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Natural Yellow3 for Dye Sensitized Solar Cell

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***Abstract*— The natural dye, Curcumin, was extracted from Curcuma longa using as a sensitizer in two types of dye sensitized solar cell (DSSC), and their characteristics were studied. The absorption spectrum of the dye solutions, as well as the wavelength of the maximum absorbance of the dye loaded TiO_2 film has been studied. The X-Ray diffraction pattern of TiO_2 film made with Doctor-Blading technique shown that the grain size of TiO_2 was equal to be 40 nm. The electrical performances in terms of short circuit current, open circuit voltage and power conversion efficiency of cells were investigated.**

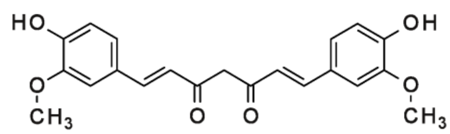
***Keywords*— Curcumin dyes, nanoparticle, natural photosensitizers, photosensitizers, solar cells.**

I. INTRODUCTION

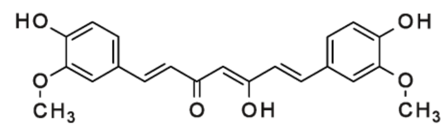
The dye sensitized solar cell (DSSC) is a photovoltaic device for the conversion of visible light into electricity, based on the sensitization of wide band gap semiconductors. Light is absorbed by the dye sensitizer, which is anchored to the surface of a wide-band-gap semiconductor [1, 2 and 3]. Charge separation takes place at the interface via photoinduced electron injection from the dye into the conduction band of the nanocrystalline solids which are metal oxides, especially titanium dioxide. The performance of the cell mainly depends on the dye used as sensitizer. The absorption spectrum of the dye and the anchorage of the dye to the surface of TiO_2 are important parameters determining the efficiency of the cell [4]. Dye sensitized solar cells (DSSCs), a new type of solar cells; have attracted considerable attention due to their environmental friendliness, non toxicity and low cost of production [1, 2 and 5].

Curcumin dye extracted from rhizomatous herbaceous perennial plant of the ginger family which is Turmeric. It is native to tropical South Asia and needs temperatures between 20 °C and 30 °C [2, 6 and 7]. Its powder commonly used as a spice in curries and other South Asian and Middle Eastern cuisine, for dyeing, and to impart color to mustard condiments [2,8]. Curcumin can be used to test the alkalinity or acidity of foods. It turns yellow in an acidic food, and it turns red in an alkaline food. Curcumin is the active substance of Turmeric and is known as C.I. 75300, or Natural Yellow 3. The systematic chemical name is (1E, 6E)-1, 7-bis (4-hydroxy-3-methoxyphenyl)-1, 6 heptadiene-3, 5-dione [2, 9 and 10].

Curcumin it can exist at least in two tautomeric, keto and enol as figure 1 shows, the keto form is preferred in solid phase and the enol form in solution. Its molecule has carbonyl and hydroxyl groups, which facilitate bind to the surface of TiO_2 particles [2, 8 and 10].



Curcumin keto form



Curcumin enol form

II. EXPERIMENT METHODS

Work have prepared two types of dye sensitized solar cell, using natural dye which is Curcumin dye as photosensitizers, with nanocrystalline semiconductor oxide of TiO_2 deposited and C- coated electrode as photo and counter electrode respectively.

- First type cell without treated TiO_2 photo electrode called (bare TiO_2 cell).
- Second type cell with treated TiO_2 photo electrode called (treated TiO_2 cell).

A. Materials

Curcumin dye ($C_{21}H_{20}O_6$) with M_W (368.38 g/mol) purchased from Fluka company (Switzerland), conductive glass plate FTO (7 ohm/sq) purchased from Solaronix company (Switzerland), TiO_2 anatase nanopowder less than 50 nm grain size, with purity 99.8% (China), acetone pure from Medex (United kingdom), PEG from Himedia with M_W (20.000 g/mol) (India), acetyleacetone from Riedel de Haen AG Seelz-Hnnover (Germany), Titanium tetra chloride from Fluka (Switzerland), all other solvent and the chemical employed for the experimental were of laboratory grade chemicals.

