IJEAT
International Journal of Energy Applications and Technologies
Available online at
http://dergipark.gov.tr/ijeat/issue/28599
Research Article
Vol. 4
Issue 1
pp. 28-33
Year
2017

CHARACTERIZATION OF Al DOPED ZnO NANOSTRUCTURES VIA AN ELECTROCHEMICAL ROUTE

M.R.A. Bhuiyan[1]*, M.M. Alam[2], M.A. Momin[2], Hayati Mamur[3]

[1]Department of Electrical and Electronic Engineering, Cankiri Karatekin University, Cankiri, Turkey
[2]Department of Applied Physics, Electronics and Communication Engineering,
Islamic University, Kushtia, Bangladesh
[3]Department of Electrical and Electronics Engineering, Faculty of Engineering, Manisa Celal Bayar University,45100, Manisa, Turkey

Abstract

Al doped ZnO (AZO) nanostructures were produced by using an electrochemical process. The growth structures were then characterized structurally, optically, photoluminescence and Fourier transform infrared (FTIR) spectroscopy. The X-ray diffraction (XRD) studies assessed that AZO nanostructures has been successfully grown. The scanning electron microscope (SEM) image revealed the morphology with nearly uniform grains. The photoluminance (PL) spectrum shows that the ultraviolet emission band between 384 and 537 nm occurs the strong and broad green emission. The UV-vis has a strong absorption below 350 nm and performs transparent mode in the visible range. FTIR spectrum also attributes the transmittance light in visible range is higher than the near infrared range. It has been summarized that AZO nanostructure has been successfully grown by an electrochemical route.

Key words: *AZO nanostructure; Structural and optical properties; Transparent coating*

Paper submitted: February 23, 2017

Paper accepted: April 3, 2017

Corresponding author, bhuiyan@karatekin.edu.tr

1. Introduction

Nanostructure materials are attracted more attention for its potential applications in different fields like as electronic, optical, photovoltaic and medical science. They contain high level surface areas that are able to enter easily in human cells, enhance reactivity and affect different types of microbiological systems [1-3]. Therefore, their applications have gradually expanded in various sectors [4-9].

Literature reports have been proved that the zinc oxide (ZnO) as a transparent conducting oxide (TCO) material having a wide band gap (3.3eV) [10]. It has been used as a transparent conductive window layer for solar cell and other electronic device fabrication [11-13]. Nowadays, all researchers reach to improve its TCO properties by doping other metal material with them [14-18]. The most significant implement in developing is the doping ZnO based materials in electronic, optoelectronic and photovoltaic applications. Their TCO properties are improved by doping other metals such as Al, Cu, Ni, Ag, Co with ZnO. Al is the most useful doping material that its price is minimum cost and contain little ionic radius. AZO nanostructures are used in transparent conductive window material for photovoltaic applications. The electrical conductivity and charge carriers of them are improved by substitution of Zn^{2+} ions with Al^{3+} in ZnO structure.

The synthesizing of highly crystalline AZO nanostructures has consistently been a challenge. Recently, AZO nanostructure materials can be developed by several routes such as hydrothermal, sol–gel, water-based wet chemical, thermal decomposition, and electrochemical [19-23]. The electrochemical route among them is a highly efficient process to produce of metal nanostructures.

In this paper, an AZO was developed via the one-step electrochemical route. The homogeneity of the crystals and crystal growth was properly maintained by this route no further thermal treatment of the product. However, the AZO nanostructures could be directly obtained at room temperature. The influences of the AZO were analyzed by performing structurally, optically and other spectroscopy investigations.

2. Experimental Methods

At room temperature AZO nanostructures were developed by a simple electrochemical process. The acetonitrile and tetra hydro furan (THF) were mixed in the ratio of 4:1 as a solvent for electrolytic bath. In this process, Al doped Zn and platinum (Pt) sheet (10 mm × 10 mm) used as a anode and a cathode, respectively. The white AZO nanostructures were produced and it separated by centrifugation. The collected samples were washed several times by ethanol and distill water to reduce the byproducts. In our previous report [24, 25] this procedure were discussed in details.

3. Results and Discussion

The structural properties of nanostructures including crystalline size can be obtained from an XRD spectrum. The XRD spectrum of the electrochemically developed AZO nanostructures is shown in Fig. 1.

