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Characterization of UV Detectors Based on Dye Sensitized Cell

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Abstract

Objective: Self-powered UV detectors based on TiO_2 has attracted a lot of attention due to its promising properties. Dye sensitized solar cell based-TiO_2 was previously designed to be used as an alternative to the conventional solar cell as it resembles a low cost source of renewable energy. **Methods:** In this paper, dye sensitized cell was modified and investigated to be used as a low cost practical UV light detector. TiO_2 was deposited on a glass substrate coated with Indium tin oxide conductive layer. Dye and electrolyte were added to help in absorbing photons and maintaining the charge carriers in the cell respectively. The cell was encapsulated using a second conductive glass substrate. **Findings:** To increase the detector stability, the device was sealed to isolate it from the environment using cross-linked SU-8 photo resist. A small bias was applied to the cell through its electrodes in order to control the amount of charge carriers. The detector was tested in ambient as well as underwater to check its reliability and robustness. **Application:** It shows high responsively, around 1440 A/W and fast response for on/off and continuous light irradiation. The measurements for the detector were obtained under 365 nm UV light irradiation with light intensities varying from 0.1 to 8 mW/cm^2.

Keywords: Characterization, Dye Sensitized Cell, UV Detectors

1. Introduction

Ultraviolet (UV) detectors have drawn much attention due to its industrial and military applications[1–7]. Basically, all those applications required fast response and high sensitive photodetectors. Several UV detectors technologies are currently available such as Si-based detectors and photomultipliers. Despite the high sensitivity and fast response of those detectors, they have some property limits such as the need of filters and low efficiency specifically for the Si-based detectors[8–10] and the need of high vacuum and high voltage supply for the photomultipliers, in addition to the fabrication difficulties and the high cost of those detectors. Recently, wideband gap materials such as zinc oxide and titanium dioxide semiconductors have been used in the fabrication of the UV detectors due to their wide band gap (~3 eV)[11–16]. However, these detectors required additional work before they become commercially available.

Among these, Dye Sensitized Solar Cells (DSSCs) have been extensively studied as an alternative to the conventional silicon solar cells due to its low cost and easy to fabricate.[17–19] However, the lack of efficiency has limited their commercial implementation. On the other hand, dye sensitized cell was proved to be used as a photodetectors as well. This is due to its self-powered and excellent physical and chemical properties[20–25]. In this paper, new fabrication steps were added to the original design of the dye sensitized cell photodetector to improve its properties. Additionally, new testing techniques were applied to evaluate the detector for commercial production.

2. Device Fabrication

TiO_2 nano-powder was mixed with ethanol and then sonicated for 1 h. A TiO_2 layer of ~ 200 μm was deposited on the ITO glass which has dimensions of (50 × 50 × 1) mm, then was heated on a hot plate at 180°C for 15 min to form TiO_2 electrode. The TiO_2 electrode was dipped in a dye solution (Eosin) for 15 min. After that, a drop of electrolyte was put on the TiO_2 electrode. Prior to combination of the

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two ITO glasses, a drop of electrolyte (Lugol's iodine, 2.2% iodine and 4.4% potassium iodide) was added in between the two ITO glasses. The edges were covered by SU8 2025 photo resist as it is stable and resists most acids and solvents[26]. In order to obtain cross-linked SU8, the device was soft baked for 2 min at 95°C, exposed to UV light for 20 sec and hard baked at 95°C for 3 min. After the device had cleaned by ID water and dried by N_2 gas, a silver paste was used to connect two wires to the ITO. Finally, a protection layer of PDMS was spin coated on both sides of the device. Figure 1 shows the schematic of the device.

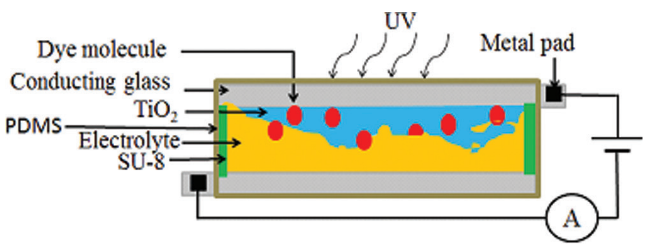

Figure 1. Schematic of the UV photodetector.

