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EVALUATION AND COMPARISON OF THE CURRENT-VOLTAGE (I-V) PERFORMANCE FOR BOTH SILICON SOLAR CELLS AND DYE SENSITIZED SOLAR CELL (DSSC) COVERED WITH NATURAL PLANT DYES

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ABSTRACT:

A new concept based on introducing natural dye-sensitized molecules on the surface of Silicon Si solar cell namely "dyed Si solar cell" is introduced. This dye/Si interface is thought to be effectively enhanced efficiency. The IV readings are compared among (a) blank and covered Si solar cells, (b) DSSC using the same sensitized molecules. The results were recorded with different physical parameters like UV-visible Spectrum dyes, light intensity, cell area, and different fabrication Also, cell stability has been recorded. These results serve simply to give some of the cutting-edge of dyed Si solar cell with a huge improvement in its efficiency up to 121% with pot marigold flower dye (CC) dye at its optimum case and 16.53% in arthropodafotos-de- flower dye (ZZ) dye at its lowest case. While in DSSC, the efficiencies associated with the same natural dyes were very limited, rather sometimes they get lower. The results have been compared with similar group studies. Our new concept may be used as a highly promising technology for the dyed Si solar cell to give higher efficiency compare with its blank Si solar cell due to the suitability of dyes with silicon semiconductor, we suggest a figure for the new cell which is an ambiguous mechanism of cooperation between excited molecule with the promoted electron of silicon semiconductor, Si.

KEYWORDS: Si solar cell; Dye-sensitized solar cells; Natural flower dyes; Power conversion efficiency.

1. INTRODUCTION

conversion of solar energy to electricity is crucial nowadays as the concentration of carbon dioxide CO_2 has been increased in the atmosphere due to the use of only crude oil fuels in transportations and industries. According to the European Environment Agency (EEA) [1], the major responsibility for the increase in CO_2 emission levels lies with road transportation in which emissions have grown by 124 million tons from 1990-2014 [2].

As a result of scientists' awareness of the side effect comes from CO_2 emission, the researchers have concentrated to improve solar cell devices. Primitive research has been done to convert solar energy to electricity through photogalvanic cells [3-6] and photoelectric cells [7]. The improvement of the efficiency of converting light to electricity has been included using different semiconductors covered with artificial dyes called dyes sensitized solar cell (DSSC) which have been originally co-invented by Michael Grätzel and Brian O'Regan in 1988. In 1991 their work was developed and the first high-efficiency by dye sensitized solar cell (DSSC) was published [8]. Also, researchers have used natural photosensitizers in fabricating dye-sensitized solar cell [9,10]. Another group of researchers tried to produce hydrogen gas fuel from water [11-13] or hydrogen sulfide [14-18] as hydrogen fuel is clean and it will produce water without any pollution. Also, they found the cost of industrial production of hydrogen fuel is expensive from water and limited from hydrogen [15]. In 2006, the international society of hydrogen led by Naman start NATO Science for Peace and Security Series C project to carry on the separation of H_2S and formation of hydrogen fuel from the black sea [19-21]. Accordingly, the scientists have begun to enhance the efficiency of solar cells and by early 2000, they were able to get 24% electricity and by 2007, modern silicon PV solar cells were operating with 28% electricity [22]. The silicon solar photovoltaic (PV) cell is now established as the dominant cell [23]. Belonging to the group of thin-film solar cells, the DSSC is a low-cost solar cell [24], but still, they cannot produce industrially due to its stability. Regarding the classical silicon solar cell which they are using nowadays, a sandwich-type solar cell with different semiconductors and different artificial dyes presented as promising devices as they are made of cheaper, non-toxic, and eco-friendly material that worldwide available.

The silicon solar cell was fabricated by covering them with different natural plant dyes that have been collected from high altitude 2500 m as these dyes resist UV radiation and they are

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cheap. The efficiency and stability of the dyed Si solar cell have been evaluated [25].

Then some research on the DSSC using the same natural plant dyes to find the increase in the efficiency in the existence of I^-/I_3 electrolyte were done. The fabrication of these types of cells was very delicate and the increasing efficiency was limited. Rather it is decreased in some cases which is worse [26].

As known, the excited electron and hole are bounded through Coulomb interaction named as 'exciton'. To transport the charges, this exciton must be dissociated with energy dependent on the dielectric constant (ε) of the material. In materials with high ε like Si solar cell, the excitons could be dissociated thermally at ambient temperatures. While in organic semiconductors, the exciton cannot be dissociated thermally because of its low dielectric constants. So, to split it and collect the electrons in the conduction band, the exciton must be transported to an interface between materials with energy levels that have an offset greater than the exciton's binding energy [27]. Wouter et al. found that high dielectric constant materials show lower exciton binding energies and hence recombination can be reduced [28]. While, Niels Benson et al. introduced nanostructured high-k materials into the organic matrix, which effectively enhance the permittivity of the organic active layer and thereby reduce the Coulomb interaction [29].

