Tanzania Journal of Science 44(4): 59-64, 2018 ISSN 0856-1761, e-ISSN 2507-7961

Effects of Thickness Variation in the Multilayer Thin Film on the Performance of Eta Solar Cell

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Abstract

A highly structured eta solar cell of the type $TiO_2/In(OH)_xS_y/Pb(OH)_xS_y$/PEDOT:PSS/Au with different layer thickness has been fabricated using various deposition techniques for each layer in the stack. The solar cell parameters, U_{oc}, FF and η have been extracted from current- voltage characteristics measurements. The buffer layer and the hole collector layer have been kept constant while the window and the absorber layer have been varied. The thickness of either of the two layers being varied has been observed to affect the performance of the solar cells. The difference in thickness has been attributed to affect the charge lifetime in the space charge region therefore affecting the performance of the solar cell.

Keywords: Thin film, TiO_2, eta solar cell, photovoltaic, spray pyrolysis, chemical bath

Introduction

The extremely thin absorber (eta) solar cell is a novel concept conceived a few years ago (Siebentritt et al. 1997, Kaiser et al, 2001) and it is modelled in similar structure to dye sensitized solar cells concept (Karber et al. 2013, O'Regan and Grätzel 1991). In eta solar cell, an extreemely thin absorber material is sandwiched between two wide band gap materials, one n-type and the other p-type, whereas in dye sensitized solar cell, an organic or metalorganic dye molecule is used instead as an absorber material. The photovoltaic effect in eta solar cell is due to charge carrier injection from the absorber material. The conversion efficiency of this type of solar cells has remained very low over the years with the best solar cell device giving less than 4% conversion efficiency. In this type of solar cells, the conversion efficiency improves when the following modifications are done: insertion of a buffer layer between n-type and eta material (O'Regan and Grätzel 1991, Musembi et al. 2008, Ernst et al. 2001 or a tunneling/ passivation layer such as MgO, Al_2O_3, ZnO, ZrO_2 and Y_2O_3 (Kasier et al. 2001, Bayon et al. 2005, Bayon et al. 2006) is used instead of the buffer layer. The aim of this study was to fabricate a highly structured eta solar cell using various deposition techniques.

Materials and Methods

The solar cell studied was fabricated using the following method: the substrate used was 15 Ω/□ sheet resistance SnO_2:F coated glass obtained from Förschungszentrum Jülich. The solar cell window layer was a 3 µm thick TiO_2 thin film coated by spray pyrolysis technique. On top of the window layer, an 80 nm thick $In(OH)_xS_y$ buffer layer was deposited by chemical bath deposition technique, the precursor material used for the buffer layer consisted of a mixture of 0.025 M $InCl_3$, 0.1 M thioacetamide, and 0.005 M HCl deposited at 70 °C, with the procedure being repeated several times by preparing fresh chemical bath after every 30 minutes duration of deposition. The absorber layer consisted of $Pb(OH)_xS_y$ 10 nm thick thin films deposited by successive ion layer absorption and reaction (SILAR) technique

(Bayon et al. 2005, Musembi et al. 2008). The SILAR preparation process cycle is a 4 step deposition method. In this method, two precursor solutions and distilled water were used: a saturated lead (II) acetate $Pb(CH_3OOH)_2$ from Merck and 0.2 M solution of sodium sulphate from Sigma Adrich. The following procedure was followed in depositing the thin film: (i) the sample was submerged in lead acetate for 10 seconds; in this step, metal ions were adsorbed. (ii) the sample was then rinsed in distilled water (iii) then, the sample was submerged in sodium sulphate for 10 seconds, a step where reaction with sulphur ions takes place (iv) finally, the sample was again rinsed in distilled water. The completion of the four steps constituted one cycle. Different samples were made with different numbers of cycles. The next layer was the hole conductor poly(3,4-ethylenedioxythiophene), doped with polystyrene sulfonate, (PEDOT: PSS), a wide band gap electrically conducting polymer material which was deposited undiluted by spin coating technique. The solar cell was completed by gold back contacts deposited using a specially made mask which gave the solar cells of 0.126 cm^2 areas.

