SCIENTIFIC PROJECT REPORT FOR EUROPEAN SCIENCE FOUNDATION PROGRAMME

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Emel Cevik

THE AIM OF VISIT

The need to develop inexpensive renewable energy sources stimulates new approaches for efficient, low cost photovoltaic devices [1]. Researchers put great effort to find new techniques to cheaply and efficiently convert sunlight into electricity. New approaches towards stable, efficient, low cost photovoltaic devices are indeed the high priority [2]. In recent years, various schemes for organic photovoltaic devices have been suggested and demonstrated: (i) dye sensitized solar cells; [3] (ii) devices based on small organic molecules fabricated by vacuum deposition; [4] (iii) blends of donor- and acceptor-like conjugated polymers and fullerenes; [5] and (iv) hybrid solar cells consisting of inorganic semiconductor nanoparticles blended in a polymer matrix [6].

A hybrid solar cell consists of a combination of both organic and inorganic semiconducting materials. It combines the unique properties of inorganic semiconductors with the film-forming properties of the conjugated polymers [7]. Owing to distinct electrical and optical properties, organic–inorganic hybrid composites have shown strong potential to be used for high-performance devices including sensors, displays, light emitting diodes, solar cells, refractive and anti-refractive materials, and so on [8,9]. In particular, organic-inorganic hybrid solar cells show technological importance due to advantages, such as low cost, easy fabrication, and the possibility to fabricate flexible devices, compared to inorganic solar cells [10, 11].

THE PURPOSE OF STUDY

In accordance with the need in hybrid solar cells, various inorganic semiconductors, such as CdSe, CdTe, CdS, and PbS, have been actively investigated because of their application to serve as an acceptor for hybrid solar cells [12–14]. However, compared to the synthesis of CdSe nanomaterials for hybrid solar cells, the fabrication of CdS nanomaterials is still in a preliminary stage [15]. CdS is a II–VI semiconductor having a direct band gap of 2.4 eV at room temperature and it has been known as one of the most promising photo-sensitive materials owing to its unique photochemical activities and strong visible-light absorption and emission [15]. Hence, it has many commercial or potential applications in light-dependent resistors, solar cells, or other photoelectronic devices [16–18]. CdS nanostructured materials have attracted a great deal of interest in hybrid photovoltaic applications due to possible enhancement in power conversion efficiency.

The aim of this visit is to fabricate and characterize hybrid solar cells using bulk CdS and conjugated polymers. In this study, we focused on organic/inorganic hybrid nanostructures for the photovoltaic applications. The project mainly dealed with bilayer hybrid solar cells using inorganic bulk semiconductor CdS, with semiconducting polymers such as poly (3-hexylthiophene) (P3HT). We prepared CdS films in our laboratory in Istanbul with cheap techniques onto indium tin oxide (ITO) coated substrates.

EXPERIMENTAL

1.1 General Characterization of a Solar Cell

The basic parameters describing the performance of a solar cell can be deduced from a current-voltage (I-V) curve (see figure 1).