In this research, the work on the dyed Si solar cells is expanded for the aim of comparing the effect of the same natural plant dyes on both dyed Si solar cell and DSSC efficiencies regarding their IV characteristics. This study has also been compared with different attempts of groups abroad to improve the efficiency of the solar cell. So, our new suggestion model mechanism is compared with the work done by Grätzel and co-workers on the DSSC in which they explain the mechanism of electron movement between dye molecules and semiconductors through anode and cathode [30]. Also this work is compared with the another group's work on organic light-emitting diodes (OLEDs) in which they found difficulties in fabrication beside they had used different types of efficiencies regarding dye wavelength [31].

2. EXPERIMENTAL

2.1. Preparation of dyed Si Solar Cells

2.1.1. Chemicals and substances: The spectroscopic grade solvents that have been used to extract the dyes from flowers are ethanol, n-Hexane, Acetone, and 2-Propanole from Fluke Co. and BDH Co, and they are used without any purification process. Monocrystalline silicon Si solar cells samples were from Al-Mansour company in Baghdad, Iraq, as a wafer with approximately 250 cm^2 area (manufactured in 04/01/1980). These solar cells were without a protective layer as this is the crucial point that should exist in our solar cells. The samples are prepared by cutting the wafer in different small rectangular areas, 0.33 cm^2, 0.65 cm^2, 0.69 cm^2, 0.70 cm^2, 0.707 cm2, 0.73 cm^2.

In this research, among a large number of flower pigments, just those which give us significant increasing efficiencies of solar cells after covering are selected to be considered as good sensitizers.

2.1.2. Apparatuses and Instruments: The setup consists of a four-prop computerized Source-Measure Unit (SMU) 2450 - KEITHLEY [32] as in figure 1. A graphical interface provides an I-V curve for indoor

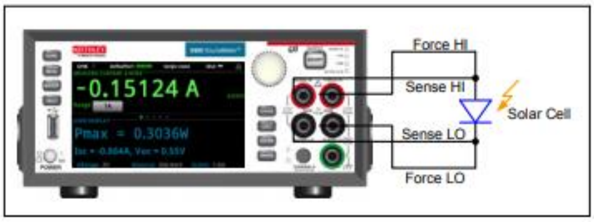

Fig. 1. Model 2450 SourceMeter connections to a solar cell. KickStart Software with MATLAB R2016a computer programs is used to quickly make measurements and get results.

and outdoor measurement of the performance of our dyed Si solar cell and DSSC, a visible light source with constant light intensity at 1.5 Air Mass (AM) for indoor measurements, Voltcraft PL-110SM Solar Light Meter. Our light source system is consisting of Housing for experiment lamp 08129.01 and Halogen lamp, lampvoet-G4, 12V/50-60Hz, 20 watts. All measurements are done at a fixed temperature which is measured by Voltcraft VC920 TRMS-DMM.

KickStart Measurement Software is the main part of our measurement systems which include the MATLAB R2016a program. The program is able for Auto measuring IV Curve beside seven performance parameters, Isc, Voc, Vpm, Ipm, Pmax, fill factor, efficiency as shown in Fig. 2.

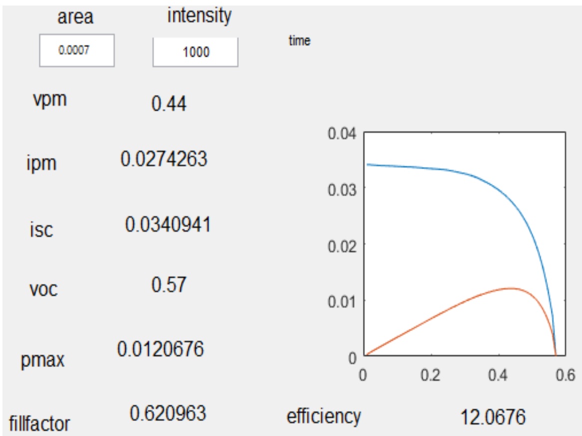

Fig. 2. The general performance parameters of the IV characteristics of our both solar cells by SMU 2450 Keithley.

2.1.3. Fabrication Process of Dyed Silicon Solar Cells: The fabrication process is done by covering Si solar cells with eight flowers dyes by the drop-casting method as shown in Fig. 3, three of them are collected from the top of Gara Mountain with high about 2500 m above sea level in the Kurdistan region, Iraq, and the rest five are from the nursery at Duhok city, (Longitude: 42.773725 and Latitude: 36.779556) see appendix

1. The extraction process for these dyes was done in a primitive way using different solvents [25 and 26].

The covering process is done under room temperature (20-30°C) and 50% humidity in just three simple steps:

1. The dye is extracted from flowers by using appropriate solvents such as ethanol, n-Hexane, Acetone, and 2-Propanol.
2. Pre-clean the bare surface of Si solar cell using water and ethanol.
3. Drop-casting method of covering Si solar cell with dyes followed by drying under room temperature to evaporate the solvents creating a thin layer of dye on the bare Si solar cell surface as in Fig. 3.

