

Experimental coatings for photovoltaic panels obtained by the sol-gel method based on compositions with the participation of Y_2O_3 and ZrO_2

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Abstract: A summary study of the development of solar energy and the main factors determining the productivity of photovoltaic systems has been carried out. The predominant surface contaminants of solar panels, reducing the efficiency of photovoltaic installations, and the existing different design types of cleaning systems for their effective removal are examined. The main trends in the development of single-layer and multi-layer hydrophobic and other oxide coatings with diverse performance indicators suitable for solar panels are traced. In laboratory conditions, experimental self-cleaning coatings (based on compositions with the participation of Y_2O_3 and ZrO_2) deposited by the sol-gel method on vitreous samples were obtained. The structure and morphology of the prepared thin films and the technological conditions for the deposition of nanoscale layers with different functional characteristics were investigated. The experimental results represent a prerequisite for the development of a series of additional compositions and a detailed technological regime for obtaining various modifications of resistant, long-lasting self-cleaning coatings, potentially applicable to photovoltaic panels.

Keywords: PHOTOVOLTAIC SYSTEMS, SOLAR ENERGY, SURFACE CLEANING, Y_2O_3 and ZrO_2

1. Introduction

As a promising energy alternative, new generations of ecological and efficient systems for electricity production based on renewable energy sources are being developed [1]: photovoltaic, wind generator, hydroelectric, geothermal, hybrid and other plants. In recent decades, there has been a trend of increasing interest in the construction of photovoltaic plants of various capacities [2-6]: from relatively small installations intended for single-family or multi-family residential and business buildings to systems for manufacturing enterprises, as well as extensive solar parks. According to the distribution of the produced electricity, solar power plants are divided into several groups [2,5,6]: stand-alone systems (providing power supply only to isolated sites), photovoltaic installations integrated with the existing electricity distribution network and combined systems combining the functional capabilities of the previous ones.

The working capacity and efficient functioning of photovoltaic installations is determined by the operating conditions and the condition of the facilities [2,7,8]: positioning of the systems, orientation of the solar modules, climatic characteristics of the designated region, seasonal weather fluctuations, dynamics of solar activity, presence of adjacent objects shading the modules, serviceability and depreciation of the facilities and others. An essential factor having a significant effect on the performance of solar systems is the condition of the working surface of the photovoltaic panels and the presence of contaminants. The main pollutants are dust particles [7] (of technogenic or other origin), heterogeneous surface deposits formed under the influence of dynamic weather conditions, products of the life cycle of a number of organisms and others.

Cleaning systems (manual, robotic and automated) with different functional capabilities and specific operating requirements are used to remove deposited pollutants from solar panels [2,8]. The designed manual cleaning systems are mostly suitable for relatively small PV installations, but are not an appropriate solution for large solar parks. At the same time, automated and robotic cleaning systems require significant capital investments and qualified service. On the other hand, to ensure high efficiency of photovoltaic systems, the use of self-cleaning coatings deposited on the working surface of the solar panels is an expedient option [5]. This allows the reduction of losses (from pollution of the photovoltaic modules) in the production of electricity. Commercially available products for the impregnation (by the users themselves) of photovoltaic panels have a limited effect within a certain period of use. The resulting coatings are characterized by an uneven distribution on the surface

of the panels and gradually deteriorate and lose their functional properties in the process of operation.

In this aspect, an effective solution to the problem is the application of technological methods [9-25], ensuring the production of long-lasting resistant coatings (for photovoltaic panels) combining different operational characteristics.

By means of atmospheric pressure chemical vapour deposition [12,13], antireflective TiO_2 coatings have been deposited, increasing the efficiency of monocrystalline and polycrystalline silicon solar cells.

Self-cleaning [18], antireflective monolayer TiO_2 [14], bilayer (SiO_2/TiO_2 and SiO_2-TiO_2/SiO_2-TiO_2) [16,18] and trilayer ($SiO_2/SiO_2-TiO_2/TiO_2$ and $SiO_2/TiO_2/SiO_2-TiO_2$) [15,17] oxide coatings for solar cells have been obtained using the sol-gel method [14-18].

Self-cleaning and weather resistance nano- SnO_2 /modified silicone oil coating suitable for photovoltaic (PV) glass have been developed [19]. Superhydrophobic self-cleaning composite coatings [20] synthesized in the binary oxide system $rGO-TiO_2$ were investigated. Various modifications of nanoscale antireflective experimental coatings for solar energy have been obtained: WO_3-TiO_2 [21], TiO_2/Ni [22], NPs/TiO_2 [23], Al_2O_3/In [23] and others.

