Journal of Achievements in Materials and Manufacturing Engineering

VOLUME 52
ISSUE 1
May
2012

Sol gel TiO_2 antireflection coatings for silicon solar cells

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Received 13.03.2012; published in revised form 01.05.2012

Materials

ABSTRACT

Purpose: The aim of this paper was to investigate changes in surface morphology and optical reflection of thin films of titanium dioxide. Thin films were prepared using sol gel spin coating method.
Design/methodology/approach: The microanalysis have been investigated by the Energy-dispersive X-ray spectroscopy EDS. The changes in surface topography was observed by the atomic force microscope AFM and scanning electron microscope SEM. The results of roughness have been prepared in the software XEI Park Systems and optical reflection by the spectrometer UV/VIS.
Findings: Results and their analysis allow to conclude that the titanium isopropoxide concentration in solution and spin speed, which is an important factor in spin coating technology has a significant influence on surface morphology and optical reflection of thin films titanium dioxide.
Practical implications: Known sol gel titanium dioxide optical parameters and the possibility of obtaining a uniform thin films show that it can be good material for photovoltaic application.
Originality/value: The paper presents some researches of titanium dioxide thin films deposited by sol gel spin coating method on monocrystalline silicon.
Keywords: Titanium dioxide; Antireflection coating; Atomic force microscope; Scanning electron microscope; Spectroscopy UV/VIS; Silicon solar cells

Reference to this paper should be given in the following way:
L.A. Dobrzański, M. Szindler, Sol gel TiO_2 antireflection coatings for silicon solar cells, Journal of Achievements in Materials and Manufacturing Engineering 52/1 (2012) 7-14.

1. Introduction

Solar cells have a number of losses mechanisms, all of which can be minimized. Optical losses arise from reflection at the semiconductor surface and they can be reduced by surface texturing and depositing of antireflection coatings. The surface texturing, which bends incoming rays into a more horizontal direction and thus increase their path length inside the silicon [1-4]. The material used to deposit an antireflection coating must have a refractive index equal $n=(n_{si}\times n_s)^{1/2}$, where n_s is the refractive index of the surrounding medium. In industry, single solar cells are combined into modules with a protective layer of glass. Therefore, the reflection coefficient of glass has to be taken into account [1, 2]. One of the interesting materials used in the prepare of optical coatings is TiO_2. The main advantages of optical titanium dioxide is a large value of refractive index (over 2.3) and very good transparency (over 90%) over a wide spectral range (from about 320 to about 6000 nm). In addition to good optical properties of TiO_2 it has also many other desirable properties such as high mechanical resistance, chemical resistance and long term stability. The specific functional characteristics of titanium dioxide are closely related to its crystal structure. Monocrystalline TiO_2

can occur in three different crystallographic modifications: brookite, anatase and rutile [5, 6].

A specific type of crystal structure of the TiO_2 coatings is dependent on many factors. The most significant are: the selection of process conditions, the chosen method of manufacture, selection of additives to the base matrix of TiO_2, the use of additional treatments such as annealing at the proper temperature. The traditional antireflection coatings are produced by high-temperature methods like physical vapour deposition (PVD) or chemical vapour deposition (CVD). Interesting also seems the use of sol gel method. Sol-gel method allows the preparation of coatings from the liquid phase. Generally the sol gel method consists in a few steps as shown in Figure 1 [7-10].

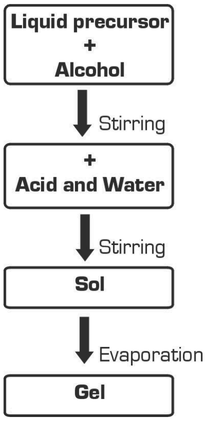

Fig. 1. Schematic representation of the sol-gel method

In comparison to the CVD, PVD, sol-gel technology requires far less complicated equipment, is less expensive, and the depositing does not require high temperatures.

In this technique alcohols are being usually used so the connection with the arrangement of bonds metal-oxygen-carbon, which after hydrolysis and condensation form gels. Gels by giving the desired shape, such as thin film and then an appropriate heat treatment, can be made into amorphous or crystalline material at a temperature much lower than used in conventional methods. This has been marked this technology as one of the most promising fields of contemporary material science. This may indicate a report of the number of publications in recent years concerning the sol-gel method based on the database Web of Knowledge (Fig. 2) [6, 11].

