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ILLUMINATION WITH ELECTROCHROMATIC WINDOWS IN VIRTUAL REALITY

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Abstract: *Electrochromatic materials are characterized by reversible colour change when placed in an external electric field. One of the possible applications of such electrochromatic films is in the "Smart windows" that are used to modulate the transmitted light in objects. Thin electrochromatic films of copper oxide are obtained by the chemical deposition method of two solutions. The spectral transmission of the resulting films was recorded in a state as obtained, in a coloured and shaded state, in the visible part of the spectrum. From the sum of the intensity of the incident solar spectrum AM 1.5 and the amount of intensity of the spent radiation through the films, the mean values of the transmission coefficient of the films in the three states are determined, in the wave interval from 350 to 820 nm. The obtained results for the mean value of the transmission coefficient are used to simulate the illumination in the virtual reality, to a real object in which the outer illumination is modulated when passing light on the case when the windows would be examined films in the state as the film was obtained, in a coloured and shades condition. The simulation of the process is using Quest3D software for virtual reality.*

Key words: Electrochromic materials, copper oxide, virtual reality, 3d model, illumination

1. INTRODUCTION

Electrochromatic materials are characterized by the change in their optical properties, when small ions and electrons are brought or taken in the presence of an external electric field. The optical properties of electrochromatic materials are reversible, i.e. by changing the polarity of the applied voltage, the material returns to its initial state. Optical changes occur when applying a low-power electric with low voltages from one volt to several volts. A large number of materials, organic and inorganic, in liquid or solid state, that have electrochromic properties (Granqvist, 1995). In recent decades, the properties of these materials have been widely explored for the possibility of their use in different optical devices. The electrochromatic properties of various materials depend on the method of their production, with great influence of the structure, stoichiometry, the presence of water in the film. When describing the electrochromatic properties of a material, a detailed description of the procedure for obtaining it should be given. Electrochemical properties also show thin films from CuO, Cu_2O (Neškovska et al., 2007; Ristova et al., 2007; Ristova et al., 2015). These films can be obtained by different methods: thermal oxidation at lower or higher temperatures, electrode deposition, dispersion, anode and chemical oxidation of a copper plate and others. In order to see the optical changes occurring in electrochromatic films when changing the polarity of the outer field, the films should be deposited on a transparent conductive substrate. Thus, the methods for producing thin copper oxide electrochromic films are limited by the substrate on which they are deposited. In this scientific work, the films were deposited on glass substrates by the chemical deposition method of two solutions (Ristov et al., 1985). After that, an electrochromic test device was constructed to record the transmission coefficients of the films in the visible part of the spectrum in the interval of the wavelength of the fallen radiation from 300 to 850 nm in a state as obtained in a coloured and shaded state (Ristova et al., 2007).

Furthermore, the absorption coefficients of the film were calculated in the three states and the obtained results were used to determine the intensity of the transmitted radiation that passes through the films and the mean value of the transmission coefficients, and for the fallen radiation the solar spectrum of AM 1.5 was taken. The mean value of the transmission coefficient for the three states of the film is taken to simulate the illumination of the interior of a real object, when the existing windows would be the examined electrochromic films in the state as they were obtained in a coloured and shaded state. The simulation is using Quest3D virtual reality software. In this model, a virtual environment of a realistic model of the sports hall in Skopje was made. The hall is 40m x 20m, which includes a panel for 500 spectators. To create virtual environment, the following steps were made: collect data from the real model (appearance, dimensions), creating the same model in 3D Studio Max, importing models in the virtual reality software Quest3D and connect the models with the appropriate channels and their programming.

2. EXPERIMENTAL RESEARCH

Films from Cu_2O were deposited on glass substrates over which a transparent film of tin oxide doping with fluor was applied, SnO_2: F, also known as FTO, which also serves to store ions. For this purpose, the clear glass was heated to 400 °C and was sprayed with 300 ml of a 0.05 M aqueous solution of tin (II) chloride dihydrate ($SnCl_2 \cdot 2H_2O$), in which were added 2.4 g crystals of ammonium fluoride, NH4F, to obtain a solution with pH ~ 7 (Ristov et al., 1997). The preparation was sprayed with BOSCH Type 0603 260 403 sprayer. In this way were obtained homogeneous, conductive FTO substrates with a resistance of 18-40 Ω/cm^2, with a white light transmission of about 80% and a thickness of about 2 µm (Ristova et al., 2007).

