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Extremely Thin Absorber (ETA) Solar Cells Using CdTe Semiconductor and Solid State Dye Sensitized Solar Cells Using Calix[4]arene Perylene Derivative

Objectives:

The need to develop inexpensive renewable energy sources stimulates scientific research for efficient, low-cost photovoltaic devices. The organic, conjugated polymers are very important for the production of low-cost and flexible photovoltaic cells.[1]

First of all, conventional solar cells were built from inorganic materials like a silicon. The efficiency of inorganic based solar cells reached up to %24. However, fabrication process of such solar cells is quite expensive. In addition silicon based solar cell show low efficiency at high temperatures. Recently, hybrid composites, which are blends of conjugated polymers and inorganic materials that offer high electron mobility or improved spectral coverage, have been investigated for photovoltaic applications.[2]

Hybrid and photoelectrochemical (dye sensitized) solar cells have been the alternatives for conventional silicon solar cells. A hybrid solar cell, consisting of a combination of both organic and inorganic materials therefore, combines the unique properties of inorganic semiconductors with the film forming properties of the conjugated polymers. [3,4]

The main purpose of this scientific visit is to fabricate and characterize hybrid of solar cells. This project is made up of two parts. First part of the project will mainly focus on hybrid solar cells using TiO_2/CdTe electrodes with semiconducting polymers such as poly (3-hexylthiophene) (P3HT). In the second part, solid state dye sensitized solar cells using a novel dye Calix[4]arene perylene derivative synthesized by the group of Prof. Dr. Mustafa Yilmaz and Ass. Prof. Dr. Mahmut Kus from Konya Selcuk University, Turkey.

1. Description of the work carried out during the visit

1.1 General Characterization of a Solar Cell

The current-voltage characteristics of a solar cell in the dark and under illumination are shown in Figure 1. In the dark, there is almost no current flowing, until the contacts start to inject at forward bias for voltages larger than the open circuit voltage. (a) Short-circuit current condition where the maximum generated photocurrent flows (b) Flat band condition where the photogenerated current is balanced to zero. The fourth quandrant (between (a) and (b)) the device generates power. At maximum power point (MPP), the product of current and voltage is the largest.[5]

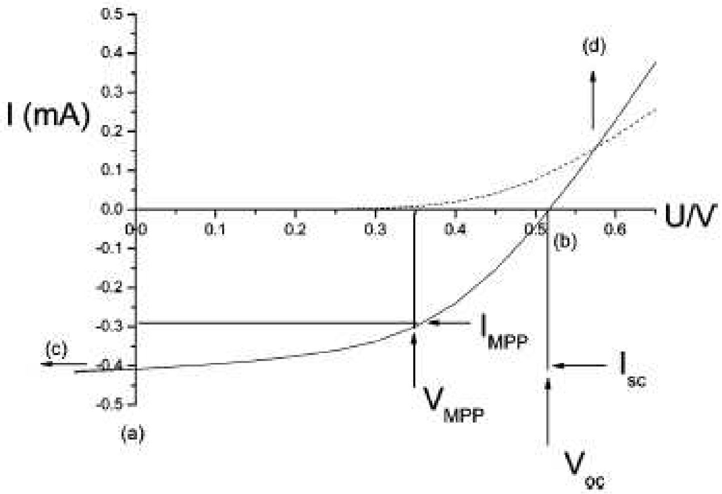


Figure 1 : Current-voltage characteristics of a solar cell

The photovoltaic power conversion efficiency of a solar cell is determined by the following formula:

$$\eta_e = \frac{V_{oc} * I_{sc} * FF}{P_{in}}$$

$$FF = \frac{I_{mpp} * V_{mpp}}{I_{sc} * V_{oc}}$$

where V_{oc} is the open circuit voltage, I_{sc} is the short circuit current, FF is the fill factor and P_{in} is the incident light power density, which is standardized at 1000 W/m^2 for solar cell testing with a spectral intensity distribution matching that of the sun on the earth`s surface at an incident angle of 48.2^0, which is called the AM 1.5 spectrum.[6] I_{mpp} and V_{mpp} are the current and voltage at the maximum power point in the fourth quadrant of the current-voltage characteristics.

