Pyranine Dye as Solar Cell Concentration

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Abstract
A method was proposed to construct a luminescent solar concentrator (LSC) by using a Pyranine dye. it's organic dye , fluorine and sensitive to light. The efficiency of silicon solar cell was measured before and after using the (LSC). Significant improvement was noticed in the solar cell efficiency (η) Where the increase was of efficiency from (0.619) to (2.192). and also, the (absorption & fluorescence), stokes shift (Δη), radiated lifetime (τ_{fm}) , fluorescence lifetime (τ_f) and quantum efficiency (Q_{fm}) was calculated.

Keywords — Conversion efficiency Solar cell, Dye concentrator, Organic Dyes.

I. INTRODUCTION

The technology of energy has a central role in social and economic development over wide range of scales. the energy is highly connected to the environmental pollution, one the biggest and most important problems on earth. Today, mostly we are dependent on non-renewable fossil fuels that have been and will continue to be a major reason of pollution and climate change. as becaoes these problems and our dwindling supply of petroleum, finding sustainable alternatives is becoming increasingly urgent. Perhaps the greatest challenge in realizing a sustainable future is to develop technology for integration and control of renewable energy sources in smart grid distributed generation [1]. One of the most importent and largest sources of reneweble enargy for life on Earth is the sun [2]. The sun is mainly for two types of energy, which are light and heat that is harnessed using a range of eve revolving technologies [3][4]. And light travels from the horizon of sun to the horizon of Earth in about (8) minutes and (19) seconds [5]. Above the photosphere visible-sunlight is free to propagate into space, and almost all of sun's energy escapes it entirely [6]. The potential for solar photovoltaic is enormoues, with the intensity of direct sunlight on surface of the earth exceeding (1000 W/m2) [7].A solar cell, or (photovoltaic cell), is an electrical device that converts the energy of light directly into electricity by means of the photoelectric effect, which is a chemical and physical phenomenon [8]. To indicate that photovoltaic cells are not only environmentally friendly, but they provide clean, efficient, reliable and uninterrupted power sources [9]. Photovoltaic energy is the direct production of the electric current and voltage of electromagnetic (such as light visible , infrared and ultraviolet radiation) [10]. The energy source of a solar cell is photons coming from the sun. This input is distributed, in ways that depend on variables such as latitude, longitude, and weather conditions, across different wavelengths. Different possible distributions are called solar spectra. This photovoltaic input product, in the case of solar cells, is electrical energy that can be used in the form of current and voltage [10]. The best way to reduce the costs of solar cells is simply to use less material. If we concentrating light onto a smaller area, we the price of a photovoltaic system can be cut considerably. The standard ways of concentrating involve using mirrors to refract, lenses or reflect light onto a smaller area. Unfortunately, all that intense light starts to heat up the solar cell (SC), and it has been demonstrated that the efficiency of a photovoltaic cell worsen as temperature increases [11]. Another difficulty for traditional concentrators is that they must track the path of the sun in order to ensure that the light is directed to the correct point. The electronics and engines required to track the sun add a big cost to the system [12]. An alternative method of concentrating light is the use of Luminescent Solar Concentrators (LSC). An LSC is made of a luminescent dye or (Fluorinated materials) in a transparent substrate, usually glass or plastic, with photo-voltaic cells placed around the edges. The Light enters the face of the substrate, where it is absorbed by the material (dye). The dye reemits another photon at a longer wavelength, and this is waveguided to the edge of the substrate via total internal reflection. So the new photon reaches the edge, it can be absorbed by the photovoltaic cell. When a photo-voltaic cell absorbs a photon with energy greater than the band gap of the photo-voltaic cell, the excess energy is converted into heat. Luminescent material (dye) emit most of their light at longer wavelengths than they absorb, so that the light that the solar cells absorb is neaver to the peak of the responsivity. This means that the solar cells absorb light more efficiently, and the (LSC) do not heat up the solar cells. Also, (LSC) do not need to track the sun because they work just as well, if not better, in diffuse light rather than direct light [12]. A Luminescent Solar Concentrator (LSC) generally consists from a planar waveguide doped with luminescent materials and a solar cell attached to one or more edges of the waveguide. Such design is capable of collecting sunlight over a large area, converting it into luminescent light, and concentrating the luminescent light into a small area by the total internal reflection (TIR) mechanism [13]. Based on this concept, (LSC) is expected to output a relatively higher power than the attached solar cell under the same sunlight, and meanwhile significantly reduce the use of solar cell materials.[14]. The (LSC) concept is based on a planar device in which a fraction of the diffuse or direct sunlight, entering through the top of a transparent medium (glass or plastic),that is converted to fluorescent light by luminescent materials deposited on top of or embedded within the medium. furthermore, the solar spectrum can be segmented by using stacked concentrators and bandgap matched photo-voltaics to increase conversion efficiency. The parameter space in luminescent solar concentrator design, nevertheless, is vast and optimizing their performance empirically is a daunting challenge [15]..

