INVERTED POLYMER SOLAR CELLS IMPLEMENTING ZnO AS AN ELECTRON TRANSPORT LAYER

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ABSTRACT—Zinc Oxide (ZnO) nanorods were implemented as an electron transport layer (ETL) on a low-cost inverted polymer solar cells. The ZnO nanorods were synthesized by the hydrothermal method using two growth times, in order to find the optimal time to provide the best power conversion efficiency. The active layer of PC61BM: P3HTwas prepared via spin casting method in an N2 controlled glove box. Silver electrodes were evaporated on the active polymer layer.

Keywords—ZnO, hydrothermal method, inverted polymer solar cell, power conversion efficiency

I. INTRODUCTION

The international production rate of oil and gas will decrease with a great frequency in the near future [1]. Also, their prices are expected to increase with the same rate, which will lead to the implementation of renewable energy sources such as solar energy, wind energy systems, tidal, and many other green energy sources as a practical alternative [2].

Solar energy is the energy of the future, due to the fact of it is renewable, cheap, and clean. The implementation of solar energy means the utilization of solar cells in order to convert solar energy into electricity. Solar cells can produce approximately twice the amount of energy produced by fossil fuels and much more than the energy produced by nuclear fission reactors. But the drawback of the implementation of solar energy today is due to the high cost compared to the relatively low power conversion efficiency (PCE). The commercial solar cells available in the market are silicon-based photovoltaic cells, which are somewhat expensive due to their complex and expensive fabrication. Therefore, there is a trend to use other types of materials to synthesize solar cells apart from silicon, such as dye-sensitized solar cells, which were found to be economic and also have a high PCE since they depend on dye sensitizers to absorb the visible light and generate an electron transfer reaction [3]. Perovskite solar cells (PSCs) are another type of economic solar cells, but they are not widely used due to its instability [4]. Organic photovoltaics (OPVs) are also another cost-effective alternative, and have unique properties such as being light-weighted, docile, semitransparent, and do not have a complex fabrication process [5]. However, there still exist some issues considering the requirements of the commercialization of OPVs [6].

II. INVERTED POLYMER SOLAR CELLS

A typical OPV consists of a bulk heterojunction (BHJ) structure, in which the most commonly used photoactive material is a combination of poly(3-hexylthiophene) (P3HT) and the fullerene derivative (6,6)-phenylC61butyric acid methyl ester (PCBM). Generally, there are two types of OPVs; conventional and inverted. The conventional OPV is composed of an anode/hole transport layer/active material/electron transport layer/cathode. The main issue with conventional OPV is the instability of the device in the air. This is known to be closely related to the hole transport layer material poly
(3,4ethylenedioxioxythiophene): poly (styrene sulfonate) (PEDOT: PSS) that causes the degradation of both the photoactive material and anode due to its hygroscopicity and acidity. Thus, to resolve this problem, the inverted structure for OPV has been proposed in which the electron transport layer (ETL) and the hole transport layer (HTL) are interchanged to improve stability. However, the PCE of the inverted OPV is generally lower than that of the conventional OPV. Therefore, the usage of a high-quality ETL and optimization of the interfacial characteristics between the pho-to active layer and the electrode is required to increase the PCE of the inverted OPV [7]. A family of metal oxides such as TiO2 [8–10] and ZnO has been commonly used as the ETL material in the inverted OPV. The TiO2 and ZnO are preferred due to their well aligned band gap distribution in the OPV structure. In particular, ZnO is more favored as an ETL in OPV because of its relatively high electron mobility. In addition, 3D nanostructuring in the ETL rather than a planar structure has been suggested to achieve a high surface area, which leads to an increase in charge extraction efficiency between the photoactive layer and the cathode [10].

III. MATERIAL AND METHODS

The inverted polymer solar cell was composed of four layers and Ag poles connected at the edges as demonstrated in fig. 1. All the layers were synthesized using inexpensive methods. The first layer was the substrate and it consisted of a glass plate covered by an FTO layer. The second layer was the ZnO seed layer and it was synthesized by the sol-gel method , then a spin coating process was applied so as to form a homogeneous ZnO seed layer also, drop cast and deep coat techniques were also used to form the ZnO seed layer. The third layer consisted of ZnO nanorods that were synthesized via the hydrothermal method. The inverted polymer layer consisted of P3HT: PCBM was prepared with a ratio of 1:1.

via spin casting method in an N2 controlled glove box. And finally, the Ag electrodes were evaporated on the active polymer layer.