2. Experimental

2.1 Fabrication and Characterization of Hybrid Solar Cells Using CdTe and Conjugated Polymers:

Solar cells were prepared as following: As substrates, glass sheets of 1.5x 1.5 cm^2 covered with ITO, from Merck KG Darmstadt, were used with an ITO thickness of about 120 nm and sheet sheet resistance < 15 Ωcm^{-2}.

The ITO was cleaned by etching with an acid mixture of $HCl_{konz}:HNO_{3konz}:H_2O$ (4.6:0.4:5) for ~ 30 min. The part of the substrate which forms the contact is covered with a scotch tape preventing the etching. The scotch tape was removed after etching and the substrate was then cleaned by using acetone in an ultrasonic bath and finally with iso-propanol.

The compact TiO_2 layers were prepared as described in the literature using a titanium tetra isopropoxide precursor. [7] Compact TiO_2 layers were spincast under ambient conditions on top of the cleaned and patterned ITO substrates by using 8000 rpm. After spin coating, the substrates were placed in an oven and sintered at 450 ^oC for 30 minutes yielding insoluble compact layers. A commercially available TiO_2 from Solaronix was used to prepare porous TiO_2 electrodes. CdTe layers were deposited using close sublimation technique.

10 mg of poly(3-hexylthiophene) (P3HT) was dissolved in 1 ml of chlorobenzene. Figure 2 shows the chemical structure of the P3HT. Regioregular P3HT has been used in this work. P3HT is highly soluble in common organic solvents and has a broad absorption spectra with a maximum around 550 nm.

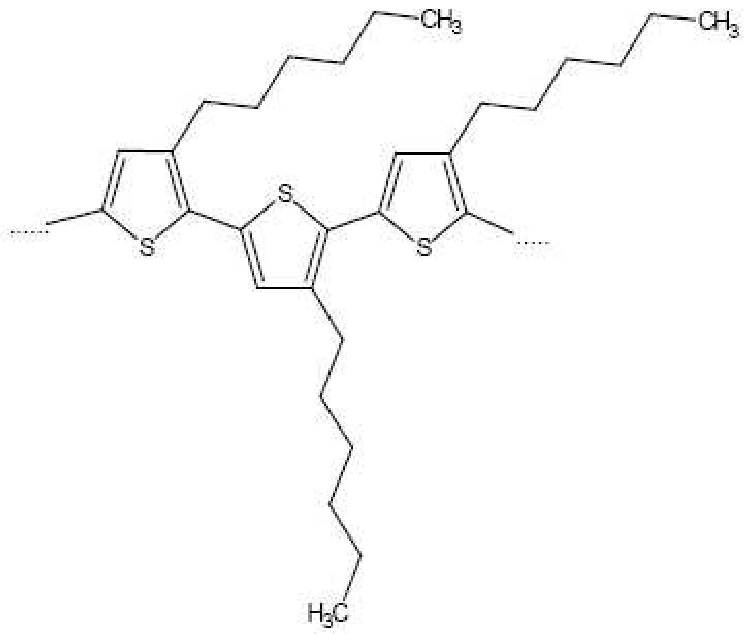


Figure 2 : Chemical structure of P3HT

We prepared two different solar cells. First solar cells were prepared by drop casting P3HT solution onto the ITO/CdTe layers which were prepared as described above. 100 nm of gold (Au) was deposited as top metal electrode. Second type solar cells were prepared by drop casting P3HT solution onto TiO_2 and CdTe (ITO/TiO_2/CdTe) coated substrates. Finally, 100 nm Au was evaporated as top contact (see figure 3). As references, a cell consisting of bare P3HT and a cell consisting of P3HT on TiO_2 electrodes were also prepared.

Figure 3 : Schematic description of hybrid solar cells using bulk CdTe and P3HT with TiO_2.

All current–voltage (I–V) characteristics of the PV devices were measured (using a Keithley SMU 236) under nitrogen in a dry glove box immediately after production. A Steuernagel solar simulator, simulating AM1.5 conditions, was used as the excitation source with an input power of 100 mW/cm^2 white-light illumination.

