
КОНДЕНСАЦИЯ ЛАНҒАН КҮЙДІҢ ФИЗИКАСЫ ФИЗИКА КОНДЕНСИРОВАННОГО СОСТОЯНИЯ PHYSICS OF THE CONDENSED MATTER

Article

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A.K. Mussabekova^{1✉}, A.K. Aimukhanov¹, A.K. Zeinidenov¹,
A.Z. Ziyat¹, K.T. Abdrakhman¹, A.M. Alexeev²

¹*Buketov University, Scientific Center of nanotechnology and functional nanomaterials, Karaganda, Kazakhstan;*

²*Kazan Federal University, Kazan, Russia*

The Influence of Al₂O₃ Nanoparticles on Electron Transport in a Polymer Solar Cell

The effect of Al₂O₃ nanoparticles on the electron transport of SnO₂-based electron transport layer (ETL) in polymer solar cells was studied. Comprehensive studies of the morphology, optical, electrophysical and photoelectric properties of the composite films were carried out. It was found that doping SnO₂ films with Al₂O₃ nanoparticles leads to a decrease in the surface roughness of the composite films. According to the absorption spectra, it was shown that an increase in the concentration of Al₂O₃ nanoparticles in SnO₂ films leads to a decrease in the optical bandgap. Analysis of the impedance spectra showed that there is a critical concentration of Al₂O₃ nanoparticles at which the maximum improvement in the electrotransport characteristics of SnO₂ films is observed. At high Al₂O₃ concentrations (over 15 %), a decrease in electron mobility and an increase in recombination in the studied composite film are observed. Photovoltaic measurements have demonstrated that the highest efficiency of 2.8 % polymer solar cells is achieved at an optimal concentration of Al₂O₃ nanoparticles equal to 15 %. Further increase in the content of Al₂O₃ nanoparticles leads to a decrease in the efficiency of polymer solar cells. Since localized negative charges in Al₂O₃ nanoparticles create a local electric field, they screen the recombination of minority charge carriers in ETL SnO₂. This suppresses the leakage current in devices. Therefore, it is important to investigate the charge transfer mechanism in SnO₂:Al₂O₃ films and evaluate their potential for application in polymer solar cells.

Keywords: SnO₂, Al₂O₃, morphology, absorption, band gap, Bode plots, impedance, current-voltage characteristics

✉ *Corresponding author:* Assel K. Mussabekova, assel50193@gmail.com

Introduction

The demand for transparent conductive oxides (TCO) materials that combine high optical transparency and good electrical conductivity is growing rapidly due to the development of optoelectronic technologies. Such materials are in demand in thin-film solar cells [1], charge storage devices [2], flat-panel displays [3], gas sensors [4] and other applications. The most studied TCOs are films based on TiO₂, ZnO, SnO₂ and others, research that has been ongoing for over 40 years. These materials are wide-bandgap n-type semiconductors. Among the known n-type TCOs, the best characteristics are demonstrated by In₂O₃:Sn, SnO₂:F and ZnO:Al composites [5], which have a transparency above 90 % and a specific resistance of about 10⁻⁴ Ohm·cm [6, 7].

SnO₂ and its composite materials are widely known for their pronounced structural and optical properties when scaled down to the nanoscale. The efficiency of devices based on them is largely determined by the electrical and optical properties of transparent electrodes, as well as the technology of their production [8]. It is known that the degree of improvement of these properties depends significantly on the chemical composition, particle size and specific surface area of SnO₂.

One of the major challenges in obtaining high-performance SnO₂-based organic solar cells (OSCs) is the presence of defects such as oxygen vacancy [9] and other surface-related defects [10, 11]. These can lead to poor charge transport and low power conversion efficiency (PCE) in devices [12]. In addition, oxygen-induced degradation of the photoactive layer can occur in the metal oxide layer, allowing atmospheric oxygen to diffuse into the cell, resulting in an increase in defects that adversely affect the performance of the device [13]. Minimizing defects and reducing carrier recombination in the SnO₂ film by passivating the ETL/photoactive layer interface is critical in the fabrication of high-performance OSCs.

Wu et al. reported that the defect states of ZnO were suppressed by modifying its surface with an ultrathin Al layer, which could be partially oxidized to AlO_x [14]. It is known that the ultrathin Al₂O₃ film is an effective surface passivation method in silicon-based solar cells by utilizing its unique ability to form a layer without point defects [15]. It not only provides good chemical passivation by reducing the defect density at the interface through the hydrogen passivation associated with the deposition process, but also leads to a decrease in the minority carrier concentration near the interface due to the built-in electric field, which is called field effect passivation [16, 17]. In this case, the negative charges localized in the Al₂O₃ layer create a local electric field that screens the recombination of minority carriers [18]. Moreover, it is reported that the Al₂O₃ layer can also suppress the leakage current in the device, which turns out to be another advantage of Al₂O₃ passivation [19]. Currently, Al₂O₃ composites are at the threshold of commercial solar cell production and large-scale photovoltaic cell production [20], while there are rare reports of their use for OSC passivation. Thus, the use of Al₂O₃ may have potential applications in the field of photovoltaics.

