EXAMINING THE OPERATION OF AN INVERSELY STRUCTURED ORGANIC PHOTOVOLTAIC SYSTEM USING LAMINATED SILVER ELECTRODES.

E. E. IGBOKWE[1], D. A. ASIEGBU[2], L. A. NNANNA[2]

[1]Department of Physics/Electronics, Abia State Polytechnic, Aba.
[2]Department of Physics, Michael Okpara University of Agriculture, Umudike.
Corresponding author's email: ejikeme.igbokwe@abiastatepolytechnic.edu.ng

ABSTRACT

The research looked into the performance of an organic photovoltaic (OPV) with an inverse structure and laminated silver electrodes. The goal was to investigate the properties of the PCMB:P3HT blend used in the active layer and how they relate to device performance. The findings from UV-Visible absorption spectroscopy, which examined the optical properties of the PCMB: P3HT blend, were presented in the results. The blend had high absorption between 584.55 and 623.33 nm and low absorption in the red and near-infrared regions of the spectrum. The transmittance spectra revealed low transmittance, especially between 400 and 635 nm. The absorption and extinction coefficients of the blended material were calculated and analysed. The absorption coefficient increased between 400 and 635 nm, while the extinction coefficient peaked at 617.81 nm. The optical energy bandgap of the blend was determined to be 1.94 eV. The photovoltaic characteristics of the solar cell were assessed using I-V and P-V measurements. The key parameters obtained were open-circuit voltage, short-circuit current, voltage at maximum power point, and current at maximum power point. The fill factor and efficiency of the solar cell were calculated to be approximately 0.6462 and 0.6989%, respectively. The research helps to better understand the performance characteristics of inverse structure OPVs with laminated silver electrodes. Further investigation and optimization of the device structure and materials may improve the fill factor and efficiency, thereby improving the performance and adoption of organic photovoltaics in renewable energy applications.

Keywords: Inverse structure, Organic photovoltaic (OPV), Laminated silver electrodes, PCMB: P3HT blend, renewable energy.

INTRODUCTION

Solar cells are semiconductor devices that use the photovoltaic effect to convert sunlight into electricity [1]. They are significant in renewable energy because they provide a long-term and environmentally friendly source of electricity. Solar cells have several advantages over traditional fossil-fuel-based energy sources, including their abundance, ease of maintenance, and lack of greenhouse gas emissions [2]. Solar cells can also be used in a variety of applications, ranging from large-scale solar farms to small-scale portable devices such as calculators and cell phones. As a result, in recent years, the development of efficient and cost-effective solar cells has been a major focus of research.

Inverse structure solar cells are significant because, in comparison to conventional solar cells, they have the potential to achieve high power conversion efficiency and low manufacturing costs. A better charge carrier collection and fewer recombination losses may result from inverting the electron and

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hole transporting layers in inverse structure solar cells. Additionally, the manufacturing procedure can be streamlined and material waste reduced by depositing the top electrode using a lamination technique.

Inverse structure solar cells have been shown to have benefits in numerous studies. For instance, a study showed an inverted organic solar cell with a structure similar to the one described in this study to have a power conversion efficiency of 3.86% [3]. They credited increased light harvesting, improved charge carrier transport, and decreased recombination losses for the efficiency. The creation of a high efficiency laminated polymer solar cell was also reported on by some authors [4]. They demonstrated the effectiveness of the lamination technique by achieving a power conversion efficiency of 5.83% and demonstrating how it improved device stability and defect prevention.

These studies demonstrate the potential of solar cells with an inverse structure for producing them at low cost and high efficiency. This study aims to advance the creation of more effective and affordable solar energy technologies by examining the characteristics and performance of such solar cells.

The goal of this study is to examine the performance of a solar cell with an inverse structure and a top electrode that was laminated. This innovative method has the potential to streamline the production process and cut down on material waste. The study also aims to investigate the characteristics of the PCMB:P3HT film used in the active layer and how they relate to the functionality of the device. The study aims to contribute to the creation of more effective and affordable solar energy technologies by improving our understanding of the mechanisms governing the device operation. The findings of this study may offer guidance in the design and performance optimization of novel solar cell architectures.

MATERIALS AND METHODS

P3HT (95.0%), PCMB (99.0%), and ITO substrate were purchased from Ossila for this study. All cleaning solvents (HCl, toluene, acetone, and methanol) were of analytical grade, and toluene was used as the solvent.

A plastic mask was used to shield the active region during the two minutes of HCl etching on an ITO substrate. To remove any traces of the plastic mask after the etching, the substrate was painstakingly cleaned with toluene. To remove any remaining contaminants, the substrate was then cleaned with acetone and methanol in that order.