Results and Discussion

The effect of varying thickness of the stacked multilayers of the eta solar cell of the type $TiO_2/In(OH)_xS_y/Pb(OH)_xS_y$/PEDOT:PSS is shown by the device parameters: open circuit voltage, U_{oc}, fill factor FF and conversion efficiency, η as a function of current density statistics for various solar cells numbered A, B, C and D. Each of these solar cells, the thickness for given layer has been varied while other layers have been kept constant. Table 1 shows the various coating cycles per layer for different solar cells.

Table 1: Number of cycles per layer

	TiO_2	In(OH)S	Pb(OH)S	PEDOT
A	10	3	9	2
B	10	3	6	2
C	10	3	3	2
D	20	3	6	2

In Figure 1, the layer thickness is controlled by the number of coating cycles in respective layer.

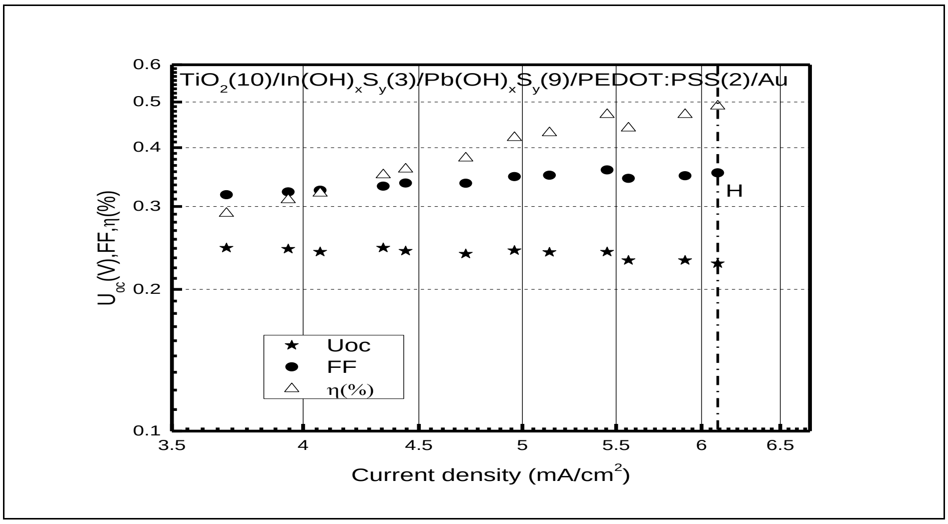

Figure 1: Solar cell A showing statistics of 15 eta solar cells.

The solar cell shown is type A where TiO_2 was coated in 10 cycles of spray pyrolysis, $In(OH)_xS_y$ was coated 3 cycles of chemical bath deposition, $Pb(OH)_xS_y$ was coated 9 cycles of SILAR method, while PEDOT:PSS was coated 2 times by spin coating technique.

For easier interpretation of the data in Figure 1, a dash-dot vertical line labelled H has been traced to show parameters of one of the cells, the values marked are U_{oc} = 0.227 V, FF = 0.356, J_{sc} = 6.1 mA/cm^2, and η = 0.49%. The diagram shows a general decrease in U_{oc} for the different solar cells with a corresponding increase in FF and current density for the same solar cells. Despite of the decrease in open circuit voltage, a high current density with corresponding high FF resulted into the observed increase in conversion efficiency for the corresponding solar cells.

The solar cells shown by data in Figure 2, the thicknesses of titanium dioxide, indium hydroxysulphide and PEDOT:PSS were kept constant while that of lead hydroxysulphide was decreased to 6 cycles. The fill factors of the cells from the statistics in Figure 2 indicated that they were fairly constant at approximately 0.37, also the open circuit voltage of the device remained constant at an average value of about 0.3 V for current density J_{sc}< 4.7 mA/cm^2 but for J_{sc}> 4.8 the U_{oc} decreased to 0.26 V average for different cells. The high conversion efficiency observed is due to the high short circuit current density recorded in those particular cells which is attributed to decrease in losses of photogenerated charges after improved charge lifetime in the absorber material.