3. Detector Operation

The expose of dye sensitized cell to UV causes electrons in the dye to get excited. The electrons then ejected from the dye into the conducting band of the TiO_2 layer. Regeneration of the lost electrons is handled by the electrolyte[27]. The electrons that were ejected from the dye diffuse through the TiO_2 layer than into the conductive glass and finally the electrons flow through the output wires that are connected to the metal pads. Basically, the current flowing through the cell is depending on the 7 amount of the UV intensity. As depicted in Figure 1, a small amount of biasing is applied to the cell to motivate the electrons of the cell to flow and also to control the current gain and elevate the responsivity of the detector.

4. Experimental Results

The I-V characteristic of the device is shown in Figure 2. The UV irradiation at 1 V bias, wavelength of 365 nm and intensity of 0.1 mW/cm^2, the photo current could reach 0.9 mA. This means increasing bias voltage from 0 to 1 V leads to increase in the photocurrent by more than 3 orders of magnitude.

The responsivity of the detector can be determine by $R = I/AE$[16], where R is the responsivity, I is the photo current, A is the effective area of the device and E is the irradiation of the UV light. The responsivity was calculated to be 1440 A/W, which is higher than the reported values[28]. The higher responsivity indicates high internal photoelectric current gain. This gain can be expressed by $g = \tau\mu V_B/L$[29], where τ is the mean lifetime of the charge carrier, L is the inter-electrode spacing, V_B is the applied bias and μ is the electron mobility.

A UV Light-Emitting Diode (LED) with a peak wavelength of 365 nm was used in our experiment. The LED was driven by a function generator (RIGOL-G1022), which was used to drive the UV LEDs and also to control the light intensity and to obtain both discrete (pulses) and continuous (sinewave) light signals. The photocurrent was measured using HP 4145B semiconductor parameter analyzer. In all experiments, the photodetector was biased at 0.1 V to increase the device photocurrent.

Before device testing, the intensity of the LEDs torch was measured and calibrated by AB-M model 100-C UV intensity meter [Figure 3a]. The calibration curve was obtained by applying several voltage values to the UV LEDs array and measuring the corresponding intensities. The calibration curve showed linear relationship [Figure 3b].

The response speed is a significant parameter which can be used to determine the property of the photodetectors. Figure 4 shows incident light dependent current measured at 50 mV bias with a light pulse of 50 mHz and light intensity of 0.25 mW/cm^2. It is obvious that the rise time and fall time of the detector are almost the same, < 0.1 s, which is good Compared to the other photodetector technologies[16]. Additionally, since the device is encapsulated, then it would not be attacked by the oxygen of the environment. As a result, the number of trapped holes would be minimized, and then the combination between the negative and positive charge carriers would be increased, thus, the fall time would decrease.

In the reported articles only discrete time (on/off) response of UV detectors has been study. In this work, the response for continuous UV light was studied too. Sinewave light with a frequency of 50 mHz was irradiated on the detector [Figure. 5]. The response observes a perfect sinewave photocurrent response with no distortion. This means that the detector has perfect response for analog as well as digital light signal irradiations.

Photocurrent of the device versus incident light intensities were investigated [Figure 6]. The photocurrent measurements were carried out at 100 mV bias and under 365 nm UV light irradiation with light intensities varying from 0.1 W/cm^2 to 8 mW/cm^2. The photocurrent increases linearly with the light intensity. This linear relation suggests that the device can be used not only as a UV detector but also for precise UV measurements.

