

# Synthesis and characterization of nanostructured coatings on glass from oxides of transition elements with the participation of $\text{Eu}_2\text{O}_3$ obtained by sol-gel technology

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**Abstract:** Obtained experimental self-cleaning coatings (based on compositions with the participation of  $\text{Eu}_2\text{O}_3$ ), applied by the sol-gel method on glass slides. This study attempts to improve the overall efficiency of a photovoltaic solar panel by using a  $\text{ZrO}_2$ -based coating, with  $\text{Y}_2\text{O}_3$  and addition of  $\text{Eu}_2\text{O}_3$ . The optical characterization and phase composition of the obtained experimental samples were investigated using UV-VIS-NIR, XRD and XRF methods. The coatings are nanocrystalline according to XRD and XRF analyzes and show transmittance close to that of pure glass when tested with a UV-VIS-NIR spectrophotometer. 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:** SOL GEL, SELF-CLEANING COATINGS, DIP COATING, SOLAR CELLS, PHOTOVOLTAICS,  $\text{Eu}_2\text{O}_3$

## 1. Introduction

The formation of europium oxide nanocrystallites in a silicon matrix is known, which significantly change the structural and luminescent properties of the resulting nanopowder. The reduction of  $\text{Eu}^{3+}$  -  $\text{Eu}^{2+}$  ion due to the applied annealing conditions, which gives effective luminescence in the blue-red region, is explained. The resulting vitreous transparent luminescent matrix can have great potential as a spectrum modification layer for incoming solar radiation as well as an anti-reflective property when integrated with various optoelectronic devices [1]. The  $\text{Eu}_2\text{O}_3$ - $\text{SiO}_2$  system prepared using tetraethoxysilane was investigated and nanocrystallinity with a particle size of 8–40 nm was obtained [2]. The optical properties of the  $\text{Eu}^{3+}$ -doped  $\text{Y}_2\text{O}_3$ -stabilized  $\text{ZrO}_2$  crystals demonstrate potential for various applications based on their intense emission of orange light. The synthesis, structure, and optical properties are reported for a series of yttrium-stabilized zirconia crystals in which some  $\text{Y}^{3+}$  was replaced by  $\text{Eu}^{3+}$ . These crystals were grown by the optical floating zone (OFZ) method and were transparent without inclusions, cracks, or bubbles. They were all exclusively in the cubic phase, whereas the corresponding ceramic samples had a mixture of monoclinic and cubic phases [3]. The synthesis of undoped and  $\text{Eu}_2\text{O}_3$ -doped bismuth gallate glasses, their radiation response optical characteristics were investigated in detail. Bismuth gallate glass doped with 1.0%  $\text{Eu}_2\text{O}_3$  showed the highest PL and scintillation intensity [4]. It has been proven that increasing the concentration of  $\text{Eu}_2\text{O}_3$  in the glass reduces the formation of crystalline phases. Raman spectra revealed the presence of interstitial molecular oxygen in the glass. Photoluminescence has shown that  $\text{Eu}^{3+}$  ions are not reduced after heat treatment [5]. Immersion oil was also used between the solar cell and the luminescent layer to match the differences between the linear indices of refraction. The luminescence of rare earth elements in the visible spectra can be enhanced by metal nanoparticles used as a capping layer. An efficiency increase of about 18.42% has been demonstrated for silicon solar cells coated with  $\text{GeO}_2$ - $\text{PbO}$  glasses doped with  $\text{Eu}^{3+}$  ions and containing spherical gold nanoparticles with an average size of about 8 nm [6]. A hydrophobic sol-gel based self-cleaning coating for a solar panel was synthesized and the hydrophobic sol-gel based self-cleaning coating was characterized. The solution was prepared by a sol-gel process, which consists of three different materials, including vinyltriethoxysilane (VTES), tetraethoxysilane (TEOS), and tetrabutoxytitanate (TTBU), named VTT (VTES-TEOS-TTBU) sol as an organic-inorganic hybrid sol [7].