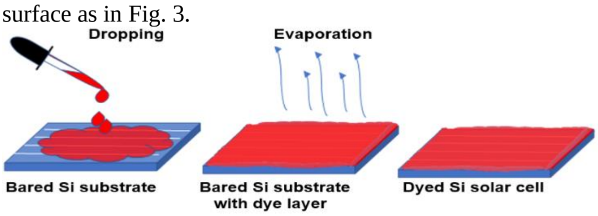

Fig. 3. Drop-casting method of covering Si semiconductor solar cell with dye.

The layer of dye-sensitized molecules was relatively stable with aging time. Virtually, any crake or surface irregularity wasn't found during the study. However, the main problem to be solved is how to clean the surface of the cell from the surrounding dust without affecting the dye layer deposited on the surface. To overcome this problem, the samples were kept covered with fabric to reduce the rate of dust on them.

Each cell was connected separately in a tight manner on a wooden base to avoid any movement that would change the angle of exposure to light. Also, the wires were stripped of the surrounding plastic at the closest point to the cell and were tightly tied to the wooden base to avoid the bad connection, hence reduce any leakage of current or voltage during work as shown in Fig. 4.

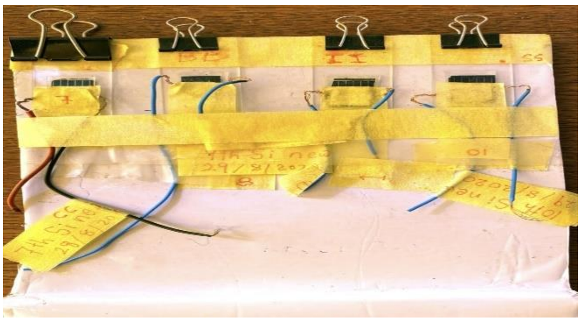

Fig. 4. Silicone solar cells are covered with different natural dyes connected with anode and cathode on the wooden base.

The performance of blank Si solar cells without dye and Si solar cells after covering with dye were tested. Current-Voltage curve consisting of all other parameters that have been mentioned earlier were measured using 2450 Source Meter. Then a comparison between blank and dyed Si solar cells is done to find out the effect of these dyes on light-harvesting efficiency at both indoor and outdoor measurements.

Tremendous research has been done on the energy conversion efficiencies indoor all over the world, but for outdoor measurements, it is not an easy job to control metrological beside some other parameters such as the angle of the incident sunlight to be 90°, intensity of light, temperature, and spectral distribution which affect the output electricity. So, a double experiment has been done for each sample of the Si cell separately at the same time around midnight before and after staining with dyes to control the above environmental conditions as much as possible.

In our new model, we have only two components that hopped to be more suitable between excited dye molecules, and Si semiconductor; there is no need for electrolyte in our cell. It is believed that there is a kind of attraction between dye molecules and Si semiconductor regarding physical adsorption or chemosorption by the formation of bounding between dyes and Si semiconductor which thought to has a great factor for the stability of this cell especially when it is chemosorption and it needs special annealing of the dyes with the semiconductor.

Our suggestion for the working principle of dyed Si solar cell is that we have here two sources for the free electrons' generation process under illumination as in Fig. 5 and Fig. 7. One from excited dye molecules on the surface of Si semiconductor and the other is from Si semiconductor conduction band, which we believe that there is a cooperation between them.

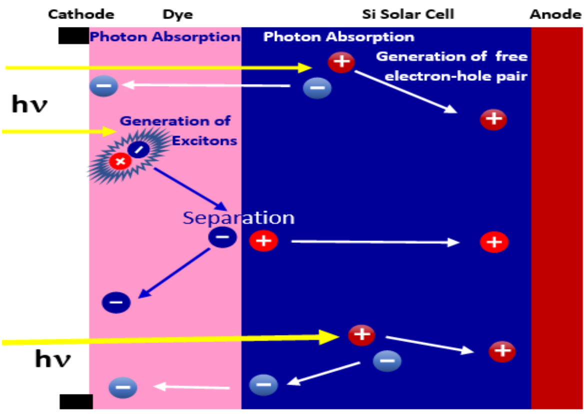

Fig. 5. The basic mechanism of a dyed Si solar cell under illumination.

A photon is absorbed by a dye-sensitized molecule generating an exciton, this exciton transport to the interface with Si solar cell which has a higher offset energy level to be dissociated letting the different charges reach the electrodes. Also, in the bulk of the Si solar cell, a free electron-hole pair is generated [33]. These electrons and holes are then transported to the electrodes too.

It is believed that the existence of sensitized dye molecules in contact with Si semiconductor will push down its conduction band level in the band diagram, getting a lower bandgap (Eg) [16, 34], and hence increasing power conversion efficiency as shown in fig. 6.

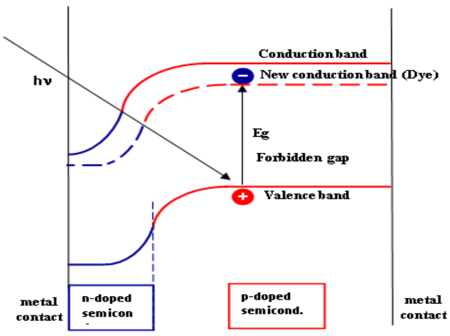

Fig. 6. Band diagram of a dyed Si solar cell, corresponding a new conduction band after covering with dye. It is believed that the dye molecules cooperate with Si semiconductors decreasing the energy gap resulting in increased efficiency.