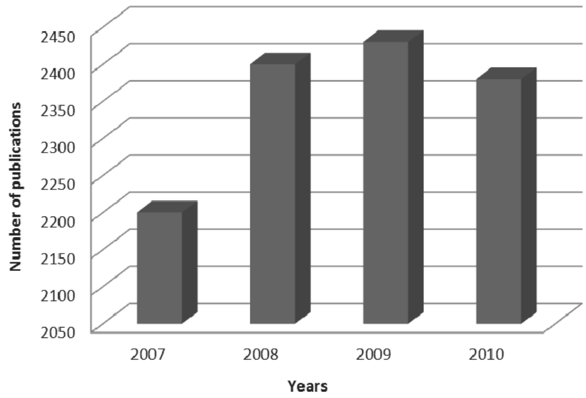

Fig. 2. The report of the number of published articles about the sol-gel method based on the database Web of Knowledge

There are many kinds methods of deposition thin films from solutions, e.g. spinning, dipping or spraying. Spin coating is a fast and easy method to prepare thin and homogeneous organic and inorganic films. Spin coating is a procedure used to apply uniform thin films to flat substrates. An excess amount of a solution is placed on the substrate, which is then rotated at high speed in order to spread the fluid by centrifugal force. A machine used for spin coating is called a spin coater. A typical spin process consists of a dispense step in which the fluid is deposited onto the substrate surface, a high speed spin step to thin the fluid, and a drying step to eliminate excess solvents from the resulting film (Fig. 3) [12-15].

In the present work, the titanium dioxide thin films prepared by sol gel method have been examined. The aim of this paper is an attempt to describe the changes in surface morphology, roughness and optical reflection of TiO_2 thin films, by the atomic force microscope, scanning electron microscope and spectrometer UV/VIS as dependent on conditions of the thin films preparation.

2. Materials and methodology

TiO_2 thin films were prepared by the sol–gel spin coating technique. The Titanium isopropoxide was used as precursor material, absolute ethyl alcohol was used as a solvent and hydrochloric acid as a catalyst. The mixture was vigorously stirred using a magnetic stirrer for 2 h. Then the solution was spin coated

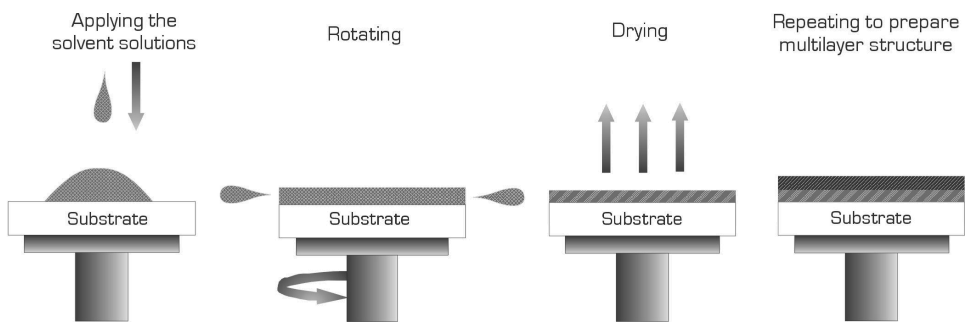

Fig. 3. The stages of the deposition thin films by spin coating method

with the various spin speed (2000, 3000 and 4000 rpm) on the polished monocrystalline silicon substrates and annealed at 600ºC for 2h. Two solutions were prepared with different ratio between titanium isoproxide and absolute ethyl alcohol (respectively: solution A is 1:6 and B is 1:8) (Table 1).

Table 1.
Deposition process parameters

Thin film	Solution	Spin speed, rpm	Temperature of heat treatment, °C
A1	A	2000	600
A2		3000	
A3		4000	
B1	B	2000	
B2		3000	
B3		4000	

3. Results and discussion

The microanalysis of the as-prepared thin films has been carried out by the Energy-dispersive X-ray spectroscopy. In Figures 4-5 are shown the EDS spectra of thin films of sol gel TiO_2. There are observed peaks at about 0.5 and 4.5 KeV in these EDS spectra's, which are assigned to titanium. Such an analysis can be confirmed the presence of titanium dioxide.

