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FULL PAPER

Study of the Influence of Nb_2O_5 in ZnO Solar Cells

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Abstract:

The solar cells of semiconductors oxides have been largely studied. The zinc oxide (ZnO) and niobium oxide (Nb_2O_5) used in this work presented important physical-chemical characteristics in use of photovoltaic devices. The Nb_2O_5 presents the capacity of minimizing effects of charge recombination in the process of energetic conversion of solar cells. The oxides used in this work were characterized by the technique X-ray diffraction. The solar cells containing 5% of Nb_2O_5 presented of best results in a relationship of the electron transfer process, reaching the efficiency of 0.42%.

Keywords: charge recombination; electrochemistry; efficiency; photovoltaic devices

1. Introduction

Dye-sensitized solar cells (DSSCs) have attracted increasing attention of the scientific community, due to the low-cost, high application potential, relatively high efficiency and easy manufacturing [1, 2]. Different oxides have been employees in the DSSCs as titanium oxide (TiO_2), zinc oxide (ZnO), tin oxide (SnO_2), niobium oxide (Nb_2O_5) etc. being that TiO_2 is the most used as working electrode. Recently, ZnO, with similar band gap to the TiO_2, appears as an alternative material for the fabrication of high-efficiency DSSCs [3-5]. The ZnO is a promising material for various applications due high optical transparency in the visible range and great electrical conductivity. Is a metallic oxide utilized in the absorption of UV radiation, has acting as photocatalyst and presents a gamma of applications, between them an application in solar cells [1, 6].

In the energy conversion process of DSSCs an important source of energy loss, it is the load recombination or dark current, that may occur for two possible factors: the first one may occur with oxidized dye molecules and the second one with redox species in the electrolyte [7]. Studies developed in the attempt of minimize dark current bring the use of new semiconductor oxides as SnO_2, ZrO_2, Nb_2O_5, and the mixture of oxides [8, 9]. The differences in the parameters photovoltaic generated by the application of different oxides are associated to two main factors: the different energy gap to each oxide and the particle size [7, 9, 10].

The Nb_2O_5 has the capacity to minimizing effects of charge recombination by the formation of an energy barrier due your band gap is larger when compared the other semiconductors [10]. Works in the literature report that the difference of potential of the conduction band of Nb_2O_5 and TiO_2 can form an energy barrier electrolyte interface thus reducing the rate of recombination of the photoinjected electrons and improving the cell efficiency. This behavior is expected using the mixture of ZnO with Nb_2O_5 [11, 12]. Therefore, the present work has the objective produce sensitized solar cells by N-719 composed by the addition of Nb_2O_5 in ZnO, aiming to decrease the effects of the recombination process by creating an energy

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barrier in the interface of DSSCs.

2. Material and Methods

2.1 Preparation of niobium oxide (Nb_2O_5)

The procedure for obtaining the particles of Nb_2O_5, was based on the methodology presented by Pechini, in that ethylene glycol was maintained under constant stirring and temperature of 70 °C, after that was added the citric acid until complete dissolution. The ammoniacal complex of niobium ($NH_4H_2[NbO(C_2O_4)_3].nH_2O$) was added slowly and the solution remained under constant stirring for 30 minutes. After cooling it was calcined the 350 °C by 4 h with a heating rate of 2 °C/min and 4 h at 350 °C in which the sample was macerated [10].

2.2 Preparation of the ZnO films with Nb_2O_5

The films were prepared by adding the niobium pentoxide obtained by the method Pechini to commercial ZnO in the proportions: 5% and 15% m/m. For preparation of films containing 5% of Nb_2O_5 was used 2.85 g of ZnO and 0.15 g of Nb_2O_5, for the films containing 15% de Nb_2O_5 of niobium was used 2.55 g of ZnO and 0.45 g of Nb_2O_5, then was added 0.1 mL of polyethylene glycol and macerated the mixture by 30 min, after that, 0.1 mL of Triton X-100, 0.1 mL acetylacetone 99.5% and 4 mL of deionized H_2O were added and was mixed for more 40 min.