On them were deposited thin films of copper (I) oxide following the method of chemical deposition (Ristova et al., 2015). In the process of obtaining the films, a cold and warm solution was used. For the deposition of several films with a thickness of less than 1 µm, 200 ml of the cold solution were enough, prepared from 20 ml of a 0.5 M solution of copper sulphate $CuSO_4$, in which gradually added 1 M solution of $Na_2S_2O_3$ (sodium thiosulphate) and getting a colourless solution. Then, a complex solution of $3Cu_2S_2O_3 \cdot 2Na_2S_2O_3$ was obtained. This complex solution was supplemented with distilled water to 200 ml. The hot solution was 200 ml of 2 M sodium hydroxide solution, NaOH, which was heated and maintained at a temperature of 60-80°C. Clean glass tiles with FTO base alternately submerged 1-2 sec. in hot and cold solution, until films with desired thickness were obtained. According to the method of chemical deposition (Ristov et al., 1985), every ten indigenous immersions give a film with a thickness of 100 nm. The films examined in this scientific work were with a thickness of 150 nm.

For research on the electrochromatic properties of thin films from copper(I)oxide, was constructed electrochromic test device with working electrode from glass substrate/FTO/ Cu_2O film and a glass substrate/FTO film as the opposite electrode. The electrodes were immersed in a liquid electrolyte of a 0.1 M aqueous solution of sodium hydroxide, NaOH. There was a small voltage across the electrodes.

3. RESULTS AND DISCUSSION

Transmission, reflection and absorption, as well as emission, are optical characteristics that can be measured experimentally and from the obtained values some conclusions can be done. The coefficient of transmission of electrochromatic films is change with the state of the film, ie it is different in the shaded and coloured state. In this study, the coefficient of transmission of films in the visible part of the spectrum was recorded in the interval of the wavelength of the fallen radiation from 300 to 850 nm, in a coloured and shaded state. The measurements were performed using the Varian Cary 50 Scan UV-Visible Spectrophotometer. The colouring and shading of films was performed with a voltage of -4 V and +4 V, respectively.

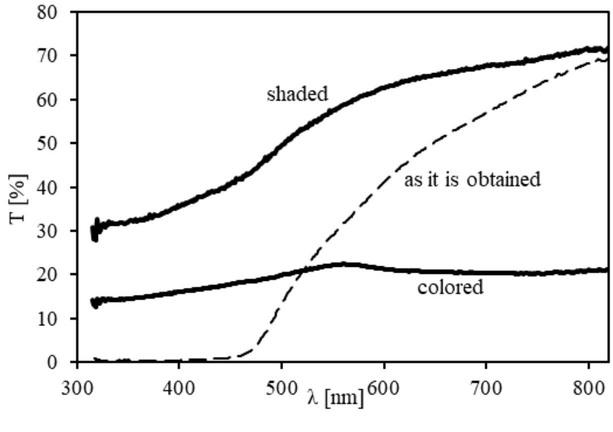

Figure 1: Dependence of the transmission coefficient of the wavelength, in the visible part of the spectrum, for a film of copper(I)oxide, obtained with method of chemical deposition

The intensity I(λ) of radiation passing through a film with thickness d and absorption coefficient α(λ), with the intensity I0(λ) (Figure 2) of the fallen radiation is related to the Equation (1):

$$I(\lambda) = I_0(\lambda) e^{-\alpha(\lambda) d} \quad (1)$$

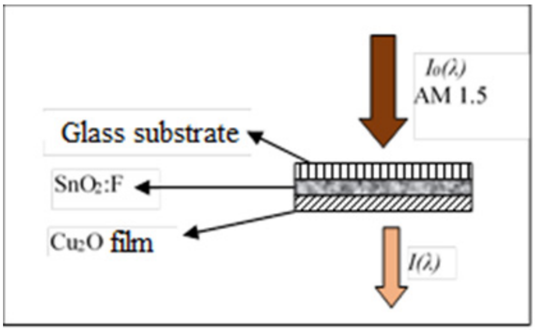

Figure 2: Schematic of modulation of the light

In calculating the intensity of radiation I(λ) through the films of the solar spectrum AM 1.5 was taken for a fallen rays. AM 1.5 gives the distribution of solar spectral irradiance (diffuse and direct) that comes to a surface located at 0m elevation at an angle of 37°, at 14.2 mm water vapor and 3.4 mm ozone (Smith et al., 2016).