The sample showed the hexagonal in structure to correspondence with the other researcher's report [26, 27]. The spectrum exhibited the diffraction peaks of zinc oxide and $ZnAl_2O_4$. Moreover, the result attributing to a low quantity of Al was substituted in Zn sites of the structure. The expected diffraction peaks were (100), (002), (101), (102), (110) and (103) for these AZO nanostructures [28]. In Fig. 1, (101), (102) and (103) peak results were presented. These were observed by using ASTM data sheet (JCP22CA 23-1490, 36-1451). The intensity and position of (101) peak was a good agreement with expected peak. Therefore, the (101) peak was prominent peak and other researchers also obtained (101) peak of higher intensity [29]. The crystalline dimension of the AZO structures was calculated by using the Scherrer formula [30] for the (101) peak:

$$d=k\lambda/\beta\cos\theta \qquad (1)$$

where, the crystalline shape factor value k is 0.827 for the AZO nanostructure, the wavelength value λ is 0.154 nm (CuK$_{\alpha}$ radiation), β is the selected diffraction peak (half intensity width in degrees) and the Bragg angle is β. Using equation 1, the mean crystalline dimension of the AZO nanostructure was calculated to be ~ 25 nm, which was conformed the other researcher finding [31]. The result implied that the AZO nanostructures were successfully developed.

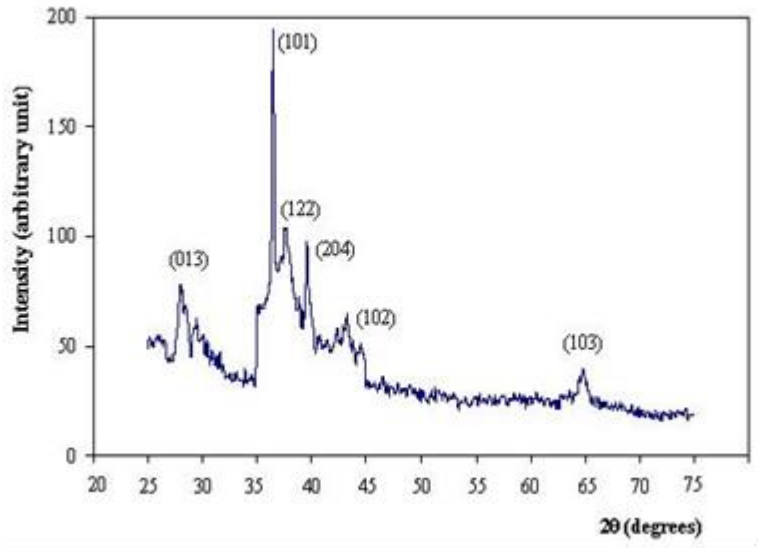

Fig. 1. X-ray diffraction patterns of Al doped ZnO nanoparticles.

The SEM image of AZO nanostructures is shown in Fig. 2. It reveals that the prepared sample is uniform grains with rough homogeneity in the structures. It also reveals the distribution of AZO nanostructures with their size and shape on its surface, which differs from that of ZnO nanostructures. This might be attributing to the influence of Aluminum (Al) doping in zinc oxide.

The PL spectrum recorded for AZO nanostructure is given in Fig. 3. It exhibits the two emission peaks that the strong and weak emission peak was observed at 384 and 537 nm, respectively; which were assigned due to the ultraviolet to near band-edge emission. The strong and weak peaks are developed may be attributed to the high crystallinity which conform the Al concentrations.

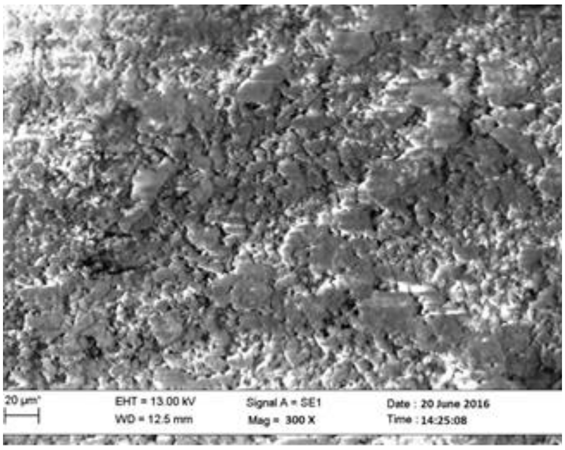

Fig. 2. SEM images of Al doped ZnO nanoparticles.