2.3 Composition of DSSCs

Sensitization of the sample was made with immersion in dye Di-tetrabutylammonium cis-bis(isothiocyanato)bis(2,2'-bipyridyl-4,4'-dicarboxylato)ruthenium(II) (N-719, Sigma Aldrich, Figure 1) at 24 h. Platinum was used as the counter electrode, K_2PtCl_6 was electrodeposited on FTO and the electrolyte was an iodide/triiodide solution. The cells were produced in a sandwich with an area of 0.2 cm^2, the anode being the FTO coated with oxide films/N-719 and the cathode an FTO deposited with platinum.

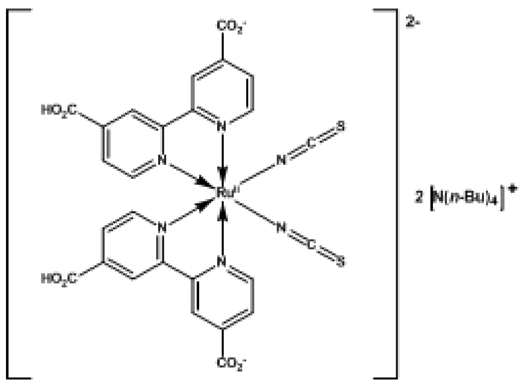

Figure 1. Dye representation N719.

3. Results and Discussion

3.1 Characterization of oxides by X-ray diffraction (DRX)

The figures 2 and 3 present the X-ray diffraction for to ZnO and Nb_2O_5. X-ray diffraction analyses were performed with intent in the investigate the crystal phase of the oxides.

The DRX result (Figure 2) confirmed that the ZnO presented crystalline phase of the wurtzite type, with diffraction peaks at 2θ: 31.83; 34.55 and 36.36, which correspond, respectively, to the planes (100), (002) and (101), and peaks at 2θ: 47.50; 56.56; 63.04; 67.95 and 69.12, which correspond, respectively, to the planes (102), (110), (103), (200), (112) and (201), which represent unitary cells in a hexagonal compact system that are characteristic of ZnO according to PDF 96-230-0113 of the ICDD [6, 13]. The DRX of Nb_2O_5 obtained by Pechini method (Figure 3) presented the peaks characteristics of orthorhombic crystalline structure, with diffraction peaks at 2θ: 22.7; 28.34 and 36.72, which correspond, respectively, to the planes (001), (180) and (181), and peaks at 2θ: 46.11; 50.92 and 55.52, which correspond, respectively, to the planes (002), (380) and (212) according to PDF 96-210-6535 of ICDD [14, 15].

3.2 Scanning electron microscopy (SEM)

The morphology of oxides used was studied by scanning electron microscopy and are presented in Figure 4. The SEM images were in 2000x, both presented heterogeneous and irregular forms. The ZnO (Figure 4a) presented a more porous structure, already the Nb_2O_5 (Figure 4b) has an indefinite morphology. It is possible to observe the difference in particle size from ZnO (figure 4a) to Nb_2O_5 (Figure 4b), this difference proves the possible formation of an energy barrier decreasing charge recombination [7, 9, 10].

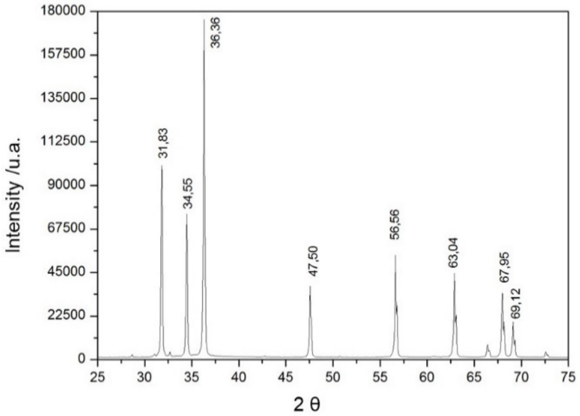

Figure 2. X-ray diffraction of ZnO.