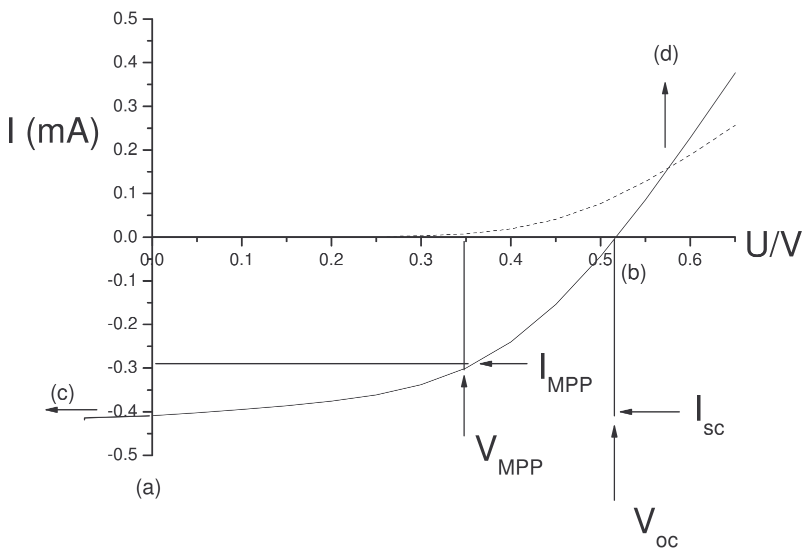


Figure 1. Current-voltage characteristics of a solar cell

In the dark, there is almost no current flowing, until the contacts start to inject heavily 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 [19].

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 [20]. I_{mpp} and V_{mpp} are the current and voltage at the maximum power point in the fourth quadrant of the current-voltage characteristics.

P3HT

Figure 2 shows the chemical structure of the frequently used organic semiconductor poly(3-hexylthiophene) (P3HT) for photovoltaic applications. 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.

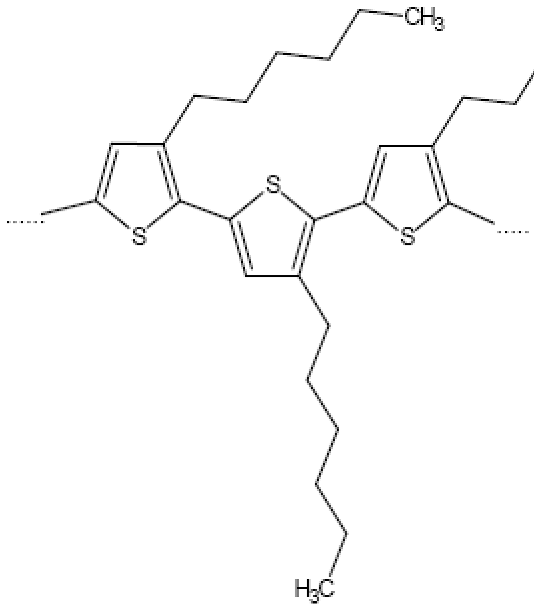


Figure 2 : Molecular structure of P3HT

CdS (Cadmium sulphide)

Cadmium sulfide is yellow in colour and is a semiconductor. It exists in nature as two different minerals, hexagonal greenockite and cubic hawleyite. Cadmium sulfide is a direct band gap semiconductor (gap 2.42 eV) and has many applications for example in light detectors [21].

1. Fabrication and Characterization of Hybrid Solar Cells Using bulk CdS Semiconductor and Conjugated Polymers:

As substrates, glass sheets of 1.5x 1.5 cm2 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 Merck KG Darmstadt was used in all experiments. ITO glasses were etched with an acid mixture of HClBkonzB:HNOB3konzB:HB2BO (4.6:0.4:5) for an hour. The scotch tape was used to protect the determined area of ITO from etching. After etching, the substrate was cleaned by using acetone, ethanol, iso-propanol and finally with distilled water in an ultrasonic bath.

CdS films were deposited onto indium tin oxide (ITO) coated substrates using cheap techniques (close sublimation). 10 mg of P3HT was dissolved in 1 ml chlorobenzene.

All current–voltage (I–V) characteristics of the PV devices were measured (using a Keithley SMU 236) under nitrogene 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:

