

IMPACT OF ZnO NANO ROD AS ELECTRON TRANSPORT LAYER ON THE PERFORMANCE OF PCBM:P3HT POLYMER SOLAR CELLS

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ABSTRACT

Effects of growth time (15 and 30 min) of Zinc oxide (ZnO) nano-rods that used as an electron transport layer (ETL) for polymer based solar cells were investigated. ZnO nano-rods thin films were synthesized using the hydrothermal method at 90 °C for 15 and 30 min growth time. The PCBM:PH3 was spin coated on top of the grown ZnO nanorod layer in side glove box. Silver contacts were evaporated on the polymer, and the solar cell J-V curve was drowned. The refinement of X-Ray diffraction (XRD) pattern was used to investigate the structural properties of the nano-rods. The morphology the ZnO nano-rods were observed by a atomic force microscope (AFM), while the optical band gap energy was obtained using UV-VIS-NIR absorbance spectroscopy. The results indicate that PCBM:P3HT cells has optimal efficiency of 2.65% and fill factor of 0.562 by using ZnO-nano rod grow at 15 min as electron transport layer.

Keywords: ZnO nanorod; Polymer solar cells; hydrothermal method; electron transport layer

INTRODUCTION

Organic solar cells (OSCs) are a promising source of energy technology which could overcome the challenge of rising global energy demand. This technology represents a cost-effective alternative to silicon based photovoltaic, due to its potential of providing environmentally safe, flexible, lightweight and inexpensive solar cell. However, their longevity and a relatively low power conversion efficiency compared to inorganic solar cell have been the major limitation for faster commercialization.

ZnO is a direct wide band gap, $E_g = 3.37$ eV, at room temperature. It is belong to II-VI binary compound semiconductor and crystallizes in three forms hexagonal wurtzite, cubic zinc blende, and rarely observed cubic rock salt [6]. Direct band materials have intrinsically high luminescence yield compared to indirect band gap materials and increase in the band gap reduces the leakage current of the devices and their temperature dependence significantly [7, 10]. Among the II-VI semiconductor, ZnO has relatively higher and stable excitation binding energy of 60 meV at 300 K. It is one of the reasons that ZnO is so attractive for optoelectronic devices.

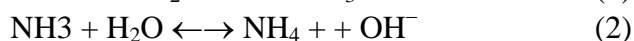
Higher excitation binding energy materials give brighter emission, because exaction is already a bound system, which radioactively recombine with higher efficiency without require traps to localize the carriers [7, 10]. Other favorable aspects of ZnO are that it is non-toxic, cheap, relatively a bound source materials and chemically stable. In particular, 1-D ZnO nanorods are potential useful for various nanodevices such as diodes, transistor, solar cell, leds, and piezoelectric devices, because of their high aspect ratio and large surface area to volume ratio ensure high efficiency and sensitivity in these applications. The aim of this research is to produce ZnO nanorods with optimum characteristics that can be used as ETL in the construction of low-cost polymer solar cells. The factors affecting the Polymer solar cells efficiency, such as the growth time and the roughness of nanorod are also investigated.

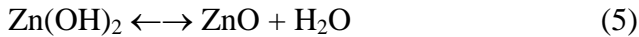
EXPERIMENTAL

Sol-gel and hydrothermal method were used to fabricate ZnO seed layer and ZnO nano rod, respectively. A 0.2 M of Zinc Acetate dehydrate (sigma Aldrich 99.0 %) was dilute in mixture of absolute ethanol and 0.2M (DEA) (sigma Aldrich). The mixture was heated on hot plate at 60°C and stirred with 500 RPM for 30 to 60 mins then aging overnight. A few drop of the aged solution was spin coated on ITO substare at 300 RPM for 30s. The film was dried at 100 °C for 20 min. These steps were repeated for three times. Finally, the substrates were annealed at 300°C for 60 mins in oven to decompose the acetate. After that the substrates was ready for the growth procedure.