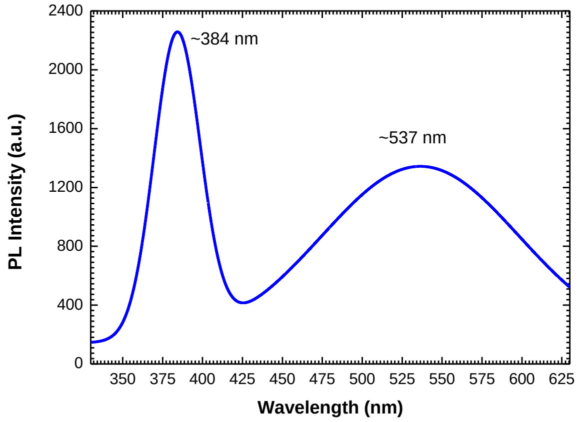

Fig. 3. Photoluminescence spectrum of Al doped ZnO nanoparticles.

In the ultraviolet emission and near infrared band, a strong & broad green emission and a transition from conduction to valence band occurred around at 384 and 537 nm, respectively.

The UV-vis absorption spectrum of AZO nanostructures is shown in Fig. 4. It was clearly seen that the strong ultraviolet emission was observed around at 300 to 350 nm, which indicated that the absorption band edge was slightly shifted from lower wavelength to higher wavelength region compere to the ZnO, which may be due to the doping of Al could influence the ultraviolet peak position of ZnO nanostructures. Further, from the absorption spectrum the calculated band gap was found to be ~3.38 eV. The increase of the band gap of the ZnO was the indication for the introducing of Al inside the ZnO structure. The crystalline quality decrease, the grains grew more easily, the stresses generated and TCO properties were improved by a large amount of Al doping in ZnO that resulted in lattice disorder.

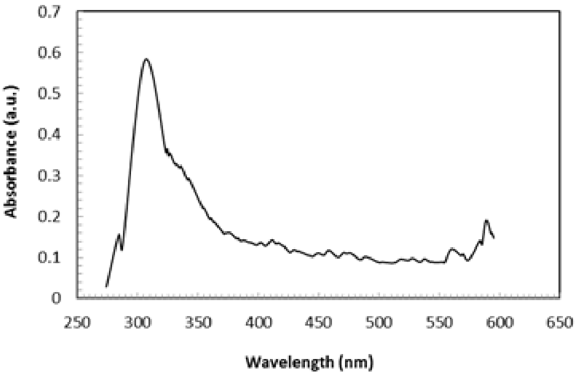

Fig. 4. Absorbance spectrum of Al doped ZnO nanoparticles.

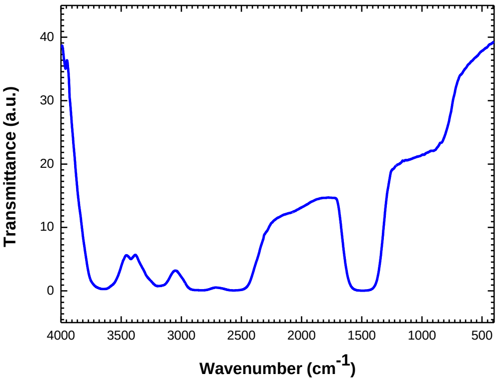

Fig. 5. FTIR spectrum of Al doped ZnO nanoparticles.

The sample had a strong absorption below 350 nm and performs in more transparent in the visible range. Doping of Al ions in the tetrahedral wurtzite structure was confirmed by the optical spectroscopy. The spectrum was also similar to the other researcher reports [32].

In order to analyze the presence of functional groups in molecules, the FTIR spectrum was used. Dopants presence was also supported by using the spectrum. Fig. 5 shows the FTIR spectrum recorded in the range of 500 to 4000 cm^{-1} of AZO nanostructures.

The FTIR spectrum was consisted of different absorption bands around its range. Their three strong absorption peaks were exhibited at 550, 1483 and 3552 cm^{-1} that attributed to some doping of Al in ZnO structure. The peak appeared at 550 cm^{-1} show the existence of Zn-O stretching vibration. The best electrical conductivity possess with the AZO structures in the optimal infrared region. Therefore, the transparent coatings were produced by incorporation of AZO nanostructures. The light transmittance in near infrared region was lower than the visible region that it could be meeting the luminosity inside its buildings. The results were reasonably well to other literature report [33].

4. Conclusion

AZO nanostructures were grown by electrochemical process in the present work and characterized by structurally, optically to assess the quality of nanostructures. From these studies, it was assessed that AZO nanostructures was successfully synthesized and hexagonal in structure. SEM image showed that there was a rough surface in the structures. Additionally, a PL spectrum showed the ultraviolet emission band around 384 and 537 nm that strong and broad green emission band occurs. The UV-vis had a strong absorption below 350 nm and performs in a more transparent in the visible range. A FTIR spectrum attributed the transmittance of light in near infrared region was lower than the invisible region.