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

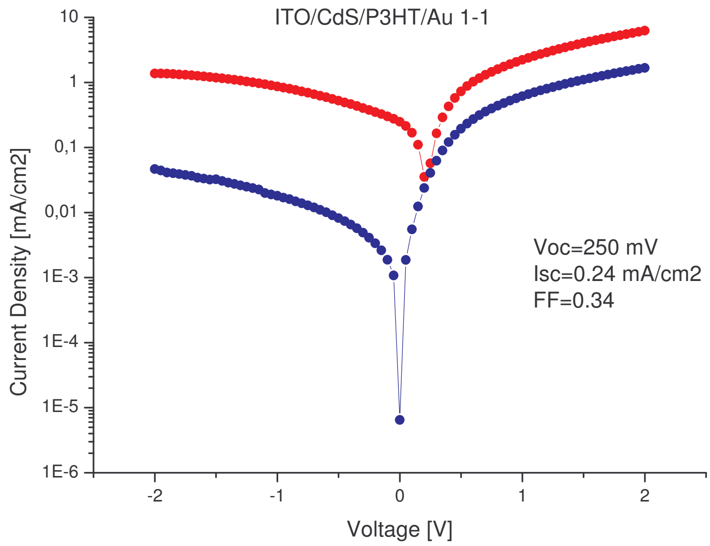
where Isc ($\mu A/cm^2$) is the measured current under short-circuit conditions of the solar cell,Pin (W/m^2) is the incident light power, measured with a calibrated silicon diode, and λ (nm) is the incident photon wavelength.

RESULTS

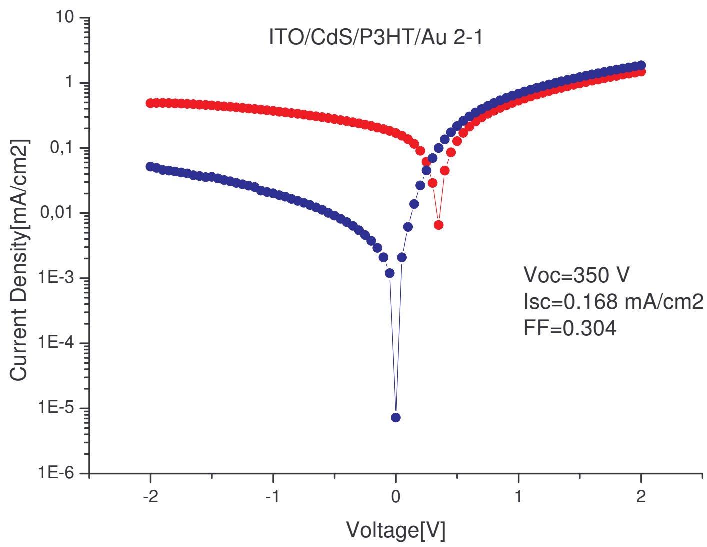
Results of ITO/CdS/P3HT/Au

Device fabrication.

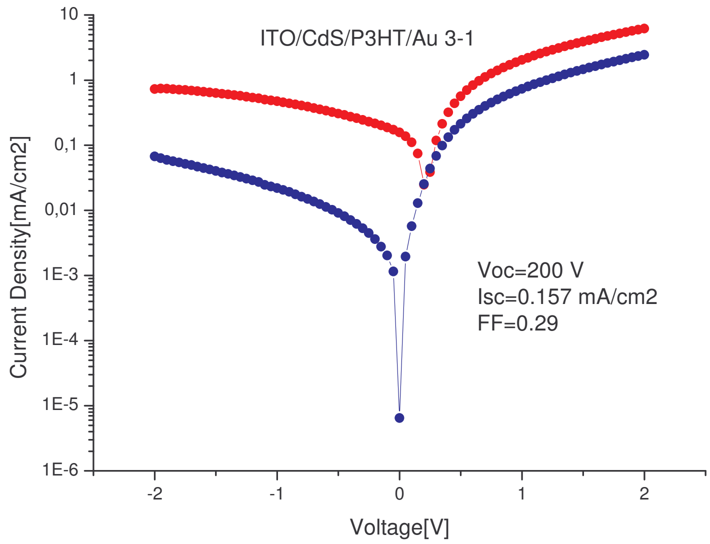
Solar cells were fabricated on an indium tin oxide (ITO)-coated glass substrate with the following structure: The ITO coated glass substrates were first cleaned with detergent, ultrasonicated in acetone and isopropyl alcohol. CdS layers were deposited onto ITO substrates. Solar cells were prepared by dropcasting P3HT solution onto CdS covered ITO substrates and 100 nm of Au was evaporated as top electrode. We investigated the effect of different thicknesses of CdS (50nm 1-1, 100nm 2-1,150nm 3-1, 200nm 4-1, respectively) on the performance of hybrid solar cells. As a reference cell, solar cells consisting of bare P3HT was also prepared. This type of solar cells didn`t significantly generate any photocurrent and voltage. This shows that the CdS improves the photovoltaic performance of bare P3HT cells and contribute to the photocurrent generation.