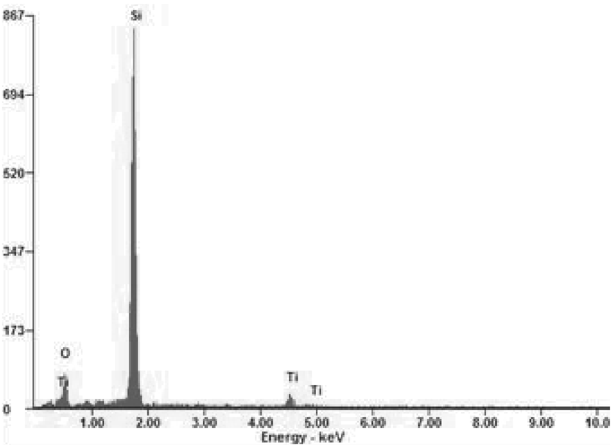

Fig. 4. EDS spectrum a thin film of TiO_2 deposited with 4000 rpm spin speed of solution A

The study of the surface topography was performed using scanning electron microscope SEM (Figure 6, 7). At too high concentrations of the titanium isopropoxide in a solution on the surface of a thin film there are a number of delaminations and precipitations as shown in Figure 6. The reduction of the concentration of titanium isopropoxide in the solution and increase the spin speed allows a deposition of the uniform TiO_2 thin films without any delaminations (Figure 7).

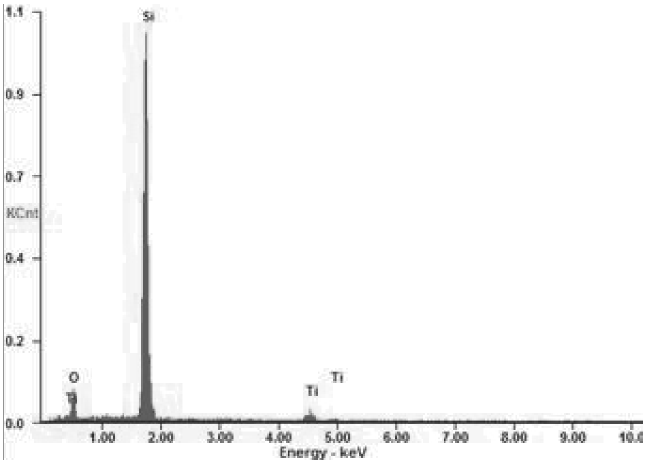

Fig. 5. EDS spectrum a thin film of TiO_2 deposited with 4000 rpm spin speed of solution B

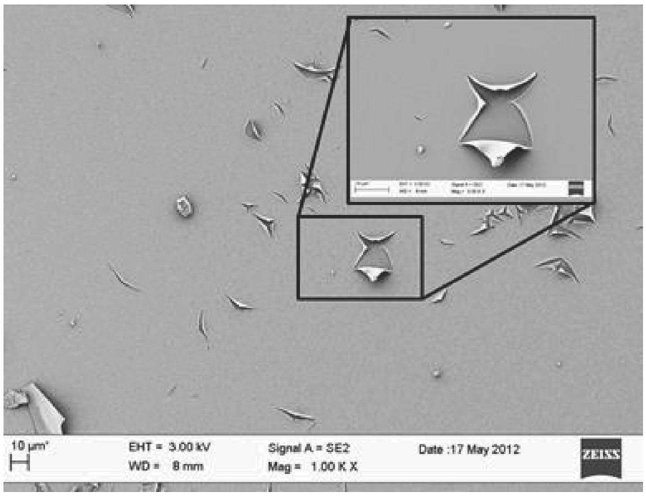

Fig. 6. SEM image of the surface topography of TiO_2 thin film deposited with a spin speed 2000 rpm from a solution of A

The study of the surface topography was performed by atomic force microscope AFM working in a non-contact mode. Figure 8 shows an AFM 3D image of the surface topography of TiO_2 thin films deposited with a spin speed 4000 rpm from a solution of A and B. Deposited thin films are characterized by a uniform surface topography without any precipitations. The roughness results was made in the XEI software. The Figure 9 and Table 2 presents an analysis of the roughness of a thin films deposited with a spin speed 4000 rpm from a solution of A and B in the program XEI Park Systems. Surface roughness was characterized by calculating the roughness parameters R_q and R_a maximum evaluation and presenting histograms.

