Hybrid thermoelectric photovoltaic cell based on organic-inorganic heterojunction

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Here we investigatethe organic-inorganic heterojunction solar cell fabricated on n-Si substrate. A thermoelectric material i.e. Bi_2Te_3 is used in combination with CuPc to convert the heat produced by sunlight into electrical energy. We utilized Ag/n-Si/Bi_2Te_3/CuPc/Al structured photovoltaic device for conversion of light and heat energy of the sun into electrical energy.Current-voltage (J-V)characteristics of the solar cell are analyzed under dark and illumination. An open circuit voltage (V_{oc}) of 1.12V and short circuit current (J_{sc}) of 1.24 μA/cm^2 is observed. The fill factor (FF) is found to be 54.9 %and the efficiency of the cell is calculated to be 1.2 %.

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1. Introduction

Energy is one of the salient aspects that precisely affect the benchmark of human life. The conversion technologies of energy have been classified into renewable as well as non-renewable[1,2].The technology improvementof renewable energy at present is increasing around the world day by day[3,4]. For high efficiency renewable energy conversionseveral types of solar and thermo-electric cells are practically utilized [5-10].Organic photovoltaic (OPV) structures have initiated a novel way for renewable source of electrical energy.OPVs are of great interest due to their prospective features as flexible, lightweight and inexpensive devices[11-14]. They can be utilized in power portable electronics, from personal appliancesto space exploration probes[15,16]. OPV have their fine advantages such as low fabrication cost and easy processing on flexible substrate.

Since Tang suggested two-layer OPV structures containing donor and acceptor (D/A) heterojunction to improve power conversion efficiency.The first important discovery was recognized by the discovery of improved dissociation of excitons into free charges at a D/Ainterface. Tang attained an open circuit voltage (V_{oc}) of 450 mV and a short circuit current density(J_{sc}) of 2.3mA/cm^2, under ‘‘one Sun’’ illumination in CuPc-based structures[17]. Peumans et al achieved aV_{oc} of 480 mV andJ_{sc} of 4.2 mA/cm^2 for this system[18].This was further enhancedby switching to a homogeneously distributed junction from a planar junction, the so-called donor/acceptor bulk heterojunction[19].Kwong et al also reported a comparatively highV_{oc} of 0.96Vin a CuPc for ITO/CuPc/Al structure [20]. Salzman et al suggested that V_{oc} can be improved by incorporating films CuPc of high purity[21]. M Reuter et al showed that the performance of a cell can be affected by the nature of back contact. An enhancement inV_{oc} may also be caused by the high performance of back contact[22].A number of factors affect the power conversion efficiency of organic PV structures. One such hurdle is the inferior alignment of D/A molecule orbital levels which outputs in a small V_{oc}. Another important hurdle is the low photo-current and poor fill factor (FF) caused by the unbalanced charge transport[23].In order to enhance device efficiency, a suitable energy level of donor and acceptor materials and an efficient charge separation are the best options for applicationsof organic D/A PV structures. To capture the heat energy of the sun light thermoelectric material like Bi2Te3 can be used to increase the overall efficiency of the device[24,25].

In this work, we present an organic-inorganic heterojunction solar cell with the structure Ag/n-Si/Bi_2Te_3/CuPc/Al. Bi_2Te_3 is incorporated in the device to utilize the heat energy of the sunlight for the efficient production of electrical energy. We obtained an open circuit voltage (V_{oc}) of 1.12 V and short circuit current (J_{sc}) of 1.24 μA/cm^2. The fill factor (FF) of our device was found to be 54.9 % and the power conversion efficiency of 1.2 % was observed.

2. Experimental details

The solar cell was fabricated on n-Si substrate, which waswashed twice inacetone before the deposition of active layers.After drying in dust free environment the substrate was positioned in substrate holder of thermal vacuum evaporator. The solid and fine pieces of Bi_2Te_3were then placed inside the boat.The distance between substrate holder and boat was approximately 12 cm and prior to deposition of active layers substrate was plasma cleaned in the vacuum thermal evaporator at a pressure of ~ 10^{-1} torr for the better plasma cleaning. After plasma cleaning thin films of $Bi_2Te_3$and CuPc were successively depositedwith thickness of 100 nm each. The deposition rate was kept at 0.1 nm/s and pressure was maintained at ~10^{-6}torr. The top electrode of aluminum (Al) and bottom electrode of silver (Ag) were then deposited at same pressure and deposition rate. The device structure is schematically depicted in Fig. 1a.