The spectrally resolved photocurrent was measured with a EG&G Instruments 7260 lock-in amplifier. The samples were illuminated with monochromatic light from a Xenon lamp. The incident photon to current efficiency (% IPCE) was calculated according to the following equation:

$$\text{IPCE (\%)} = \frac{I_{sc} * 1240}{P_{in} * \lambda_{incident}},$$

where Isc (µA/cm^2) is the measured current under short-circuit conditions of the solar cell, Pin (W/m^2) is the incident light power, measured with a calibrated silicon diode, and λ (nm) is the incident photon wavelength.

2.2. Fabrication and Characterization of Solid State Dye Sensitized Solar Cells Using Calix[4]arene Perylene Derivative and Poly(3 hexylthiophene) (P3HT):

As substrates, glass sheets of 1.5x 1.5 cm^2 covered with ITO, from Merck KG Darmstadt, were used with an ITO thickness of about 120 nm and sheet sheet resistance < 15 Ωcm^{-2}.

The ITO was cleaned by etching with an acid mixture of HCl_{konz}:HNO_{3konz}:H_2O (4.6:0.4:5) for ~ 30 min. The part of the substrate which forms the contact is covered with a scotch tape preventing the etching. The scotch tape was removed after etching and the substrate was then cleaned by using acetone in an ultrasonic bath and finally with iso-propanol.

The compact TiO_2 layers were prepared as described in the literature using a titanium tetra isopropoxide precursor. Compact TiO_2 layers were spincast under ambient conditions on top of the cleaned and patterned ITO substrates by using 8000 rpm. After spin coating, the substrates were placed in an oven and sintered at 450 ^oC for 30 minutes yielding insoluble compact layers. A commercially available TiO_2 from Solaronix was used as porous electrodes.

Calix[4]arene Perylene derivative was obtained from Ass. Prof. Dr. Mahmut Kus and coworkers from Turkey. First, Calix[4]arene was dissolved in chlorobenzene, the concentration was 5 mg/ml. Then a solution of poly(3-hexylthiophene) (P3HT) was prepared in the same organic solvent, concentration was 10 mg/ml. Both of them were mixed together. The final solution was drop cast on compact and porous TiO_2 covered ITO glasses and 100 nm Au was evaporated as top contacts (see figure 4). As a reference, a cell consisting of P3HT on top of TiO_2 substrates were prepared.

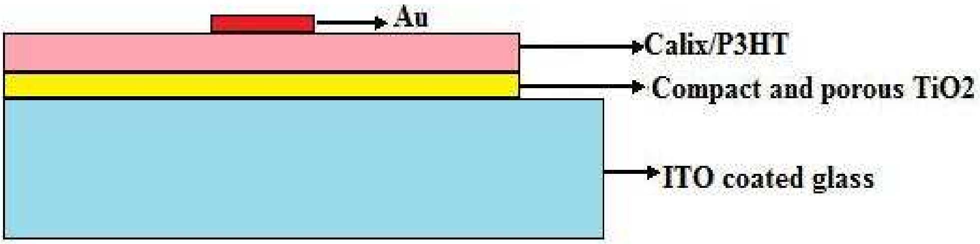
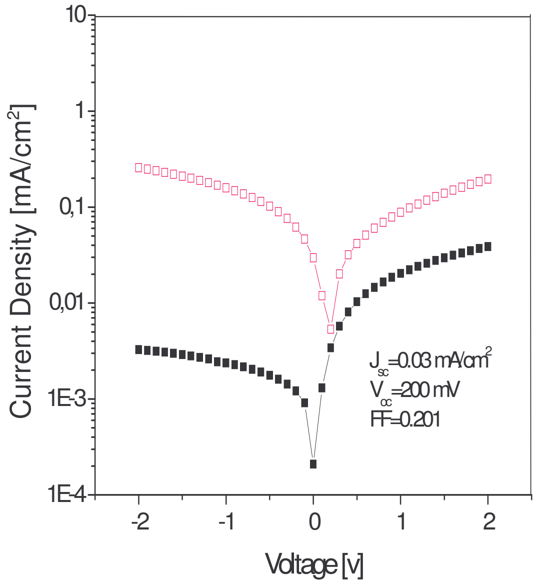


Figure 4 : Schematic description of solid state dye sensitized solar cell using P3HT.