II. PYRANINE DYE

Pyranine is a hydrophilic, pH-sensitive fluorescent dye from the group of chemicals known as arylsulfonates [16,17]. Pyranine is soluble in water and has applications as a coloring agent, biological stain, optical detecting reagent, and a pH indicator [18,19]. One example would be the measurement of intracellular pH [20]. Pyranine is also found in yellow highlighters, giving them their characteristic fluorescence and bright yellow-green colour. It is also found in some types of soap [21]. Figure(1) shows the chemical composition of the pyranine dye and Table(1) shows the physical and chemical properties of pyranine dye.

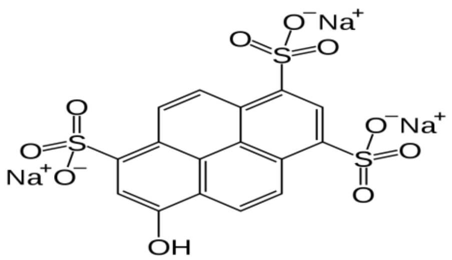


Fig 1: The structure of pyranine dye.

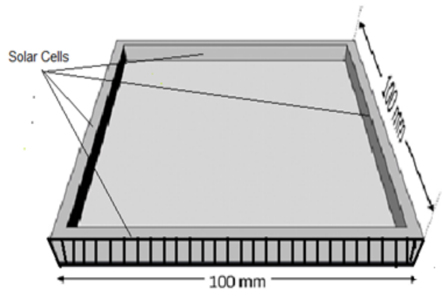
TABLE I

shows the physical and chemical properties of pyranine dye

Properties	
Mulcarole formula	$C_{16}H_7Na_3O_{10}S_3$
Molar mass	524.37 g/mol
Physical state	yellow to greenish crystalline powder
Melting point	> 300 C
Solubility in water	Soluble
Other names	arylsulfonates
Main hazards	XI
λmax of Absorbance	454 nm
λmax of fluorescence	511 nm

III. EXPERIMENT

A number of different concentrations of the Pyranine dye were prepared in the laboratory .the fluorine and absorbent wase measured by using uv-spectrovotometer and fluoricens devices we desigh cubic shape having small solar cell in all side of this design all of them conected to ghther as showen in figure (2) to in easarement the effrciencyn of this design in different dye concentrator



. Fig 2: Design of LSC.

IV. RESULTS AND DISCUSSION

The absorption and Fluorescence Spectrum have been studied for Eight concentrations of Pyranine dyes in Water (11×10^{-4}, 15×10^{-4}, 38×10^{-4}, 57×10^{-4}, 76×10^{-4} , 95×10^{-4}, 11×10^{-3} and 15×10^{-3}) *mol/L*. The Pyranine dyes have a large absorption spectrum in the region (300-500) nm. At minimum concentration (11×10^{-4} *mol/L*) the peak of absorption spectrum is (0.392) at wavelength(453) nm, and maximum concentration (15×10^{-3} *mol/L*) the peak of absorption spectrum is (2.91) at wavelength (459) nm as shown in figure(3). Also the fluorescence spectrum intensity extendat from 450 to 640 *nm* at the lowest concentration (11×10^{-4} *mol/L*) the peak of fluorescence spectrum is (521) at wavelength (510) *nm* and so for a high concentration (15×10^{-3} *mol/L*) the peak of fluorescence spectrum is (270) at wavelength (512) *nm* as shown in figur (4).