Despite the studies conducted on the synthesis of SnO₂ films doped with Al₂O₃ [21], their electrotransport properties are still poorly understood. Therefore, it is important to study the charge transfer mechanism in such films and evaluate their potential for use in optoelectronic devices. This paper presents the results of a study of the effect of Al₂O₃ nanoparticles on electron transport in ETL SnO₂ polymer solar cells.

Experimental

Thin films preparation

The preparation of FTO substrates was carried out according to the procedure detailed in reference [22]. Composite films based on SnO₂ were obtained by the sol-gel method. The scheme for preparing composite films is shown in Figure 1. The initial reagents were SnCl₂ (99.9 %, Sigma Aldrich) in an amount of 2.25 g and AlCl₃ (99.9 %, Sigma Aldrich) in an amount corresponding to Al₂O₃ concentrations of 5 % (0.0667 g), 10 % (0.1334 g), 15 % (0.2001 g), 20 % (0.2268 g) and 25 % (0.33335 g). SnCl₂ and Al₂O₃ were dissolved in 1 ml of ethyl alcohol (99.9 %, Sigma Aldrich).

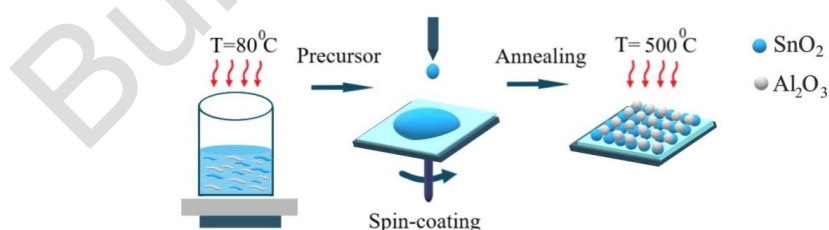


Figure 1. Scheme for preparing SnO₂:Al₂O₃ composite films

Afterwards, the prepared solutions were continuously stirred at 80 °C for 2 hours, followed by 24 hours at room temperature to complete the reactions and composition. Then, the obtained solution was applied to the surface of the substrates by centrifugation (on a SPIN150i centrifuge, Semiconductor Production System) at a rotation speed of 4000 rpm. The rotation time of the centrifuge at this rotation speed was 30 seconds. The obtained films were thermally annealed in air at a temperature of 500 °C for 1 hour.

To assemble the FTO/SnO₂:Al₂O₃/P3HT:PCBM/PEDOT:PSS/AgOSC, the photoactive material P3HT:PCBM was dissolved in chlorobenzene and stirred for 24 hours at room temperature. The photoactive layer was applied by centrifugation at a rotation speed of 2000 rpm on the FTO substrate, previously

deposited with the $\text{SnO}_2:\text{Al}_2\text{O}_3$ film. Afterwards, the obtained film was annealed in air at a temperature of 140°C . The hole-transport layer of PEDOT:PSS was applied to the surface of the photoactive layer at a substrate rotation speed of 3000 rpm, after which the substrate was annealed at a temperature of 120°C . At the final stage of OSC assembly, a silver electrode was applied to the surface of the hole-transport layer by vacuum-thermal deposition.

Analysis methods

Film surface morphology images were obtained using a MIRA 3LMU (TESCAN) electron microscope. A Co sample (9905-17, Micro-Analysis Consultants Ltd Unit 19, Edison Road, St Ives Cambridgeshire PE27 3 LF U.K.) was used as a standard for EDX analysis. The surface topography of the samples was studied using a JSPM-5400 atomic force microscope manufactured by JEOL Ltd. Probes manufactured by NT-MDT were used for scanning. Scanning was performed in a semi-contact mode with resonance frequency parameters of 140–390 kHz, cantilever stiffness of 3.1–37.6 N/m, and probe rounding radius of 10 nm; the scanning speed was $10\ \mu\text{m/s}$. Surface morphology parameters were calculated using the WinspmII Data Processing software package manufactured by JEOL Ltd.

The absorption spectra of the films were measured using the Avantes universal spectrometric complex based on the AvaSpec-ULS2048CL-EVO spectrometer and the AvaLight-DHc deuterium-halogen combined light source with a spectral emission range of 200–2500 nm.