For the hydrothermal growth of ZnO nano rod, an equimolar 0.04 M of zinc nitrate hex-hydrate, $Zn(NO_3)_2 \cdot 6H_2O$ and hexamethylenetetramine (HMTA) were dissolved in fresh deionized water (DI) (20ml), then the mixture was shacked until there is no crystal was found.

The seeded substrates loaded were placed face down in the aqueous solution and transferred into autoclave at 90 °C for 15 and 30 mins. Then the substrates were cleaned carefully in DI and dried into the hot plate for 10 mins at $T = 100^\circ C$. The reaction of ZnO nano rod growth mechanism can be described as followed,





The samples were subjected to characterization. Prior to the coating of the substrates by the ZnO seed solution standard cleaning procedure were used.

Fabrication of solar cell layer

P3HT:PCBM was prepared with a ratio of 1:1, with each 20 mg. Then Chlorobenzene is injected to each of the polymer bottles, with 500 μl each. The polymer bottles were put into beakers, to avoid sliding, and then heated in a heat pan, and stirred at 600 RPM at 60°C, for minimum 2 hours preferable is 4 hours. The bottles were covered with an empty box to avoid exposure to light source. After 2.5 hrs, the PCBM solution, was extracted and injected to the P3HT solution. The OTD (1,8 - octanedithiol) was inserted to the P3HT:PCBM mixture, at 2% of the mixture (20 μl). The stirring rate was increased to 800 RPM from 600 rpm, and the heating temperature is 60°C, and stirred for 24 hours. The PCBM:PH3 used by spin coating in side glove box. Silver contacts were evaporated on the polymer for J-V measurement.

RESULTS AND DISCUSSION

Optical Properties

The optical properties of the ZnO nanoparticles were determined from the UV spectrums. The absorption spectrum of ZnO nanoparticles presented a peak located at 363 nm as illustrated in Figure.1, which corresponds to the optical band gap of ZnO, that was calculated using Energy equation (3) and was found to be 3.41 eV.