Table 2.
The roughness parameters of a thin films deposited with a spin speed 4000 rpm from a solution of A and B

Thin film	Max height, nm	R_a, nm	R_q, nm
A3	25.85	1.330	1.768
B3	5.963	0.267	0.374

The UV/VIS spectrometer was used to investigate optical reflection of the obtain thin films. Reflectance was measured for thin films of TiO_2 sol gel before and after heat treatment. The satisfactory results of the reflection were obtained in the wavelength range 500-700 nm and ranged between 1-7%. With the increase of spin speed the range is shifted to lower wavelengths. The heat treatment at 600°C has worsened the optical properties of the deposited thin films.

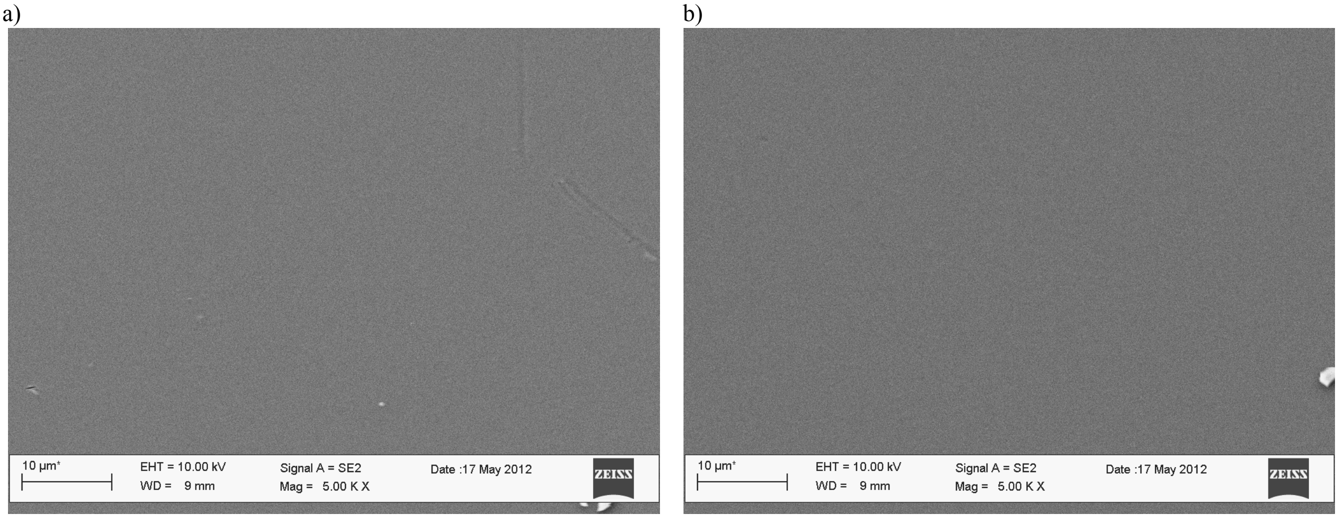

Fig. 7. SEM image of the surface topography of TiO_2 thin film deposited with a spin speed 4000 rpm from: a) a solution of A, b) a solution of B

