PHOTOVOLTAIC PARAMETERS OF HYBRID SOLAR CELL BASED ON ORGANIC PHOTOSENSITIZER XYLENOL ORANGE

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Abstract: Organic dyes are eco-friendly and cost effective alternative of expensive inorganic dyes used in various solar cells. The present study deals with the optical and photovoltaic properties of hybrid bulk heterojunction solar cells based on blend of inorganic metal (zinc) oxide (ZnO) and organic dye xylenol orange (XO). ZnO was used because this is a low cost and environmental friendly material [1]. The thin films of ZnO nano crystals show high electron mobility [2]. The fabricated device showed short circuit current density (1.455 mA/cm^2), open circuit voltage (0.54 V), FF (0.56) and efficiency (0.44 %)

Keywords: hybrid bulk heterojunction, electron acceptor, electron donor, efficiency.

I. INTRODUCTION

Over the recent years, bulk heterojunction (BHJ) solar cells based on small molecules or semiconducting polymers have grown as hopeful substitutes to conventional inorganic photovoltaic devices. But to tackle the inherent restrictions of organic materials, such as durability, charge transport and charge separation yield, new approach of hybrid inorganic/organic materials being investigated [3]. In one such approach the mesoporous inorganic nanostructures are explored as electron acceptors, which have the potential to manage the morphology of active layer. The morphology of the active layer can be controlled through synthesis processing of nanoparticle. Such devices are known as hybrid bulk heterojunction (HBJ) solar cells.

In present work the hybrid bulk heterojunction (HBJ) was formed between inorganic semiconducting nanocrystals zinc oxide (ZnO) (used as electron acceptor) and organic xylenol orange (XO) (used as electron donor) with the device structure of ITO/PEDOT: PSS/XO: ZnO/Al. The energy level diagram of the HBJ involving XO as donor and ZnO as acceptor is shown in Fig. 1.

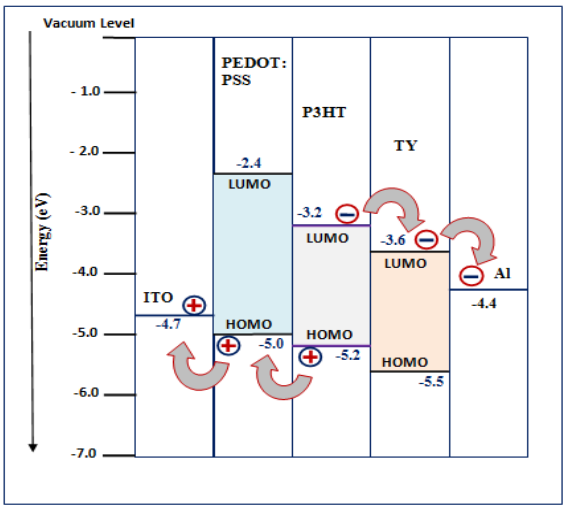

Fig. 1 Energy level diagram of XO-ZnO based HBJ

II. EXPERIMENTAL DETAILS

2.1 MATERIALS USED

ZnO with molecular weight: 81.379 g/mol and xylenol orange (XO) dye with molecular formula

$C_{31}H_{32}N_2O_{13}S$ and molecular weight 672.658 g/mol were procured from Loba Chemie, Mumbai. The chemical structure of the xylenol orange is shown in Fig. 2. Poly (3,4-ethylenedioxy thiophene)-poly(styrenesulfonate) (PEDOT: PSS) was purchased from Sigma-Aldrich. Indium tin Oxide (ITO) coated glass was used as substrate and it was purchased from Techinstro having dimensions = L 25mm x W 25 mm x Thickness 1.1 mm and sheet Resistivity ~ 10-15 Ω/sq with ITO film thickness ~ 180-200 nm. The aluminum foil used for electrode deposition was procured from Across organics.