The current-voltage characteristics of the solar cells were measured using the PVIV-1A setup (Newport, Canada). The Sol3A solar energy simulator (class AAA, Newport, Canada) with a radiation intensity of $100\ \text{mW/cm}^2$ was used as a light source.

The impedance spectra were measured using a P-45X potentiostat-galvanostat (Elins, Russia) with an additional FRA-24M frequency analyzer module installed to measure the electrophysical characteristics on alternating current.

Results and Discussion

Surface morphology

Figure 2 shows scanning electron microscope (SEM) images of the surface morphology of SnO_2 and $\text{SnO}_2:\text{Al}_2\text{O}_3$ (25 %) films, as well as a cross-section of the films. Analysis of the SEM images demonstrates the presence of micro-holes on the surface of the SnO_2 films, which is typical for thin-film structures [23]. Comparison of $\text{SnO}_2:\text{Al}_2\text{O}_3$ films with different concentrations of Al_2O_3 shows that the addition of 25 % Al_2O_3 to SnO_2 leads to the formation of a more uniform surface structure: the films become smoother and fine-grained, indicating a change in morphology when doped with Al_2O_3 nanoparticles.

Cross-section images of the studied films demonstrate that the film thickness increases with the addition of Al_2O_3 nanoparticles to SnO_2 from 79.69 nm to 93.73 nm.

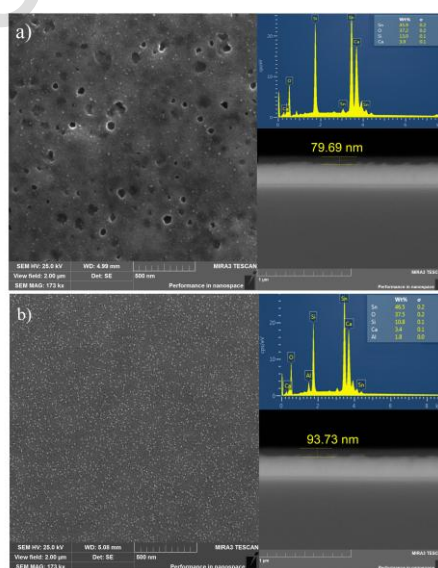


Figure 2. SEM images of the morphology of films and cross-section of SnO_2 , $\text{SnO}_2:\text{Al}_2\text{O}_3$ (25 %). Inset shows EDX spectra

Figure 3 shows atomic force microscope (AFM) images of SnO₂ and SnO₂:Al₂O₃ (25 %) films. The root mean square roughness (RMS) values for SnO₂ and SnO₂:Al₂O₃ (25 %) films are 2.4 and 1.83, respectively.

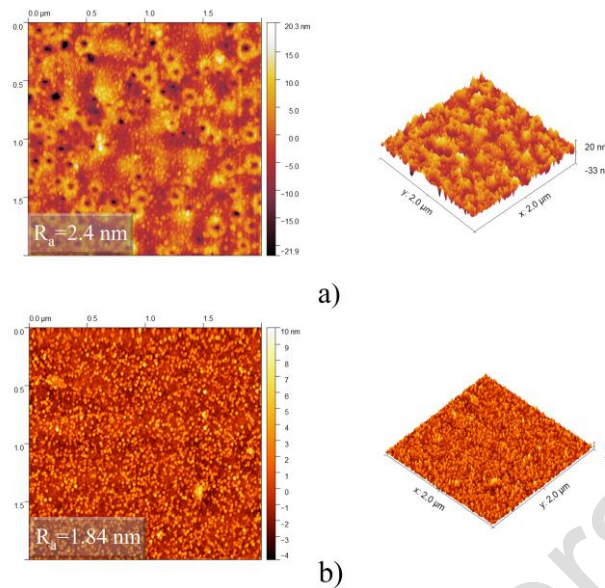


Figure 3. AFM images of SnO₂ and SnO₂:Al₂O₃ (25 %) films

From the analysis of the surface morphology it follows that the addition of Al₂O₃ helps to reduce the roughness of the films. This phenomenon can be explained by the fact that Al₂O₃ helps to reduce and fill the micro-holes present on the surface of SnO₂ films, thereby improving the texture and increasing the homogeneity of the surface.