2.2. Preparation of the dye-sensitized solar cell (DSSC)

In this research, we relied on the ready-made dye-sensitized solar cells that were used in our previous study [26].

These DSSC had been immersed in the same eight flower dyes that were used with Si solar cells in this study. Another comparison has been summarized, between the dyed Si solar cell and DSSC to find the effect of the dyes on their performance. In contrast to inorganic Si solar cells, the DSSC is a complex solid/liquid system. The fast charge transfer gives fast recombination and decreased efficiency, while slow charge transfer also leads to decreased efficiencies [35]. A major problem with this kind of dye cell is that the increased efficiency is a function of different factors through several steps that must be in harmony with each other. As in Fig. 7 (left), first of all, the energy gap of semiconductor play an important role and it must be regarded [33, 35]. Second, the electron in its vouge starting from photoexcitation of charge transfer dye molecules and ending with its migration through the external electrical circuit is faced at least different eight velocities [33]. The dye is supposed to absorb light radiation to release photo-excited electrons jumping from highest occupied molecular orbital HOMO to the lowest unoccupied molecular orbital LUMO at V_1, which then should be injected into the conduction band (CB) in the semiconductor at V_2, the excited LUMO electron now transfer to the conduction band of TiO_2 at V_3 to reach the anode through an external circuit, yielding a sensitizer hole that should be regenerated by electron donation from iodide in the electrolyte at V_4, now this iodide must be regenerated by reduction process of triiodide on the counter electrode at V_5 on the cathode. On the other hand, recombination at the oxide/dye interface at V_6 and electrolyte/oxide interface at V_7 besides a relaxation of the excited dye to its ground state at V_8 also occur and so a lower efficiency is gotten as a result [33, 34]. Since all these motions have been done at different velocities, so the rate-determining steps of the efficiency is depending on the lowest velocity step which is either at the semiconductor, dye, or electrolyte. If the difference between them is big so one can say that there is no cooperation among these three materials. Besides, many other important phenomena in DSSC like, the role of interface polarizability, exciton transport rate, interfacial electronic states, the process of interfacial charge–carrier recombination, etc., are not well understood [36]. On other hand, under the illumination of dyed Si solar cell as in Fig. 7 (right), the excited dye molecules will pump electrons to the new conduction band of Si semiconductor forming holes (anode). Now, Si semiconductor new conduction band pumps the electrons to the cathode to flow through the external circuit (16, 34).

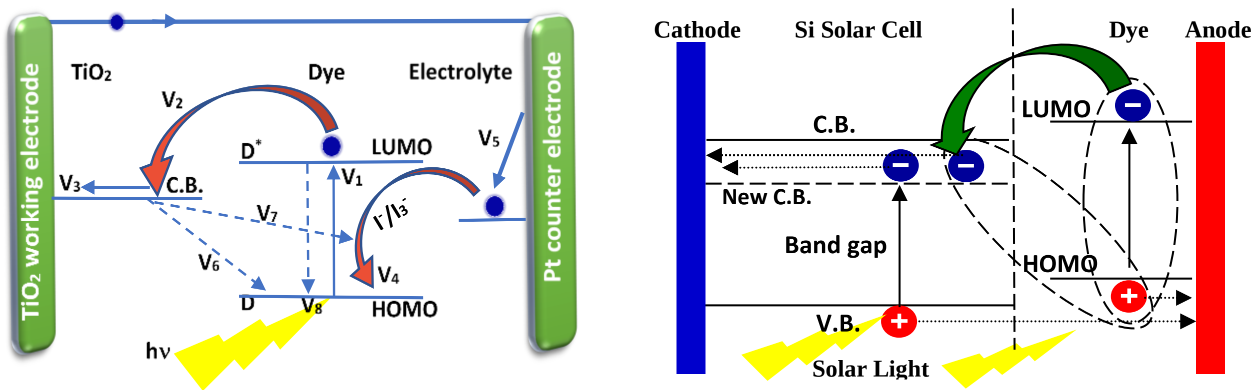

Fig. 7. Construction of DSSC cell with dye molecules based on TiO_2 semiconductor and I^-/I_3^- electrolyte (sandwich cell) (left) compared with the construction of our dyed Si solar cell with its energy levels (including the new conduction band) of the silicon semiconductor and dye components without the existence of electrolyte (right). [16, 34].

3. RESULTS AND DISCUSSION

Characterization of both dyed Si solar cell and DSSC performance for similar dyes is depending on the absorption of these dyes to solar light and the current-voltage curve of both cells. The optical density of the dyes can be obtained from the UV-Vis spectra. While, IV characterization for each cell determines the efficiency of conversion of light to electrical energy which is tabulated for Si cells in Tables 1 and 2, and DSSC cells in Table 3.