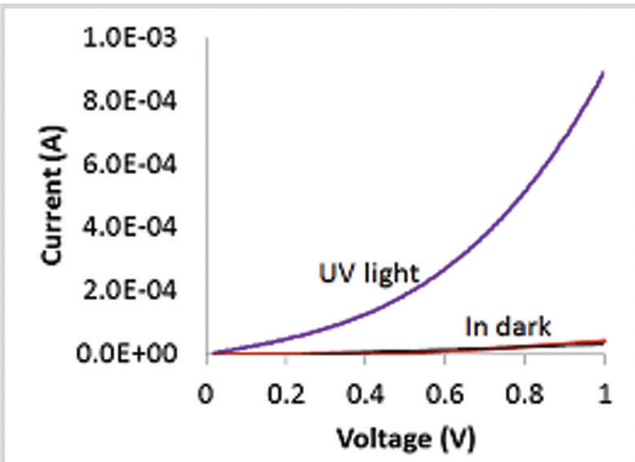

Figure 2. I-V characteristics of the device with no irradiation and under the incident light of 365 nm.

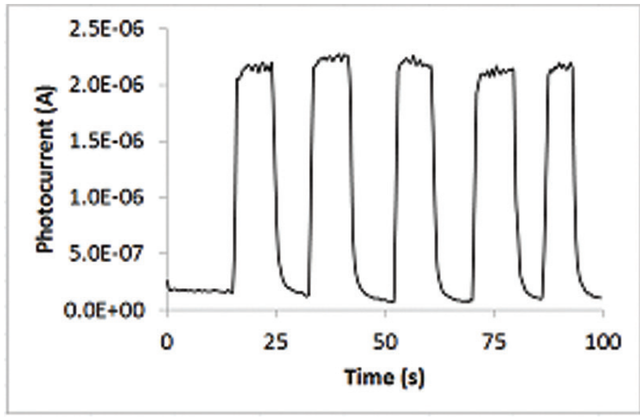

Figure 4. Time response of the device to on/off light pulses.

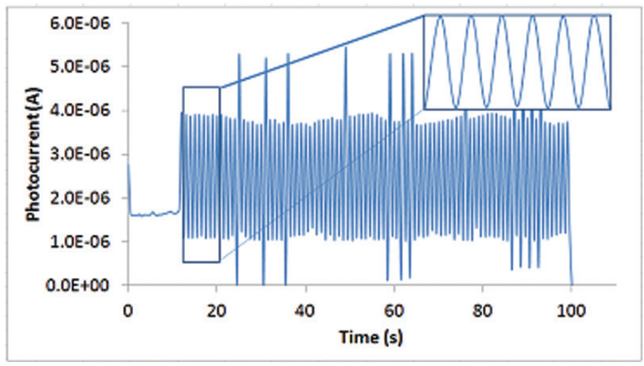

Figure 5. Time response of the device to continuous sinewave light irradiation.