The team works in the field of self-cleaning coatings to improve the performance of solar cells under contamination to improve the management of the incident solar spectrum. Maintaining PV performance from contamination issues through manual cleaning is expensive and difficult, which is a major concern in the implementation of this technology. Therefore, a

fouling mitigation technique with self-cleaning properties is effective in minimizing the performance degradation of PV panels using sol-gel as a low-cost and scalable fabrication method.

In the present paper, the effect of  $\text{Eu}_2\text{O}_3$  on anti-reflective and self-cleaning coatings is investigated in order to obtain less reflection and greater light transmission for use in photovoltaics. The most common method is used - sol-gel with immersion. When applied to PV modules, it is crucial to consider factors such as self-cleaning, transparency, anti-reflection, anti-icing and durability. In future research, it is important to improve the transparency, durability and self-cleaning properties of the coatings.

## 2. Experimental procedures

All compounds were supplied as analytical grades and were used without further modification. Thin film coatings were performed on slides from AGC Glass Europe.  $\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ ,  $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ,  $\text{Eu}_2\text{O}_3$ , 99.9% ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ), all purchased from Alfa Aesar Germany. The stabilizer is nitric acid / $\text{HNO}_3$ .

Preparation of the glass substrate. Before being cleaned, the slides were cut to size (20 mm x 70 mm x 2 mm). Substrate cleaning is important prior to the deposition process, as this allows the cleaning and removal of submicron particles from the substrate surface. This is decisive for the quality of the adhesive film on the base. The glass substrates were cleaned/washed/in 99.9% ethyl alcohol for 15 minutes and acetone for 15 minutes and then dried for 30 minutes at 100°C. Cleaning the glass substrates improves the adhesion of the coating material to the substrate and prevents contamination of the formed coating. In table 1 presents the compositions and the technology of obtaining.

Sample	Main Composition	Drying Time 150°C	T°C	layers
ZrYEu1.3	$\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ – 9.889 g / $\text{ZrO}_2$ – 3.414g / $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ - 0.829 g $\text{Eu}_2\text{O}_3$ – 0.407 mg	60 min per layer	420°C- 2 hour Delay 15 min	1
ZrYEu2.3	$\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ – 9.889 g / $\text{ZrO}_2$ – 3.414g / $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ - 0.831 g $\text{Eu}_2\text{O}_3$ – 0.407 mg	60 min per layer	420°C- 2 hour Delay 15 min	2
ZrYEu3.3	$\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ – 9.889 g / $\text{ZrO}_2$ – 3.414g / $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ - 0.831 g $\text{Eu}_2\text{O}_3$ – 0.407 mg	60 min per layer	420°C- 2 hour Delay 15 min	3

ZrYEu2.1	ZrOCl <sub>2</sub> .8H <sub>2</sub> O – 1.982 g Y(NO <sub>3</sub> ) <sub>3</sub> .6H <sub>2</sub> O - 0.831 g Eu <sub>2</sub> O <sub>3</sub> – 0.290 mg	60 min per layer	400°C- 2 hour Delay 15 min	2
ZrYEu2.2	ZrOCl <sub>2</sub> .8H <sub>2</sub> O – 2.942 g Y(NO <sub>3</sub> ) <sub>3</sub> .6H <sub>2</sub> O - 0.7292 g Eu <sub>2</sub> O <sub>3</sub> – 0.226 mg	60 min per layer	400°C- 2 hour Delay 15 min	2

The table shows the compositions and production technology of **GLS-ZrYEu3, 4, 6 and 7**

Sol-gel technology is applied. ZrOCl<sub>2</sub>.8H<sub>2</sub>O is dissolved in absolute alcohol - so that a 0.3 - 0.4 molar solution is obtained. Y(NO<sub>3</sub>)<sub>3</sub>.6H<sub>2</sub>O is added to it slowly with vigorous stirring. After 60 min, Eu<sub>2</sub>O<sub>3</sub> was added. During hydrolysis, nitric acid is added or stirred until clear, i.e. until completely dissolved. To cover the glass samples with the resulting solution, the Dip Coating technology is applied.