3.1. Optical Properties of Dyes

The absorption peaks of the spectra for both Gara mountain flower dyes and nursery Duhok city flower dyes extracts were measured. The optical densities are plotted against wavelengths as shown in Fig. 8 (a, b, and c).

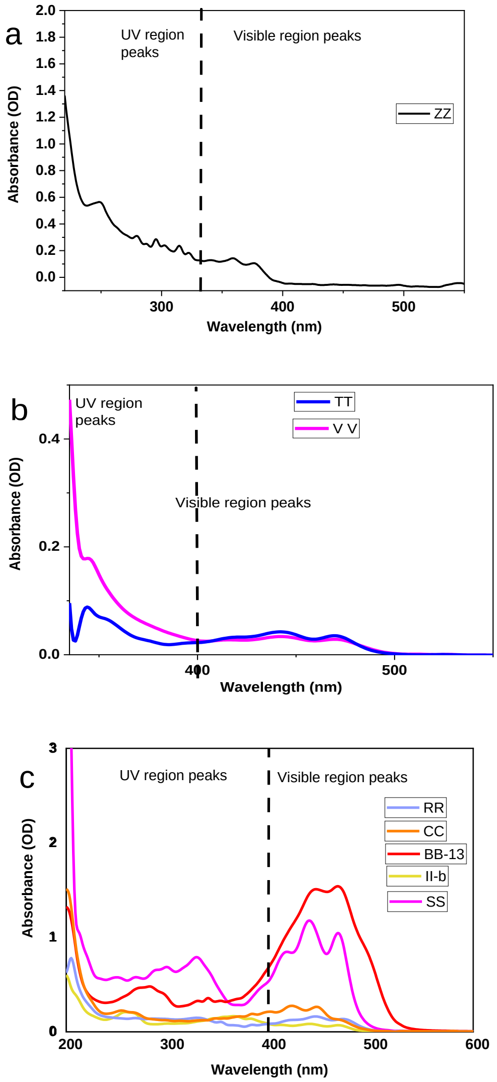

Fig. 8. The absorption spectra of Gara mountain flowers dyes (a & b), nursery Duhok city flower dyes (c), at a different rate of optical densities. The same weight of flowers and the same volume of solvents are used [26].

From the spectra in Fig. 8 (a and b) the absorptions of mountain dyes ZZ, VV, TT in the ultraviolet are much higher than in the visible region which means they have a resistivity to UV. While from Fig 8 (c), it is clear that the dyes from the nursery have a lot of absorbance in the visible region. These dyes absorb a lot of visible light but are weak and unstable against the UV light of solar radiation [26].

3. 2. Outdoor Characterizations of Dyed Si Solar Cells

The efficiency for each of the eight Si solar cells was measured before covering it with dye and considering it as a blank efficiency. Although the blank efficiencies of these eight cells differ from each other as in Table 1 & 2, this may be due to our experimental error during connecting the wires to electrodes manually in a small cell area. This step was the most delegated step to be controlled for one is ought to be careful to prevent the anode and cathode terminals from directly shorting while soldering the wires to the electrodes in a small area.

Table 1 illustrates the outdoor measurements of blank and dyed Si solar cells with light intensity ~ 700 W/m^2 for different cells area.

According to the spectra absorptions of those dyes in fig. 8 (a, b, and c), it was thought that the increase in efficiencies of Si cells with mountain plant dyes might be significantly different from those covered with nursery plant dyes. Unlike what we thought, and what is astonishing in the actual experimental data is that almost all dyed Si cells efficiencies have been increased significantly to varying degrees. as shown in table 1.

Table 1. Outdoor IV characteristics of blank and dyed Si solar cells covered with natural plant dyes: RR, ZZ, VV, TT, CC, BB, II, SS.

Sample	Area cm^2	Isc × 10^{-2} Amp.	Voc volt	FF	Effie. %	Change in Effie. Δη	Percentage increase Δη %
Blank Si solar cell and covered with ZZ dye molecules/ Mountain							
Blank	0.69	2.34	0.44	0.34	7.18		
ZZ		2.42	0.46	0.34	7.94	0.76	10.58
Blank Si solar cell and covered with V V dye molecules/ Mountain							
Blank	0.707	2.78	0.47	0.49	13.03		
VV		2.75	0.5	0.49	13.61	0.58	4.45
Blank Si solar cell and covered with TT dye molecules/ Mountain							
Blank	0.70	2.83	0.49	0.45	12.70		
TT		3.33	0.51	0.46	15.87	3.17	24.96
Blank Si solar cell and covered with RR dye molecules/ Nursery							
Blank	0.33	1.67	0.48	0.46	15.89		
RR		1.77	0.49	0.49	18.22	2.33	14.66
Blank Si solar cell and covered with CC dye molecules/ Nursery							
Blank	0.70	2.30	0.45	0.48	10.05		

CC		2.81	0.48	0.51	14.17	4.11	40.99
Blank Si solar cell and covered with BB dye molecules/ Nursery							
Blank	0.65	2.04	0.52	0.53	12.36		
BB		2.28	0.53	0.50	13.20	0.84	6.79
Blank Si solar cell and covered with II dye molecules/ Nursery							
Blank	0.70	3.28	0.48	0.47	15.10		
II		3.53	0.49	0.43	15.14	0.04	0.26
Blank Si solar cell and covered with SS dye molecules/ Nursery							
Blank	0.73	3.36	0.47	0.48	14.85		
SS		3.47	0.48	0.47	15.40	0.55	3.70

3. 3. Indoor Characterizations of Dyed Si Solar Cells

A series of experiments have been done on indoor IV characteristics of Si solar cells covered with the following dyes: ZZ, VV, TT from Gara mountain, and RR, CC, BB, II, and SS from a Duhok nursery as shown in Table 2. The energy conversion efficiencies were measured using SMU under 1000W/m^2 halogen lamp (1.5 AM).