Acknowledgement

The project was supported by the University Grant Commission (UGC) of Bangladesh. The authors are grateful to the authority of Islamic University, Kushtia for allow to submitted the project.

References

[1] Huang, C.C., Aronstam, R.S., Chen, D.R. and Huang, Y.W., 2010, “Oxidative stress, calcium homeostasis, and altered gene expression in human lung epithelial cells exposed to ZnO nanoparticles”, Toxicology in Vitro, 24(1), 45-55.

[2] Willander, M., Klason, P., Yang, L.L., Al-Hilli, S.M., Zhao, Q.X. and Nur, O., 2008, “ZnO nanowires: chemical growth, electrodeposition, and application to intracellular nano-sensors”, Physica Status Solidi (c), 5(9), 3076-3083.

[3] Rasmussen, J.W., Martinez, E., Louka, P. and Wingett, D.G., 2010, “Zinc oxide nanoparticles for selective destruction of tumor cells and potential for drug delivery applications”, Expert Opinion on Drug Delivery, 7(9), 1063-1077.

[4] Lu, Y., Zhang, Z., Emanetoglu, N.W., Inouye, M. and Mirochnitchenko, O., 2005, “Multifunctional biosensor based on ZnO nanostructures”, U.S. Patent, US6914279 B2.

[5] Nedelcu, I.A., Ficai, A., Sonmez, M., Ficai, D., Oprea, O. and Andronescu, E., 2014, “Silver based materials for biomedical applications”, Current Organic Chemistry, 18(2), 173-184.

[6] Solanki, P.R., Kaushik, A., Agrawal, V.V. and Malhotra, B.D., 2011, “Nanostructured metal oxide-based biosensors”, NPG Asia Materials, 3(1), 17-24.

[7] Navale, S.C., Ravi, V., Mulla, I.S., Gosavi, S.W. and Kulkarni, S.K., 2007, “Low temperature synthesis and NOx sensing properties of nanostructured Al-doped ZnO”, Sensors and Actuators B: Chemical, 126(2), 382-386.

[8] Yun, S., Lee, J., Chung, J. and Lim, S., 2010, “Improvement of ZnO nanorod-based dye-sensitized solar cell efficiency by Al-doping”, Journal of Physics and Chemistry of Solids, 71(12), 1724-1731.

[9] Lee, S.H., Han, S.H., Jung, H.S., Shin, H., Lee, J., Noh, J.H., Lee, S., Cho, I.S., Lee, J.K., Kim, J. and Shin, H., 2010, “Al-doped ZnO thin film: a new transparent conducting layer for ZnO nanowire-based dye-sensitized solar cells”, The Journal of Physical Chemistry C, 114(15), 7185-7189.

[10] Lee, S.H., Han, S.H., Jung, H.S., Shin, H., Lee, J., Noh, J.H., Lee, S., Cho, I.S., Lee, J.K., Kim, J. and Shin, H., 2010, “Al-doped ZnO thin film: a new transparent conducting layer for ZnO nanowire-based dye-sensitized solar cells”, The Journal of Physical Chemistry C, 114(15), 7185-7189.

[11] Kim, D., Yun, I. and Kim, H., 2010, “Fabrication of rough Al doped ZnO films deposited by low pressure chemical vapor deposition for high efficiency thin film solar cells”, Current Applied Physics, 10(3), S459-S462.

[12] Lupan, O., Shishiyanu, S., Ursaki, V., Khallaf, H., Chow, L., Shishiyanu, T., Sontea, V., Monaico, E. and Railean, S., 2009, “Synthesis of nanostructured Al-doped zinc oxide films on Si for solar cells applications”, Solar Energy Materials and Solar Cells, 93(8), 1417-1422.

[13] Lee, S.H., Han, S.H., Jung, H.S., Shin, H., Lee, J., Noh, J.H., Lee, S., Cho, I.S., Lee, J.K., Kim, J. and Shin, H., 2010, “Al-doped ZnO thin film: a new transparent conducting layer for ZnO nanowire-based dye-sensitized solar cells”, The Journal of Physical Chemistry C, 114(15), 7185-7189.

[14] Yang, Z., Huang, Y., Chen, G., Guo, Z., Cheng, S. and Huang, S., 2009, “Ethanol gas sensor based on Al-doped ZnO nanomaterial with many gas diffusing channels”, Sensors and Actuators B: Chemical, 140(2), 549-556.

[15] Zeferino, R.S., Flores, M.B. and Pal, U., 2011, “Photoluminescence and Raman scattering in Ag-doped ZnO nanoparticles”, Journal of Applied Physics, 109(1), 014308.