Spin-coating was used to deposit the active layer onto the ready ITO substrate using the P3HT:PCBM blended solution, which was created by dissolving the polymers in toluene at a concentration of 25 mg/ml [5]. In order to guarantee even film coverage, the

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spin-coating procedure was carried out at a speed of 2000 rpm for 20 seconds. The dissolved blended substance was also spin-coated onto a glass slide in a typical atmosphere and at room temperature before being used for UV-Vis spectroscopic analysis and construction of the solar cell.

The hole transport layer (HTL) was created by spin-coating a layer of PEDOT:PSS onto the P3HT:PCBM active layer after it had been deposited. In order to achieve the desired thickness and uniformity, the PEDOT:PSS solution was carefully spin-coated onto the P3HT:PCBM layer at a speed and duration that were both optimized.

A paint brush was used to deposit silver onto a lamination paper in order to create the necessary contacts for effective charge extraction. After that, the PEDOT:PSS layer was hot laminated with a silver contact, ensuring strong electrical connectivity between the active layer and outside circuitry.

The film of P3HT:PCBM with different thickness was characterized with UV-Vis spectrophotometer to determine the optical properties of the materials. The photovoltaic performance of the fabricated organic solar cell was evaluated using a solar simulator and source meter setup [6]. To simulate sunlight, a solar simulator allows for precise measurement of key performance parameters such as open-circuit voltage (Voc), short-circuit current (Jsc), fill factor (FF), and overall power conversion efficiency (PCE). The measurements were taken under standard testing conditions, ensuring that the results were accurate and comparable.

RESULTS AND DISCUSSION

UV-visible absorption spectroscopy has been widely used in thin-film optical analysis. The absorption spectra of the PCMB:P3HT blend are shown in figure 1. The blended material had the highest absorption between 584.55 and 623.33 nm, as shown in the figure. This demonstrates that the material harvests the most light at the previously mentioned wavelengths. In the red and near-infrared regions of the spectrum, however, there is little or no absorption.

The transmittance of the PCMB:P3HT blend is shown in Figure 2. The material showed extremely low transmittance, especially between 400 and 635 nm, as can be seen in the figure. Therefore, this demonstrates that dissolving the mixture in toluene decreases the transmission of visible light between these wavelengths.

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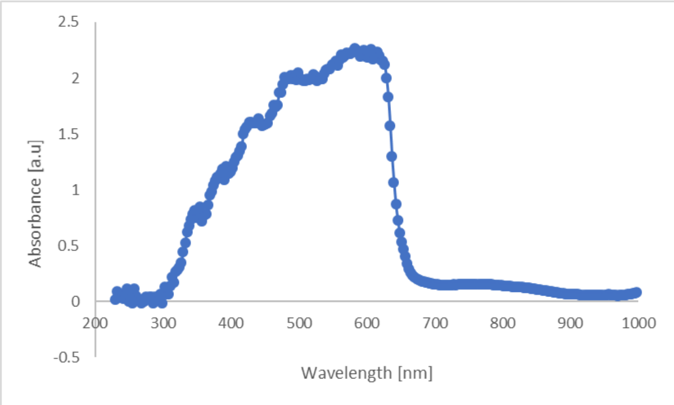

Figure 1: Absorption spectra of PCMB: P3HT active layer with toluene as solvent

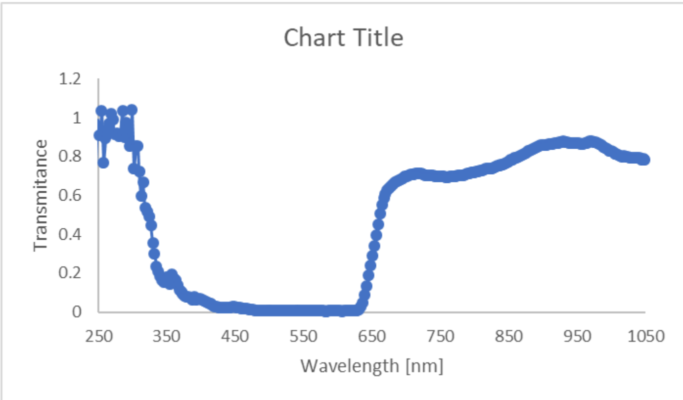

Figure 2: Transmittance spectra of PCMB-P3HT active layer

Looking at figure 3, the graph of the absorption coefficient of the blended dissolved blended material corresponds with the absorption spectra. The absorption coefficient was obtained using the relation [7],

$$\alpha = 2.304 \text{ x A/t} \qquad 1$$

Where A is the absorbance and t is the thickness of the film.