The most striking result to emerge from the data in Table 2 is that getting different jumps in the efficiencies of the blank Si solar cells after covering them with different dyes as shown in Fig. 9 for some dyes. The tabulated data in both tables (1 and 2) are the average of several readings. From these tables, the change in efficiency $\Delta\eta$ of dyed Si solar cell ranges between 0.04 for II to 4.11 for CC at outdoor measurements, and between 2.06 for ZZ to 12.00 for CC at indoor readings.

Table 2. Indoor IV characteristics of dyed Si solar cells covered with natural plant dyes: RR, ZZ, V V, TT, CC, BB, II, SS

Sample	Age of cell/day	Area cm^2	Isc × 10^{-2} Amp.	Voc volt	FF	Effie. %	Change in Effie. $\Delta\eta$	Percentage increase $\Delta\eta$%
Blank Si solar cell and covered with ZZ dye molecules / Mountain								
Blank	0	0.69	4.00	0.51	0.42	12.46		
ZZ	0		4.10	0.50	0.40	11.64		
ZZ	1		3.90	0.50	0.42	11.75		
ZZ	4		4.88	0.53	0.39	14.52	2.06	16.53
ZZ	6		4.48	0.52	0.38	12.69		
Blank Si solar cell and covered with V V dye molecules/ Mountain								
Blank	0	0.707	4.03	0.53	0.53	16.00		
VV	0		4.09	0.53	0.56	17.32		
VV	1		4.43	0.54	0.54	18.16		
VV	4		4.89	0.55	0.53	20.23	4.23	26.43
VV	6		4.40	0.55	0.53	18.17		
Blank Si solar cell and covered with TT dye molecules/ Mountain								
Blank	0	0.70	4.32	0.54	0.53	17.62		
TT	0		4.72	0.54	0.53	19.33		
TT	1		5.02	0.55	0.52	20.53		
TT	4		5.31	0.56	0.55	23.30	5.68	32.22
TT	6		5.31	0.55	0.50	20.80		
Blank Si solar cell and covered with RR dye molecules/ Nursery								
Blank	0	0.33	2.32	0.51	0.45	16.01		
RR	0		2.42	0.51	0.45	16.77		
RR	1		2.49	0.52	0.44	17.41		
RR	4		2.73	0.53	0.46	20.23		
RR	6		2.91	0.54	0.48	22.74	6.73	42.03
Blank Si solar cell and covered with CC dye molecules/ Nursery								
Blank	0	0.70	4.00	0.51	0.34	9.87		
CC	0		4.00	0.5	0.49	13.93		
CC	1		4.23	0.51	0.53	16.42		
CC	4		5.19	0.53	0.53	20.83		
CC	6		5.56	0.53	0.52	21.87	12.00	121.58
Blank Si solar cell and covered with BB dye molecules/ Nursery								

Blank	0	0.65	3.95	0.56	0.54	18.50		
BB	0		3.87	0.56	0.52	17.20		
BB	1		4.15	0.56	0.54	19.24		
BB	4		5.00	0.57	0.53	23.24		
BB	6		4.93	0.58	0.53	23.27	4.77	25.78
Blank Si solar cell and covered with II dye molecules/ Nursery								
Blank	0	0.70	4.56	0.52	0.41	14.03		
II	0		4.34	0.51	0.49	15.45		
II	1		4.40	0.52	0.47	15.50		
II	4		5.29	0.54	0.40	16.49	2.46	17.53
II	6		3.57	0.53	0.37	10.13		
Blank Si solar cell and covered with SS dye molecules/ Nursery								
Blank	0	0.73	4.97	0.52	0.50	17.61		
SS	0		4.50	0.50	0.50	15.55		
SS	1		4.94	0.52	0.52	18.24		
SS	4		5.61	0.54	0.51	21.25		
SS	6		6.05	0.52	0.51	22.09	4.48	25.44