ITO/CdS/P3HT/Au 1-1
Voc=250 mV
Isc=0.24 mA/cm2
FF=0.34
Current Density [mA/cm2]
Voltage [V]
10
1
0,1
0,01
1E-3
1E-4
1E-5
1E-6
-2
-1
0
1
2

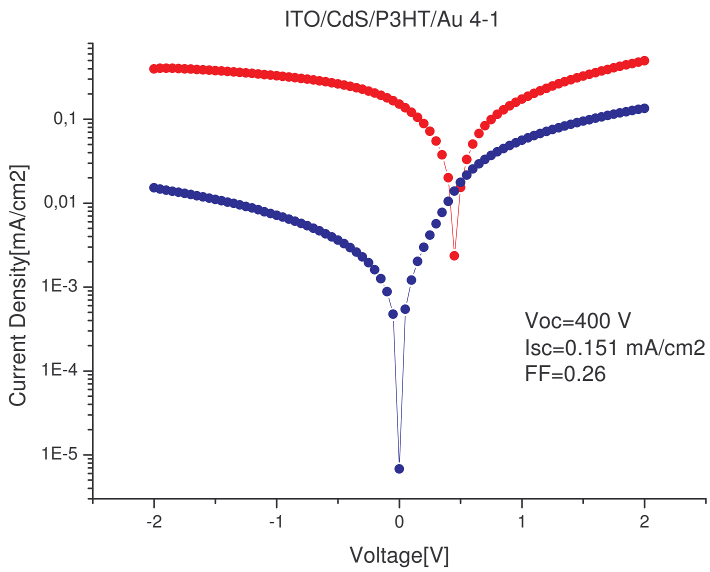
(a)


ITO/CdS/P3HT/Au 2-1
Voc=350 V
Isc=0.168 mA/cm2
FF=0.304
Current Density[mA/cm2]
Voltage[V]
10
1
0,1
0,01
1E-3
1E-4
1E-5
1E-6
-2
-1
0
1
2

(b)



(c)



(d)

Figure3. The current voltage characteristics of ITO/CdS/P3HT/Au solar cells with different thicknesses (a) 50 nm (b) 100 nm (c) 150 nm (d) 200 nm.

IPCE RESULTS OF ITO/CdS/P3HT/Au

Figure 4 shows the IPCE spectra of ITO/CdS/P3HT/Au with different CdS thicknesses. The data is in accordance with the current values.