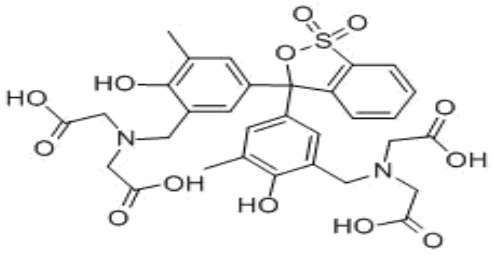

Fig. 2 Chemical structure of xylenol orange used in HBJ

2.2 ETCHING AND CLEANING OF THE SUBSTRATE

Transparent conducting oxide (TCO) is an essential part in the fabrication of optoelectronic devices such as OLED, solar cells etc. In bulk hetero junction devices Indium tin Oxide (ITO) glass substrate is used due to its versatile properties such as high transparency in visible region(≥85%), strong substrate adherence and low electrical resistivity ($\rho \sim 10^{-4}$ Ω cm) [4]. The ITO having dimensions = L 25mm x W 25 mm x Thickness 1.1 mm and sheet Resistivity ~ 10-15 Ω/sq with ITO film thickness ~ 180-200 nm is used in our study. To avoid short circuit while making contacts to electrodes, some part of the commercially available ITO is etched. For etching around ¾ part of ITO is covered with an adhesive tape and ¼ exposed part is dipped into etching solution (1 part HNO_3 : 3 parts HCl) and kept for 10 minutes and then cleaned properly. For cleaning the ITO is sonicated with soap solution, acetone and IPA respectively using ultrasonic bath (Model: Sonicor SG-3042). After this, ITO substrate is put under plasma treatment by using plasma cleaner (Model: Harrick Plasma, PDC-002).

2.3 SPIN COATING OF PEDOT:PSS LAYER

Generally, the ITO anode is tailored to improve the device performance bulk heterojunction solar cells. Mostly a thin film of poly (3, 4-ethylene dioxythio- phene): poly styrene sulfonate) (PEDOT: PSS) is used as hole extracting layer (HEL) ; also known as electron blocking layer (EBL) or anode buffer layer. [5-7]. It is used due to many favourable properties such as good transparency, high work function and good conductivity. The PEDOT: PSS facilitates the collection of the holes from the highest occupied molecular orbital (HOMO) of the photoactive organic layer [8].

Before coating; the etched substrate is masked by transparent adhesive tape. While masking; the tape is pasted on substrate in such a way that a small etched portion is also masked leaving all other part exposed for coating of anode buffer layer and photo active layer. A thin film of PEDOT: PSS dissolved in DMSO is coated using spin coating unit with RPM controller. The thickness of the film is normally of the order of 80-100 nm. Then substrate having PEDOT: PSS layer is left overnight in vacuum for drying and finally annealed for 10 minutes at 120 °C in vacuum.

2.4 DEPOSITION OF PHOTO ACTIVE LAYER

Then a blend of donor (p-type) XO and acceptor (n-type) ZnO were taken in 1:10 ratio and dissolved in common solvent methanol and stirred for 2 hours and sonicated for 10 minutes. After recording the absorption spectra, this blend was spin coated on PEDOT: PSS film to get photo active layer and absorption spectra were recorded. Then this was annealed for 20 minutes at 70 °C in vacuum and again absorption was taken. The thickness of active layer was approximately 500 nm. The layer thickness is a function of concentration, choice of solvent, viscosity of the solution and spin speed [9].

2.5 ELECTRODE DEPOSITION BY THERMAL EVAPORATION TECHNIQUE

The work function of the metal is a decisive factor for choosing the counter electrode (cathode) which

decides the Fermi level of the semiconductor that where an ohmic contact or a blocking contact will be formed. Here Aluminum (Al) metal has been used in the fabrication of HBJ in our devices. The metal electrode is deposited in the form of a thin film using vacuum evaporation technique. To define the area to be exposed (20 mm^2), the substrate (consisting of thin films of PEDOT: PSS and active layer) is covered properly with a stainless steel shadow mask. The thickness of Al electrode was approximately 100 nm.

2.6 CHARACTERISATIONS

In this study the UV-VIS absorption spectra of both donor and acceptor materials were taken in methanol. Also the UV-VIS spectra of the HBJ thin film before and after annealing was taken in the wavelength range 200 nm-800 nm using UV-VIS spectrophotometer (Model: Specord S 600-analytic jena).

The photovoltaic characterization of fabricated devices having active area of 20 mm^2 was performed using semiconductor parameter analyzer (Model: HP 4145B) under solar light with the input power 100 mW/cm^2. Different photovoltaic parameters short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and power conversion efficiency (η) were obtained using J-V curves of fabricated devices.

III. RESULTS AND DISCUSSION

3.1 OPTICAL CHARACTERISATION

Absorption spectra of thin films of XO, ZnO and blend of both were recorded as shown in Fig. 3.