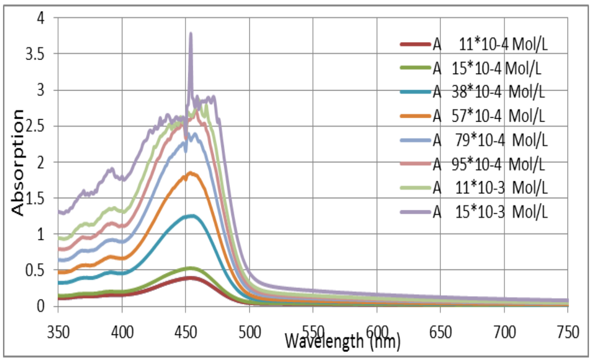


Fig 3: Absorption spectrum of Pyranine dye at different concentrations.

It is noticed that the highest absorption intensity of (15×10^{-3} *mol/L*) and it decreases in low concentrations according to Bert Lambert Law because there is a relationship between light absorptivity and substance properties through which the light penetrates. According to figure(3), it was noticed that the top of the absorption spectrum of the high concentrations is broad (a deviation in the Bert Lambert Law) due to the interaction or the effect of the solute molecules together, and the high concentrations increase the strength of the attraction and repulsion between the particles, which leads to the dispersion of light instead of absorption.

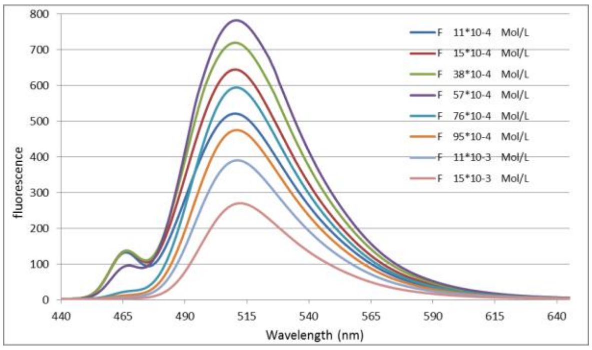


Fig 4: fluorescence spectrum of Pyranine dye at different Concentrations.

Figure (4) shows that Pyranine dye fluorescence is higher with low concentrations. When Visible light is falls on the solution of pyranine dye, the molecule absorbs this radiation and the electron its atoms move to a higher level and then return to a low level with emission of their photons in a process called relaxation

The highest fluorescence intensity is in the wavelength (511 nm) with concentration (57×10^{-4} *mol/L*) where it reaches (782) and the minimum fluorescence intensity is in the wavelength (512 nm) with concentration (15×10^{-3} *mol/L*) where it reaches (270).we were able to calculate the area under the curve of molar absorptivity using the Matlab Program, and calculated the radiation lifetime (τ_{fm}), quantum efficiency (Q_{fm}) and fluorine life time (τ_f), as shown in Figure (5). table (2) show wavelengths for higher absorption, as well as wavelengths for higher fluorescence, Stokes shift, radiation lifetime (τ_{fm}), fluoridation lifetime (τ_f), and quantum efficiency (Q_{fm}) of Pyranine dye were calculated through the following equations [22]:

$Q_{fm} = \int F((v^-) dv^-) / (\int \varepsilon (v^-) dv^-)$ ………..……….(1)

Where $\int F((v^-) dv^-)$ is the total area under the curve of the fluorescence, and $\int \varepsilon (v^-) dv^-$ is the area under the curve of the molar absorption coefficient which is a function of the wave number (v^-). And the Radiated lift time (τ_{fm}) and fluorescence life time (τ_f) calculate according to the equation as follows [22]:

$\tau fm = 1/Kfm$ ………………………………….(2)

τ_{fm} is the radiative lifetime and its unit (s), Where Kfm is the rate of disappearance of the unit (s^{-1}). which can be calculated using the Einstein coefficient for self-emission equation [22].

$\tau f = Qfm \times \tau fm$ ………………….…………(3)

τ_f is fluorescence lifetime and its unit (s).

TABLE III

Wavelength of maximum absorbance (λ_{Amax})and fluorescence (λ_{Fmax}) , stokes shift ($\Delta\lambda$) , radiated and fluorescence life time (τ_{fm}, τ_f), and quantum efficiency(Q_{fm})of pyranine dyes at different con Concentration.