Optical properties

Figure 4a shows the absorption spectra of SnO₂ films and SnO₂:Al₂O₃ composite films with different concentrations of Al₂O₃ nanoparticles (5 %, 10 %, 15 %, 20 %, 25 %). It follows from the analysis of the spectra that all the studied samples have a relatively high absorption coefficient in the region of $\lambda < 600$ nm, the value of which increases with an increase in the content of Al₂O₃ nanoparticles. In addition, the graph shows the wavelength of the optical absorption edge, determined by the method of linear extrapolation of the steeply increasing section of the spectrum. The dependence of the absorption edge position on the concentration of Al₂O₃ nanoparticles is presented in Table 1. The optical absorption edge corresponds to the energy threshold of the interband transition and reflects the fundamental width of the band gap [24].

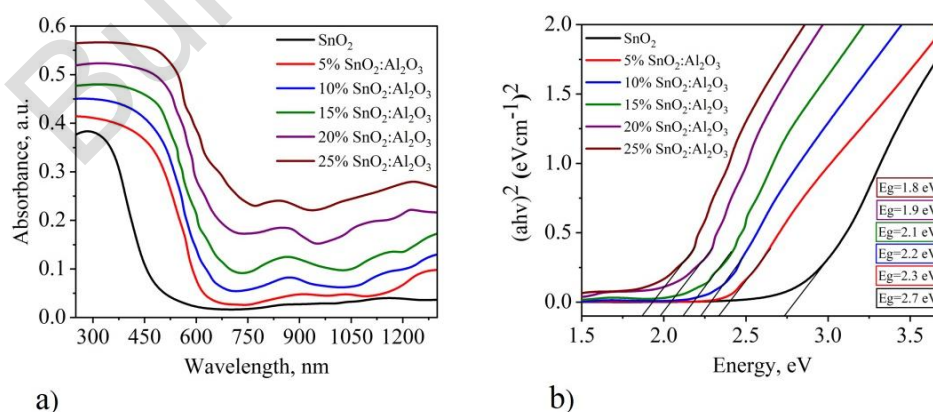


Figure 4. Absorption and Tauc plot of SnO₂ and SnO₂:Al₂O₃ (5 %, 10 %, 15 %, 20 %, 25 %)

With increasing concentration of Al₂O₃, a regular shift of the absorption edge to the region of longer wavelengths is observed, which indicates a change in the optical width of the forbidden material. In particular, for the SnO₂ film, the wavelength of the absorption edge is 320 nm, whereas for films with Al₂O₃ nano-

particles in concentrations of 5 %, 10 %, 15 %, 20 % and 25 %, this parameter increases to 419 nm, 451 nm, 482 nm, 498 nm and 506 nm.

Table 1

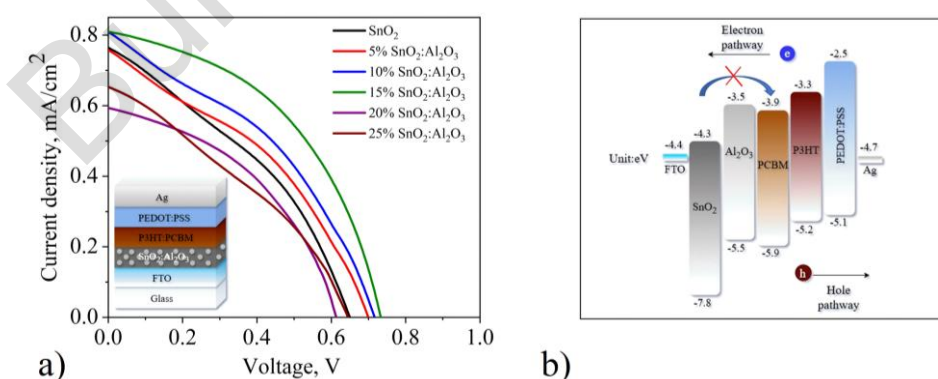
Optical parameters of SnO₂ and SnO₂:Al₂O₃ (5 %, 10 %, 15 %, 20 %, 25 %)

Samples	λ_{edge} , nm	D_i , optical density	Optical band gap (eV)
SnO ₂	320	0.37	2.83
5 % SnO ₂ :Al ₂ O ₃	419	0.41	2.33
10 % SnO ₂ :Al ₂ O ₃	451	0.44	2.24
15 % SnO ₂ :Al ₂ O ₃	482	0.47	2.12
20 % SnO ₂ :Al ₂ O ₃	498	0.51	1.98
25 % SnO ₂ :Al ₂ O ₃	506	0.56	1.87

Figure 4b shows the dependence of the optical band gap on the concentration of Al₂O₃ nanoparticles in SnO₂ and SnO₂:Al₂O₃ thin films with a content of 5 %, 10 %, 15 %, 20 % and 25 %. The optical band gap values of the films were calculated using the Tauc plot method [25]. The change in the optical band gap allows characterizing the electrical properties of the material, since it is directly related to the energy difference between the valence band and the conduction band. According to the data presented in Table 1, an increase in the concentration of Al₂O₃ nanoparticles leads to a consistent decrease in the optical band gap: for the SnO₂ film it is 2.83 eV, while for the composite films it decreases to 1.87 eV with an increase in the concentration of Al₂O₃ nanoparticles. It should be noted that reducing the optical band gap improves the transition of electrons from the valence band to the conduction band, resulting in an increase in the conductivity of the material [26].