There were two solar cells prepared; the first cell had ZnO nanorods with a growth time of 15 minutes, and the second cell had ZnO nanorods with a growth time of 30 minutes. The solar cells were subjected to 100mW/cm2 xenon solar simulator lamp and then the optical energy bandgap for the samples was calculated by Tauc's equation:

$$E(eV) = \frac{hC}{\lambda} \approx \frac{1240}{\lambda} \quad (1)$$

Also, the optical bandgap of the ZnO nanoparticles was determined from the UV data using both absorbance and reflectance spectrums. Then, the J-V characteristics were found and hence the fill factor (FF) was found from (2) and the PCE, η was calculated from (3).

$$FF = JmaxVmax/JscVoc \quad (2)$$

Where J_{max} is the maximum current density, V_{max} is the maximum voltage, J_{sc} is the short circuit current density and V_{oc} is the open-circuit voltage.

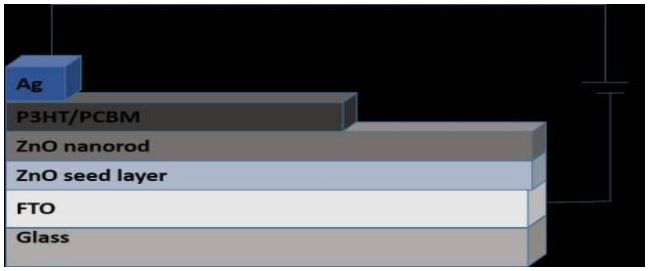

Fig. 1. Block diagram of the inverted polymer solar cell

$$\eta = J_{max}V_{max}/P_{in} \quad (3)$$

Where P_{in} is the input power

IV. RESULT AND DISCUSSION

The optical energy gap was found to be ~3.4 due to the absorption spectrum of the ZnO nanoparticles as illustrated in Fig. 2. While the optical energy gap of ZnO nanoparticles which was found form the reflectance spectrum was also ~ 3.4 and is displayed in Fig.3. Then ZnO bandgap was calculated using (1) and was found to be ~ 3.42 nm. By The two obtained results using different spectrums were compared and they were found to be almost equal.

The transmission properties of the sample were also evaluated and the result is showed in Fig 4. and Fig. 5. It was noticed that 60 % of the light is transmitted through the sample at the visible region and most of the light is absorbed at the UV region (< 300 nm).

The J-V characteristics of the ZnO nanorods solar cells were plotted in Fig. 6, and Fig.7. And J_{sc}, V_{oc}, FF, and PCE were found and shown in the table. 1. And it was found that the open-circuit voltage for the 15 min. growth is inverted polymer solar cells had an efficiency of 1.62% and fill factor of 0.46 respectively. This fact proves that the growth time affects the efficiency and the fill factor of the polymer solar cells.

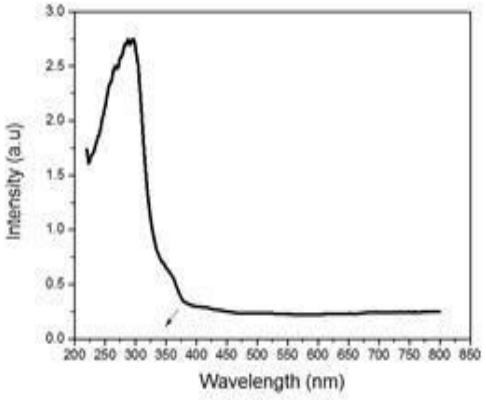

Fig. 2. ZnO nanoparticles optical bandgap from the reflectance spectrum

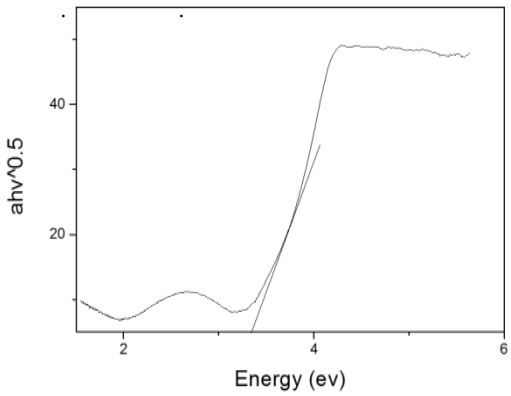

Fig. 3 ZnO nanorods optical bandgap from the reflectance spectrum

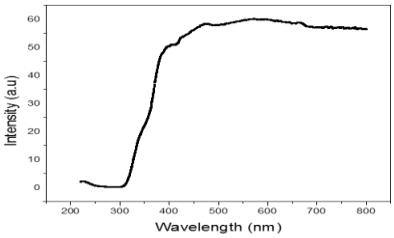

Fig. 4. Transmission spectrum for ZnO nanorod growth at 15 minutes

V. CONCLUSION

By comparing the two inverted polymer solar cells, the 15 min. growth ZnO nanorod inverted polymer solar cell was found to be more efficient with an efficiency of 2.65% and fill factor of 0.56, while the 30 min. growth ZnO nanorods