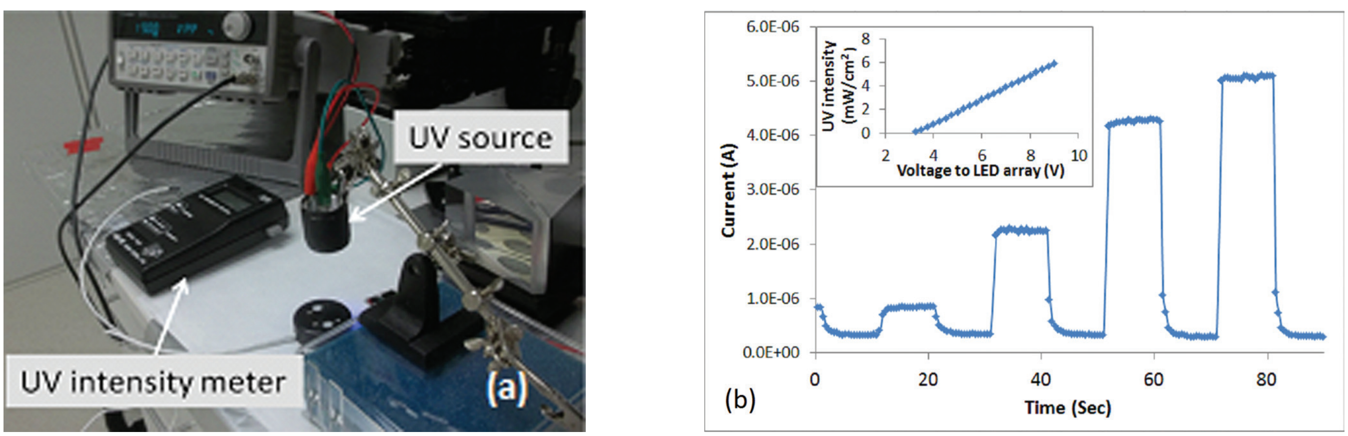

Figure 3. Device calibration
a The experimental setup for calibration of the UV LEDs torch.
b detector photocurrent at different intensities. Inset is the linear relationship obtained from the calibration.

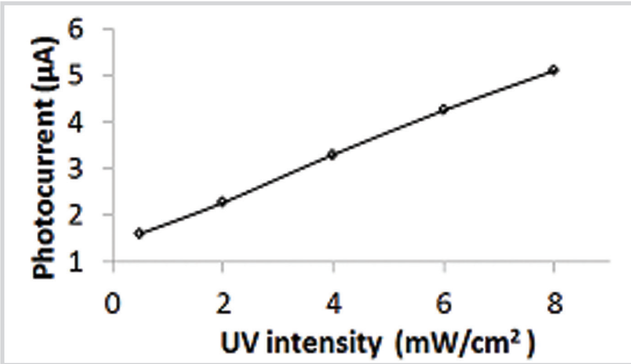

Figure 6. Photocurrent as a function of the incident UV (λ = 365 nm).

5. Waterproof Test

The device was also tested in water based on the reported articles[30]. Several factors affect underwater UV measurements. First, the view angle of the UV detector is reduced and then a small amount of UV light reaches the detector. Second, is the light scattering due to impurities, especially when measurement done in ocean or unclean water. Therefore, it is expected to achieve a smaller photocurrent values underwater measurements compared to the in air measurements. To run underwater test, a glass tank was used with a jacket, as a light isolator. Testing was done in the depth of 30 cm. Figure 7 shows the testing setup of the device. No significant differences in the time response were observed, however, an attenuation in the photocurrent was recognized which can be attributed to the absorption characteristic of the UV underwater[30–32]. Results show the ability for using the photodetector underwater as well as in air.

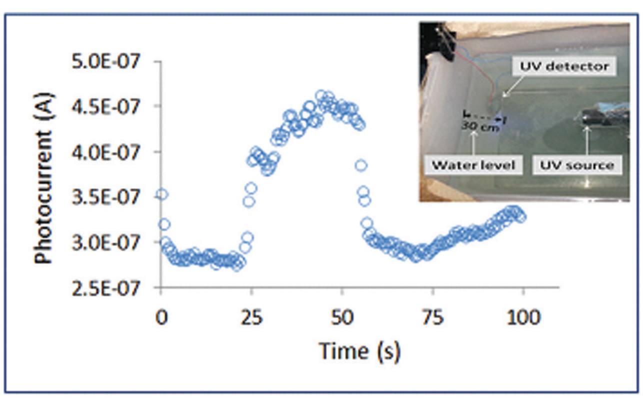

Figure 7. Underwater testing, inset is the testing setup.

6. Conclusion

Dye sensitized cell was characterized and modified. The device exhibits fast response and high sensitivity for both discrete and continuous light intensity variations. Bias voltage was applied in order to control the gain and then the responsivity of the detector. The device shows stable characteristic in ambient as well as underwater. No significant change in the underwater detector characteristic except attenuation in the photocurrent that can be attributed to the water absorption and scattering of the UV light that leads to decline in the UV energy. This type of photo- detector technology seems promising towards commercial production of optoelectronic components.

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