 – 30 nm.

3. Results and Discussion

By the methods described (1) polysiloxane layer with width of 40 nm, (2) antireflective cover consisting of layers SiO_2 with width 85 nm (n = 1.47), ZrO_2 with width of 63 nm (n = 1.98), and SiO_2 with width of 85 nm (n = 1.47), and (3) aquaphobic cover with width of 20 nm were obtained.

Using the spectrometer ULS 2040 of the Dutch company Avantes Avaspec, the spectral feature were explored before and after coating with antireflective layers (Fig. 4.).

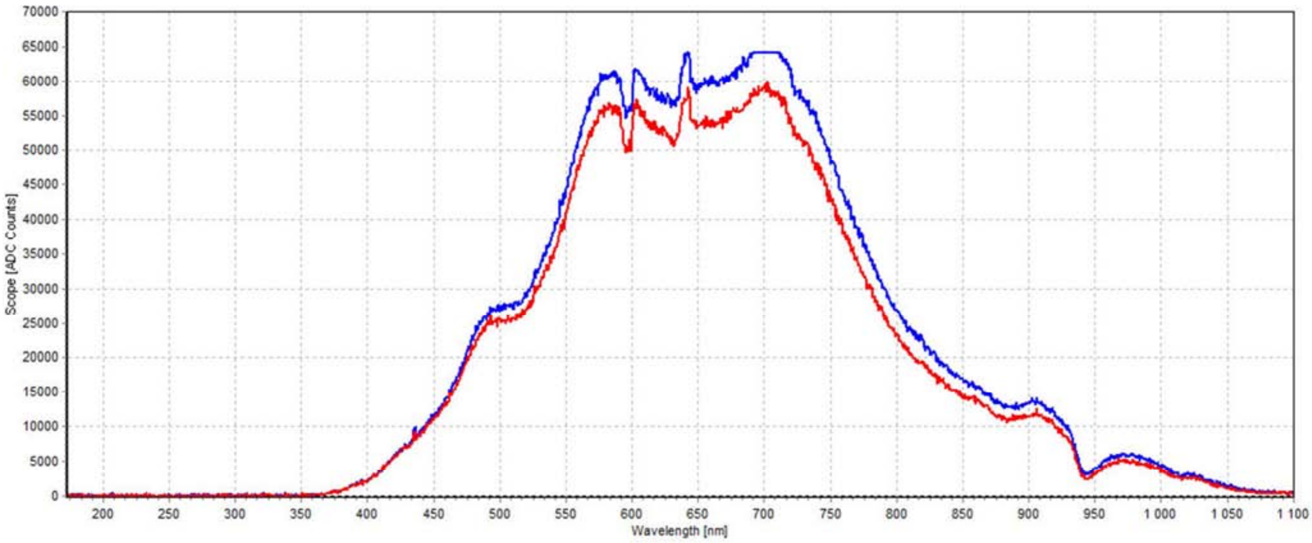

Figure 4. *Spectral feature of the lens before coating with antireflective layer (lower curve) and after coating (upper curve).*

Table 1. *Research results of antireflective coated lens concentrators.*

Solar radiation intensity W/m^2 (time, h)	Electric power received from the photocell, W·10^{-3}			
	Without concentrator	With concentrator, concentration degree of 35		
		Without antireflective coating	With antireflective coating	Increase of power received, %
600 (12)	2.30	77.0	78.70	2.20
760 (13)	2.91	90.5	92.60	2.30
740 (14)	2.84	89.2	91.25	2.30
700 (16)	2.68	84,8	86.70	2.25

We can see from the spectral features that after antireflection intensity of the light going through the lens at the spectral range of 500 – 900 nm it has considerably increased, growth reaches 10% at certain wavelengths [9, 10].

At the next stage the antireflective lens was explored as a concentrator. A stand was constructed that consisted of photocell and lens-concentrator fixing. The fixing allowed us to replace the lens at the same photocell, use as a concentrator with the same parameter lens with antireflection and without antireflection. Experiment was conducted during the different parts of the day, with the different intensity of the sun. Lens diameter was 30 mm, and that of the photocell was 5 mm. Given optical concentration degree was 35. Solar radiation intensity altered between 600 and 750 W / m^2 (Tab. 1).

As shown in the Table 1, the increase of electric power received using antireflective lens-concentrators is important and its maximal value reaches 2.3%.

The research above was conducted on the glass lens. Energy conversion efficiency (ECE) of solar photoelectric ECE was 25%. Power increase of higher ECE photoelectric converter will accordingly be higher.

The following researches concerned the hydrophobicity of the lens that is valued by the edge angle moisture. The higher is the angle, the higher will be the hydrophobic surface. The photographic method [11, 12] was used in given paper for the research.

At the first stage the lenses were explored with the antireflective layers but without hydrophobic layers. The research showed that hydrophobisity is considerably low in this case as edge angle moisture was about 20°. After, the same lenses were explored with hydrophobic fluoroplast layer of about 2 nm width. Measurements showed that hydrophobisity has considerably increased as edge angle moisture was already between 100 and 110°. The research showed that the edge angel moisture rate supposedly depends on the thickness of the hydrophobic layer. To define optimal width it is necessary to conduct more accurate measurements that are the aim of our next studies. At this stage we can conclude that if we cover the lens-concentrator with fluoroplast layer of thickness of 20 – 30 nm hydrophobisity will considerably increase.

4. Conclusion

According to the conducted research we can conclude that concentrator quality is important in efficient transformation of solar energy when using lens-concentrators in the solar photovoltaic blocks.

At first the concentrator must have minimal losses on the outer and inner surfaces, i.e. maximum energy of light must reach the photocell.

Moreover, the concentrator must be resistant against environmental conditions. The hydrophobisity is most important in this case.

To solve the first task we have performed calculations and on their basis covered the outer and the inner surfaces of the lens with the following antireflective layers: SiO_2 with thickness of 85 nm (n = 1.47), ZrO_2 with thickness of 63 nm (n

= 1.98), and SiO_2 with thickness of 85 nm (n = 1.47), and achieved considerable increase (for some wavelengths up to 10%) in energy of light passing through for wavelengths of 0.6 – 0.8 μm range.

To solve the second task fluoroplast layer of thickness of 20 – 30 nm was formed above the antireflective layer of the concentrator. Hydrophobisity has considerably increased when adding this layer. That has been confirmed when tested it in natural moistening, also measuring the edge angle moisture that has increased for its part in about 80°.

Technological processes that are used to form the above layers are processed or altered by us existing equipment. At present the final refinement of these processes and respective equipment is being carried out. Later, that will give us opportunity to produce more efficient lens-concentrators without considerable increase in their cost.

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