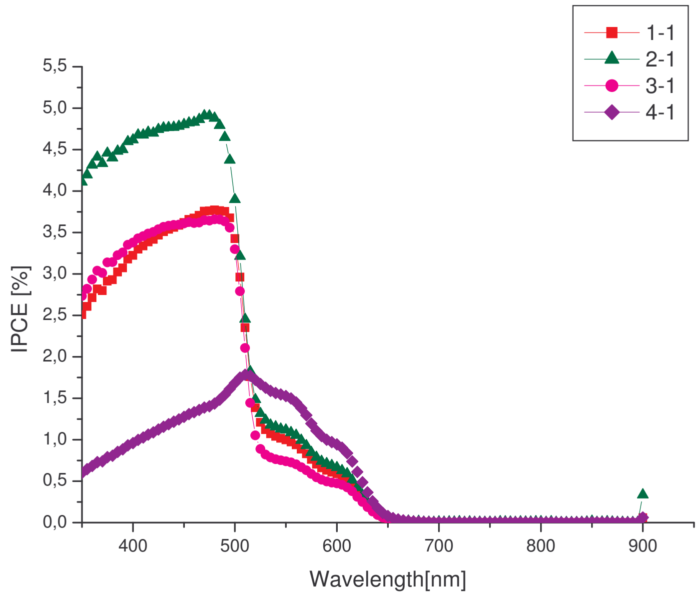
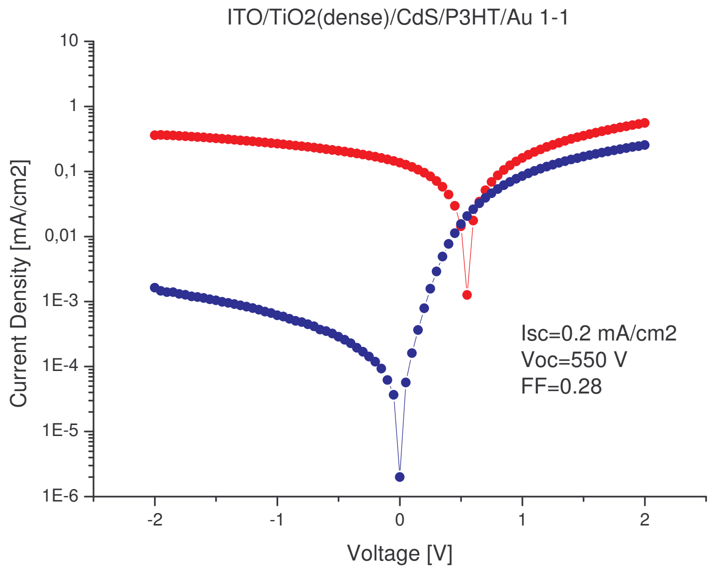


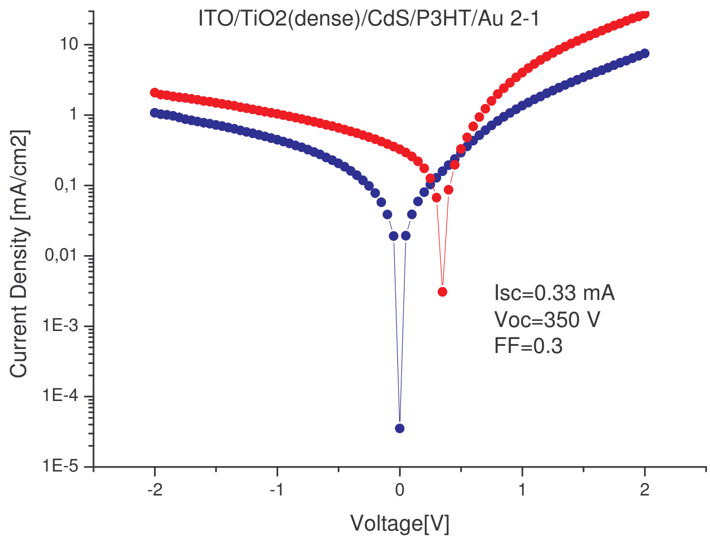
Figure 4. IPCE spectra of ITO/CdS/P3HT/Au solar cells with different CdS thicknesses.