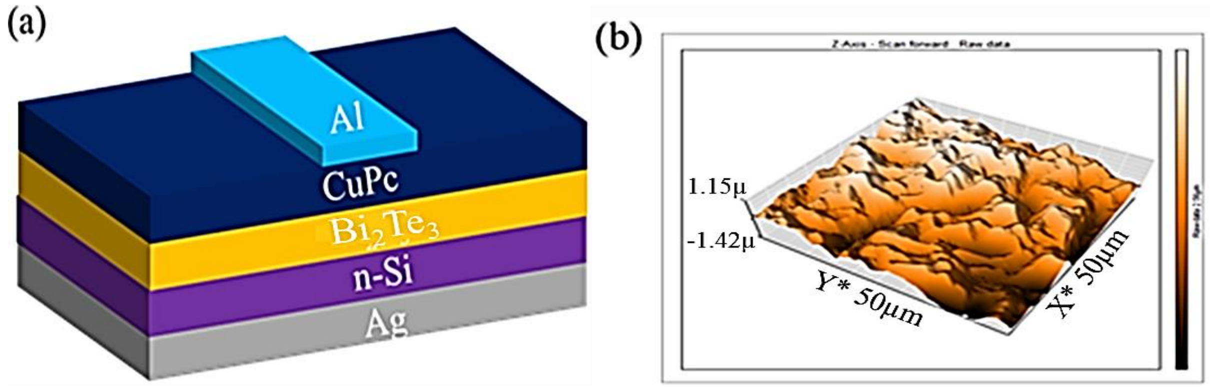

Fig. 1. (a) Schematic illustration of Ag/n-Si/Bi_2Te_3/CuPc/Al solar cell. (b) AFM image of the CuPc Layer of the device showing surface morphology

The surface morphology of the film was investigated by using atomic force microscopy (AFM). The absorption spectra were obtained using UV-visible spectrometer. J-V curves were obtained by using Digital multi-meter meter (DMM), trainer board, tungsten lamp and LUX meter.

3. Result and discussion

Fig. 1b shows the AFM image of the device. The topography of the fabricated solar cell follows the structure of the n-Si substrate. The roughness of the surface results in enhanced absorption of light due to the internal scattering of the light inside the device and help in increasing the number of excitons generated from the incident light. Fig. 2 displays the absorption spectrum of CuPc and Bi_2Te_3. The CuPc layer absorbs maximum light in the visible region and Bi_2Te_3 absorbs in the ultra-violet region and a little fraction in the infrared region on electromagnetic spectrum.

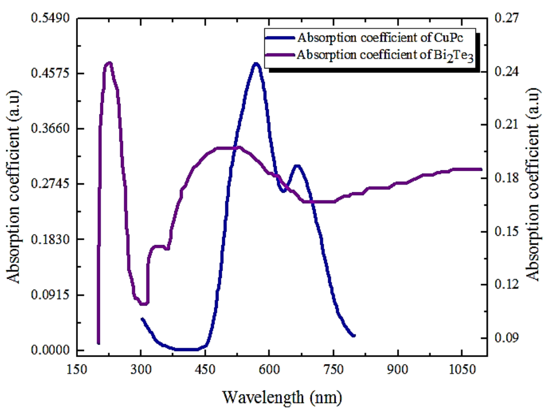

Fig. 2.UV-visible-NIR spectra of Bi_2Te_3 andCuPc layers

The current–voltage (J–V) characteristic curves of the photovoltaic cellunder illumination are demonstrated in Fig. 3(a-b). An open circuit voltage (V_{oc}) of 1.12 V and short circuit current (J_{sc}) of 1.24 µA/cm^2 is observed.