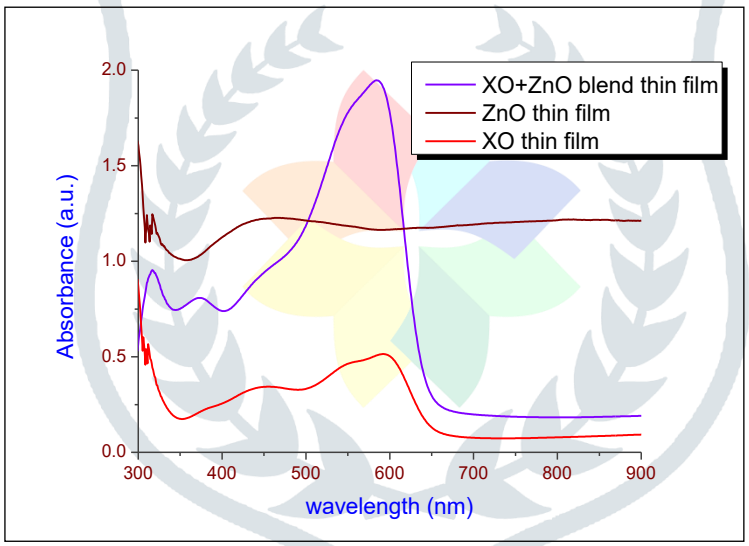

Fig. 3 Comparison of absorption spectra of different thin films on ITO

It is clear that amount of absorption in XO-ZnO blend thin film on ITO has much higher value than that of individual films of XO and ZnO on ITO. The blend of donor and acceptor materials has rendered significant improvement in coverage as well as amount of absorption.

The thermal annealing of thin films of photo active layers affects morphology and the performance of the bulk heterojunction devices [10]. The fill factor of organic photovoltaic based on bulk heterojunction is generally found to be low, typically in the range of 50 -60 % and the open circuit voltage (V_{OC}) remains unaffected by the duration of annealing [11-13]. The donor-acceptor interfacial area reduces due to longer anneal time. Similarly exciton dissociation also decreases with increased annealing. On the other hand, the longer annealing time makes electron-hole transport more feasible. Therefore; an optimized annealing duration is very crucial to counter balance these factors. Most importantly maximum short circuit current (J_{SC}) is obtained for an optimum anneal time. Hence various parameters need to be optimized for the desired performance of the HBJ for a given pair of donor and acceptor materials.

The effect of thermal annealing was also studied for the device. The thermal annealing significantly improved the absorption of the blend XO-ZnO as shown in Fig. 4.

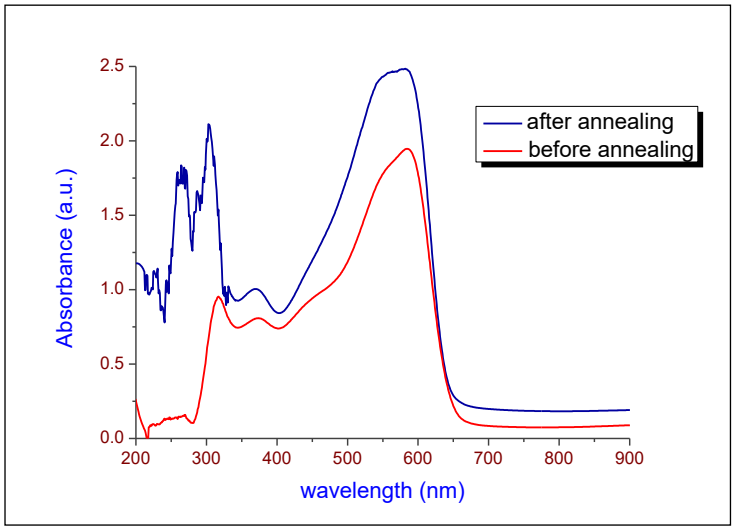

Fig. 4 Effect of thermal annealing on absorption of thin film of XO-ZnO

3.2 PHOTOVOLTAIC PROPERTIES

The photo response measurement of fabricated device with an active area of 20 mm^2 was carried out under solar illumination with the incident light having input power (P_{in}) 100 mW/cm^2. Various photovoltaic parameters (listed in Table 1) were obtained using J-V curves of the fabricated device. The fill factor (FF) and power conversion efficiency (η) of the fabricated device were calculated using following formulae:

$$FF = \frac{V_m \times J_m}{V_{oc} \times J_{sc}} \quad \text{--- (1)}$$

$$\eta = \frac{V_m \times J_m}{P_{in}} = \frac{V_{oc} \times J_{sc} \times FF}{P_{in}} \quad \text{--- (2)}$$

Where V_{oc} is the open circuit voltage, V_m is the maximum voltage J_{sc} is the short circuit current density, J_m is the maximum current density; FF is the fill factor, η is the power conversion efficiency and P_{in} is the intensity of the incident light. Fig. 5 shows the J-V characteristics of the fabricated device.