B. *Preparation of TiO_2 Photo Electrode*

1- Preparation of Bare TiO_2 Photo Electrode: The photo electrode was prepared by depositing TiO_2 film on the conducting glass FTO. Prior to the film deposition the glass substrate was cleaning by using denatured alcohol such as ethyl alcohol (purity 96%), and left to dry in air. The edges of the conductive glass were then masked with a scotch tape to give an active area of 1.5 cm^2 and to control the film thickness as well as to provide uncoated area for electrical contact. The TiO_2 paste was prepared by the incremental addition of 1.6 ml of de-ionized water and 0.02 ml acetylacetone to 1 g of TiO_2 powder and 20 wt% (with respect to TiO_2 wt) of PEG (Poly ethylene glycol M_W 20,000) was added as a binder, then grinding for 30 min.

The TiO_2 paste was spread uniformly on the conducting side of substrate by Doctor-Blading technique [11, 16 and 4], then left it dried at room temperature for approximately 7 min to reduce the surface irregularities. The TiO_2 layer was sintered for 30 min at 450 ºC, and then allowed cool slowly at room temperature, thereafter dipped into the Curcumin dye solution 10^{-3} M for 19 hour in a dark place. The substrate was rinsed with organic solvent like acetone and then left to dry and immediately used in mounted cells.

2- Preparation of Treated TiO_2 Photo Electrode: The treated electrode was prepared by using the same method for preparation bare TiO_2 but when the TiO_2 past sintered and left to cool slowly at room temperature, then immersed in a 0.1M HCl solution for an hour and then washed with de-ionized water and dried the sides by cotton swab. Now the device was kept in $TiCl_4$ solution for an hour, rinsed with de-ionized water, after that TiO_2 coated FTO substrate was dipped into the Curcumin dye solution 10^{-3} M for 19 hour in a dark place. The substrate was rinsed with organic solvent like acetone. Thereafter they were left to dry and immediately used in mounted cells. This method is repeated with changing the concentration of dye. By illuminating the cells with a light source, the current, voltage, power conversion efficiency across each individual cell can be measured. The power conversion efficiency (η) of the solar cell devices were calculated by using the values of open circuit photovoltage (V_{oc}), short circuits photocurrent (I_{sc}), fill factor (FF), and the power of incident light (P_{in}). The power conversion efficiency (η) defines as [4, 12 and 13].

$$\eta = \frac{P_{out}}{P_{in}} \qquad \eta = \frac{I_{sc} \cdot FF \cdot V_{oc}}{P_{in}} \qquad FF = \frac{V_{max} \cdot I_{max}}{V_{oc} \cdot I_{sc}}$$

Where:

η = power conversion efficiency of solar cell (%)
I_{sc} = solar cell short circuit photocurrent (A)

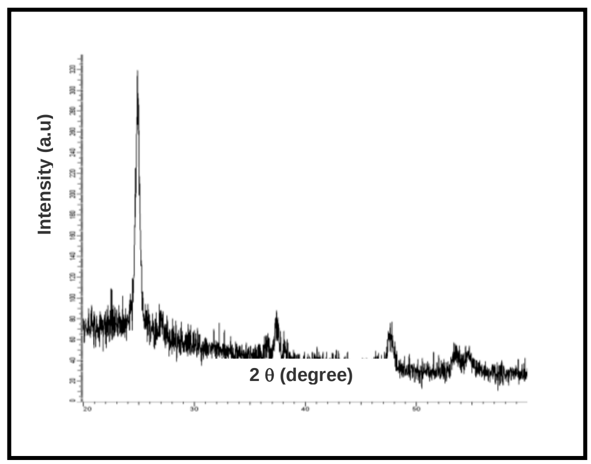
V_{oc} = solar cell open circuit photovoltage (V)
FF = fill factor of the solar cell, it is the ratio of the maximum output power from the solar cell to the theoretical maximum power. Its value is always less than unity.
P_{in} = power of incident light (W)

