

A Fabricated Solar Cell from ZnO/a-Si/Polymers

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Abstract

In this paper, a Al/ZnO/a-Si/polymer solar cell is fabricated by using the sputtering technique. The current–voltage characteristic curve indicates that the cell efficiency increased from 0.05453% to 0.484% for ZnO/Si/poly(3-hexylthiophene) as the Si film thickness increased. When the cell was fabricated using ZnO/Si/polyvinyl chloride and ZnO/Si/paraphenylene vinylene, the efficiencies increased from 0.505% to 2.793% and from 1.6% to 2.934%, respectively, as the Si film thickness increased.

Keywords: *polymer, solar cell, ZnO/Si/PVC, ZnO/Si/P3HT, and ZnO/Si/PPV*

1. Introduction

Glass or metal sheets are commonly used as substrate materials for amorphous silicon (a-Si) solar cells [1]. However, polymer film is a more suitable substrate than glass or metal sheets because its present state of development shows that the efficiency of industrially produced a-Si solar modules will remain below 10% (from 6% to 9%) in the future [2]. At this level, the only way to compete with the dominant crystalline silicon technology is by offering a radically lower cost and advantages in polymer film application, such as an easier integration of artificial elements [1].

Organic photovoltaics were extensively investigated because of their potentially low-cost nature and envisaged simplicity in fabrication [1]. The interest in organic/inorganic heterojunctions (HJs) has grown simultaneously with most studies on titanium-based photovoltaics [2]. Studies pertaining to hydrogenated a-Si/polymer HJ solar cells were reported in [3, 4]. The active participation of polymer in photocurrent generation was also confirmed [4]. The efficiency of these hybrid devices is low; for an a-Si/polymer cell, the best reported efficiency is 0.4%. The less studied n–i–p structure offers the possibility of using non-transparent materials as substrates (stainless steel or plastic films). In this paper, the cell is directly exposed to light. Moreover, the substrate must be very reflective and, if possible, show a light-trapping effect (Figure 1). However, a disadvantage of polymer film substrates is that solar cell efficiencies are systematically inferior to those obtained from glass or metal substrates. Hence, if we start from a technology developed on glass substrates, the device performance of solar cells on polymer substrates can be optimized step by step. However, these multilayered solar cell structures are too complex to produce and expensive, which make them unsuitable for mainstream use. Researchers are actively finding ways to harness solar energy with greater efficiency because traditional energy sources such as coal and oil are being depleted and, more significantly, polluting the Earth's atmosphere. [4].

The need to develop inexpensive, renewable energy sources stimulates scientific research on efficient, low-cost photovoltaics. In this study, hybrid photovoltaic devices use a blend of different polymers and n-type Si to convert sunlight into charges [5].

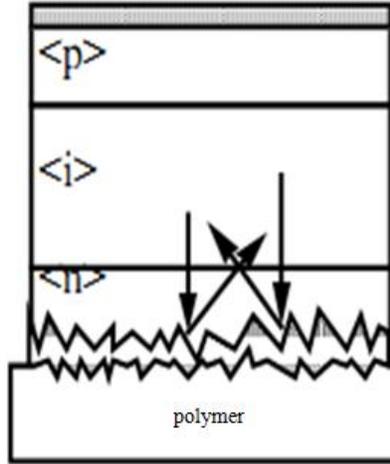


Figure 1. "Standard" p-i-n Structure

2. Parameters of the Solar Cell

The structure and electrical properties of the solar cell are briefly reviewed below [6].

2.1. Solar Cell

Solar cell is a large-area p-n junction designed to convert sunlight into electric current efficiently. Solar cells use the photovoltaic effect, whereby excess photo-generated minority carriers are influenced by the device performance [7]. Figure 2 shows the current-voltage (I-V) characteristics of a solar cell in the dark and under illumination.