Photoelectrical characterizations

Figure 5 shows the current-voltage characteristics of polymer solar cells with the FTO/SnO₂:Al₂O₃/P3HT:PCBM/PEDOT:PSS/Ag structure with ETL based on SnO₂ with different contents of Al₂O₃ nanoparticles. The current-voltage characteristics parameters are given in Table 2. Upon photoexcitation of the photoactive P3HT:PCBM layer, an electron-hole pair is formed, which then disintegrates into free charge carriers at the SnO₂/P3HT:PCBM and P3HT:PCBM/PEDOT:PSS interface. As a result, electrons are injected into the ETL layer of SnO₂, and holes into the hole transport layer (HTL) of PEDOT:PSS (Fig. 5b). As a result of this process, a photocurrent will flow in the circuit under study. Al₂O₃ nanoparticles in the ETL serve to block the process of reverse electron transfer from SnO₂ to the PCBM acceptor. Addition of Al₂O₃ nanoparticles to a concentration of 15 % in the SnO₂ film promotes an increase in the short-circuit current density by 32 %. A further increase in the concentration of Al₂O₃ nanoparticles leads to a decrease in the short-circuit current density. The efficiency of the cell with SnO₂ was 1.9 %, while it increased to 2.8 % with the addition of Al₂O₃ nanoparticles at a concentration of 15 %.

Figure 5. Current-voltage characteristics of SnO₂ and SnO₂:Al₂O₃ (5 %, 10 %, 15 %, 20 %, 25 %)

The increase in short-circuit current and cell efficiency with the addition of Al₂O₃ nanoparticles is associated with an increase in the concentration of free charge carriers in the composite film [27]. Additionally, Al₂O₃ nanoparticles reduce the number of surface defects, which decreases the probability of electron-hole recombination.

The decrease in efficiency with an increase in the content of Al₂O₃ nanoparticles above 15 % is obviously associated with the formation of structural and interphase defects that contribute to an increase in the recombination of charge carriers [28].

Table 2

Current-voltage parameters of SnO₂ and SnO₂:Al₂O₃ (5 %, 10 %, 15 %, 20 %, 25 %)

Samples	U_{oc} (V)	J_{sc} (mA/cm ²)	U_{max} (V)	J_{max} (mA/cm ²)	FF	PCE %
SnO ₂	0.65±0.01	7.65±0.05	0.41±0.01	4.4±0.05	0.37	1.9±0.05
5 % SnO ₂ :Al ₂ O ₃	0.7±0.01	7.55±0.05	0.43±0.01	4.6±0.05	0.38	2±0.05
10 % SnO ₂ :Al ₂ O ₃	0.72±0.01	8 ±0.05	0.46±0.01	4.9±0.05	0.39	2.3±0.05
15 % SnO ₂ :Al ₂ O ₃	0.73±0.01	8.1±0.05	0.51±0.01	5.4±0.05	0.46	2.8±0.05
20 % SnO ₂ :Al ₂ O ₃	0.64±0.01	6.55±0.05	0.37±0.01	3.9±0.05	0.35	1.5±0.05
25 % SnO ₂ :Al ₂ O ₃	0.61±0.01	5.9±0.05	0.38±0.01	4.1±0.05	0.43	1.6±0.05

To investigate the effect of Al₂O₃ nanoparticles on the electron transport of SnO₂ in polymer solar cells, electrical impedance spectra were measured (Fig. 6a).