V_{max} = maximum solar cell photovoltage (V)
I_{max} = maximum solar cell photocurrent (A)

III. Result And Discussion

A. *Structural Properties*

1- X-Ray Diffraction Patterns: Figure 2 shows the XRD patterns of TiO_2 film indicate the crystalline structure of its. The diffraction peaks at 2θ (25°, 38°, 48°, 55°) confirms that TiO_2 anatase nanostructure with high purity and grain size equal to be 40 nm.



B. *Optical properties*

1- UV-Vis Absorption Spectroscopy: Figure 3 Shows the effect of dye solution concentration on treated TiO_2 and notice 10^{-3} M concentration of dye solution is the best concentration to increasing absorbance for treated TiO_2.

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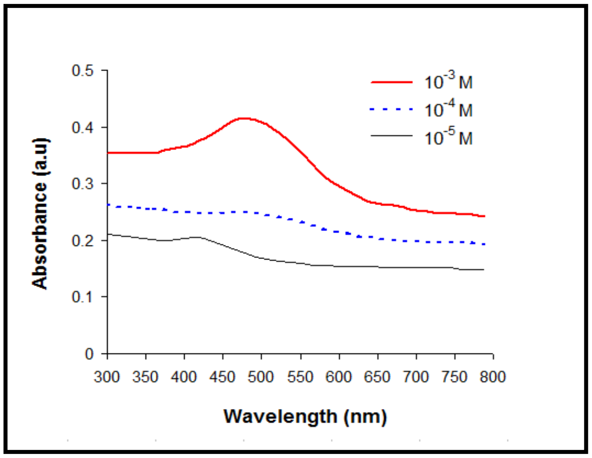

Fig. 3 Effect of dye solution concentration on treated TiO_2

Figure 4 shows the effect of immersion time in dye solution with concentration 10^{-3}M on treated TiO_2. It is clearly seen 19 hour is the best immersion time in dye solution to increasing absorbance for treated TiO_2.

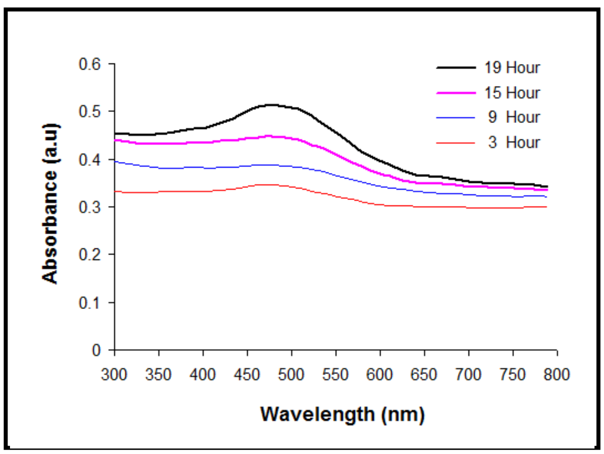

Fig. 4 Effect of immersion time in dye solution on treated TiO_2

Figure 3 and 4 shows that 10^{-3} M concentration of dye solution and 19 hour immersion time in it are the optimum condition to increase the absorbance of treated TiO_2.

Figure 5 shows the absorption spectrum of photo electrodes (bare TiO_2, treated TiO_2) and Curcumin dye were recorded by using UV-Vis spectrophotometer. Figure shows the increasing absorbance for bare TiO_2 and treated TiO_2 also shifting to the long wavelength of visible light which is evidence and indicate decreasing the energy gab of TiO_2 by sensitized with Curcumin dye as show in table I.