$$E(\text{eV}) = 1240/\lambda \quad (6)$$

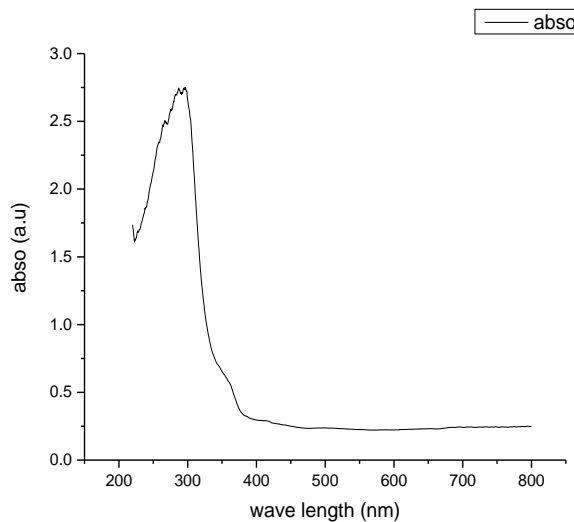


Figure 1: UV absorbance spectrum of the ZnO nanorods

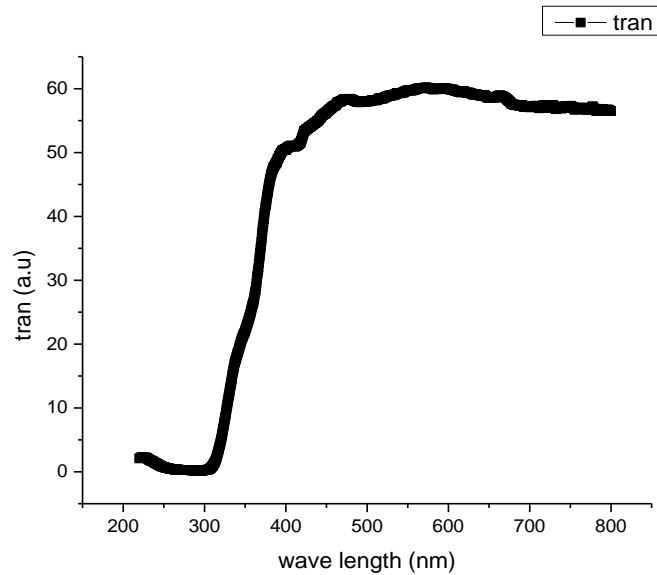


Figure 2: UV transmisson spectrum of the ZnO nanorods

Structural Properties

The X-Ray Diffraction patterns for the ZnO produced at 15-mins and 30-min growth time are shown in Figure 3 and Figure 4, respectively. The XRD was characterized by sharp reflections peaks that were assigned to a hexagonal single phase of ZnO. The atomic and molecular structure of the ZnO structure is clearly preserved throughout the hydrothermal route.

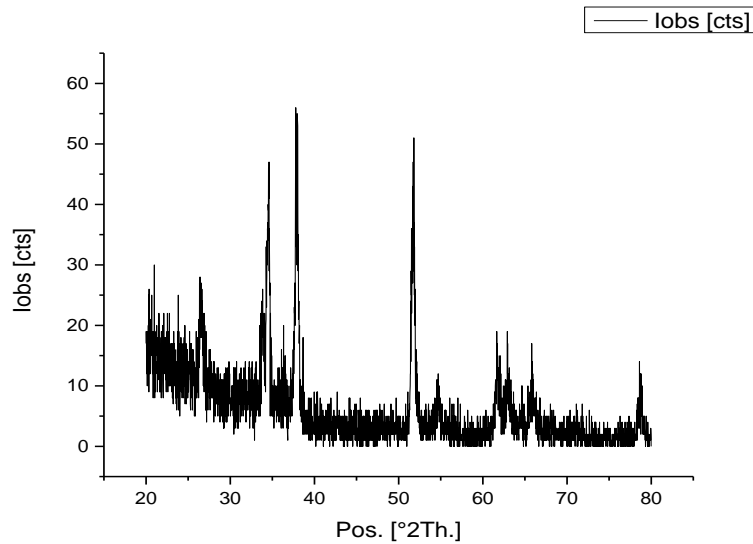


Figure 3: XRD pattern ZnO nanorods at 15 mins growth time

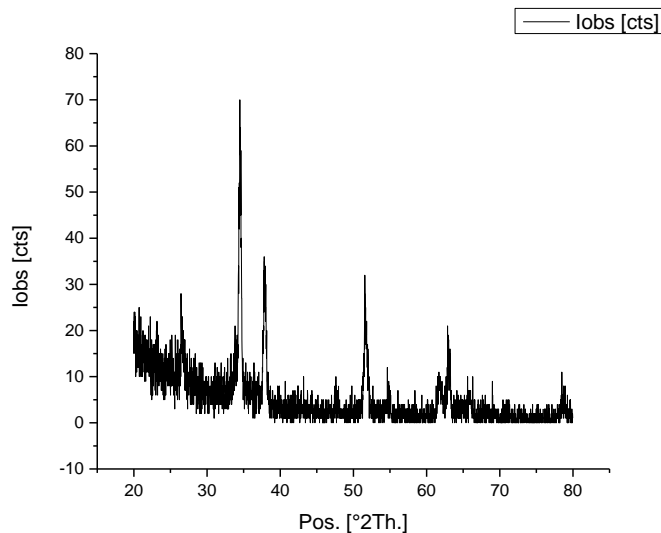


Figure 4: XRD pattern ZnO nanorods at 30 mins growth time

Atomic force microscopy

Atomic force microscope (AFM) image was used to investigate the morphology and size of the ZnO nanoparticles as shown in Figure 5. The AFM image demonstrated that the particles are nanorods and the root mean square roughness ($R_q= 18, 25$ and 11 nm for 15- and 30-min growth time ZnO nano rod and ZnO seed layer, respectively).