[16] Dar, G.N., Umar, A., Zaidi, S.A., Ibrahim, A.A., Abaker, M., Baskoutas, S. and Al-Assiri, M.S., 2012, “Ce-doped ZnO nanorods for the detection of hazardous chemical”, Sensors and Actuators B: Chemical, 173, 72-78.

[17] Gogurla, N., Sinha, A.K., Santra, S., Manna, S. and Ray, S.K., 2014, “Multifunctional Au-ZnO plasmonic nanostructures for enhanced UV photodetector and room temperature NO sensing devices”, Scientific Reports, 4, 6483.

[18] Kim, K., Song, Y.W., Chang, S., Kim, I.H., Kim, S. and Lee, S.Y., 2009, “Fabrication and characterization of Ga-doped ZnO nanowire gas sensor for the detection of CO”, Thin Solid Films, 518(4) 1190-1193.

[19] Piticescu, R.R., Piticescu, R.M. and Monty, C.J., 2006, “Synthesis of Al-doped ZnO nanomaterials with controlled luminescence”, Journal of the European Ceramic Society, 26(14), 2979-2983.

[20] Hjiri, M., El Mir, L., Leonardi, S.G., Pistone, A., Mavilia, L. and Neri, G., 2014, “Al-doped ZnO for highly sensitive CO gas sensors”, Sensors and Actuators B: Chemical, 196, 413-420.

[21] Van den Rul, H., Mondelaers, D., Van Bael, M.K. and Mullens, J., 2006, "Water-based wet chemical synthesis of (doped) ZnO nanostructures", Journal of Sol-gel Science and Technology, 39(1), 41-47.

[22] Thu, T.V. and Maenosono, S., 2010, "Synthesis of high-quality Al-doped ZnO nanoink", Journal of Applied Physics, 107(1), 014308.

[23] Kadam, P., Agashe, C. and Mahamuni, S., 2008, "Al-doped ZnO nanocrystals", Journal of Applied Physics, 104(10), 103501.

[24] Bhuiyan, M.R.A., Alam, M.M., Momin, M.A., Uddin, M.J. and Islam, M., 2012, "Synthesis an d characterization of barium titanate (BaTiO3) nanoparticle", International Journal of Material and Mechanical Engineering, 1, 21-24.

[25] Bhuiyan, M.R.A. and Rahman, M.K., 2014, "Synthesis and characterization of Ni doped ZnO nanoparticles", International Journal of Engineering and Manufacturing, 4(1), 10-17.

[26] Suwanboon, S., Amornpitoksuk, P., Haidoux, A. and Tedenac, J.C., 2008, "Structural and optical properties of undoped and aluminium doped zinc oxide nanoparticles via precipitation method at low temperature", Journal of Alloys and Compounds, 462(1), 335-339.

[27] Chen, K.J., Fang, T.H., Hung, F.Y., Ji, L.W., Chang, S.J., Young, S.J. and Hsiao, Y.J., 2008, "The crystallization and physical properties of Al-doped ZnO nanoparticles", Applied Surface Science, 254(18), 5791-5795.

[28] Vadivel, M., Ramesh, B.R. and Ramamurthi, K., 2014, "Studies on the structural, optical and magnetic properties of al doped ZnO nanoparticles", International Journal of Chem Tech Research, 7(3), 1206-1211.

[29] Mohite, R.M. and Kothawale, R.R., 2015, "Al-doped zinc oxide nanostructures as transparent conductive window layer for photovoltaic applications", Indian Journal of Chemistry, 54A, 872-876.

[30] Du, S., Tian, Y., Liu, H., Liu, J. and Chen, Y., 2006, "Calcination effects on the properties of gallium-doped zinc oxide powders", Journal of the American Ceramic Society, 89(8), 2440-2443.

[31] Akdağ, A., Budak, H.F., Yılmaz, M., Efe, A., Büyükaydın, M., Can, M., Turgut, G. and Sönmez, E., 2016, "Structural and Morphological Properties of Al doped ZnO Nanoparticles", Journal of Physics: Conference Series, 707(1), 012020).

[32] Vanaja, A., Ramaraju, G.V. and Rao, S., 2016, "Structural and optical investigation of Al doped ZnO nanoparticles synthesized by sol-gel process", Indian Journal of Science and Technology, 9(12), 87013.

[33] Buonsanti, R., Llordes, A., Aloni, S., Helms, B.A. and Milliron, D.J., 2011, "Tunable infrared absorption and visible transparency of colloidal aluminum-doped zinc oxide nanocrystals", Nano Letters, 11(11), 4706-4710.