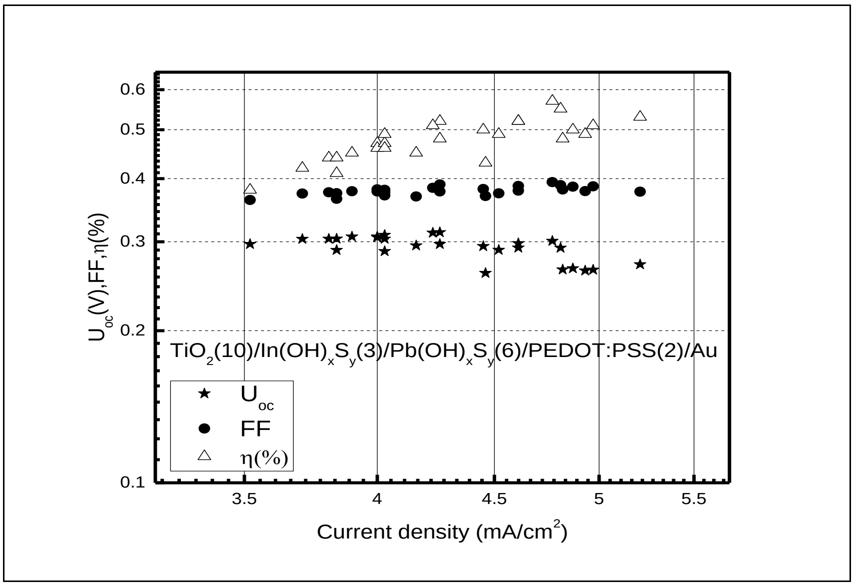

Figure 2: Solar cell B showing statistics of 25 eta solar cells.

The effect of decreasing the thickness of $Pb(OH)_xS_y$ further by coating it in 3 cycles is shown by the statistics of different solar cell parameters in Figure 3. In Figure 3, the thicknesses of TiO_2, $In(OH)_xS_y$ and PEDOT:PSS were maintained at constant values at 10, 3 and 2 cycles, respectively.

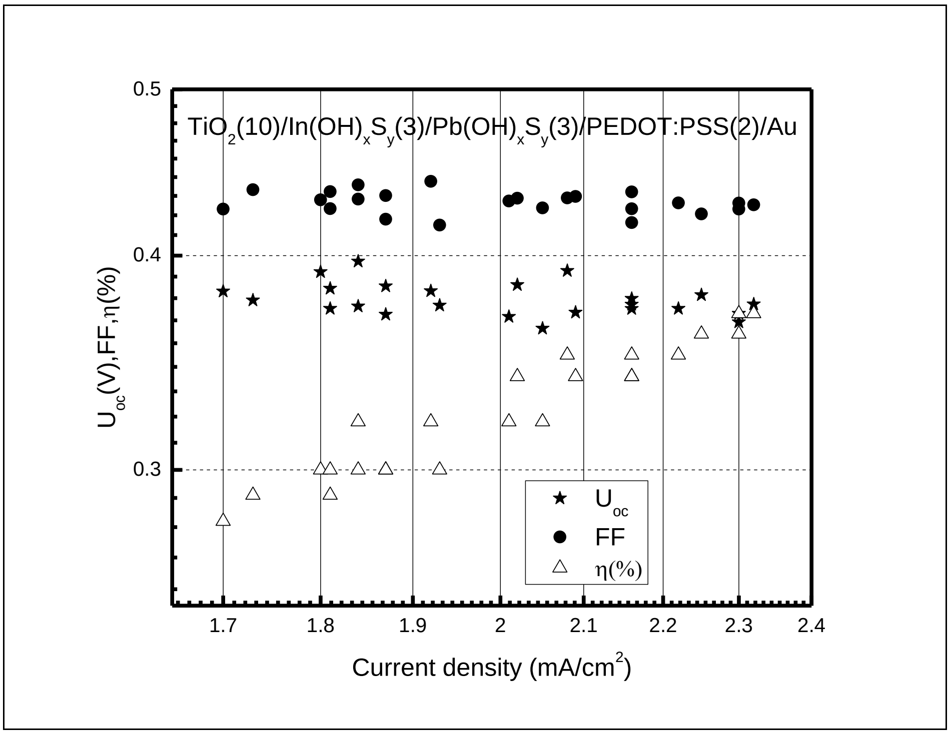

Figure 3: Solar cell C showing statistics of 27 eta solar cells.

The fill factors of the solar cells were constant at approximately 0.43, while the open circuit voltage was approximately 0.38 V. The solar cell device recorded very low overall conversion efficiency despite of the high fill factors and open circuit voltage. The low conversion efficiencies are due to the low short circuit current density recorded from the devices. The dismal performance can be attributed to recombination of the photogenerated charges at the interface between the absorber and the buffer layer.