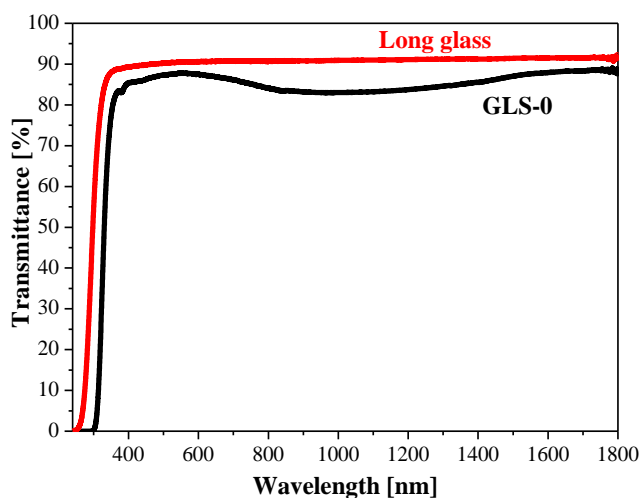
### 3. Results and Discussion

Optical characterization was performed with UV-VIS-NIR Shimadzu 3600 double-beam spectrophotometer (Shimadzu Corporation, Kyoto, Japan) in the spectral region of 240-1800 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

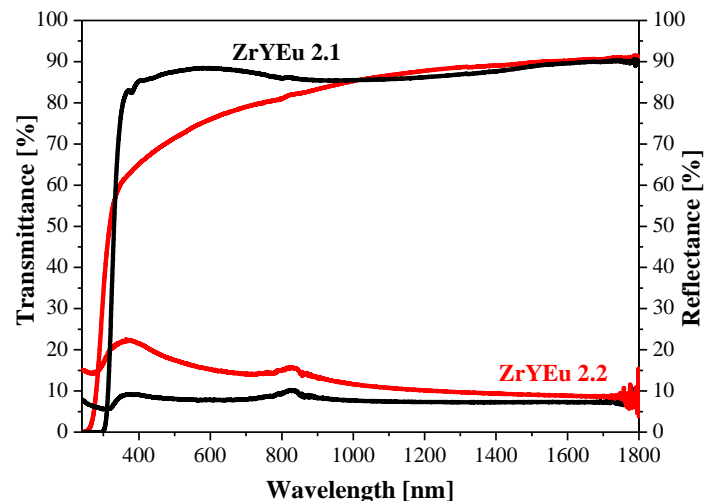
The synthesised materials were studied using an X-ray powder diffractometer (XRD), specifically a PANalytical Aeris, which uses CuK $\alpha$  radiation ( $\lambda = 1.5406 \text{ \AA}$ ) in a  $\theta$ - $\theta$  configuration following the Bragg-Brentano geometry. The  $2\theta$  scan range was set from 20° to 40° with a scan step of 0.02° for 60 seconds per step. The diffractograms were analysed using the PDF-2 2022 database.

The thickness of the layer and its elemental composition were measured using energy-dispersive X-ray fluorescence spectrometry (EDXRF) with an EPSILON 1 spectrometer (PANalytical, Malvern, UK). The Omnia and Stratos software modules were used for quantitative and layer thickness analysis respectively.

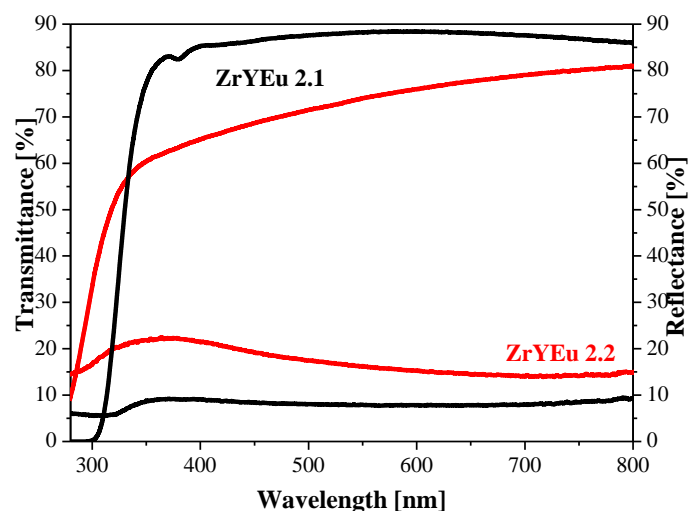
Figure 1 shows the transmission spectrum of a clean glass substrate. The figures 2 and 3 shows the transmission and reflection spectrum of an experimental coating on a glass substrate in the region 300 - 800 nm and 400 - 1800 nm /on sample /



