



Desposition temperature optimisation of hafnium and cerium codoped ZnO thins films for solar spectral matching in solar cell

Z. Makir^{1,2}, Oumar A. Niassé¹, I. El Ouedghiri², F. Dia¹, N. Mbengue¹, Z. Sofiani²

¹Laboratory of Semiconductors and Solar Energy, Dept of Physics, Faculty of Sciences, University Cheikh Anta Diop of Dakar, Sénégal. makir.z2020@gmail.com

²LAMP CER Lab., Phys. Dept., Faculty of Sciences and Technologies of Mohammedia, University Hassan II of Casablanca, Morocco. zouhair.sofiani@gmail.com

Abstract We present an investigation of structural, electrical and photoluminescence properties of Zinc oxide doped cerium and codoped hafnium thin films deposited at different substrate temperature. There is a great interest in the investigation of rare earth doped ZnO properties in view of applications in photons conversion and electrode for solar cells. This work is based on visible photoluminescence spectra after Ultraviolet (UV) in order to adjust the solar spectrum to the solar cell absorption, and consequently to enhance its efficiency.

Keywords ZnO, rare earth, temperature effect

Introduction

The transparent conductive oxides (TCO) [1-5] used in Thin films form have been well studied due to their good opto-electrical properties and potential applications in various fields such as optoelectronics [6,7]. The most used (TCO) is indium tin-doped oxide (ITO) [5, 8-11]. However, the growth of the optoelectronic devices production has led to a great demand for ITO material which will cause the shortage of indium resources which worries the researchers and industrials. In addition, the diffusion of indium into the organic layer can significantly degrade the performance of the devices, and the toxic nature of indium is dangerous for the environment. Thus, it is absolutely necessary to find an abundant and less expensive alternative to ITO. Doped zinc oxide (ZnO) is a possible alternative to ITO due to its comparable optical and electrical characteristics. Due to its wide band gap of around 3.33 eV as well as the high binding energy. In addition, the physicochemical properties of ZnO in the thin films are related to the structure, morphology, size and intrinsic or extrinsic (dopants) defects in the crystallites. It can be used as an anode [12-13] or as a down conversion (DC) films [14-16] in order to improve the adaptation of the solar spectrum to the absorption band of the active material. Indeed, the polychromaticity of the solar spectrum limits the efficiency of solar cells. To increase this efficiency, it is necessary to convert the energy of the incident photons so that it corresponds to the gap of the active material. In the case of the transformation of low energy photons into higher energy photons (up conversion). For high-energy photons, of which only part of it is converted into electrical energy, they must on the contrary be converted into lower-energy photons (DC). It is this last effect that will interest us in this study where we seek to convert UV light into visible light by benefiting from the luminescence of cerium.

The purpose of this article is to study the effect of the deposition temperature of ZnO co-doped Cerium and Hafnium thin films on their structural, electrical and optical properties and justify the use ZnO: Hf: Ce as anode and as a down-converting layer in photovoltaic cells.



Experimental Details

Thin films are prepared using the spray pyrolysis technique. Thin films of zinc oxide co-doped with hafnium and cerium are deposited glass substrates heated to 400, 450 and 500 °C. The experimental details are given in previous work [17],

Results and Discussion

Figure 1 shows the X-ray diffraction diffractograms of thin layers of 5% Ce and 2% Hf codoped ZnO produced at different substrate temperatures. These spectra do not show any change in orientation of the crystallites, on the other hand a better crystallization is obtained for the layers produced at $T_s = 450$ °C.

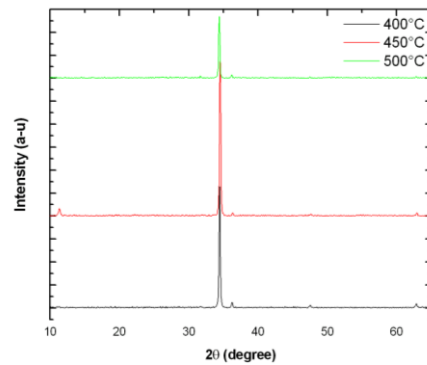


Figure 1: X-ray diffraction spectra of 5% Ce and 2% Hf codoped ZnO films prepared at different substrate temperature 400, 450 and 500 °C

In figure 2 we have represented the transmission spectra of the doped ZnO films deposited at different substrate temperatures. Analysis of these spectra showed an evolution of transmission as a function of temperature. In fact, the average transmission goes from 80% for a temperature of 400 °C to 85% for a temperature of 450 °C. We also noticed the presence of interference fringes which become more accentuated in the case of a substrate temperature of 450 °C. This is explained by the improvement of the crystallinity and the homogeneity of the state of the surface by increasing the temperature of the substrate. These same results were obtained by KTR Reddy et al. for gallium-doped ZnO layers prepared by spray [18].