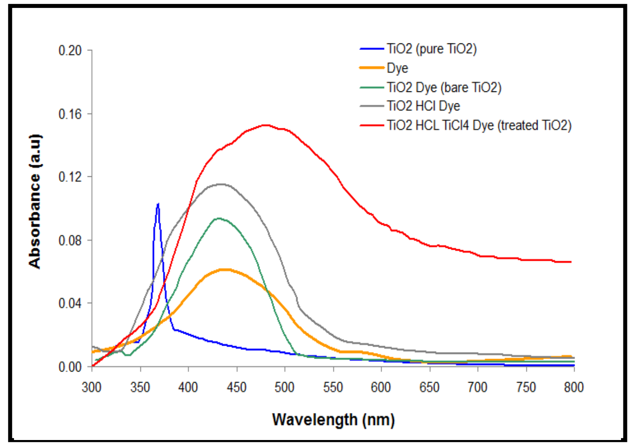

Fig.5 Absorption spectrum of photo electrodes (bare TiO_2, treated TiO_2), Curcumin dye and pure TiO_2

Table I shows the decreasing in E_g for treated TiO_2 more than bare TiO_2 that interpreted the increasing of absorbance and shifting to long wave of visible light for treated TiO_2 larger than bare TiO_2.

TABLE I
ENERGY GABS OF ALL PREPARED TiO_2 SAMPLE

Sample		Energy Gap (eV)
TiO_2	(pure TiO_2)	3.2
Dye		2.3
TiO_2 dye	(bare TiO_2)	2.5
TiO_2 HCl dye		2.4
TiO_2 HCl $TiCl_4$ dye	(treated TiO_2)	2.0

C. Electrical (photovoltaic) properties

Figure 6 shows the directly proportional of short circuit current with intensity of light for two types of DSSC. It is clearly appear the current in treated TiO_2 cell greater than bare TiO_2 cell that is attributed to increase the thickness of film which led to increase current that is related with increase the electron injection from exited dye to the conduction band of TiO_2. This results in agreement with work of [12, 14, and 15].

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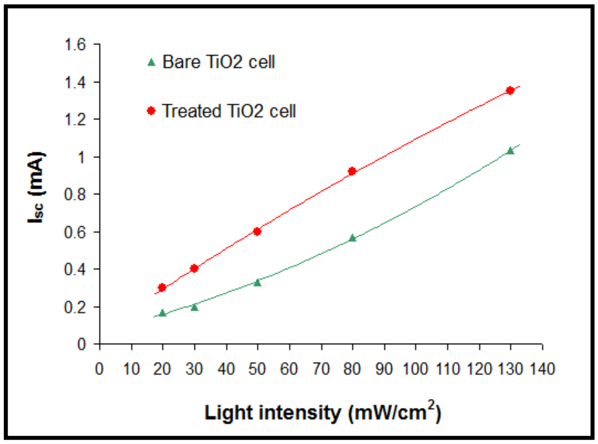

Fig. 6 Short circuit current curves for two types of constructed DSSC

Figure 7 shows the open circuit voltage changing with the intensity of light for two types of DSSC, also it is clearly seen the voltage for treated TiO_2 cell greater than bare TiO_2 as discussed in previous section.

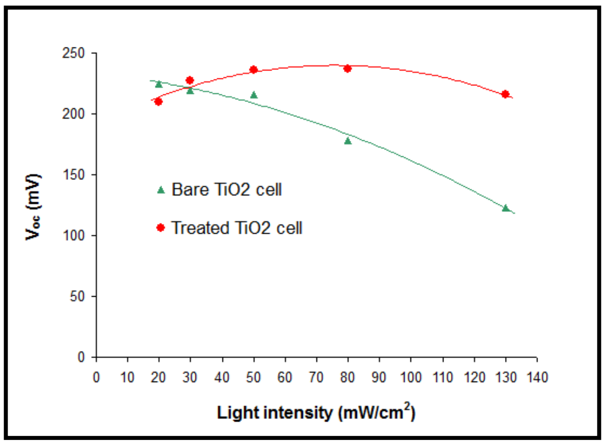

Fig. 7 Open circuit voltage curves for two types of DSSC

Figure 8 shows the comparison between the power conversion efficiency for two types of DSSC (bare TiO_2, treated TiO_2). As it is clearly appear the power conversion efficiency for bare TiO_2 cell larger than treated TiO_2 cell at different intensity of light. This is interpreted as clear from table II the current increase with increasing film thickness while fill factor and efficiency decrease, this result in agreement with [14, 15 and 16].