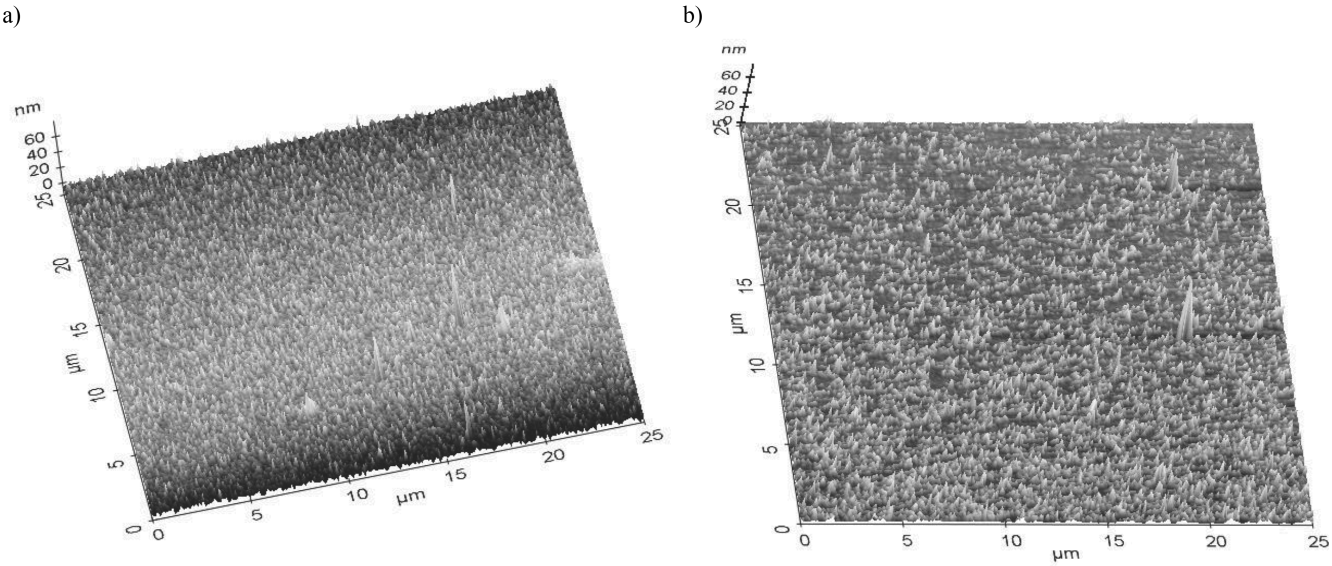

Fig. 8. AFM 3D image of the surface topography of TiO_2 thin film deposited with a spin speed 4000 rpm from: a) a solution of A, b) a solution of B

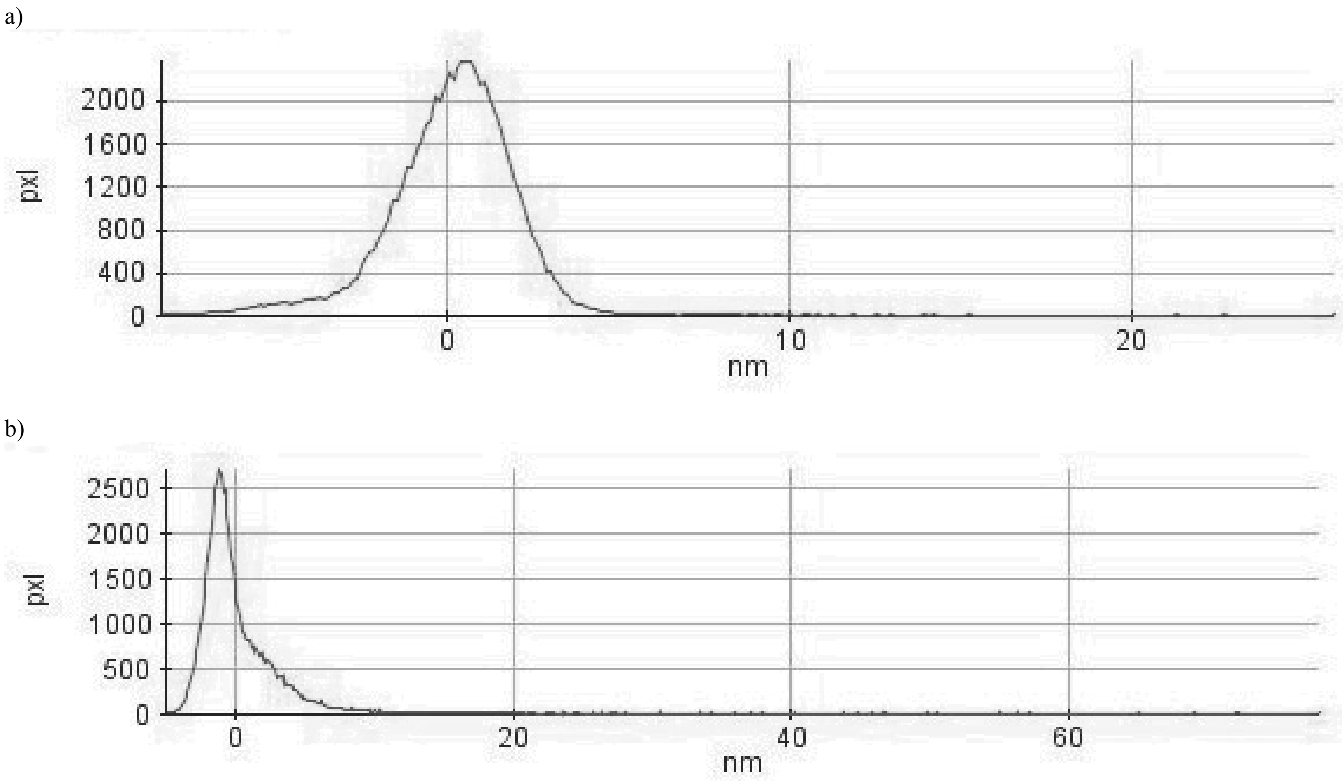

Fig. 9. The histogram of frequency of the occur height for a thin film TiO_2 coated with a spin speed at 4000 rpm. from: a) a solution A, b) a solution B