The short circuit current density and open circuit voltage record higher values than the conversion efficiency when the thickness of TiO_2 thin film is increased from a coating of 10 spray cycle to 20 spray cycle as shown in Figure 4.

The thicknesses of the other layers are the same as those of the devices shown in Figure 2. The FF and U_{oc} had average values of approximately 0.359 and 0.284 V, respectively. The low conversion efficiency recorded for this type of device in spite of the high fill factors and high short circuit current density can be attributed to the low open circuit voltage of the solar cells. Varying thickness of the stacked multilayer in a solar cell affects the space charge region of the device leading to the changes in parameters like fill factor, open circuit voltage, short circuit density and overall conversion efficiency.

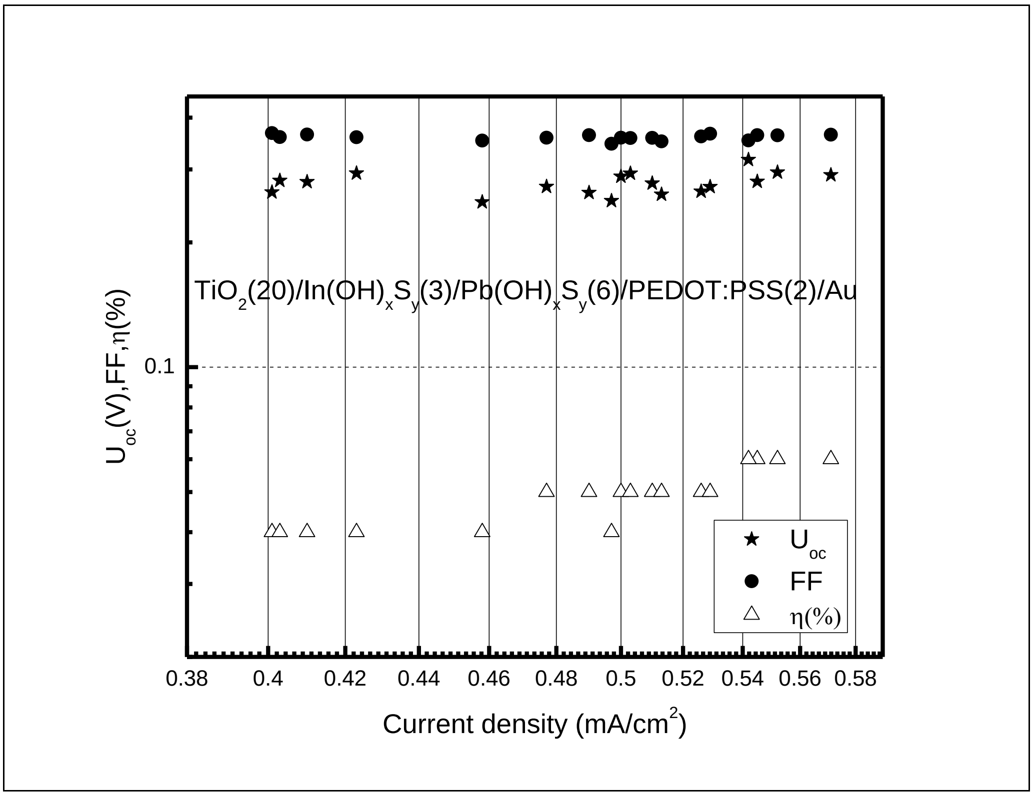

Figure 4: Solar cell C showing statistics of 18 eta solar cells.

Conclusion

Different solar cells with varying thin film thicknesses of stacked layers have been analysed. In all the solar cells, the buffer layer and the hole conductor have been kept constant while the n-type window layer as well as the absorber layer materials have been varied therefore affecting their thicknesses. Varying thickness of either the window layer or the absorber material has been observed to affect the space charge region of the solar cell either increasing or decreasing recombination of the photogenerated charges. The absorber layer deposited after 6 cycles has been observed to give the best results.

Acknowledgements

The author is grateful to the DAAD (German Academic Exchange Service) and ISP (International Science Programme)-Sweden for financial support. The following institutions are also thanked: Helmholtz Centre for Materials & Energy and University of Nairobi for access of laboratory equipment, and for support, respectively.

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