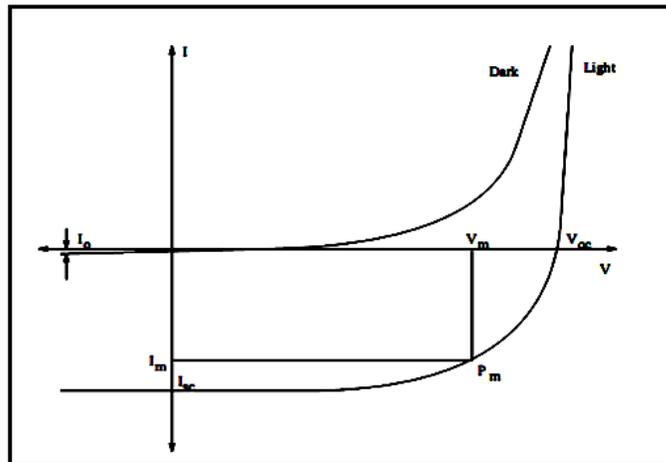


Figure 2. I-V Curve of the Solar Cell in the Dark and under Illumination [7]

An interesting parameter of the solar cell is the fill factor, which is given by the relation

$$FF = V_m I_m / V_{oc} I_{sc} \quad (1)$$

The photovoltaic conversion efficiency is another important parameter. It is a measure of the amount of light energy converted into electrical energy, and is given by

$$\eta = P_m/P_{in} = FF \times I_{sc} \times V_{oc}/P_{in} , \quad (2)$$

where P_m is the area of the maximum power rectangle, and P_{in} is the incident power level [7].

2.2. Heterojunction Solar Cells

This section will be confined to the p–n type because this type is used for the HJ in this work. In the formation of an HJ with a narrow bandgap material, when the forbidden bandgap of the wide-gap material completely overlaps the bandgap of the narrow-gap material, it is called straddling (Figure 3a); the other possibilities are called staggered and broken gap (Figures 3b and 3c, respectively) [8].

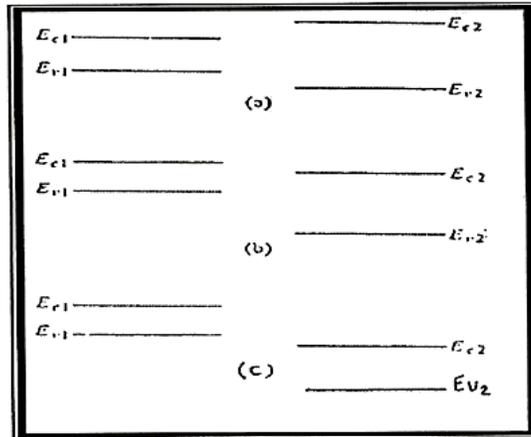


Figure 3. Relationship between narrow-bandgap and wide-bandgap energies: (a) straddling (b) staggered (c) broken gap [8]

In contrast to the homojunction solar cells, HJ solar cells are fabricated using two different semiconductors with different bandgaps. The band diagram of a typical energy band profile is shown in Figure 3, in which a spike and a notch occur in the conduction band edges at the interface. The two semiconductors are assumed to have different bandgaps (E_g), different dielectric constants (ϵ), different work functions (ϕ), and different electron affinities (x).

Work function and electron affinity are defined as the energy required to remove an electron from the Fermi level (E_f) and from the bottom of the conduction band (E_c), respectively, to a position outside of the material (the vacuum level).

The top of the valence band is represented by E_v , where subscripts 1 and 2 refer to the p- and n-type semiconductors, respectively. The discontinuity in the conduction band edges ΔE_c is equal to the difference in the electron affinities of the two semiconductors.

The difference between the two conduction band energies is denoted by ΔE_v . From Figure 3, the following may be derived:

$$\Delta E_c = x_n - x_p \quad (3)$$

$$\Delta E_v = (E_{gp} - E_{gn}) - (x_n - x_p) \quad (4)$$

$$\Delta E_c + \Delta E_v = E_{gp} - E_{gn} = \Delta E_G \quad (5)$$

where E_{gp} and E_{gn} are the energy gaps of the wide-bandgap and the narrow-bandgap materials, respectively [7]. We also have the following equation:

$$\Delta E_v = V_{bi} + E_{an} + E_{ap} - E_{g1} \quad (6)$$

where V_{bi} = built-in potential; E_{an}, E_{ap} = activation energy for n-type and p-type semiconductors, respectively; and E_{g1} = optical energy for n-type semiconductors. Figure 3b shows the energy band diagram of an n-p HJ in thermal equilibrium. To align the Fermi levels in the two materials, electrons from the narrow-gap n-region and holes from the wide-gap p-region must flow across the junction, as in the case of a homojunction.