Results OF ITO/TiO_2(dense)/CdS/P3HT/Au

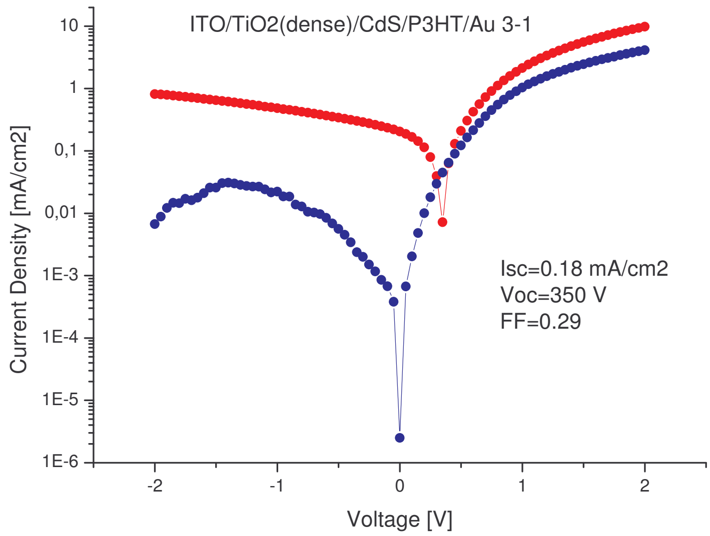
Device fabrication. Solar cells were fabricated on an indium tin oxide (ITO)-coated glass substrate with the following structure: Compact TiO_2 layers were prepared according to ref [22] except the addition of isopropanol and were spincast under ambient conditions on top of the cleaned and patterned ITO substrates by using 8000 rpm. After spin coating, the substrates were placed in an oven and sintered at 450 ^{o}C for 30 minutes yielding insoluble compact layers. And then, CdS layers were deposited onto TiO_2 coated substrates. P3HT was drop cast onto TiO_2/CdS films and finally 100 nm of Au was deposited as top electrode. Figure 5 shows the current-voltage characteristics of the solar cells consisting of different thicknesses of CdS. Also, as a reference cell, a solar cell consisting of ITO/TiO_2 and P3HT was also prepared to investigate whether there will be any improvement upon CdS addition into the solar cell configuration.


ITO/TiO2(dense)/CdS/P3HT/Au 1-1
Current Density [mA/cm2]
10
1
0,1
0,01
1E-3
1E-4
1E-5
1E-6
-2
-1
0
1
2
Voltage [V]
Isc=0.2 mA/cm2
Voc=550 V
FF=0.28

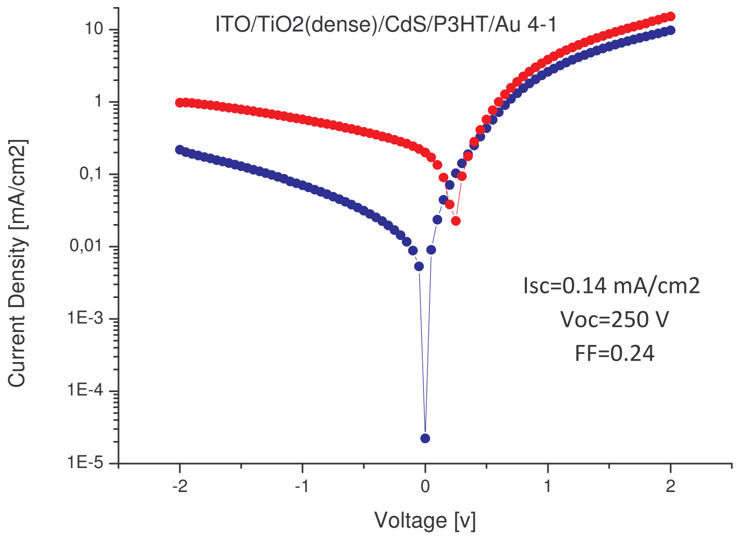
(a)


ITO/TiO2(dense)/CdS/P3HT/Au 2-1
Current Density [mA/cm2]
10
1
0,1
0,01
1E-3
1E-4
1E-5
-2
-1
0
1
2
Voltage[V]
Isc=0.33 mA
Voc=350 V
FF=0.3