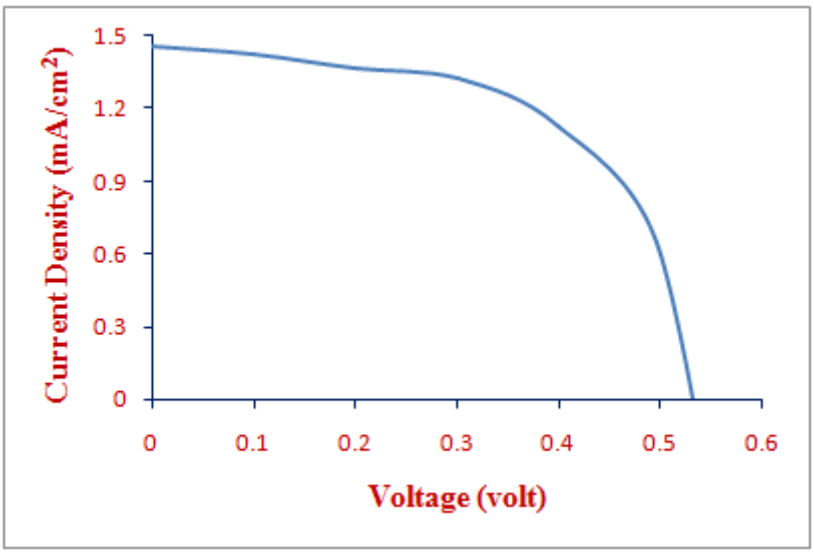

Fig. 5 Current density vs. voltage curve of XO-ZnO based HBJ device

Table 1 Photovoltaic parameters of the fabricated hybrid bulk heterojunction device

Device Configuration	V_{oc} (volt)	J_{sc} (mA/cm^2)	Fill Factor (FF)	Efficiency η (%)
ITO/PEDOT: PSS/ XO-ZnO/Al	0.54	1.455	0.56	0.44

Due to dissimilar refractive indices of various stacked layers in the photo active blend, the absorption cannot be 100 % in an actual device and hence a limited efficiency can be expected. It is clear that the device based on XO-ZnO shows short circuit current density (1.455 mA/cm^2), open circuit voltage (0.54 V), fill factor FF (0.56) and efficiency (0.44 %). The open circuit voltage V_{oc} is proportional to the difference between the LUMO level of the acceptor and the HOMO level of the donor material [14] and remains unaffected by annealing duration [10].

Although the fabricated device was not able to deliver the efficiency compared to the high efficiencies reported on acceptor ZnO in bulk heterojunction photovoltaics. This may be due to high recombination rate of excitons at the interface of XO/ZnO network. The UV-VIS absorption of the blend was better than that of individual material, but photo current in the prepared device was not higher due to recombination.

There may be various issues related to the working conditions in ambient environment. All the steps involved in the fabrication of HBJ were executed in ambient conditions at room temperature. The high power conversion efficiencies of HBJ solar cells are often achieved by special device fabrication methods in clean room and glove box using argon (inert) gas atmosphere. But the under ambient laboratory condition adversely affects the efficiency of such photovoltaic devices. Moreover, the use of such sophisticated treatments would undoubtedly raise the cost of device preparation. For that reason, exhaustive research efforts are still in development stage to counter balance the conversion efficiency and simultaneously trimming down the cost of device preparation.

IV. CONCLUSION

The hybrid bulk heterojunction device ITO/PEDOT: PSS/XO: ZnO/Al based on XO-ZnO was fabricated successfully and characterized. In this device hybrid bulk heterojunction was formed between electron acceptor zinc oxide nano particles and electron donor xylenol orange. UV-VIS spectra of XO-ZnO blend showed an increased absorption as compared to those individual materials. Significant improvement was observed in the absorption of thin films of the blend XO-ZnO after thermal annealing as expected. The efficiency of fabricated device was not found to be very high, may be due to various issues pertaining to environmental conditions during fabrication process. But this lays the foundation for further work addressing the factors affecting the morphology and performance of HBJ devices.

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