The efficiency 1.15% for bare TiO_2 cell achieved solar power conversion efficiency which is the highest efficiency obtained among all solar cell sensitized by Curcumin dye as comparison with previous literature of [1, 2, 4 and 10].

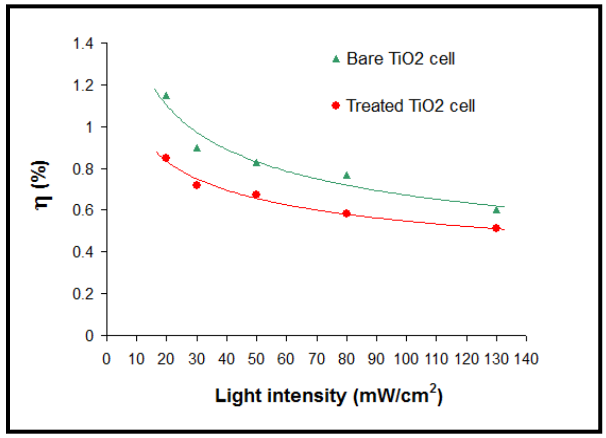

Fig. 8 The comparison between the power conversion efficiency for two types of DSSC

Table II Represents the performance of the DSSC in terms of short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and power conversion efficiency (η) for two types of DSSC [(bare TiO_2 and treated TiO_2) photo electrode] sensitized with Curcumin dye, under different intensity of light, for active area 1.5 cm^2.

TABLE II
PHOTOVOLTAIC PROPERTIES FOR TWO TYPES OF DSSC (BARE TiO_2 AND TREATED TiO_2) PHOTO ELECTRODE SENSITIZED WITH CURCUMIN DYE

Cell Types	Thickness (nm)	Light Intensity (mW/cm^2)	V_{oc} (mV)	I_{sc} (mA)	FF	η %
Bare TiO_2	895	20	225	0.17	0.907	1.15
		30	219	0.20	0.928	0.90
		50	216	0.33	0.883	0.83
		80	178	0.57	0.912	0.77
		130	123	1.03	0.923	0.60
Treated TiO_2	985	20	210	0.30	0.406	0.85
		30	227	0.40	0.368	0.72
		50	236	0.60	0.356	0.67
		80	237	0.92	0.321	0.58
		130	216	1.35	0.343	0.51

IV. CONCLUSION

This work has constructed two types of dye solar cell sensitized with Curcumin dye and a comparison made between their optical and electrical properties concluded the following:

1- Increasing absorbance for bare TiO_2 film and treated TiO_2 film also shifting to the long wavelength by sensitized with Curcumin dye.
2- Absorbance and shifting to long wave of visible light for treated TiO_2 film larger than bare TiO_2 film.
3- Decreasing energy gab for treated TiO_2 film sensitize with Curcumin dye more than bare TiO_2 film.
4- Concentration 10^{-3} M of dye solution and 19 hour immersion time in it are the optimum condition to increase the absorbance of treated TiO_2 film and shifting to long wave length of visible light.
5- Electrical parameters (voltage, current) for treated TiO_2 cell larger than bare TiO_2 cell.
6- Maximum value of current for two types of cell obtained at 130 mW/cm^2 intensity of light and decrease with decreasing this intensity.
7- Power conversion efficiency for bare TiO_2 cell larger than treated TiO_2 cell at different intensity of light and the maximum value for two types obtained at 20 mW/cm^2 intensity of light.

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