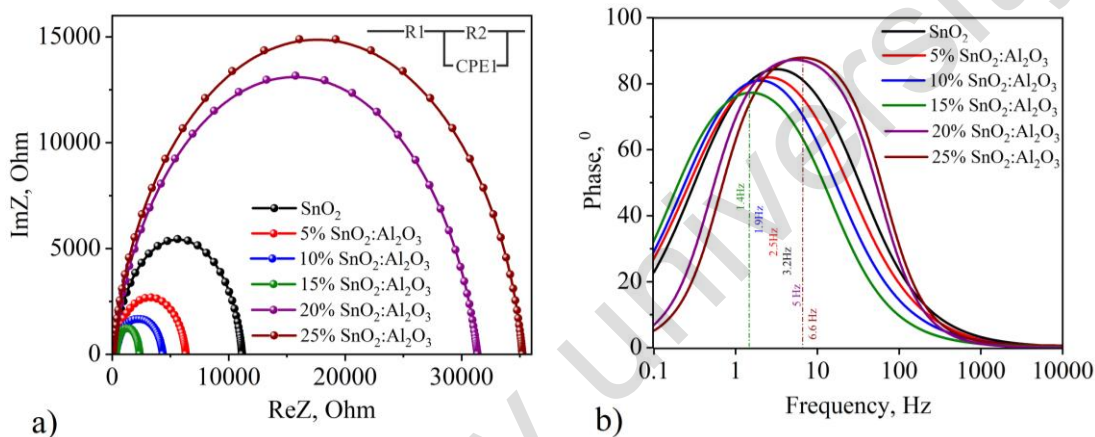
Figure 6. Impedance spectra and Bode plot SnO₂ and SnO₂:Al₂O₃ (5 %, 10 %, 15 %, 20 %, 25 %)

Figure 6(a) shows the impedance plots of the organic solar cells with the FTO/SnO₂:Al₂O₃/P3HT:PCBM/PEDOT:PSS/Ag structure. The electrical parameters were calculated based on the spectral data (Table 3) using the equivalent electrical circuit shown in the inset of Figure 6(a).

In this scheme, R_w denotes the equivalent resistance of the external electrodes (including R_{FTO}, R_{SnO₂:Al₂O₃}, PEDOT:PSS and Ag), and R_{tr} reflects the resistance associated with electron transfer at the interfaces between the P3HT:PCBM/SnO₂:Al₂O₃ and P3HT:PCBM/PEDOT:PSS layers. Table 3 shows the electrophysical parameters of the FTO/SnO₂:Al₂O₃/P3HT:PCBM/PEDOT:PSS/Ag structure. The organic solar cell is a multilayer structure. Since the photoactive layer and the electrodes were deposited under the same conditions, the R_w value is almost the same in all cases. Its slight change with an increase in the Al₂O₃ concentration is associated with an insignificant change in the film thickness. Changes in the R_{tr} value indicate the influence of the P3HT:PCBM/ETL interface on the electron transfer process. A decrease in R_{tr} indicates an improvement in electron transport at the interface. As can be seen from Table 1, the cells with ETL with a concentration of Al₂O₃ nanoparticles of 15 % have the lowest resistance R_{tr} , which indicates the formation of a film with improved conductivity and a lower degree of defectiveness. However, with an increase in the concentration of Al₂O₃ nanoparticles above 15 %, an increase in recombination at the P3HT:PCBM/SnO₂:Al₂O₃ interface is observed, which is associated with the formation of structural and interphase defects.

The mobility of charge carriers is one of the most important electrotransport parameters of thin films. There are a number of methods for its experimental determination [29], but each of them is characterized by certain limitations and disadvantages [30]. In this work, we used the impedance spectroscopy method to determine the conditional mobility of charge carriers μ , in the studied samples described in detail in [31].

The diffusion coefficient Dn was determined by the following formula:

$$Dn = \frac{L^2}{\tau D}. \quad (1)$$

Where L is the film thickness, τD is the effective time of charge passage through the OSC. The value of the conditional hole mobility μ was determined by the formula:

$$\mu = \frac{e^* Dn}{k_B^* T}. \quad (2)$$

Where e is the electron charge, k_B is the Boltzmann constant, T is the temperature.

As can be seen from Table 1, the conditional electron mobility increases and has a maximum value for OSC with ETL based on SnO_2 with a concentration of Al_2O_3 nanoparticles equal to 15 %. The minimum value of the conditional electron mobility in OSC is observed for OSC with ETL based on SnO_2 with Al_2O_3 nanoparticles with a concentration of 25 %. Obviously, the observed decrease in the values of the conditional electron mobility in OSC with exceeding the concentration of Al_2O_3 nanoparticles of 15 % is explained by the different degrees of probability of electron scattering on defects formed at the P3HT:PCBM/ SnO_2 : Al_2O_3 interface.

Figure 6(b) shows the Bode plot analysis, which allows estimating the carrier lifetime in OSC [32]. As can be seen from Figure 6(b), the phase angle maximum for the cell (with 15 % Al_2O_3 nanoparticles in ETL) is shifted to lower frequencies compared to pure SnO_2 -based ETL, indicating a longer carrier lifetime. This indicates a more effective suppression of charge recombination. Thus, the data clearly demonstrates the importance of the spatial separation of electron transport channels achieved by the incorporation of Al_2O_3 nanoparticles.