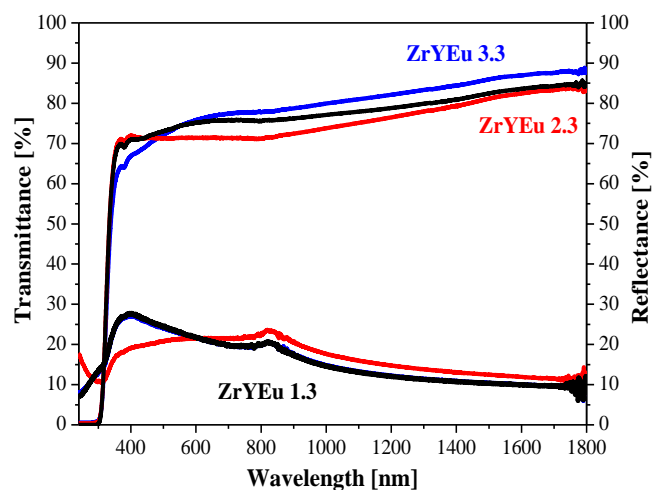
**Figure 1.** The figure shows the transmission spectrum of a clean glass substrate /GLS-0/



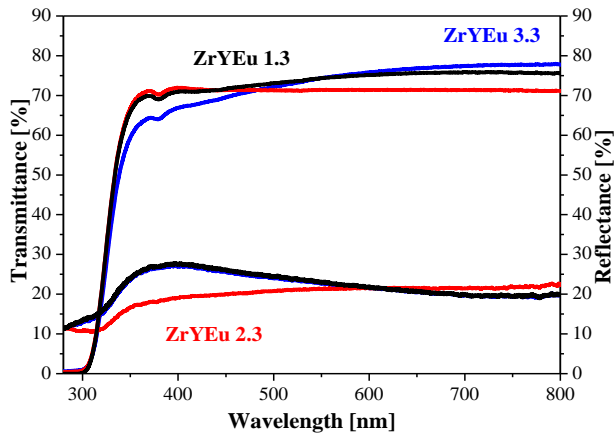
**Figure 2.** The figure shows the transmission and reflection spectrum of an experimental coating on a glass substrate in the region 400 - 1800 nm /ZrYEu 2.1 and 2.2/



**Figure 3.** The figure shows the transmission and reflection spectrum of an experimental coating on a glass substrate in the region 300 - 800 nm /ZrYEu 2.1, and 2.2/

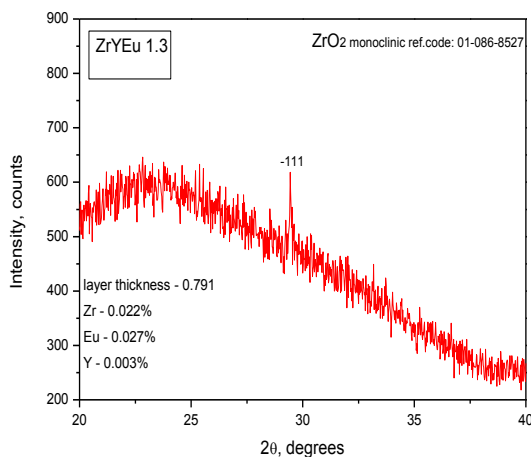


**Figure 4.** The figure shows the transmission and reflection spectrum of an experimental coating on a glass substrate in the region 400 - 1800 nm /ZrYEu 1.3, 2.3 and 3.3/