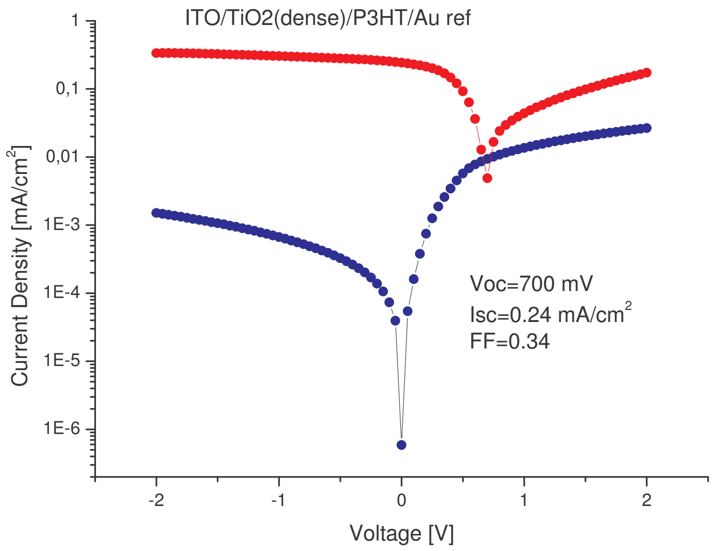
(b)


ITO/TiO2(dense)/CdS/P3HT/Au 3-1
Current Density [mA/cm2]
10
1
0,1
0,01
1E-3
1E-4
1E-5
1E-6
-2
-1
0
1
2
Voltage [V]
Isc=0.18 mA/cm2
Voc=350 V
FF=0.29

(c)


ITO/TiO2(dense)/CdS/P3HT/Au 4-1
Current Density [mA/cm2]
10
1
0,1
0,01
1E-3
1E-4
1E-5
-2
-1
0
1
2
Voltage [v]
Isc=0.14 mA/cm2
Voc=250 V
FF=0.24

(d)



(e)

Figure 5. Current-Voltage characteristics of ITO/TiO2/CdS/P3HT/Au solar cells with different CdS thicknesses (a) 50 nm (b) 100 nm (c)150 nm (d) 200 nm (e) Reference cell

IPCE Results of ITO/TiO2/CdS/P3HT/Au

Figure 6 shows the IPCE spectra of ITO/TiO_2/CdS/Au solar cells with different CdS thicknesses.

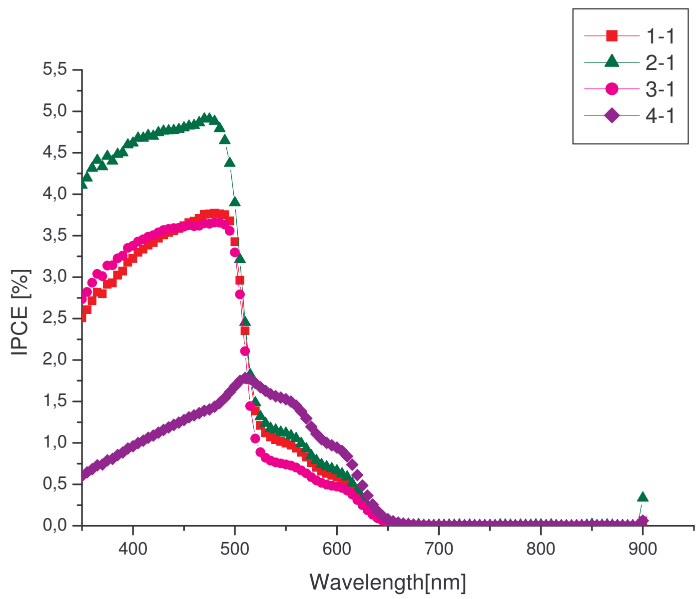


Figure 6. IPCE spectra of ITO/TiO2/CdS/P3HT/Au solar cells with different CdS thicknesses.

Conclusion

We investigated hybrid solar cells using bulk CdS semiconductor and P3HT. Hybrid solar cells consisting of CdS and P3HT showed better photovoltaic performance as compared to solar cells consisting of bare P3HT layers. To investigate the effect of CdS layers on the performance of TiO_2 based solar cells we prepared solar cells comprising of ITO/TiO_2/CdS/P3HT/Au. As a reference cell, a solar cell consisting of only TiO_2 and P3HT was also prepared. We observed that hybrid solar cells consisting of only CdS and P3HT showed better photovoltaic performance than solar cells consisting of TiO_2, CdS and P3HT.

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.

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