Table 3

Impedance parameters of SnO_2 and SnO_2 : Al_2O_3 (5 %, 10 %, 15 %, 20 %, 25 %)

Samples	R_{w_s} (Ohm)	R_{tr_s} (Ohm)	C , (pF)	τ_{D_s} (ps)	D_n , ($\text{cm}^2 \cdot \text{s}^{-1}$)	μ , ($\text{cm}^2 \text{V}^{-1} \cdot \text{s}^{-1}$)
SnO_2	68	11107	2.2517E-08	153	39.74	1.5
5 % SnO_2 : Al_2O_3	72	6247	1.8231E-08	131	46.35	1.8
10 % SnO_2 : Al_2O_3	81	4219	1.4762E-07	119	50.9	2
15 % SnO_2 : Al_2O_3	87	2694	1.0923E-07	95	64	2.5
20 % SnO_2 : Al_2O_3	64	31328	3.103E-08	198	30.64	1.2
25 % SnO_2 : Al_2O_3	59	33105	3.719E-08	219	27.73	1.1

Thus, the conducted study demonstrates how the use of Al_2O_3 nanoparticles in ETL affects the efficiency of polymer solar cells. The obtained data can be applied in the development of optoelectronic devices, including integrated circuits, microelectronic optical systems, as well as organic photoconverters, sensors and light-emitting diodes (OLEDs).

Conclusions

Composite SnO_2 films with different contents of Al_2O_3 nanoparticles were obtained by the sol-gel method. The effect of Al_2O_3 nanoparticles on the surface morphology of the films was studied using scanning electron microscopy and atomic force microscopy. It is shown that the addition of Al_2O_3 nanoparticles to SnO_2 promotes the formation of a more uniform and smooth surface. This may be due to the improvement of film formation conditions and a decrease in grain size due to the introduction of Al_2O_3 nanoparticles, which affect the growth of crystals in the film. The results of measuring the absorption spectra showed that an increase in the concentration of Al_2O_3 nanoparticles in the structure leads to a gradual decrease in the width of the optical bandgap of the material from 2.33 eV to 1.87 eV. This decrease indicates a change in the electronic structure, probably associated with the formation of new energy sublevels resulting from the interaction of Al_2O_3 nanoparticles with the SnO_2 matrix. Impedance spectroscopy revealed a reduction in recombination and an increase in charge carrier mobility at an Al_2O_3 nanoparticle concentration of 15 %, which contributes to the improvement of the material's transport properties. However, at high concentrations of Al_2O_3 nanoparticles (over 15 %), the opposite effect is observed — increased recombination and decreased mobility, which is associated with the formation of interphase defects that disrupt the continuity of the conductive paths. Photoelectric measurements showed that the maximum efficiency of solar cells was 2.5 % at

the optimal concentration of Al₂O₃. With a further increase in the content of Al₂O₃ nanoparticles (over 15 %), a decrease in efficiency is observed. This can be explained by an increase in the density of defects that impair the collection and transport of charges.

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Ә.Қ. Мұсабекова, А.К. Аймуханов, А.К. Зейниденов,
А.З. Зият, К.Т. Абдрахман, А.М. Алексеев

Al₂O₃ нанобөлшектерінің полимерлі күн элементіндегі электрондарды тасымалдауға әсері

Полимерлі күн элементтерінде SnO₂ негізінде алынған электрон тасымалдаушы қабатына (ETL) Al₂O₃ нанобөлшектерінің әсері зерттелді. Композиттік қабыршақтардың морфологиялық, оптикалық, электрофизикалық және фотоэлектрлік қасиеттерінің кешенді зерттеулері жүргізілді. SnO₂ қабыршақтарына Al₂O₃ нанобөлшектерін қосу арқылы композиттік қабыршақтар бетінің кедір-бұдырлығының төмендеуі анықталды. Жұтылу спектрлері арқылы SnO₂ қабыршақтарында Al₂O₃ нанобөлшектерінің концентрациясын арттыру оптикалық тыйым салу аймағы енінің азаюына алып келетіні айқындалды. Импеданс спектрлерін талдау арқылы SnO₂ қабыршақтарында Al₂O₃ нанобөлшектерінің электрондарды тасымалдаудың жоғары сипаттамалары анықталатын критикалық концентрациясы бар екені көрсетілді. Зерттелетін композиттік қабыршақтардың Al₂O₃ нанобөлшектерінің жоғары концентрациясында (15%-дан жоғары) электрондардың қозғалғыштығының төмендеуі және рекомбинациясының жоғарылауы байқалады. Фотоэлектрлік өлшеулер арқылы ең жоғары пайдалы әсер коэффициенті (ПӘК) 2,8 % полимерлі күн элементтерінің Al₂O₃ нанобөлшектерінің оңтайлы концентрациясы 15 % екенін көрсетті. Al₂O₃ нанобөлшектерінің концентрациясының одан әрі артуы полимерлі күн элементтерінің ПӘК-нің төмендеуіне әкеледі. Al₂O₃ нанобөлшектеріндегі локализацияланған теріс зарядтар жергілікті электр өрісін тудыратындықтан, олар SnO₂ ETL-да негізгі емес заряд тасымалдаушылардың рекомбинациясын экрандайды. Бұл құрылғылардағы тоқтың ағып кетуін тежейді. Сондықтан SnO₂:Al₂O₃ қабыршақтарындағы зарядты тасымалдау механизмін зерттеу және олардың полимерлі күн элементтерінде қолдану потенциалын бағалау маңызды.