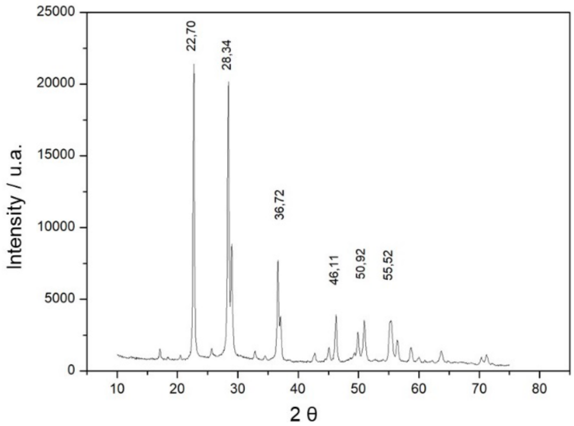

Figure 3. X-ray diffraction of Nb_2O_5.

3.3 Photocronoamperometry

Figure 5 shows the results of photocronoamperometry for the samples.

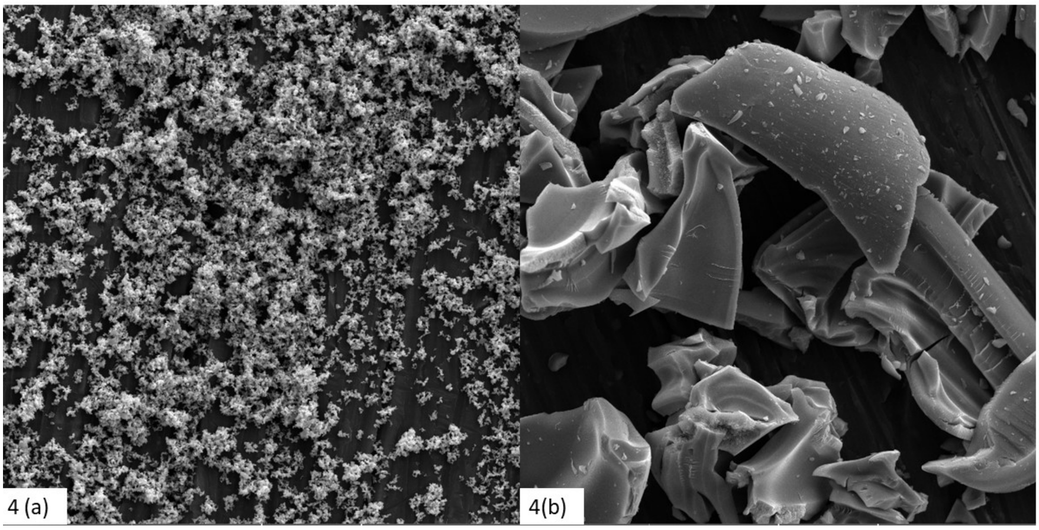

Figure 4. SEM images for sample of ZnO (a) and Nb_2O_5 (b).

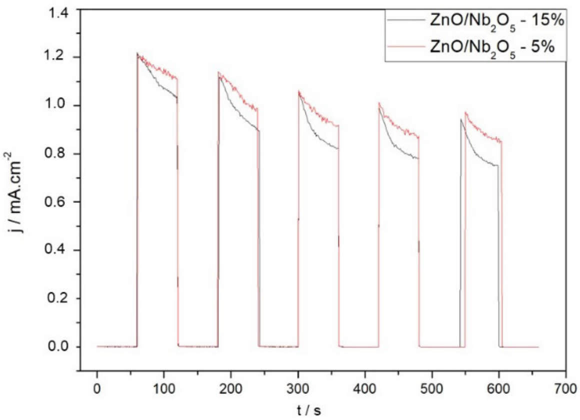

Figure 5. Photocronoamperometry for samples with lighting and without lighting in a time interval of 60 s.