Then, from the ratio of the sum of the spectral dependence of the irradiance I(λ) on the modulated radiation and the sum of the spectral dependence of the fallen radiation I0(λ), was defined the mean value of the transmission coefficient according to the Equation (2):

$$\overline{T} = \frac{\sum_{350}^{820} I(\lambda)}{\sum_{350}^{820} I_0(\lambda)} = \frac{\sum_{350}^{820} I(\lambda)}{520\ \mathrm{W/m^2}} \quad (2)$$

The intensity of the spent radiation is in a wave interval of 350 to 820 nm. The film have a value of 182.41 W/m^2, for the coloured state the value is 104.02 W/m^2 and for the shaded state W/m^2. The sum of the intensity of the fallen radiation in the same wave interval is 520 W/m^2. For the mean value of the coefficient of transmission in the same wave interval, for the condition in which the film is obtained, in the coloured and shaded state, the values are 35.08%, 20.0% and 57.60%, respectively. From the presented results it can be concluded that films of copper(I)oxide are suitable for modulating the infrared radiation in the visible part of the spectrum.

A graphic representation of the dependence of the intensity of radiation through the films as a function of the wavelength of the fallen radiation is given in Figures 3, 4 and 5.

The obtained results for the mean value of the transmission coefficient in the three conditions of the film, were used for simulation of the interior illumination of a real object, a sports hall in Skopje, when the existing windows would be examined as electrochromic films in the state as they were obtained, in coloured and shaded condition. The hall is 40 m x 20 m, which includes a panel for 500 spectators. The simulation was made using the virtual reality software Quest3D. Only external lighting was taken and the interior was switched off.

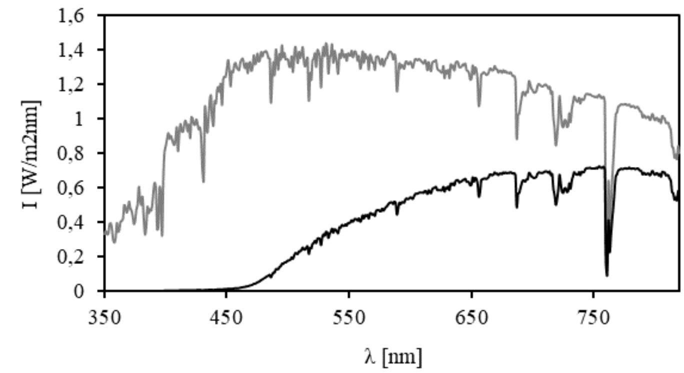

Figure 3: Iradiation I in terms of I0 for chemical deposited film, in a state as it is obtained

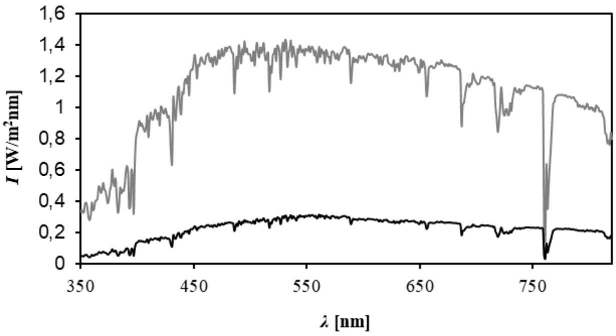

Figure 4: Iradiation I in terms of I0 for chemical deposited film, in coloured state

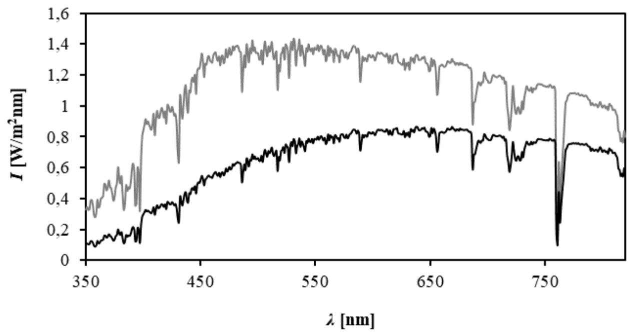

Figure 5: Iradiation I in terms of I0 for chemical deposited film, in shaded state

For creating a virtual world, we need 3D models that are developed in a suitable software package like 3DS Max, Maya, Archicad. These 3D models are exported in some virtual reality software and build virtual environments.
Quest3D is an extensive software package for creating interactive 3D scenes. It is characterized by a unique programming style. Quest3D working environment is in real time. It works directly on the virtual environment and any change in it is available. In Quest3D there are also ready-made schemes. They are predefined channels or group of channels. 3D objects are very important and can be import from external 3D modelling packages, such as 3DS Max or Maya (Popovski et al., 2014). Quest3D runs on Windows operating system. Its requirements are a more core processor, a minimum of 1 GB of RAM and a good graphics card that supports DirectX 10. It supports a large number of 3D formats, 2D formats, video and audio formats.
For the development of the 3D model, first of all was completed the data for the real object according to which the model was prepared. Then all the necessary data, dimensions, colours were completed, which started the creation of textures for the given model. Each of the textures are worked in Autodesk 3D Studio Max and then imported into the virtual reality software Quest3D.
For the needs of this research, was used 3D model developed in 3D Studio Max. The construction of the sports hall is a process in which each separate element is drawn as a separate polygon, so that later all