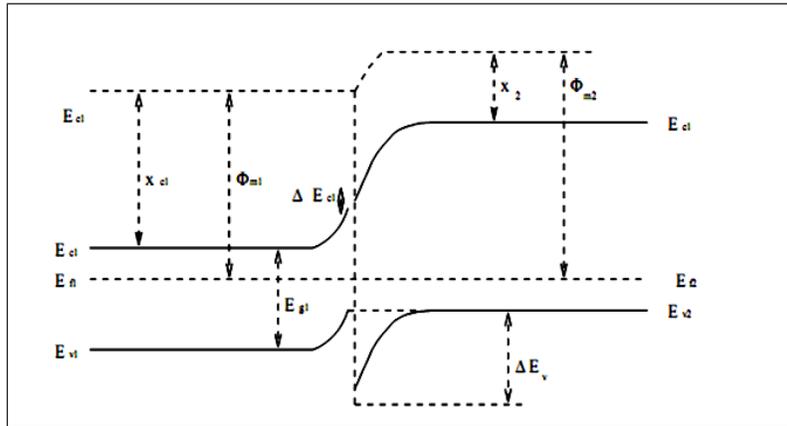


Figure 4. P-N HJ light, with energy less than E_{g1} but greater than E_{g2} , passes a semiconductor [9]

3. Experimental Work

The solar cells were deposited by the sputtering technique. The two coplanar electrodes have a surface of 105 cm², and the substrate is fixed facing down toward the upper electrode. The effective temperature was maintained between 170 and 240 °C (depending on the layer) when allowed by the substrate. For plastic films with a lower-temperature resistance, the cells were deposited at an appropriated temperature (150 °C). The metallization of the back contacts was deposited via the Joule effect or sputtering. The ZnO layers were sputtered. The cells were characterized by the illuminated I-V curves.

4. Results and Discussion

4.1. I-V Characteristics

An I-V characteristic for the forward bias and the reverse bias of ZnO/Si/polymer HJ is shown in Figure 5. In the forward bias, the current increases exponentially with the voltage as expected; in the reverse bias, the current slowly increases with the voltage (soft breakdown)

and does not show any trend of saturation or sharp breakdown. This could be a result of the dominance of the edge leakage current, which is caused by the sharp peripheral edge of the contact, and the excess carrier generation in the depletion region at higher fields. The V_{oc} and I_{sc} increase with the increasing Si film thickness (Figures 5, 6, and 7). This increase is attributed to the defects, which act as capture centers of the carrier generation and lead to increases in the recombination process and the current value.

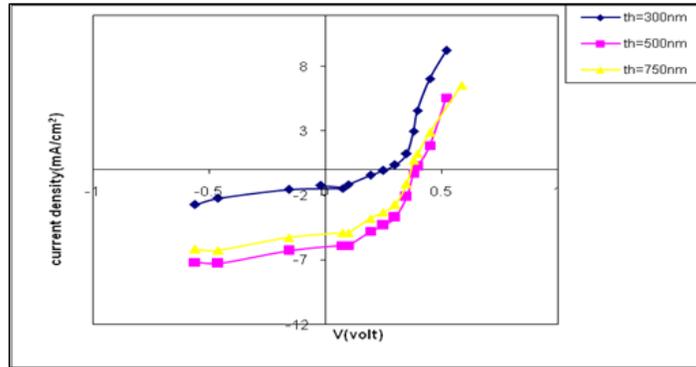


Figure 5. I-V Characteristics of the ZnO/a-Si/poly(3-hexylthiophene) (P3HT)

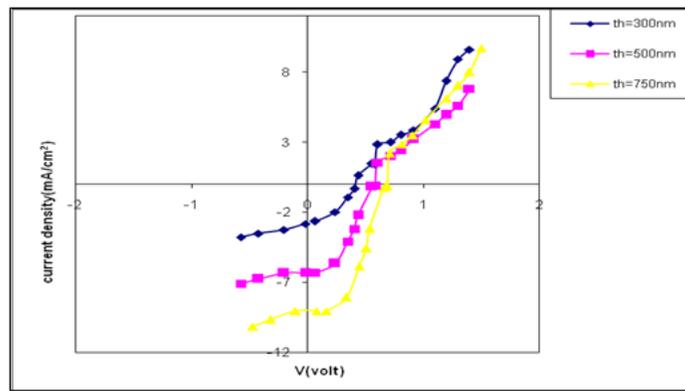


Figure 6. I-V Characteristics of the ZnO/a-Si/polyvinyl chloride (PVC)