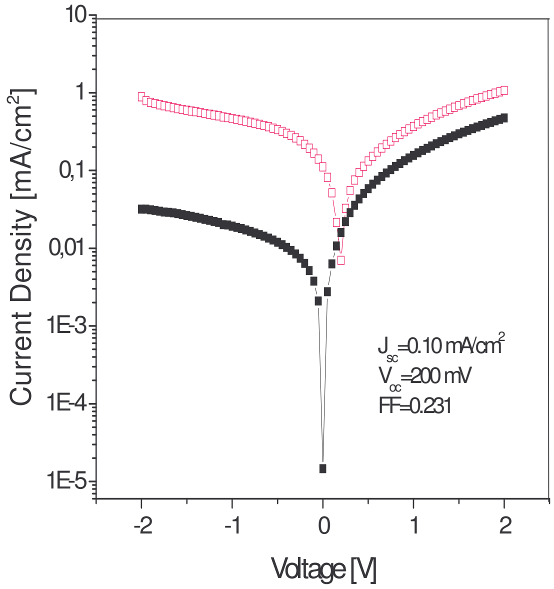
3. Results

3.1 Results of Hybrid Solar Cells Using Bulk CdTe and P3HT:

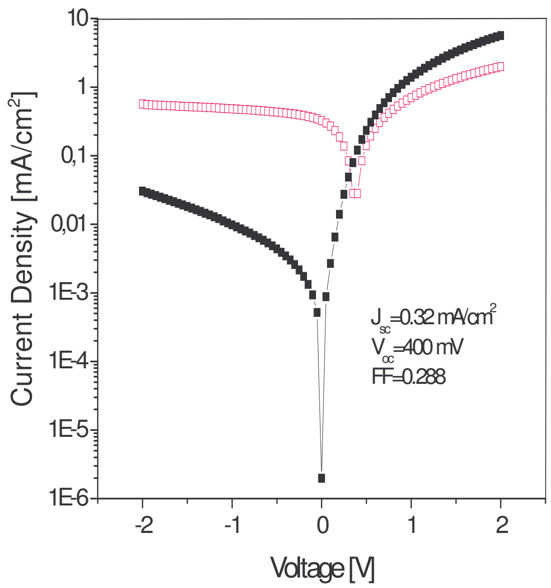
Several solar cells were prepared using the above configurations. The devices using the bulk CdTe and P3HT with the configuration of ITO/CdTe/P3HT/Au showed short circuit current density, J_{sc} of 0.03 mA/cm^2, an open circuit voltage, V_{oc} of 200 mV and fill factor of 0.201. The cell with compact and porous TiO_2, configuration is ITO/TiO_2/CdTe/P3HT/Au showed a J_{sc} of 0.10 mA/cm^2 and V_{oc} of 200 mV with a fill factor of 0.231. As a reference, a cell consisting of only compact and porous TiO_2 and P3HT with the configuration of ITO/TiO_2/P3HT/Au was prepared. This cell showed an J_{sc} of 0.32 mA/cm^2 and a V_{oc} of 400 mV with a fill factor of 0.288 (see figure 5). Solar cells composed of the bulk CdTe in the active layer didn`t significantly generate photocurrent under illumination.



(a)



(b)



(c)

Figure 5 : Current-voltage characteristics of (a) ITO/CdTe/P3HT/Au (b) ITO/TiO_2/CdTe/P3HT/Au (c) reference cell ITO/TiO_2/P3HT/Au

3.2 Incident Photon to Current Efficiency (IPCE) of TiO_2/CdTe/P3HT Solar Cells

The percent IPCE is the percentage of electrons, measured under short-circuit current conditions, which are related to the number of incident photons. It is used to obtain information on the number of photons of different energy that contributes to charge generation in the solar cell.[6]

Figure 6 shows the IPCE spectra of ITO/TiO_2/CdTe/P3HT/Au solar cells. Since the J_{sc} of ITO/CdTe/P3HT/Au solar cells were relatively lower we couldn`t detect IPCE signal for this type of solar cells.