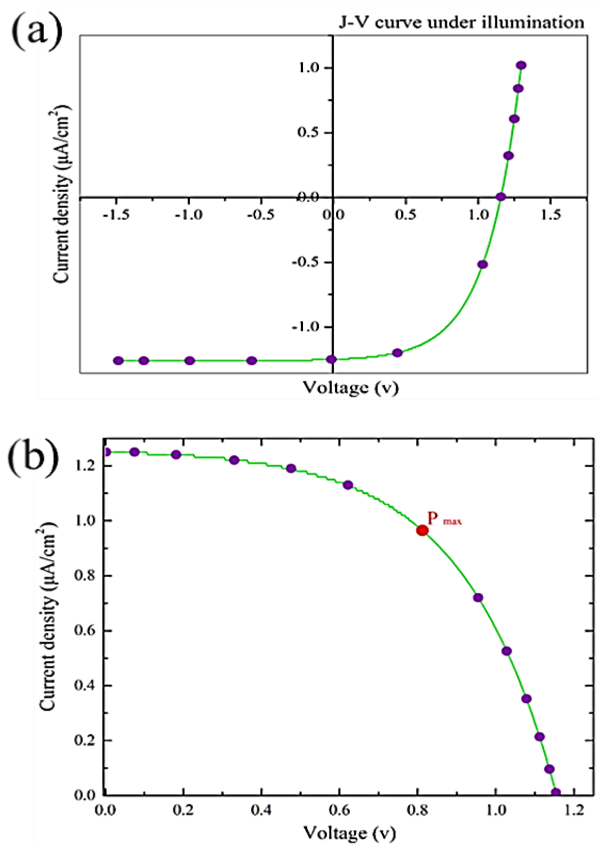

Fig.3. J-V curves of fabricated photovoltaic cell

These results can be attributed to absorption of light in the visible region by CuPc layer and heat effect of thermo-electricBi_2Te_3 layer. The high purity (99%) reduced the defects inside the activelayerswhich lead to the low traps forcharge carriers.After the de-trapping of charge carrierselectrical currents are function of Schubweg distance (S) is as follows:

$$S = \mu E\tau$$

here 'μ' is the mobility and 'τ' is the lifetime of charge carrier and 'E'is the average electric field.The relationship of the lifetime of charge carrier and traps concentration of charge carrier is as follows:

$$\tau = (H\upsilon\sigma)^{-1} \quad (2)$$

where 'H' is the traps concentration of charge carrier, 'υ' is the thermal velocity and 'σ' is the cross section for the trapping of charge carrier. As the purity of the material increases, the traps concentration (H) decreases so the lifetime of charge carried (τ) increases as a result Schubweg distance (S) also increases.

The performance of solar cell may be improved by the conversion of heat energy into useful energy. Bismuth telluride is the thermo-electric material with the ability to convert the heat energy into electrical energy. The deposition of Bi2Te3 layer under the CuPc layer support the conduction mechanism which results in the high charge transfer ratio from the device. The heat transfer fromBi_2Te_3 layerto the substrate is higher in the perpendicular direction than the parallel direction. It is also very important for the dissociation of exciton to move and dissociate at the interface. The natural tendency of the Bi_2Te_3 material is the better performance at elevated temperature. At higher temperature, the heat generated inside the cell may be utilized by the Bi_2Te_3 material for the conversion of exciton into free charge carrier i.e. it may facilitate the dissociation of exciton at the interface. Fig. 4 shows the relationship of intensity of light withV_{oc}indicating an increase in V_{oc} with increasing intensity.

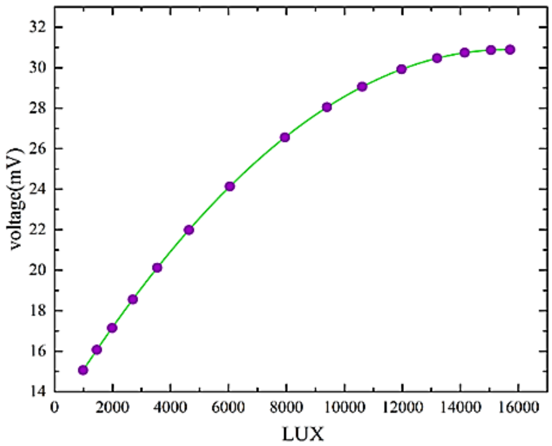

Fig. 4. Dependence of V_{oc} on the intensity of incident light

4. Conclusion

We fabricated a solar cell with structure Ag/n-Si/Bi_2Te_3/CuPc/Al. Bi_2Te_3, a thermoelectric material, is incorporated in the device to utilize the heat energy of the sunlight to produce electrical energy along with the photovoltaic material CuPc.We obtained an open circuit voltage (V_{oc}) of 1.12 V and short circuit current (J_{sc}) of 1.24 μA/cm^2. The fill factor (FF) of our device was found to be 54.9 % and the power conversion efficiency of 1.2 % was observed. We believe that our findings offer a new strategy for incorporation of thermoelectric materials (such asBi_2Te_3) in photovoltaic devices which can utilize the unwanted heat of the sun for useful electrical energy production.

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