the polygons can be joined and the 3D look of the hall is done. 1062 special polygons were made and later fit into a single whole. On each of these polygons was applies to get the final look of the sport hall.
After completing the process of modelling objects in 3D Studio Max, there was preparation for import into Quest3D. Before importing each object, it is necessary to make a triangulation. Triangulation is a process of dividing polygons that are determined by four or more points, on three-point polygons. The next step is to export each object separately in Quest3D in a format acceptable to this software. The native format in which files are stored in 3D Studio Max and are exported to Quest3D is (.X) format. This format to be visible in the 3D Studio Max menu, there are exporters called kW x-Port that can export objects. For manipulating with objects in the virtual environment, it is best to keep each object separately. Then each element in the scene is connected separately to the render and virtual environment is visible. Then start the process of shadowing and texturing of objects. The quality of the rendering depends on the type of material used in the scene, visual components such as the colour, glossiness, transparency and surface to which it is applied, which determines how much it absorbs or reflects light. Adding textures to all surfaces provides a highly realistic virtual environment.
Figure 6 shows a comparation of the real and virtual model of the sports hall. Figures from 7 to 10 shows simulations of the interior illumination of the sport hall in daylighting and the same are modulated when passing through the windows of the sports hall, when they have electrochromic film in a state as it is obtained, in a coloured and shaded condition. In the four cases, the interior lighting is off.

Figure 6: Comparison of the real and virtual model of the sports hall

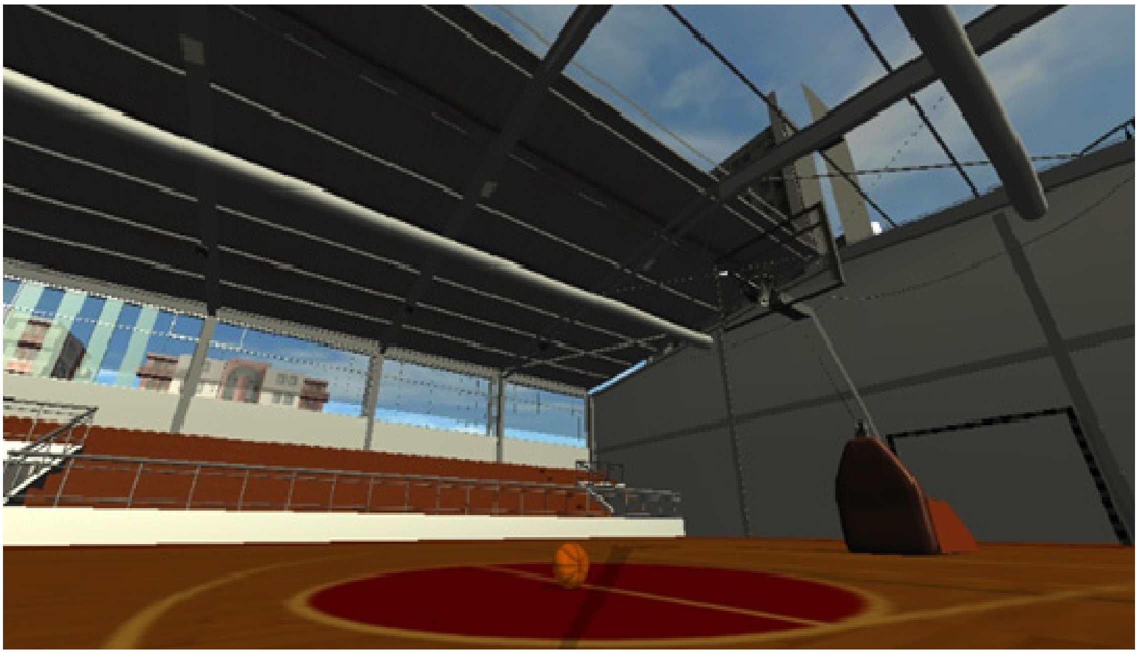

Figure 7: Simulation of the illumination in the interior of the sport hall in daylight. The interior lighting is off