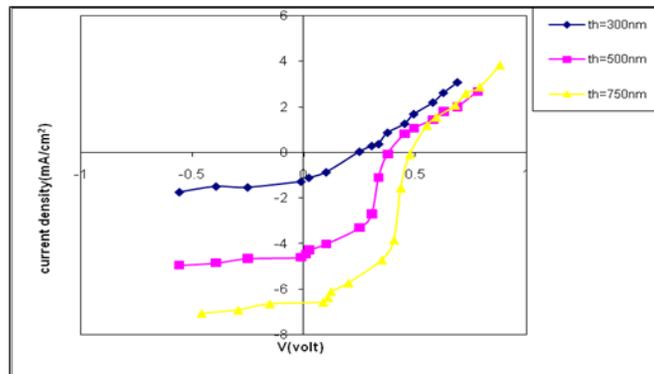


Figure 7. I-V Characteristics of the ZnO/a-Si /PPV

The I_{sc} , V_{oc} , and the efficiency increase as the Si film thickness increases, as shown in Tables 1, 2, and 3. ZnO is transparent in the visible region of the solar spectrum, whereas a-Si is strongly absorbed in this region. Under illumination, the electron-hole pairs are created. The polymer is naturally excitonic, whereas electron-hole pairs in the a-Si are probably unbound because of the extraction of binding energies under 0.1 eV [10]. The generation in the a-Si is not a significant contributor to the photocurrent, and most of the photocurrent arises from the extractions generated in the polymer.

Table 1. The Calculated Values for ZnO/a-Si /P3HT Solar Cell with Different Thickness of a-Si

a-Si thickness (nm)	Voc	Isc	Imax	Vmax	η %
300	0.21	0.19	0.133	0.123	0.05453
500	0.305	0.26	0.28	0.24	0.224
750	0.366	0.8	0.44	0.33	0.484

Table 2. The Calculated Values for ZnO/a-Si /PVC Solar Cell with Different Thickness of a-Si:H

a-Si thickness (nm)	Voc	Isc	Imax	Vmax	η %
300	0.25	1.218	1.01	0.15	0.505
500	0.38	4.88	3.79	0.195	2.4635
750	0.396	5.88	3.99	0.21	2.793

Table 3. Calculated Values for ZnO/a-Si /PPV Solar Cell with Different a-Si Thickness

a-Si thickness (nm)	Voc	Isc	Imax	Vmax	η %
300	0.41	2.83	2	0.24	1.6
500	0.59	6.34	3	0.41	4.1
750	0.66	9.01	4.5	0.43	4.45

4.2. Energy Band Diagram for Si/Polymers HJs

To fully understand the current transport mechanism of HJ, the band lineup is necessary. A considerable amount of research on the band lineup of numerous HJs was reported [11]. In our study, we suggest the construction of a Si/polymer HJ band lineup using direct current–conductivity, optical energy gap, and capacitance–voltage measurements. At an HJ, each semiconductor may be n-type or p-type doped, so four combinations are possible, namely, n–N and p–P (isotype) as well as N–p and P–n (anisotype) junctions, where the upper-case letters refer to the wider bandgap [12, 13]. In this work, the HJ P–Se/n–Si was formed, which is an abrupt HJ. The energy band diagrams for a–Si/P3HT HJ, a–Si /PVC HJ, and a–Si/PPV HJ solar cells are shown in figures 8–10.