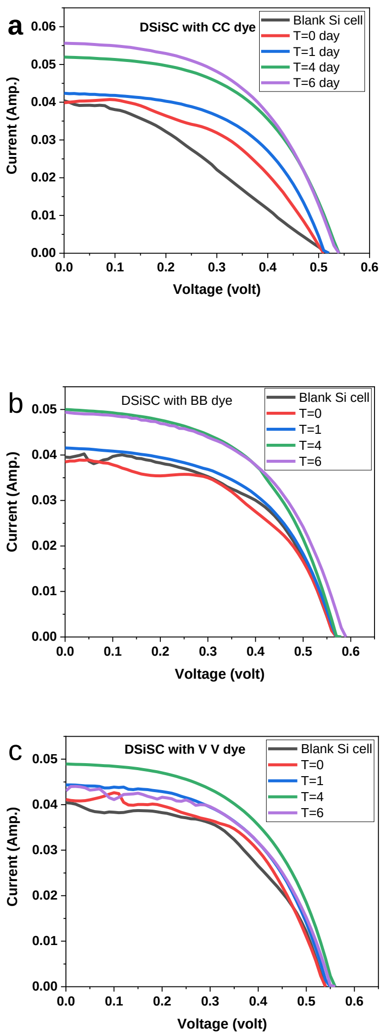

Fig. 9. The photocurrent-voltage curve of Si solar cell before and after covering with different natural flower dyes, (a) for CC dye, (b) for BB dye, and (c) for VV dye during 1 to 6 days.

The code and name of these flowers are in appendix 1 while the IV characteristics are tabulated in Table 2. Our IV characteristic calculation results are different than other workers may be our Si semiconductor solar cell hasn't the same crystal type.

A significant sharp and clear percentage increase in the efficiency of dyed Si solar cells has been achieved in this study. For example, at outdoor measurements, the efficiency has been increased in ZZ by 10.58%, in TT by 24.96%, in RR by 14.66% and in CC was 40.99%. At indoor measurements, the percentages increase of the efficiencies were 16.53%, 17.53%, 25.44%, 26.43%, 25.78%, 32.22%, 42.03% for ZZ, II, SS, VV, BB, TT, RR respectively, while the extreme percentage increase in the efficiency was in CC dye which is more than 100%. These remarkable increases in the efficiencies lead one to be optimistic about a bright future for dyed Si solar cells.

The Δη of each sample and Δη% are calculated using the following equations:

$$\Delta\eta = \eta_{max} - \eta_{Blank} \quad (1)$$

$$\Delta\eta\% = (\Delta\eta/\eta_{Blank}) \times 100\% \quad (2)$$

The Δη is calculating by subtracting blank efficiency (η_{Blank}) from the maximum value of our solar cell efficiency (η_{max}) that we get from each cell. This indicates the possibility of achieving such a high level of conversion efficiency after staining the silicon cells with natural dyes. In each cell, the fluctuation of its efficiency increases is might be due to the disadvantages of a drop-casting technique, that we depended on. In such a primitive deposition technique, it is not easy to get a uniform coating layer of dye in a certain cell beside it is hard to control the thickness of all cells manually. Also, the rate of evaporation is out of control and differs from one dye to another regarding the variation in room temperatures.

3.4. Photovoltaic Performance of the DSSC

In this section, the ready results from the previous study on DSSC [26] is depended to compare the effect of sensitized dye on the efficiencies of both these cells and our new model, dyed Si solar cells, (Table 2), using same dyes.

Different natural dyes were used in DSSC and the stability of the efficiency was studied at different periods as shown in Table 3.

3.5. Comparison between Dyes Si Solar Cell and DSSC Efficiencies

Grätzel cell, DSSC, is highly regarded due to its ability to convert sunlight to electricity with non-toxic and low-cost materials in which organometallic complex dye has been used [8].

In this study, we used only pure organic natural flower dyes (not organometallic complex). The Si solar cell has a blank sample while in DSSC, the dye is one of the cell components itself. The constructions of DSSC contains electrolyte I^-/I_3^-, Fig. 7 (left), while our new dyed Si solar cell is without electrolyte as in Fig. 7 (right).

The results revealed no significant efficiency in our DSSC. They were very limited and, in some cases, they give approximately the same efficiencies such as in ZZ, VV, and TT and in the worse cases, they were decreased with time such as in RR, CC, BB, II, and SS. This means that these dyes are not suitable for DSSC compared to the results achieved from the dyed Si solar cell. Although the fabrication of DSSC is very simple and could be done with very primitive instruments and tools, however; the cooperation between the excited electrons of dye and energy band of TiO_2 semiconductor with the existence of a liquid electrolyte is not that easy rather it is very complicated and it seems that there is no obvious a good cooperation between the excited electrons of dye with the energy levels of TiO_2 semiconductor. Maybe the excited electrons of these dyes are not giving help to promote electrons of TiO_2 semiconductor from its valance band to conduction band. This might be due to either electrolyte, the natural dyes, or TiO_2 semiconductor that result in low efficiency. Also, maybe the existence of I^-/I_3^- liquid electrolyte is not suitable for this type of DSSC.

On the other hand, Using the same eight natural plant dyes, it is found that the Si solar cell accepting natural dyes leading to a higher significant increasing efficiency much more than DSSC.

The comparison results are tabulated in Table 3. The single most interesting observation to emerge from the data comparison was that the efficiency for Si solar cell is dramatically increased especially for CC dye which increased from 9.87 to 21.87 which is more than 100%.

Table 3. Energy conversion efficiencies of both dyed Si solar cell and DSSC using the same natural plant dyes.