Multilayer $TiO_2/SiO_2/Ag$ thin films with self-cleaning properties [24] and high reflectivity suitable for solar reflectors were deposited by magnetron sputtering. The antireflective properties of multilayer $TiO_2-SiO_2/SiO_2/SiN_x$ coatings (with a specific stacks-structure) applicable for polycrystalline silicon solar cells were investigated [25].

The sol-gel method represents [14-18] a competitive and expedient technological solution for the deposition of coatings, ensuring the production of thin films with the presence of diverse functional properties at lower synthesis temperature values (when compared with other technological approaches) and without the need from using high-tech equipment. The sol-gel technology allows effective control of the parameters of the reaction medium and of the individual technological stages and is applicable for obtaining of long-lasting nano-sized mono- and polyphase, single-layer or multilayer thin films with different structural characteristics.

The use of materials with specific and unique characteristics, successfully applied in various technical fields, can be considered as a perspective possibility for obtaining new self-cleaning coatings for photovoltaic panels. In this regard, materials obtained on the basis of ZrO_2 with proven high operational properties in a variety of working environments are a suitable option.

Three phases are characteristic of ZrO_2 [26-28]: monoclinic (m- ZrO_2 , below 1170°C), tetragonal (t- ZrO_2 , in the interval from 1170°C to 2370°C) and cubic (c- ZrO_2 , above 2370°C). The transformation from one structural form to another is accompanied by the occurrence of stresses and destructive changes in the material [29,30]. The introduction of limited amounts of oxide additives (Y_2O_3 , Ce_2O_3 , MgO , CaO , etc.) allows stabilization of the tetragonal or cubic phase [27,31,32]. Therefore, ZrO_2 finds use mainly in the form of a stabilized phase, being characterized by significant wear resistance and high mechanical, thermal and other characteristics [27]. Materials based on ZrO_2 are applicable in the production of oxygen sensors, fuel cell membranes, microelectronic devices, thermal barrier coatings, refractory, insulation, abrasive and dental products. Experimental double-layer $\text{ZrO}_2/\text{SiO}_2$ antireflective coatings for silicon solar modules have been developed and investigated for the photovoltaic industry [33].

The aim of the present work is to present the characteristics of experimental self-cleaning coatings obtained on the basis of compositions with the participation of ZrO_2 and Y_2O_3 , deposited by the sol-gel method on vitreous samples. In laboratory conditions, the structure and morphology of the prepared thin films and the role of the technological conditions in the formation of their operational properties were investigated. The experimental data obtained are a prerequisite for developing an optimal technological regime for obtaining various modifications of self-cleaning coatings for photovoltaic panels.

2. Experimental procedures

Preparation of stabilized sols from Y_2O_3 doped ZrO_2 .

We strive to:

1. Obtaining stable sols or solutions that will last (with proper preservation) for months and years.
2. Obtain samples with high permeability.
3. Obtaining samples resistant to high temperatures and with high chemical stability.
4. Obtaining samples with evenly applied layers and relatively low roughness (unevenness).

Way of acting:

In this case, sol-gel technology was applied. $\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ is dissolved in absolute alcohol - so that a 0.3 - 0.4 molar solution is obtained. $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ is added to it slowly with vigorous stirring. During hydrolysis, nitric acid is added or stirred until it becomes clear, i.e. until complete dissolution. As a last resort, acetyl acetone or diethanol amine can also be used, which further stabilize the synthesized sol. The resulting liquid is stored in a refrigerator. Instrumental physicochemical study of the synthesized sol.

The figures show layers on glass based on the experiments, and the samples are numbered GLS -0, 3 and 5, where the number is the number of layers.

3. Results and Discussion

Optical characterization was performed with UV-VIS-NIR Shimadzu 3600 double-beam spectrophotometer (Shimadzu Corporation, Kyoto, Japan) in the spectral region of 280-1800 nm. The transmittance spectra of the samples were taken against air. The reflectance spectra were measured by using the specular reflectance attachment (5° incidence angle) and Al coated mirror as reference.