Concentration mol/L	λ A_{max} nm	λ F_{max} nm	Stokes Shift $\Delta\lambda=\lambda_{flo}-\lambda_{abs}$	The radiated Life time τ_{fm} n sec	The fluorescence Life time τ_f n sec	The quantum efficiency% Q_{fm}
11×10^{-4}	453	510	57	138	126	90%
15×10^{-4}	454	510	56	195	179	91%
38×10^{-4}	456	510	54	480	455	94%
57×10^{-4}	454	511	57	689	681	98%
76×10^{-4}	452	510	58	953	890	93%
95×10^{-4}	458	511	53	1175	1045	88%
11×10^{-3}	459	511	52	1358	1128	83%
15×10^{-3}	459	512	53	1463	1194	81%

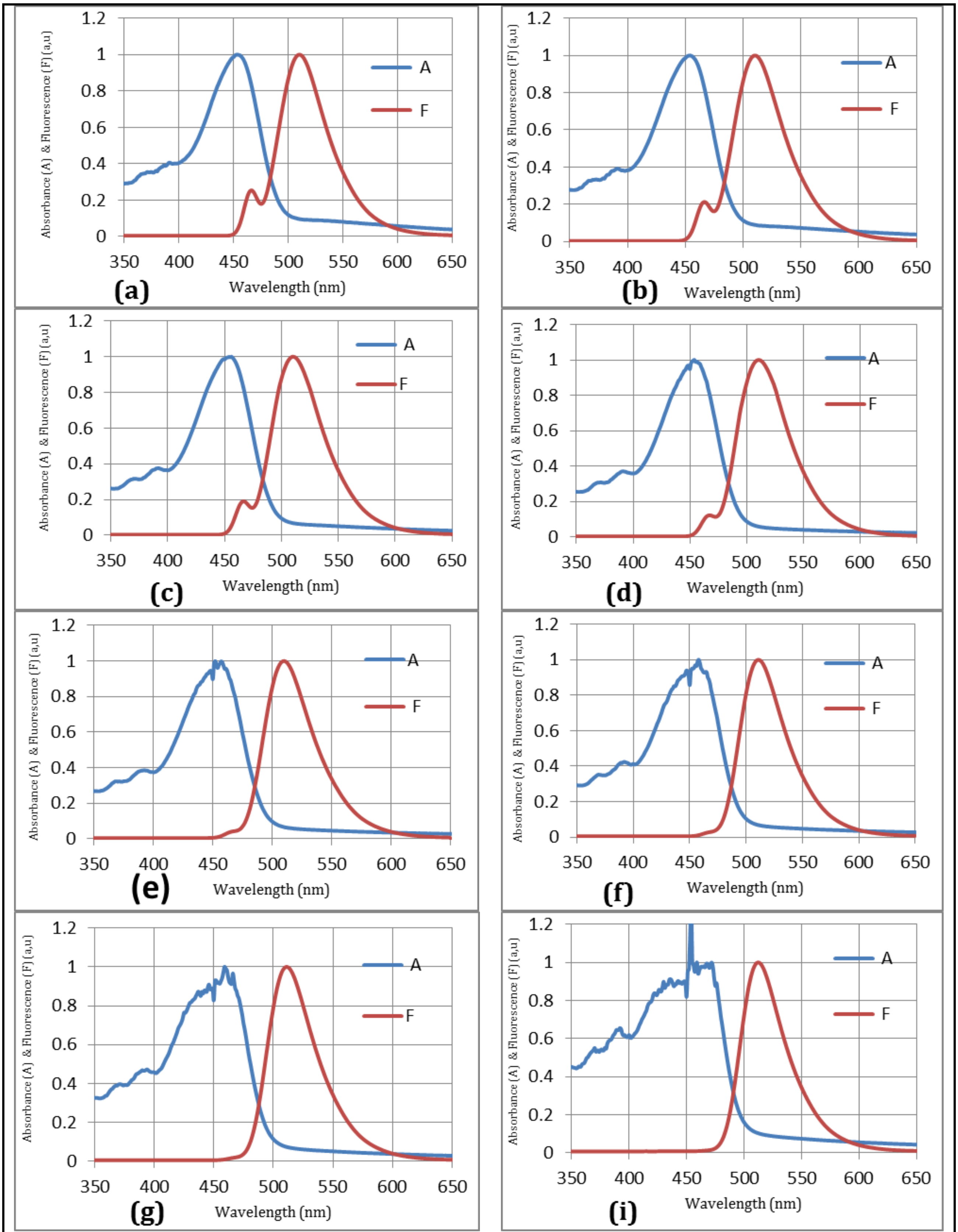


Fig 5: Spectra of absorption (A) and fluorescence (F) of the Pyranine dye at different concentration ((a) 11×10^{-4}, (b) 15×10^{-4}, (c) 38×10^{-4}, (d) 57×10^{-4}, (e) 76×10^{-4}, (f) 95×10^{-4}, (g) 11×10^{-3} and (i) 15×10^{-3}) *mol/L* respectively.