Кілт сөздер: SnO₂, Al₂O₃, морфология, жұтылу, тыйым салу аймағының ені, Боде графигі, импеданс, вольт-амперлік сипаттамалар

А.К. Мусабекова, А.К. Аймуханов, А.К. Зейниденов,
А.К. Зият, К.Т. Абдрахман, А.М. Алексеев

Влияние наночастиц Al₂O₃ на электронный транспорт в полимерном солнечном элементе

Изучено влияние наночастиц Al₂O₃ на электронный транспорт (ETL) на основе SnO₂ в полимерных солнечных элементах. Проведен комплексный исследование морфологических, оптических и электрофизических и фотоэлектрических свойств композитных пленок. Было выявлено, что допирование наночастицами Al₂O₃ пленок SnO₂ приводит к уменьшению шероховатости поверхности композитных пленок. По данным спектров поглощения показано, что увеличение концентрации наночастиц Al₂O₃ в пленках SnO₂ приводит к уменьшению оптической ширины запрещенной зоны. Анализ спектров импеданса показал, что существует критическая концентрация наночастиц Al₂O₃ при которой наблюдается максимальное улучшение электротранспортных характеристик пленок SnO₂. При высоких концентрациях Al₂O₃ (свыше 15 %) наблюдается снижение подвижности электронов и усиление рекомбинации в исследуемой композитной пленке. Фотоэлектрические измерения продемонстрировали, что наибольший коэффициент полезного действия (КПД) 2,8 % полимерных солнечных элементов достигается при оптимальной концентрации наночастиц Al₂O₃ равной 15 %. Дальнейшее увеличение содержания наночастиц Al₂O₃ приводит к снижению КПД полимерных солнечных элементов. Так как локализованные отрицательные заряды в наночастицах Al₂O₃ создают локальное электрическое поле, то они экранируют рекомбинацию неосновных носителей заряда в ETL SnO₂. Это подавляет утечку тока в устройствах. Поэтому важно исследовать механизм переноса зарядов в пленках SnO₂:Al₂O₃ и оценить их потенциал применения в полимерных солнечных элементах.

Ключевые слова: SnO₂, Al₂O₃, морфология, поглощение, ширина запрещенной зоны, график Боде, импеданс, вольт-амперные характеристики

Information about the authors

Mussabekova, Assel (*contact person*) — PhD student, Buketov University, Karaganda 100028, Kazakhstan; e-mail: assel50193@gmail.com; Scopus Author ID: 58429663700, ORCID ID: <https://orcid.org/0000-0003-3452-4622>

Aimukhanov, Aitbek — Candidate of Physical and Mathematical Sciences, Professor, Buketov University, Karaganda 100028, Kazakhstan, e-mail: a_k_aitbek@mail.ru; Scopus Author ID: 58493008700, ORCID ID: <https://orcid.org/0000-0002-4384-5164>

Zeinidenov, Assylbek — PhD, Professor, Buketov University, Karaganda 100028, Kazakhstan, e-mail: asyl-zeinidenov@mail.ru; Scopus Author ID: 56386144000; ORCID ID: <https://orcid.org/0000-0001-9232-8406>

Ziyat, Aizhuldyz — Master of Educational Sciences, Buketov University, Karaganda 100028, Kazakhstan, e-mail: aizhuldyz_12@mail.ru; ORCID ID: <https://orcid.org/0009-0005-3310-9058>

Abdrakhman, Kelbet — Master of Technical Sciences, Buketov University, Karaganda 100028, Kazakhstan, e-mail: kelbet.abdraxman@mail.ru

Alexeev, Alexandr — Candidate of Physical and Mathematical Sciences, Kazan Federal University, Kazan, Russia, e-mail: alalrus@mail.ru; Researcher ID: A-8526-2012, ORCID ID: <https://orcid.org/0000-0002-2800-6047>