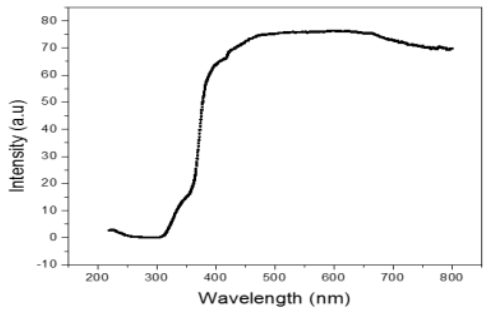

Fig. 5. Transmission spectrum for ZnO nanorod growth at 30 minutes

Table I. Device parameter for ZnO based inverted organic solar cell

. Sample	VOC in Volts	J_{SC} in mA/cm^2	Fill Factor	PCE %
15 min. ZnO nanorods	**0.51**	**9.53**	**0.56**	**2.65**
30 min. ZnO nanorods	**0.48**	**7.39**	**0.46**	**1.62**

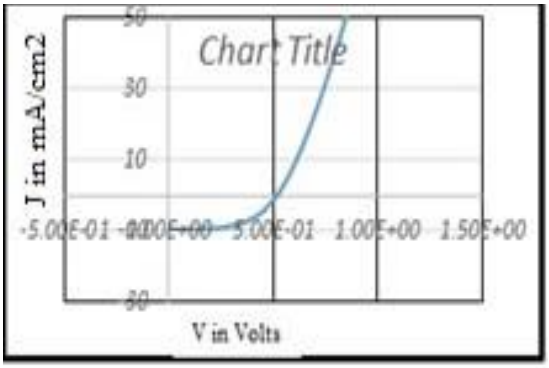

Fig. 6. J-V characteristic for ZnO nanorod growth at 15 minutes

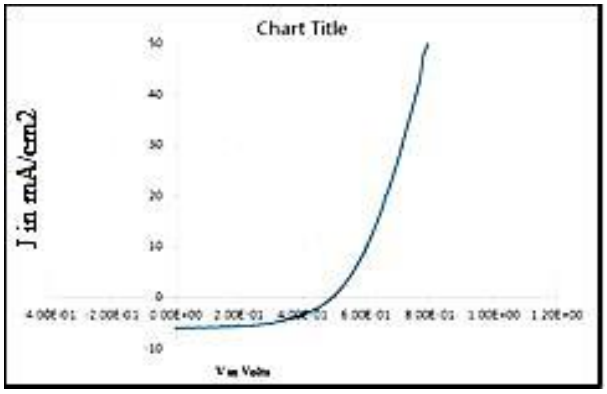

Fig. 7. J-V characteristic for ZnO 30 minutes

REFERENCES

[1] Angmo, D., and F.C. Krebs. (2015). Over 2 Years of Outdoor Operational and Storage Stability of ITO-Free, Fully Roll-to-Roll Fabricated Polymer Solar Cell Modules. Energy Technology. 3(7): 774-783.

[2] N. M. Osman, et. al. (2019). Synthesis, structural and optical properties of ZnO Nano-rods used in Solar Cells fabrication. SUST Journal of Engineering and Computer Science (JECS). Vol. 20(1): 11-16.

[3] P. Tonui, et. al. (2018). Perovskites photovoltaic solar cells: An overview of current status. Renewable and Sustainable Energy Reviews. Vol. 91:1025-1044.

[4] Zhao, J., et al. (2016). Efficient organic solar cells processed from hydrocarbon solvents. Nature Energy. 1(2). 1-7.

[5] P. Friedlingstein et al. (2014). Persistent growth of CO 2 emissions and implications for reaching climate targets. Nature geoscience. 7(10): 709-715.

[6] S. Das. (2015). Interfacial and Electrode Modifications in P 3 HT: PC 61 BM based Organic Solar Cells: Devices, Processing and Characterization. Arizona State University.

[7] D. Angmo and F.C. Krebs. (2015). Over 2 years of outdoor operationaland storage stability of ITO-free, fully roll toroll fabricated polymer solar cell modules. Energy Technology,. 3(7): 774-783.

[8] L. Duan and A. Uddin. (2020). Progress in Stability of Organic Solar Cells. Adv. Sci. Vol.7:1970-1973.

[9] K. Wang et al. (2016). Inverted organic photovoltaic cells. Chemical Society Reviews. 45(10): p. 2937-2975.

[10] M. Zafar, J. Y. Yun, and D.-H. Kim. (2017), Performance of inverted polymer solar cells with randomly oriented ZnO nanorods coupled with atomic layer deposited ZnO. Applied Surface Science. Vol. 398: p. 9-14.