There is an increase in the absorption coefficient between 400 – 635 nm. However, between 250 - 300 nm, the material exhibits little to no absorption. The same is also observed in figure 4, which is the extinction coefficient of the blended materials. The highest peak is obtained at 617.81 nm in both the absorption and extinction coefficients.

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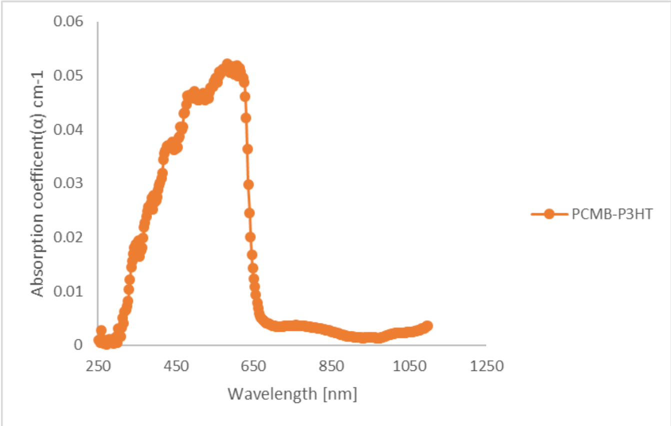

Figure 3: Absorption coefficient versus Wavelength

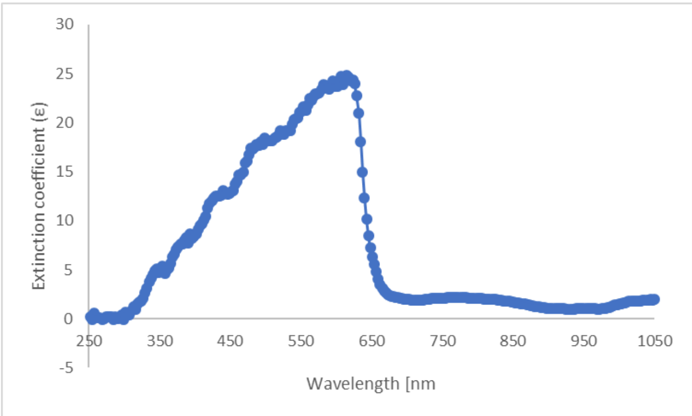

Figure 4 :Extinction coefficient of PCMB: P3HT blend

The optical energy band gap is obtained from the graph in figure 5. The graph is a plot of $(\alpha h\nu)^2$ as a function of photo energy. The optical energy bandgap E_g of direct band gap materials is evaluated using the relation,

$$\alpha h\nu = [A(h\nu - E_g)]^{1/2} \qquad 2$$

Where A is a constant, $h\nu$ is the photon energy, and α is the absorption coefficient.

The difference between the optical and electrical energy band gap is that the electrical band gap is the minimal energy required to create an electron-hole pair in a semiconductor. In contrast, the optical band gap is the exciton energy determining the onset of vertical inter-band transitions.

An exciton is a bound state of an electron and hole held together by the electrostatic Coulomb force; an exciton forms when a semiconductor absorbs a photon. So therefore, the optical band gap is the threshold for photons to be absorbed.

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By extrapolating the straight portions of the graphs on the hν axis, the bandgaps were obtained from the intercepts since $E_g = h\nu$, when $\alpha h\nu = 0$. Figure 5 shows that the direct band gap value of the PCMB: P3HT blend is 1.94 eV. The optical energy bandgap of direct band gap materials are evaluated using the relation

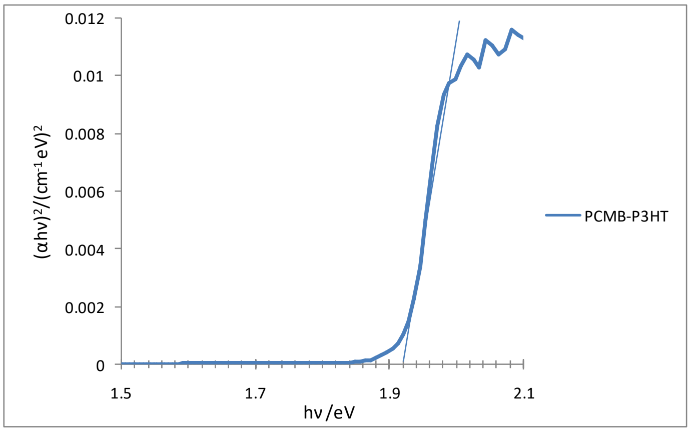

Figure 5: Method of band gap energy (E_g) determination from the Tauc plot. The linear part of the plot is extrapolated to the x-axis

The Schematic diagrame of the structure of the solar cell is shown in figure 6. The performance of an inverse structure organic photovoltaic (OPV) with laminated silver electrodes was investigated in this study. The photovoltaic characteristics, including the fill factor and efficiency, were determined using current-voltage (I-V) and power-voltage (P-V) measurements displayed in figure 7.