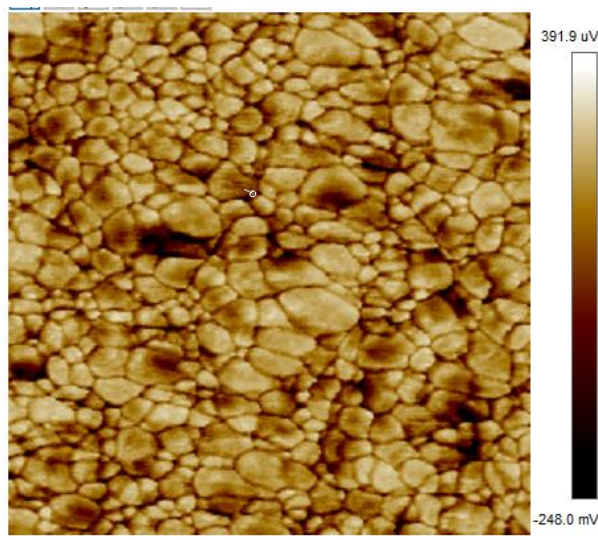


Figure 5: Adhesion AFM image of ZnO seed layer

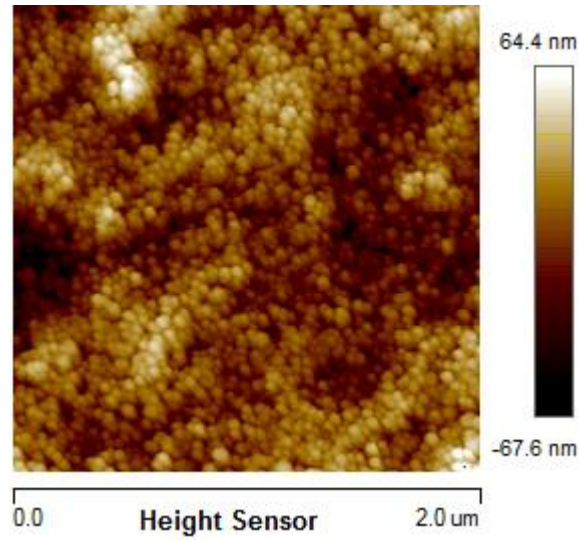


Figure 6: High sensor AFM image for 15-min growth time ZnO nanorods

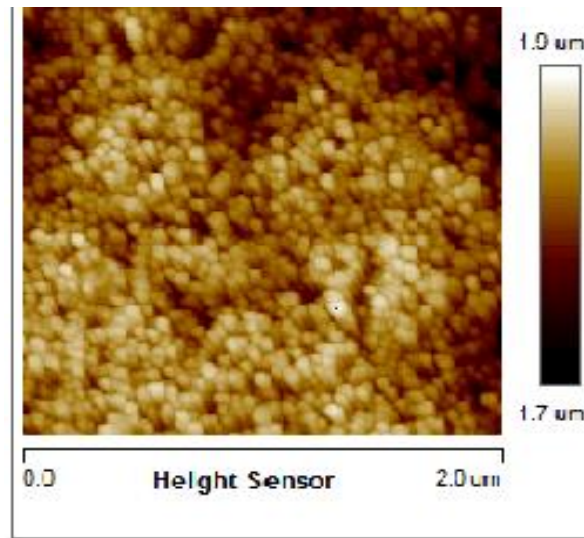


Figure 7: High sensor AFM image for 30-min growth time ZnO nano-rods

J-V measurement curve

The J-V curves of P3HT: PCBM cells using 15-min and 30-min growth time ZnO nanorod as transport layer are presented in Figure 8 and 9 respectively. The efficiency η of both cells was calculated using equation (7) and was found to be $\sim 2.65\%$ for 15-min ZnO nanorod and $\sim 1.62\%$ for 30 min-ZnO.