**Figure 5.** The figure shows the transmission and reflection spectrum of an experimental coating on a glass substrate in the region 300 - 800 nm / **ZrYEu 1.3, 2.3 and 3.3** /

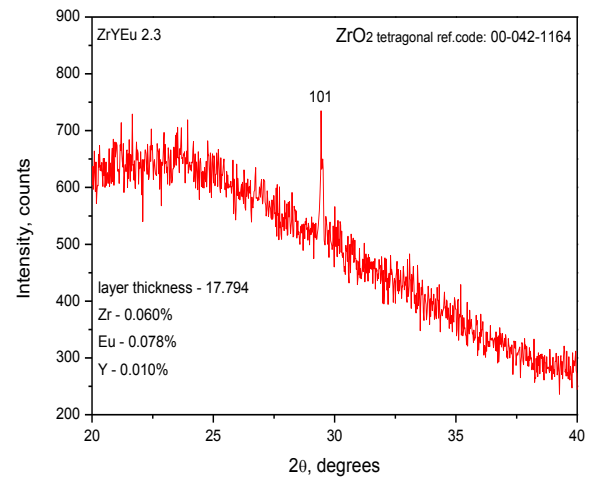
Figures 6-8 present the results of XRD and XRF analyses of the surface of the glass samples. The weak peak observed at  $29.59^\circ 2\theta$  in the diffractogram of sample ZrYEu 1.3 indicates the formation of monoclinic  $ZrO_2$  / Figure 6/ Its low intensity is associated with the minimal thickness of the coating, which is also confirmed by the XRF analysis.



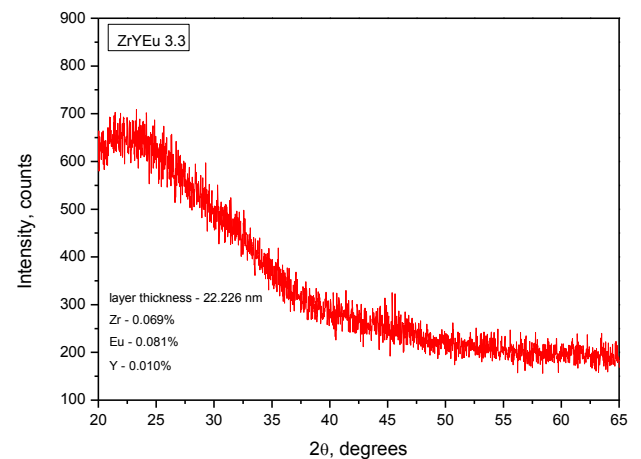
**Figure 6.** XRD and XRF analyses of the surface of the coating on glass / **ZrYEu 1.3** /

A higher concentration of the solutions leads to an increase in the thickness of the layer (Figure 7). In this case the observed peak with a slightly higher intensity at  $29.81^\circ 2\theta$  corresponds to the (101) crystallographic plane of the tetragonal structure of  $ZrO_2$ . The layer thickness of the ZrYEu 3.3 sample is approximately the same as that of ZrYEu 2.3, but no peaks indicating the formation of an oxide layer are observed (Figure 8).

These results show that it is necessary to increase the quantitative content of the layer forming elements.



**Figure 7.** XRD and XRF analyses of the surface of the coating on glass / **ZrYEu 2.3** /



**Figure 8.** XRD and XRF analyses of the surface of the coating on glass / **ZrYEu 3.3** /

#### 4. Conclusions

This study attempts to improve the overall efficiency of a photovoltaic solar panel by using a  $ZrO_2$ -based coating, with  $Y_2O_3$  and addition of  $Eu_2O_3$ .

1. The coatings are prepared by sol gel method.
2. The coatings are dense and nanocrystalline, according to XRD and XRF analyses.
3. The coatings of ZrYEu3.3 and ZrYEu2.1 samples show very good transmittance by UV-VIS-NIR spectrophotometer examination.

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.

## 5. References

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