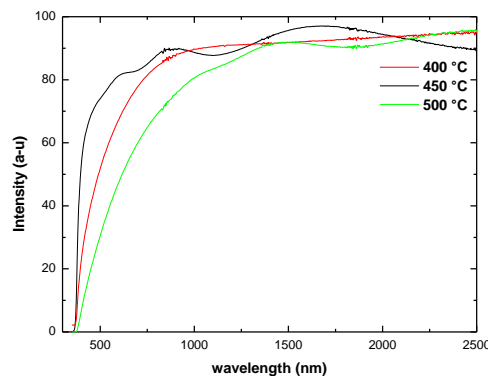


Figure 2: Transmission spectra of 5% Ce and 2% Hf codoped ZnO films prepared at different substrate temperature 400, 450 and 500 °C

Figure 3 represents the evolution of the resistivity measured at different temperatures of substrates. This figure shows that the substrate temperature is an important parameter which affects the electrical properties of these films. Indeed, the resistivity admits a minimum for a temperature of 450 °C. This behavior is the result of the substitution of the Zn^{2+} ions by the Hf^{4+} and Ce^{3+} sites creating free carriers. This confirm that the ZnO:Ce:Hf can be used as anode in photovoltaic cells especially at 450 °C, could play the role of a photovoltaic anode [9-11]



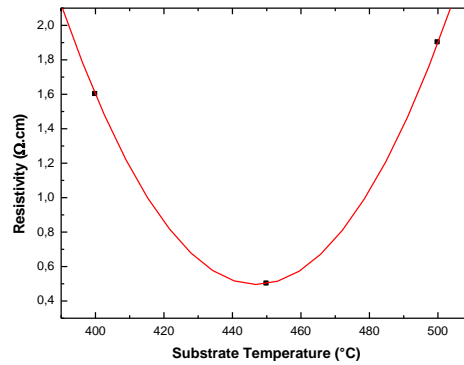


Figure 3: Evolution of the resistivity of a layer of ZnO codoped 5% Ce and 2% Hf depending on the substrate temperature 400, 450 and 500 ° C

In one of our previous works [19] we showed that an increase in the concentration of cerium in the zinc oxide matrix leads to a decrease in luminescence in the visible range due to the luminescence extinction phenomenon. This is why it is necessary to add a coactivator; this generally results in an increase in the luminescence intensity of the RE^{3+} ions. In this context, in order to reduce the effect of luminescence quenching, we used hafnium [20] as a co-dopant. The co-doped samples are produced at different temperatures 400, 450 and 500 °C in order to optimize the temperature of the substrate. Figure 4 shows the photoluminescence spectra of ZnO: 5% Ce: 2% Hf at different substrate temperatures. The spectra with and without hafnium show practically the same bands, a remarkable improvement in the case of codoping with hafnium. If we compare the spectra as a function of temperature, we notice that the spectrum at 450 °C presents a better intensity and a better resolution of the peaks compared to the other two temperatures, especially in the region 650–800 nm which could be attributed to the transitions. apart from this improvement, we also notice that the ZnO: 5% Ce: 2% Hf samples convert light from UV to visible which is absorbed by solar cells such as dye cells and organic cells. This proves that our materials are good candidates for the (DC) layer used to match the solar spectrum to the absorption band of the cells.

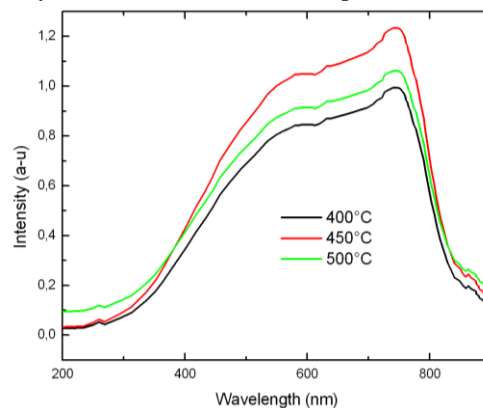


Figure 4: Photoluminescence spectra of 5% Ce and 2% Hf codoped ZnO films prepared at different substrate temperature 400, 450 and 500 ° C

Conclusion

The ZnO:Ce:Hf thin films have been deposited using spray pyrolysis techniques. The optimisation study of the temperature of substrate was done. This study revealed that the codoped zinc oxide layers prepared at a substrate temperature of 450 °C have a good transmittance (~90%) in the visible range and a low resistivity (~0.5 Ω.cm). This justifies that our thin films are one of the alternatives of ITO which can be used as anode for photovoltaics. As far as photoluminescence, after UV excitation, it shows good luminescence in the visible. this justifies that these layers can be used as (DC) layer in order to adjust the solar spectrum to the absorption of solar cells active materials.