Was possible to observe that in the presence of light (Figure 5) there was an increase in the value of current density because the dye N-719 acts as a photosensitizer in the DSSCs providing the passage of electric current assisting the material to develop your photovoltaic properties [6]. The cells studied presented similar behaviors, in which the film with 5% of Nb_2O_5 presented a lower current decay, being that the current density value at the beginning (60 s) was off 1.2 $mA.cm^{-2}$ to both the films and after 600 s the containing cell 15% of Nb_2O_5 presented current density of 0.75 $mA.cm^{-2}$ and the film with 5% of Nb_2O_5, j = 0.86 $mA.cm^{-2}$. The decay of the photocurrent was also observed, indicating that the device is limited by diffusion and is being stable.

3.4 Characterization J_{sc} -$V_{máx}$ of the ZnO/Nb_2O_5 cells

The parameters J_{sc} and $V_{máx}$ presented in Table 1, correspond respectively, to current density and voltage at the maximum output power of the cell. The current density (J_{sc}) is related to adsorption of the dye in the semiconductor oxide. Already open circuit potential (V_{oc}) is related to the processes of charge recombination. Was observed (Table 1) that in the cells using 5% of Nb_2O_5, there was an increase in the values of V_{oc} in relation to when used 15% of Nb_2O_5, indicating the decrease in recombination processes [16,17]. In work carried out by Maia *et al.* [17] where only ZnO was used in the manufacture of the cells, the values of V_{oc} found were lower than those found using the mixture of ZnO/Nb_2O_5, evidence that the use of Nb_2O_5 decreases the effects of charge recombination. Another parameter observed was the fill factor (FF), which corresponds to the relation between the maximum power generated and the theoretical power, being this latter obtained by the product between J_{sc} and V_{oc}

Table 1. Photovoltaic parameters of solar cells of ZnO with different percentages of Nb_2O_5 sensitized by dye N-719.

Sample	J_{sc} /mA.cm^{-2}	V_{oc} /V	FF	η /%
ZnO/Nb_2O_5 – 5%	1.235	0.766	0.454	0.42
ZnO/Nb_2O_5 – 15%	1.313	0.729	0.420	0.40

The results presented in Table 1 and figure 5 indicate that the samples presented values of current density of 1.235 and 1.313 mA/cm^{-2} for the cells with 5% and 15% of Nb_2O_5 respectively. The values of FF observed in the cells were low (Table 1), due to possible losses caused by numerous factors, as recombination and contact resistance, is that for an ideal device this value is the same FF = 1 [18,19]. Was verified that with increasing applied potential there is a decrease in photocurrent due to higher electron recombination and a decrease of the photocurrent to the applied potential (Figure 6). The cells containing 5% of Nb_2O_5 presented efficiency of η = 0.42% and the cells containing 15% of Nb_2O_5 η = 0.40 %, indicating an increase of η according to the amount of Nb_2O_5 used in DSSC ZnO/Nb_2O_5 [1,6].

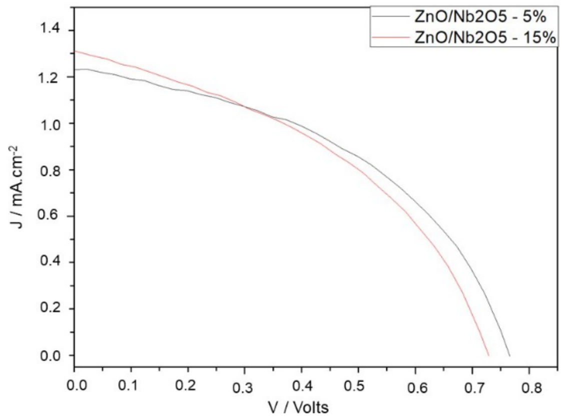

Figure 6. Curves J-V obtained under lighting of 100 mWcm^{-2} in the solar cells based on ZnO/Nb_2O_5 films.

4. Conclusions

Through the analysis of X-ray diffraction may be observed that the particles of niobium oxide formed, and the commercial zinc oxide presented crystallinity. The N719 dye-sensitized solar cells with 5% of Nb_2O_5 in the ZnO films, presented superior values of current density and efficiency than DSSCs with 15%. The difference was not significant between the values obtained, however, indicates that different amounts of Nb_2O_5 may decrease the efficiency of the cells.

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