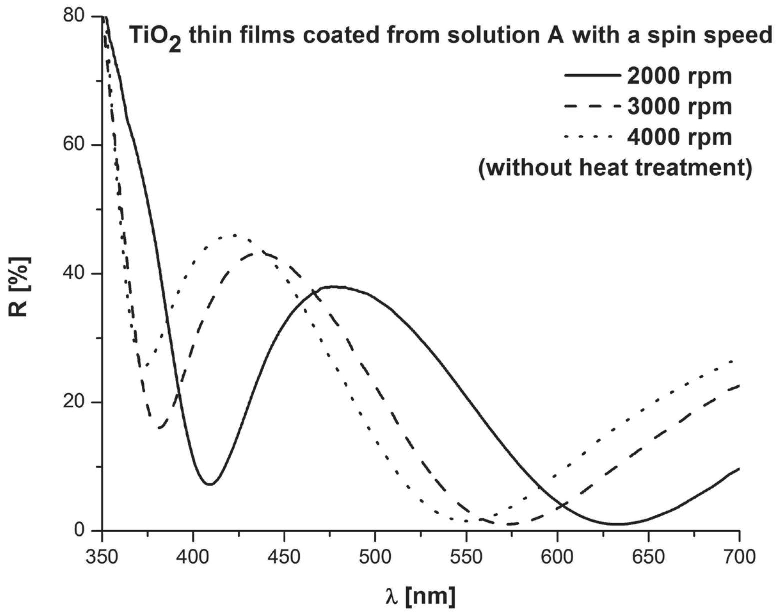

Fig. 10. The spectrum of reflection for the TiO_2 thin films obtained with three different spin speed (2000, 3000 and 4000 rpm) from solution A without heat treatment

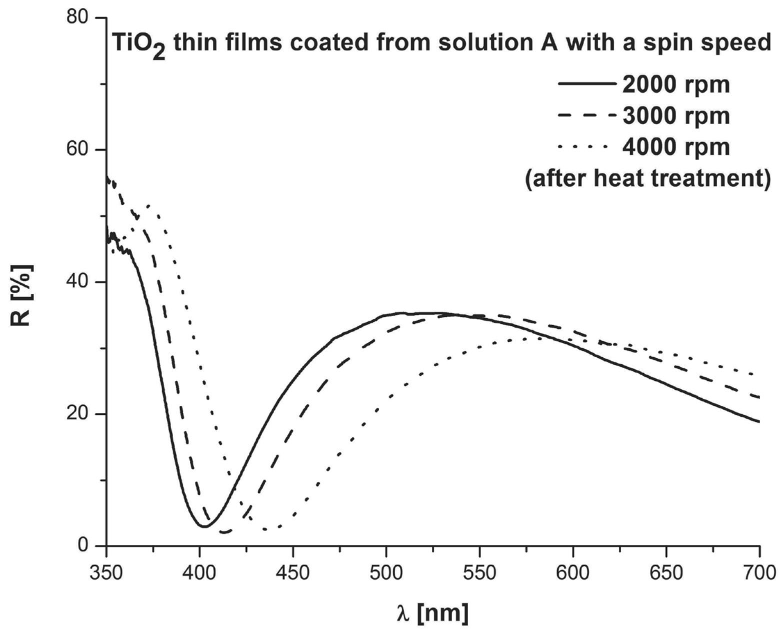

Fig. 11. The spectrum of reflection for the TiO_2 thin films obtained with three different spin speed (2000, 3000 and 4000 rpm) from solution A after heat treatment