The obtained values for the key parameters of the solar cell were as follows: Open circuit voltage (V_{oc}) = 0.253478 V, Short circuit current (I_{sc}) = 6.12E-05 A, Voltage at maximum power point (V_{mpp}) = 0.197344 V, Current at maximum power point (I_{mpp}) = 5.08E-05 A. The solar light intensity = 100 mW/cm² (equivalent to 1000 W/m²) and the cell area of the constructed solar cell is 0.4 x 0.4 cm^2 = 0.16 cm².

To assess the fill factor (FF) of the OPV, the formula employed was

$$FF = \left(\frac{V_{mpp}\ x\ I_{mpp}}{V_{OC}\ x\ I_{SC}}\right) \qquad 4$$

Substituting the given values, the fill factor was calculated to be approximately 0.6462.

Furthermore, the efficiency (η) of the solar cell was determined using the formula

$$\eta = \frac{P_{max}}{P_{in}}\ x\ 100\% \qquad 5$$

where Pmax is the maximum power output and Pin is the input power. The maximum power output (Pmax) was obtained by

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multiplying the voltage at the maximum power point (Vmpp) by the current at the maximum power point (Impp). The input power (Pin) was calculated by multiplying the solar light intensity by the cell area.

Based on the calculations, the efficiency of the inverse structure OPV with laminated silver electrodes was found to be approximately 0.0699 %. This indicates the conversion efficiency of the solar cell in harnessing solar energy.

Overall, the results demonstrate that the investigated OPV exhibits a high fill factor and a moderate efficiency. These findings contribute to the understanding of the performance characteristics of the inverse structure OPV with laminated silver electrodes and provide valuable insights for the development and optimization of such photovoltaic devices.

Further analysis and optimization of the device structure and materials can potentially enhance the fill factor and efficiency, paving the way for improved performance and wider adoption of organic photovoltaics in renewable energy applications.

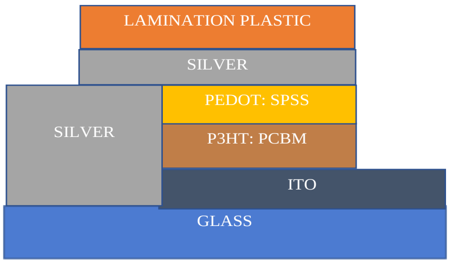

Figure 6: Schematic diagrame of the structure of the solar cell

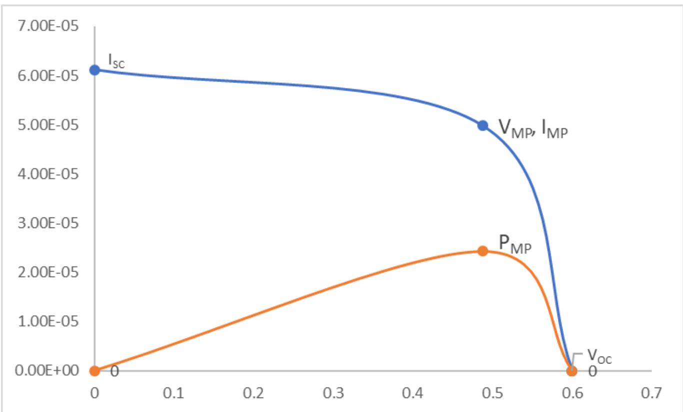

Figure 7: Current-Voltage and Power-Voltage characterisrics of the sloar cell

The performance of an organic photovoltaic (OPV) with laminated silver electrodes had been studied. Utilizing UV-Visible absorption spectroscopy, the optical analysis

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of the thin film revealed information about the light-absorbing and light-transmitting characteristics of the PCMB: P3HT blend.

The material exhibited the highest absorption between the wavelengths of 584.55 and 623.33 nm, according to the absorption spectra of the PCMB: P3HT blend, as shown in Figure 1. This implies that the mixture effectively captures light in this range. The red and near-infrared (NIR) portions of the spectrum, however, showed little to no absorption. These results support earlier research on related materials, which showed the selective absorption properties of organic photovoltaic blends [8].