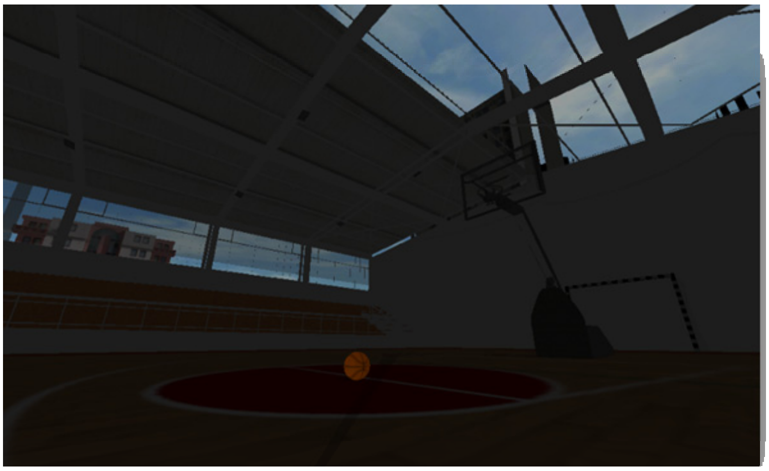

Figure 8: Simulation of the illumination in the interior of the sport hall in daylight, modulated when passing through the electrochromatic film in a state as it is obtained. The film's transmission coefficient main value is 35.08%. The solar spectrum AM 1.5 is fallen light and the interior lighting is switch offl

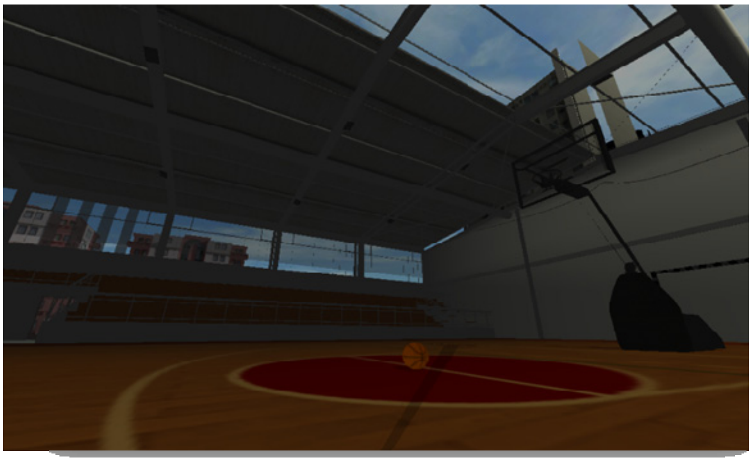

Figure 9: Simulation of the illumination in the interior of the sport hall in daylight, modulated when passing through the electrochromatic film in a shaded state. The film's transmission coefficient main value is 57.06%. The solar range AM 1.5 is fallen light and the interior lighting is switch off

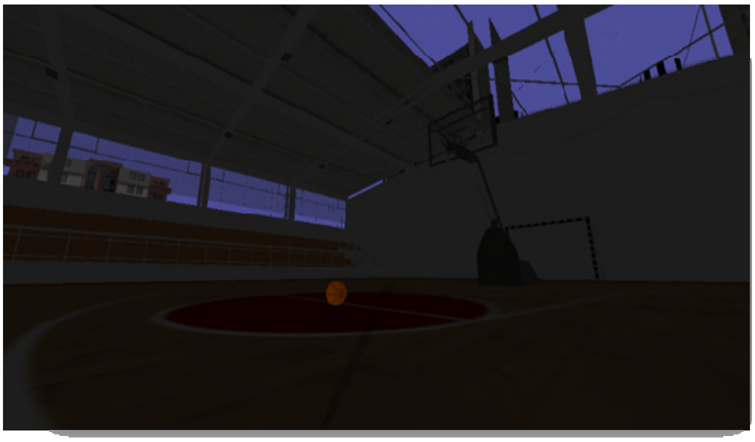

Figure 10: Simulation of the illumination in the interior of the sport hall in daylight, modulated when passing through the electrochromatic film in a coloured state. The film's transmission coefficient main value is 20,0%. The solar range AM 1.5 is fallen light and the interior lighting is switch off

4. CONCLUSIONS

In this scientific paper were obtained electrochromic films from copper(I)oxide in a fast, simple, economical and environmentally friendly method with chemical deposition of two solutions. The mean value of the transmission coefficient of the films in the visible part of the spectrum in the state as it is obtained is in a shaded and coloured state are 35.08%, 57.60% and 20.0%. The values for the transmission coefficient were used for simulation of the lighting of a real object, the sports hall "Forza" in Skopje, in case when an electrochromatic film of copper(I)oxide is set on existing windows of the building in a coloured and shaded condition. Simulations were made with the virtual reality software Quest3D and show that these films can be used in real world so-called "Smart windows".

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