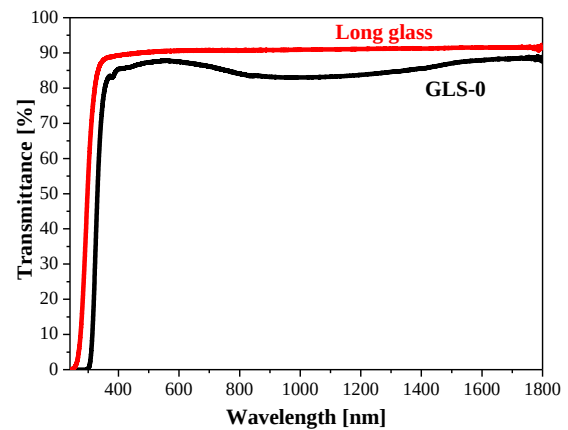


Figure 1. The figure shows the transmission spectrum of a clean GLS-0 substrate

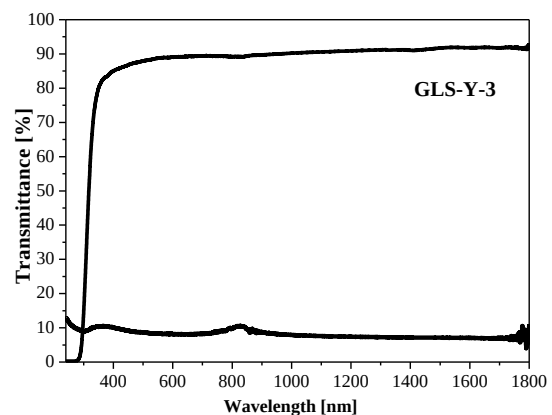


Figure 2. The figure shows the transmission spectrum of a GLS-Y-3

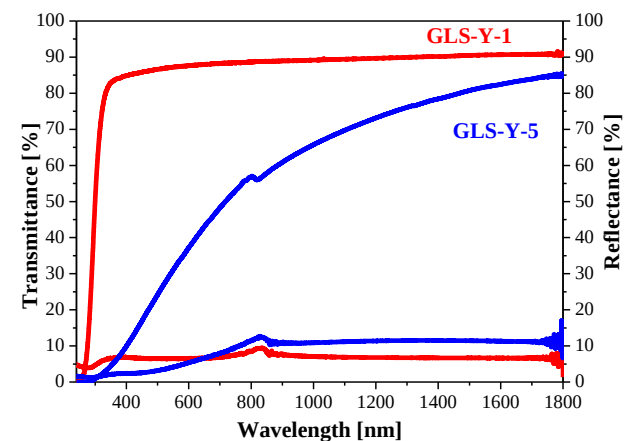


Figure 3. The figure shows the transmission spectrum of a GLS-Y-1 u GLS-Y-5

An X-ray diffractometer with a Bragg-Brentano θ -2 θ focusing system was used. The samples were examined at room temperature with $\text{Cu-K}\alpha$ radiation (monochromatic radiation with wavelength $\lambda = 154178\text{\AA}$) in the interval $20^\circ < 2\theta < 65^\circ$, at a step of 0.025 2θ for 10 seconds. A graphite monochromator was used for better peak resolution (better signal-to-noise ratio).

The size of the ZrO₂ crystallites is calculated according to the Scherrer formula:

$$D = 0.9\lambda / B \cdot \cos\theta$$

D - average crystallite size /Average Crystallite size/

λ - wavelength (in angstroms) - 1.54178 Å /X-Ray wavelength/

θ - Bragg angle (degrees) - $2\theta/2$ /Bragg angle/

B - line broadening FWHM (2 θ), /Line broadening/ must be of dimension radians (rad=20* π /180)

The positions of the X-ray diffraction peaks correspond to tetragonal ZrO₂, according to standard JCPDS card 069-1771. According to Scherrer's formula, the average crystallite size corresponding to the 111 orientation (the peak with the highest intensity) was calculated. It is 31 nm.

The layer thickness was determined on an EPSILON 1 Malvern PANalytical B.V. X-ray Energy Dispersive Spectrometer for X-ray Fluorescence Analysis. (The X-ray energy dispersive spectrometer for X-ray fluorescence analysis, model EPSILON 1 Malvern PANalytical B.V.). Stratos layer analysis software module was used for this purpose.

With this definition, a thickness of the investigated layer of 82nm was established.

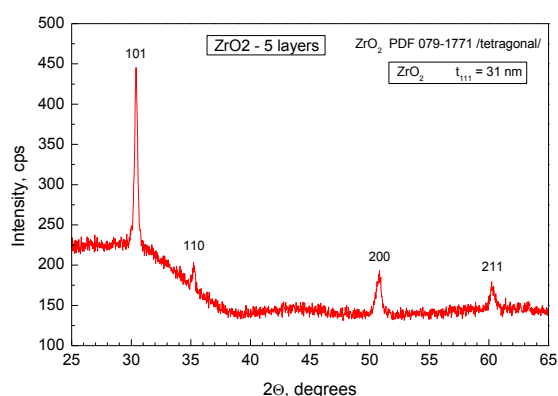


Figure 4. The figure shows the X-ray diffractometer of GLS-Y-5

4. Conclusions

1. Coatings are prepared by the sol-gel method using a dip coating technique. The present study characterizes self-cleaning ZrO₂ and Y₂O₃ thin films for photovoltaic application.

2. Tests were conducted at different layers of the included components, application rate of the solution on the glass substrate and different drying temperatures.

3. The studies were conducted by XRD studies and optically transparent according to the UV-VIS-NIR spectra

5. References

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