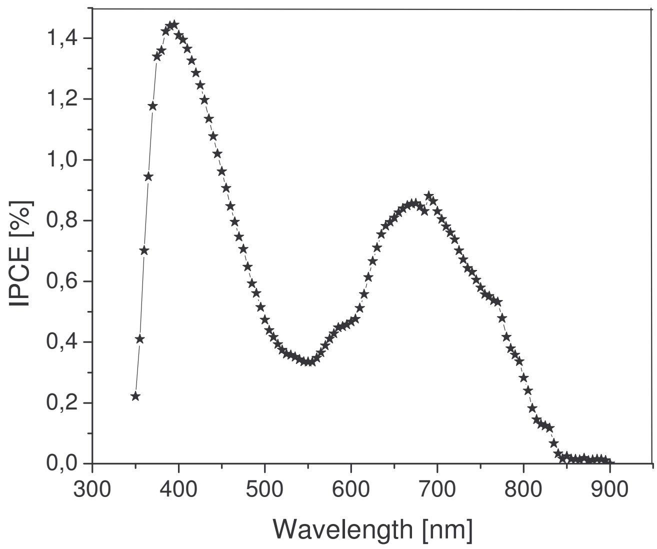


Figure 6 : IPCE spectra of TiO2/CdTe/P3HT solar cells

3.3 Results of Solid State Dye Sensitized Solar Cells Using Calix[4]arene Perylene Derivative and Poly(3 hexylthiophene) (P3HT):

Several solar cells were prepared using the above configuration. The performance of Calix[4]arene Perylene derivative was evaluated as dye in solid state dye sensitized solar cells.

The configuration of the solar cells were ITO/TiO_2/Calix:P3HT/Au. The devices using dye and P3HT showed short circuit current density, J_{sc} of 0.011 mA/cm^2, an open circuit voltage, V_{oc} of 450 mV and fill factor of 0.248. As compared to the reference cell measured above the J_{sc} values are rather low in the solar cells containing calixarene derivative (see figure 5c).

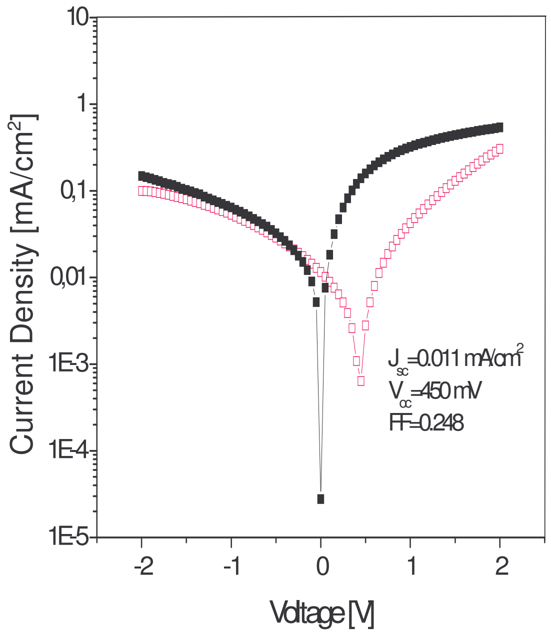


Figure 7 : Current-voltage characteristics of ITO/TiO_2/Calix:P3HT/Au

4. Description of the Main Results Obtained

As conclusion, we focused in two different types of hybrid solar cells using different absorbers We first investigated hybrid solar cells consisting of bulk CdTe and P3HT layers and solar cells consisting of bulk CdTe and TiO_2. According to the results obtained CdTe containing solar cells didn`t show significant photovoltaic response and also any improvement. We also investigated the effect of Calix[4]arene Perylene derivative on the device performance of solid state dye sensitized solar cells. Solar cells composed of this molecule in the active layer didn`t significantly generate photocurrent under illumination and it did not show any significant improvement as compared to the reference cell.

We will continue to collaborate with the host institute. Future collaboration includes photo physical characterization, mobility measurements, morphology characterization and further devices with new materials.

References

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