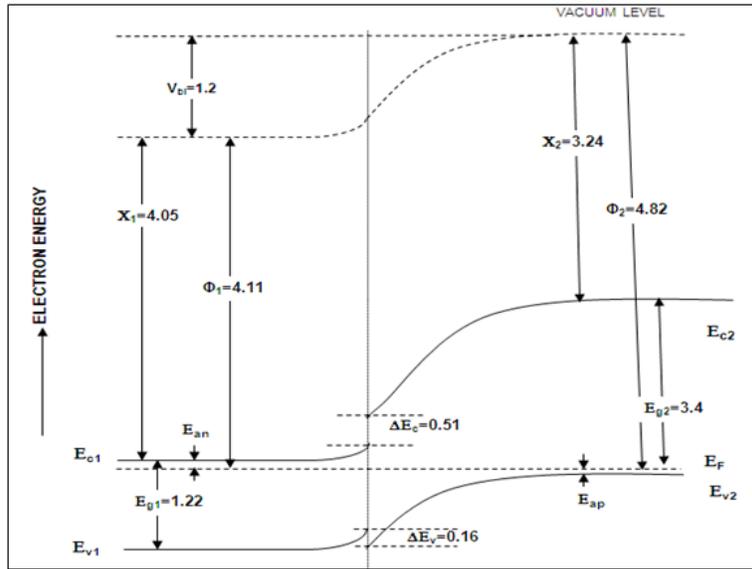


Figure 8. Energy Band Diagram for a-Si /P3HT HJ Solar Cell

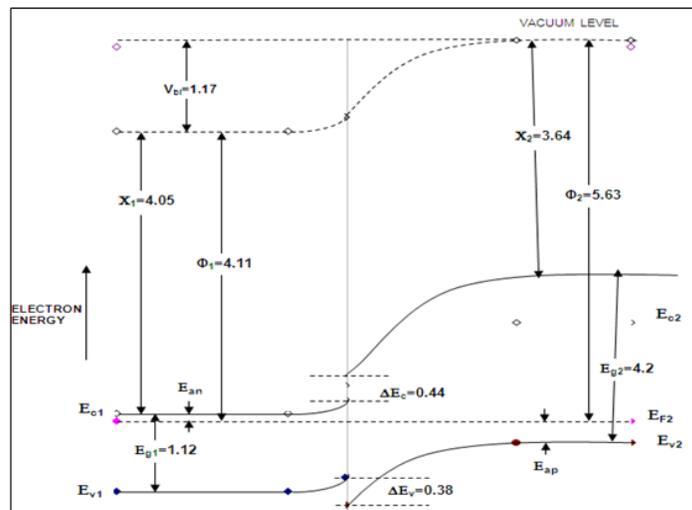


Figure 9. Energy Band Diagram for a-Si /PVC HJ Solar Cell

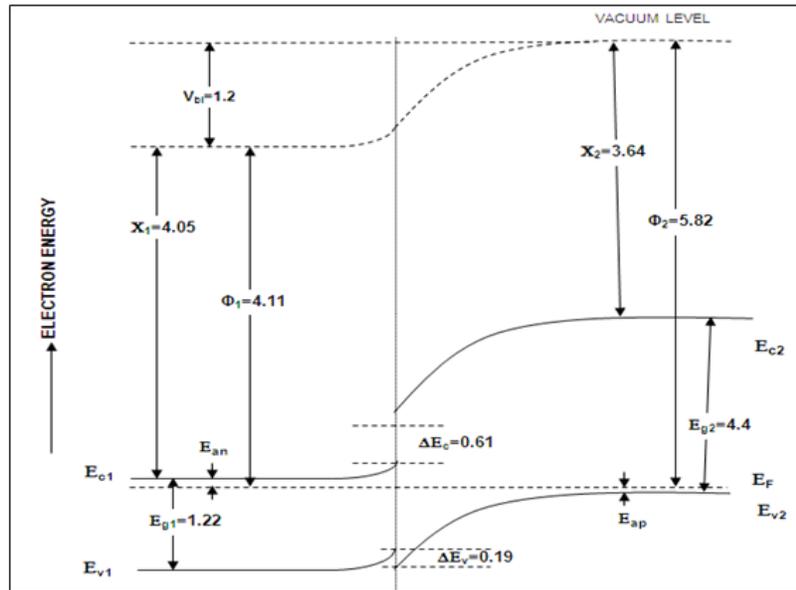


Figure 10. Energy Band Diagram for a-Si/PPV HJ Solar Cell

5. Conclusion

The a-Si/polymer HJ behaves as a poor rectifier because of the interface state between a-Si and polymers. The junction is an abrupt type, and the efficiency for the a-Si/polymer HJ solar cell increases with the increase in a-Si thin film thickness.

Acknowledgments

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