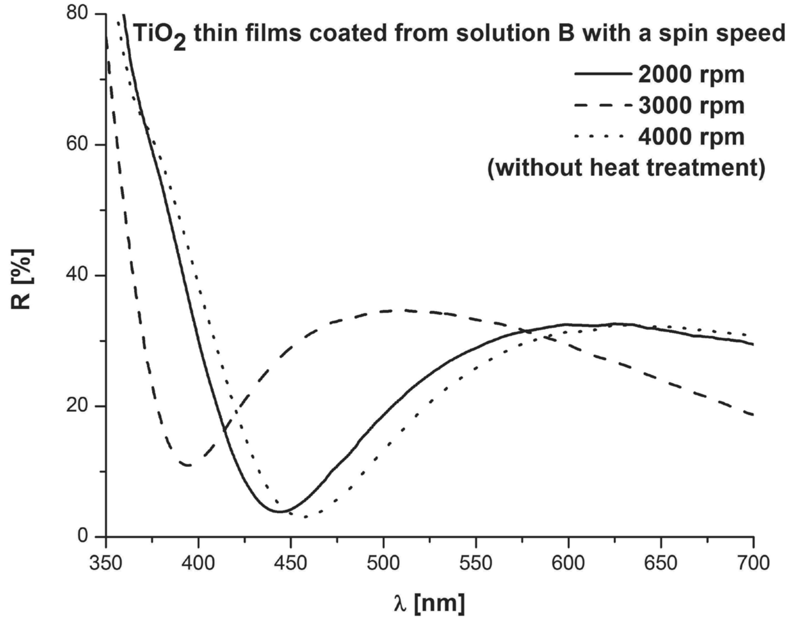

Fig. 12. The spectrum of reflection for the TiO_2 thin films obtained with three different spin speed (2000, 3000 and 4000 rpm) from solution B without heat treatment

4. Conclusions

TiO_2 thin films were prepared by the sol–gel spin coating technique. Two solutions were prepared with different ratio between titanium isoproxide and absolute ethyl alcohol. Then the solution was spin coated with the various spin speed (2000, 3000 and 4000 rpm) on the polished monocrystalline silicon substrates and heated at 600º C for 2 h. Based on the surface topography results can be concluded that a uniform thin film without any precipitates, and delaminations were obtained from solution B

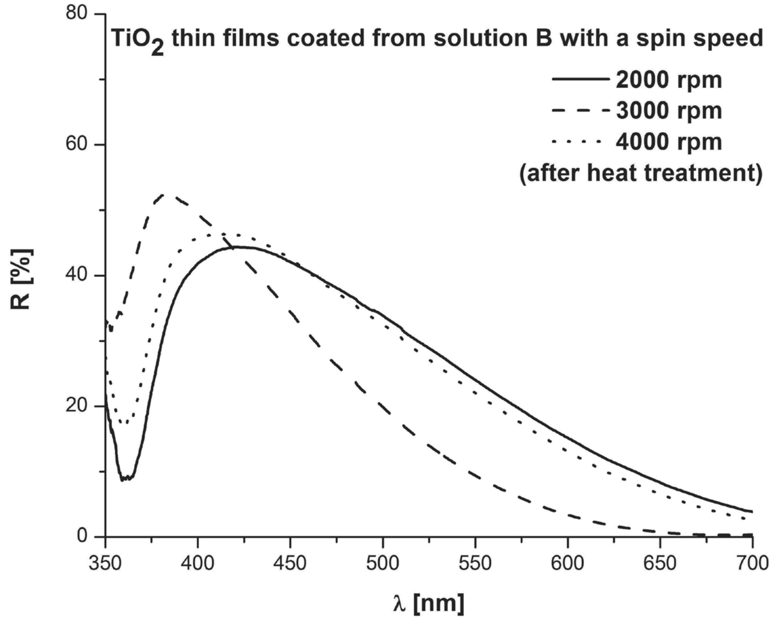

Fig. 13. The spectrum of reflection for the TiO_2 thin films obtained with three different spin speed (2000, 3000 and 4000 rpm) from solution B after heat treatment

at a 4000 rpm spin speed. The satisfactory results of the reflection were obtained in the wavelength range 500-700 nm and ranged between 1-7%. The possibility of obtaining uniform thin films characterized by good optical properties indicates the possibility of using sol gel method in photovoltaics.

Acknowledgements

Marek Szindler is a holder of scholarship from project POKL.04.01.01-00-003/09-00 entitled „Opening and development of engineering and PhD studies in the field of nanotechnology and materials science” (INFONANO), co-founded by the European Union from financial resources of European Social Fund and headed by Prof. L.A. Dobrzański.

HUMAN CAPITAL NATIONAL COHESION STRATEGY · PROJEKT infonano · EUROPEAN UNION EUROPEAN SOCIAL FUND

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