This dye absorbed the falling beams because it contains outer orbit unsaturated electronically and the absorption intensity increases with the increment of the concentrations. This is in accordance with Bert Lambert where absorptivity has a direct relation with the absorbent particles of the beam (concentrations) [23]. Moreover, is noticed for the fluorescence spectrum as the concentration is intensified because its energy loss. As for fluorescence lifetime (τ_f) which is the actual time or the main lifetime for the stimulation, it is much less than the radiation lifetime (τ_{fm}). It is the beam transmission time from the lower vibration level of the electronic stimulated case to the land level. This is because the non-radiation process competing to the fluorescence causing energy loss of the ground state [24]. The quantum efficiency (Q_{fm}) calculation was conducted by the ratio between the area under the curve of the fluoride spectrum and the area under the curve of the absorbance spectrum using Matlab software. [25]. It was found that quantum efficiency is high in the low concentrations and it decreases with higher the concentrations. The quantum efficiency is always less than one 100%, because the higher the radiation process than the non-radiation processes the quantum efficiency of the fluorescence to one will approach 100% and this is an ideal case. The quantum efficiency for Pyranine dye is 98% for the concentration (57×10^{-4} *mol/L*). It started to decrease to 81% for the concentration (15×10^{-3} *mol/L*) because of the radiation/non-radiation processes as mentioned earlier.

V. (LSC) PANELS OF PYRANINE DYE

A square-shaped glass plate was med Thickness 10mm formed around the edges of the four solar cells as shown in Figure (2). Table (3) shows that the efficiency of the solar cell before using the panels of Pyranine dye and is the basic efficiency.

TABLE III

pure solar cell efficiency and its parameters

Concentration(Mol/L)	Imax (mA)	Vmax (V)	FF	η(%)	Δη(%)
Pure cell	1.1	3.94	0.437	0.619	--------

The result illustrated in table (4) which listed the measurements of maximum current (Imax), maximum voltage (V_{max}), fill factor (FF), solar cell efficiency (η) with the use of LSC panels, and the change ratio in the efficiency (η Δ) after the use of LSC panels.

TABLE IV

solar cell parameter and efficiency with LSC

Concentretion (Ml/L)	Imax (mA)	Vmax (V)	FF	η%	Δη%
11×10-4	1.6	3.941	487	0.9	0.45
15×10-4	1.8	4.469	0.536	1.149	85
38×10-4	2.8	4.837	0.562	1.934	2.12
57×10-4	3.1	4.95	0.545	2.192	2.54
76×10-4	3.3	4.591	0.565	2.164	2.49
95×10-4	3	5.004	0.533	2.144	2.46
11×10-3	3	4.815	0.528	2.063	2.33
15×10-3	2.4	4.849	0.554	1.662	1.68

After the use of different LSC panels, measurements have been conducted and compared with the table (3) to obtain the increasing ratio (η Δ) in solar cell efficiency as shown in the following equation [26].

$$\Delta\eta=((\eta(LSC)-\eta(pure))/\eta(pure))\times100\% \quad \ldots\ldots\ldots(4)$$

From table (4) we observed that the maximum increase in efficiency is (2.54%) for the concentration (57×10^{-4} *mol/L*) and the minimum (0.45 %) for the concentration (11×10^{-4} *mol/L*). It's clear the pyranine dye improve solar cell efficiency.

VI. CONCLUSION

All (LSC) panels for Pyranine dyes succeeded to increase the efficiency of the solar cell, of certain degrees and depend on concentration. Low concentrations are preferable to use in improving the efficiency of the solar cell. The increase in the value of quantum efficiency (Q_{fm}) with the decrease in concentration also increases Raditive life time (τ_{fm}) and fluorescence life time (τ_f) where $\tau_{fm} > \tau_f$ for all samples. Best results were obtained of (LSC) panels with Pyranine dye of (57×10^{-4}Mol/L) at which the efficiency reached (2.19) and the ratio of increase in efficiency (ηΔ=2.54%) .

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