$$FF = J_{max}V_{max}/J_{sc}V_{oc} \quad (6)$$

$$\eta = J_{max}V_{max}/P_{in} \quad (7)$$

Where, FF : fill factor, V_{max} : max voltage, J_{max} : maximum current-density, J_{sc} : short-circuit current density, V_{oc} : open-circuit voltage, η : power conversion efficiency. These results were found to be acceptable when compared to [7] and [8]. But compared to the conventional silicon solar cells which have an efficiency of about 30%, these results are considered very low. Therefore the ZnO nanorods should undergo a doping process to enhance the PV conversion.

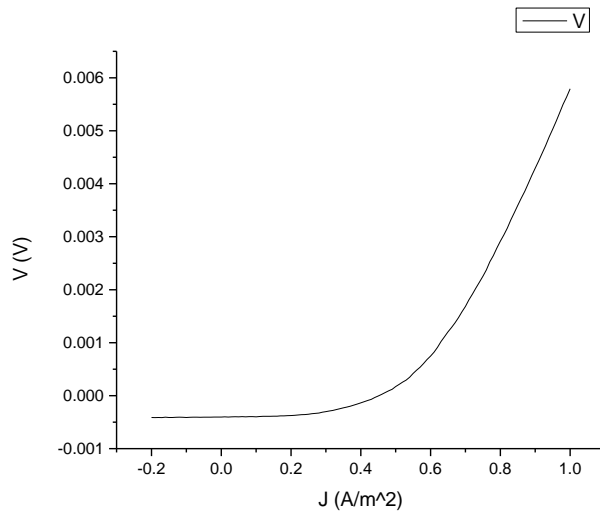


Figure 8: J-V curve of PCBM:P3HT solar cell using 15-min growth time ZnO nanorods as electron transport layer.

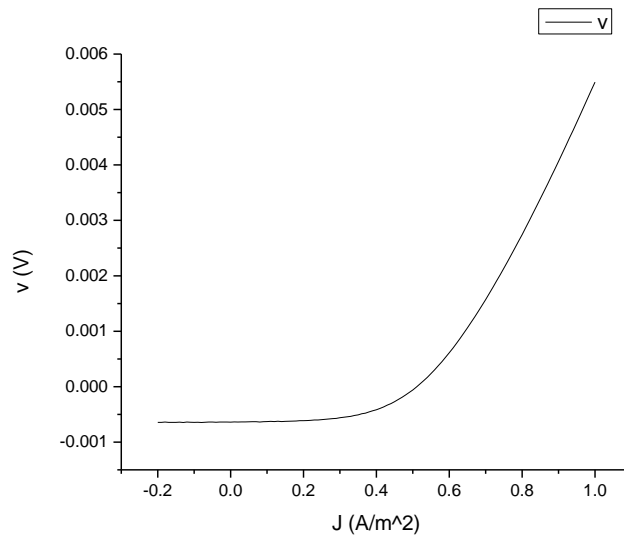


Figure 9: J-V curve of PCBM:P3HT solar cell using 30-min growth time ZnO nanorods as electron transport layer

CONCLUSIONS

ZnO nanorods thin films were successfully fabricated by the hydrothermal method at at 90 °C for 15- and 30-min growth time using sol-gel synthesized ZnO film as seed layer. The structural properties were investigated using X-Ray diffraction (XRD). XRD pattern showed that the structure of ZnO is to be hexagonal .The optical band gap energy (E_g) obtained using UV-VIS-NIR diffuse reflectance spectroscopy was approximately 3.41eV. ZnO-nano rod grown at 15 min exhibited higher efficiency of 2.65% and fill factor of 0.5625 than that grow at 30 min; efficiency1.62% and fill factor 0.46. This result clearly proves that the growth time affects the efficiency of the polymer solar cells.

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