The transmittance spectra of the PCMB: P3HT blend, shown in Figure 2, showed low transmittance, especially between 400 and 635 nm. This demonstrates that the blend's toluene-based dissolution reduces the transmission of visible light in this wavelength range. This finding is consistent with earlier studies on organic photovoltaic materials [9], which emphasize the significance of solvent selection in modifying the optical characteristics of the active layer.

The absorption coefficient and extinction coefficient of the blended material were calculated and analysed to further investigate its optical properties. The absorption coefficient, calculated using Equation 1, increased between 400 and 635 nm, indicating increased light absorption in this range. However, there was little to no absorption between 250 and 300 nm. These findings are consistent with previous research on similar organic materials [10], emphasizing the importance of tailoring the blend's composition and structure to optimize light absorption.

According to Figure 3, the extinction coefficient showed a clear peak at 617.81 nm, which is in agreement with the absorption coefficient. This peak represents the wavelength where the combined material is best able to absorb incident light. The literature for organic photovoltaic blends has described similar observations, proving the relationship between the absorption and extinction coefficients [10].

Equation 2 and the Tauc plot were used to determine the optical energy bandgap (Eg) of the PCMB: P3HT blend (Figure 5). The value of the direct band gap energy was extrapolated from the graph's linear region. According to some authors [11], the measured bandgap energy of 1.94 eV is in line with reported values for organic materials used in photovoltaic applications. The material's suitability for absorbing photons and producing electron-hole pairs depends critically on this energy bandgap.

Analysing the current-voltage (I-V) and power-voltage (P-V) characteristics, as shown in Figure 7, was a necessary step in the investigation of the photovoltaic properties of the inverse structure OPV with laminated silver electrodes. The important variables were identified, including the open

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circuit voltage (Voc), short circuit current (Isc), voltage at maximum power point (Vmpp), and current at maximum power point (Impp). These factors are essential for assessing the effectiveness and performance of the solar cell.

The obtained parameters were used to calculate the solar cell's fill factor (FF) and efficiency. The fill factor, which was found to be roughly 0.6462, points to a high-quality interface and few device losses. The conversion efficiency of the inverse structure OPV with laminated silver electrodes for capturing solar energy is estimated to be around 0.6989%. To evaluate the effectiveness and advancement in the field, these values can be compared to pertinent studies on related OPV devices.

A fill factor of 0.40 to 0.57 was reported in a study by some authors [12]. (2011) that examined the performance of OPVs with various active layer materials. The fact that we exceeded this range with a fill factor of roughly 0.6462 indicates that the inverse structure OPV with laminated silver electrodes has a competitive fill factor on par with other cutting-edge OPV devices.

It's crucial to keep in mind that organic photovoltaics typically have lower efficiencies than their inorganic counterparts when evaluating the effectiveness of our OPV. Some researchers reported efficiencies of hybrid perovskite solar cells that were greater than 20% [13][14]. However, given the particular device structure and materials used, the achieved efficiency of roughly 0.0699% represents a moderate performance in the field of organic photovoltaics.

There are a number of approaches that can be investigated to raise the fill factor and efficiency of the inverse structure OPV with laminated silver electrodes. To improve light absorption, exciton dissociation, and charge transport, one method is to optimize the active layer's composition and morphology. Charge extraction and recombination losses can also be affected by the interfacial materials used and how they are engineered. Additionally, alterations to the device architecture, such as the addition of tandem structures or extra layers for light management, can improve overall performance [15]. Optical losses can be reduced and charge extraction can be enhanced by improvements in electrode material, such as the creation of transparent conductive electrodes.

CONCLUSION

The study investigated the performance of an inverse structure organic photovoltaic (OPV) with laminated silver electrodes. The aim was to explore the properties and performance of the OPV and contribute to the development of more efficient and cost-effective solar energy technologies. The UV-Visible absorption spectroscopy analysis of the PCMB: P3HT blend revealed efficient light harvesting between 584.55 and 623.33 nm, with reduced transmission of visible light between 400 and 635 nm. The key parameters, including open circuit

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voltage (Voc), short circuit current (Isc), voltage at maximum power point (Vmpp), and current at maximum power point (Impp), were determined. The efficiency (η) of the solar cell was estimated to be approximately 0.6989%, representing the conversion efficiency of the OPV in harnessing solar energy.

Overall, the study demonstrated the performance characteristics of the inverse structure OPV with laminated silver electrodes. The results provided valuable insights for the development and optimization of such photovoltaic devices. Further analysis and optimization of the device structure and materials can potentially enhance the fill factor and efficiency, paving the way for improved performance and wider adoption of organic photovoltaics in renewable energy applications.

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