References

- [1]. Chopra, K.L.; Major, S.; Pandya, D.K. *Thin Solid Films* 1983, 102, 1–46.
- [2]. Edwards, P.P.; Porch, A.; Jones, M.O.; Morgan, D.V.; Perks, R.M. *Dalton Trans.* 2004, 19, 2995–3002.
- [3]. Kawazoe, H.; Ueda, K. *J. Am. Ceram. Soc.* 1999, 82, 3330–3336.
- [4]. Jarzebski, Z.M. *Phys. Stat. Sol.* 1982, 71, 13–41.
- [5]. Minami, T. *Thin Solid Films* 2008, 516, 5822–5828.
- [6]. Chopra KL, Major S and Pandya DK 1983 *Thin Solid Films* 102 1
- [7]. Yin LT, Chou JC, Chung WY, Sun TP and Hsiung SK 2000 *Sensors Actuators B* 71 106
- [8]. Chen, C.H.; Chang, S.J.; Su, Y.K.; Chi, G.C.; Chi, J.Y.; Chang, C.A.; Sheu, J.K.; Chen, J.F. GaN metal-semiconductor-metal ultraviolet photo-detectors with transparent indium-tin-oxide Schottky contacts. *IEEE Photonics Technol. Lett.* 2001, 13, 848–850.
- [9]. Lee BH, Kim IG, Cho SW and Lee SH 1997 *Thin Solid Films* 302 25
- [10]. Kim JS, Granstrom M, Friend RH, Johansson N, Salaneck WR, Daik R, Feast WJ and Cacialli F 1998 *J. Appl. Phys.* 84 6859
- [11]. Yong Cui, Huifeng Yao, Ling Hong, Tao Zhang, Ye Xu, Kaihu Xian, Bowei Gao, Jinzhao Qin, Jianqi Zhang, Zhixiang Wei, Jianhui Hou. *Adv. Mater.* 2019, 1808356
- [12]. Rojan Savari, Jalal Rouhi, Omid Fakhari, Saeid Kakooei, Davoud Pourzadeh, Okhtay Jahanbakhsh, Saeid Shojaei. *Ceramics International* Volume 47, Issue 22, 15 November 2021, Pages 31927-31939
- [13]. Hyesung Park, Sehoon Chang, Matthew Smith, Silvija Gradečak & Jing Kong. *Sci Rep* 3, 1581 (2013)
- [14]. Akta Verma, S.K. Sharma. *Ceramics International* Volume 43, Issue 12, 15 August 2017, Pages 8879-8885
- [15]. Jagannath Panigrahi, P.K. Singh, Govind Gupta, Vandana. *Journal of Luminescence* Volume 233, May 2021, 117797
- [16]. Fanchen Bu, Wenfei Shen, Xiaolin Zhang, Yao Wang, Laurence A. Belfiore, Jianguo Tang. *Nanomaterials* 2020, 10(1), 80
- [17]. Z. Makir, Oumar A. Niasse, I. El Ouedghiri, F. Dia, N. Mbengue, Z. Sofiani. *Journal of Materials Science and Surface Engineering*, 8(1): 987-991
- [18]. K.T. Ramakrishna, Reddy, T.B.S. Reddy, I. Forbes, R.W. Miles. *Surface and Coatings Technology* Volumes 151–152, 1 March 2002, Pages 110-113
- [19]. M. El Jouad, M. Alaoui Lamrani, Z. Sofiani, M. Addou, T. El Habbani, N. Fellahi, K. Bahedi, L. Dghoughi, A. Monteil, B. Sahraoui, S. Dabos, N. Gaumer. (2009) *Optical Materials*, 31 (9), pp. 1357-1361
- [20]. A. Monteil, M. El-Jouad, G. Alombert-Goget, S. Chausseidant, N. Gaumer, A. Chiasera, Y. Jestin, M. Ferrari. *Journal of Non-Crystalline Solids* 354 (42-44), pp. 4719-4722 (2008).