Natural Dyes	**Si Solar Cells**				**Natural Dyes**	**DSSC**			
	Period	**Efficiency (η)**	**Δη**	**Δη%**		**Period**	**Efficiency (η)**	**Δη**	**Δη%**
			(Increasing)					**(Decreasing)**	
Blank	**0 day**	**12.46**							
ZZ	0 day	11.64			ZZ Mountain	0 day	3.27		
ZZ	1 day	11.75			ZZ Mountain	12 days	3.29		
ZZ	4 days	14.52	2.06	16.53	ZZ Mountain	70 days	3.26	0.016	-0.48
ZZ	6 days	12.69							
Blank	**0 day**	**16.00**							
V V	0 day	17.32			V V Mountain	0 day	4.05		
V V	1 day	18.16			V V Mountain	12 days	4.04		
V V	4 days	20.23	4.23	26.43	V V Mountain	70 days	4.06	0.005	0.12
V V	6 days	18.17							
Blank	**0 day**	**17.62**							
TT	0 day	19.33			TT Mountain	0 day	4.82		
TT	1 day	20.53			TT Mountain	12 days	4.54		
TT	4 days	23.30	5.68	32.22	TT Mountain	70 days	4.52	-0.296	-6.14
TT	6 days	20.80							
Blank	**0 day**	**16.01**							
RR	0 day	16.77			RR Nursery	0 day	2.74		
RR	1 day	17.41			RR Nursery	12 days	2.13		
RR	4 days	20.23			RR Nursery	70 days	0.63	2.108	-76.99
RR	6 days	22.74	6.73	42.0					
Blank	**0 day**	**9.87**							
CC	0 day	13.93			CC Nursery	0 day	3.09		
CC	1 day	16.42			CC Nursery	12 days	2.19		

CC	4 days	20.83			CC Nursery	70 days	0..91	-2.172	-70.38
CC	6 days	21.87	12.00	121.58					
Blank	**0 day**	**18.50**							
BB	0 day	17.20			BB Nursery	0 day	3.15		
BB	1 day	19.24			BB Nursery	12 days	2.25		
BB	4 days	23.24			BB Nursery	70 days	1.24	-1.910	-60.77
BB	6 days	23.27	4.77	25.78					
Blank	**0 day**	**14.03**							
II	0 day	15.45			II Nursery	0 day	3.80		
II	1 day	15.50			II Nursery	12 days	3.34		
II	4 days	16.49	2.46	17.53	II Nursery	70 days	3.18	-0.621	-16.35
II	6 days	10.13							
Blank	**0 day**	**17.61**							
SS	0 day	15.55			SS Nursery	0 day	4.19		
SS	1 day	18.24			SS Nursery	12 days	3.62		
SS	4 days	21.25			SS Nursery	70 days	2.05	-2.140	51.08
SS	6 days	22.09	4.48	25.44					

4. CONCLUSION

The results in table 3 show that dye-sensitized solar cells are not well responded to our natural dyes. This may be because DSSC has complex construction especially the electrolyte I^-/I_3^- which has a temperature stability problem [37]. Besides the fabrication of DSSC containing TiO_2 with high energy gap. Also; using different intensities (indoor and outdoor) will affect the performance of DSSC, therefore replacing the TiO_2 semiconductor with other semiconductors having a lower energy gap with new electrolytes maybe will give us promising results.

Also, the low efficiency of DSSC to our dyes may be due to our primitive method of fabrication. But same primitive methods had been used in the fabrication of our dyed Si solar cell. Covering dye on the surface of Si cell by the drop-casting method and manual connection of the anode and cathode show a good response to these dyes as the efficiencies increased to the extent of more than 100%. This giving us promising increases in efficiency after covering with the dyes.

If we compare our results with the Grätzel cell [30], the mechanism of electron promotion inside this cell is different due to the structure of both cells as in fig. 7. Although they have been used in very sophisticated fabrications, while the results of OLEDs [31] have been dependent on different parameters for calculating efficiency using a different wavelength of UV and visible color for emitting polymer dye.

Due to the complex solid/liquid system and low efficiency as well as stability of DSSC, we emphasize in our research to find a simple fabrication process of the cell using natural flower dyes on Si solar cell.

Our future work will be concentrated on the mechanism of electron movement inside the dyed Si solar cell by changing Si semiconductor, new natural organic dyes beside other physical variables including intensity of light, annealing processes, the thickness of the dye, the effect of dyes spectra (UV–visible) on the stability, etc.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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APPENDIX 1. THE SCIENTIFIC NAME [38-40] THE COD, AND THE PHOTO OF EACH FLOWER IN GARA MOUNTAIN AND NURSERY GROUPS FLOWERS.

ZZ: arthropodafotos.de Colutea arborescens, Bladder senna - arthropodafotos.de 	V V: ansy (Tanacetum vulgare) 	TT: Cowslips primula veris 	RR: Osteospermum ecklonis 
CC: Pot Marigold, Calendula 	BB: Gazania rigens Orange 	II: yellow pansy (Viola pedunculata) 	SS: Gazania rigens Yellow