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Natural Dyes with Nanoparticles as Luminescent Solar Cell Concentrator

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Abstract
Zinc oxide nanoparticles (ZnO) were mixed with dyes extracted from natural plants (turmeric, Capsicum annuum) to find out their effect on these dyes. The dye fluorescent and absorbance were measured before and after the addition of zinc oxide nanoparticles in three stages, the first adding the dye without nanoparticles, the second stage mixing 75% dye with 25% ZnO, the third stage mixing 50% dye with 50% ZnO, the Stoke shift, radiative life time (f_m), fluorescence life time (τ_f), Quantitative efficiency (Q_{fm}). The link between the absorbance and fluorescence curves was displayed using the calculated data. The area under the fluorescence spectra and absorption curves was measured using MATLAB software. The fluorescence intensity of natural dyes was discovered to be higher than it was prior to the inclusion of nanoparticles, thus the quantum efficiency increases and thus the efficiency of the solar cell increases significantly when the nanomaterials are added. The amount of Luminescent Solar Cell (LSC) efficiency before adding dyes was $\eta = 0.892$, and when adding a mixture of 50% natural turmeric dye with 50% zinc nanoparticles, becomes $\eta = 2.311$. And when adding a mixture consisting of 50% of natural capsicum annuum dye with 50% of zinc oxide nanoparticles, the LSC efficiency becomes $\eta = 2.459$.

Keywords: Luminescent Solar Cell, Solar Cell Concentrator, Solar Cell Efficiency, Fluorescence and Quantitative efficiency

1. Introduction

The sun is the source of all energies. Solar energy manifests itself mostly in the form of heat and light. The environment converts and absorbs heat from the sun [1]. The sun consists mostly of hydrogen and helium atoms in the plasma state, like the majority of stars. Nuclear fusion is the source of energy in the sun [2]. Renewable energy sources came to Earth from external sources, mostly from the sun. Their main property is that renewable sources will not run out, unlike traditional energy sources based on fossil fuels such as carbon, gasoline and gas [3]. Any device that directly converts light energy into electrical energy through the photoelectric effect is referred to as a solar cell, sometimes known as a photovoltaic cell. The vast majority of solar cells are made of silicon [4]. In the race to produce electricity for renewable and sustainable energy technologies that are environmentally friendly, solar cells are becoming a great contender for higher energy sources. The Earth receives incredible solar energy that can be converted into electricity using high-performance solar cells to meet future global energy needs [5]. Conventional solar energy technologies have not been able to provide cities with renewable energy due to lack of usable surface area, high cost of land, and irregular urban cityscapes [6]. Dyes-based natural photosensitizers are a promising route for obtaining affordable and environmentally friendly solar cells [7]. Since they provide a practical way to increase the efficiency of silicon-based photovoltaics, illuminated solar concentrators (LSCs) as shown in Fig (1) have been a large research topic (PVs). In this regard, the use of natural and organic fluorescent materials is preferred to create environmentally benign and long-lasting devices [8]. Illuminated solar concentrators (LSCs) are luminescent waveguide layers that convert sunlight into specific wavelengths which are then directed to a photovoltaic device located at the edges of the LSC through total internal reflection [9]. To enhance the efficiency of solar cells, there are still a lot of areas that need to be investigated. To improve the performance, the dye molecules can be changed innumerably [10]. In its most basic form, a typical LSC consists of a waveguide made of polymer or glass with luminophores either scattered throughout the sheet. As shown in Fig (1).

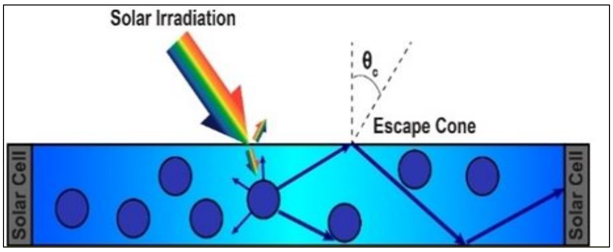


Fig 1: Schematic of a luminescent solar concentrator [11]

The difference in wavelength or frequency units between the positions of the large absorbance and emission spectra of the identical electronic transitions is known as the Stokes shift. The end-product of solvent rearrangement oscillatory relaxation or attenuation [12, 13, 14]. Fig (2) shows the shift (Stokes shift) between the absorbance spectrum and the emission spectrum (fluorescence) According to the Stokes Rule, the wavelength of a fluorescence emission should be often higher than that of absorbance. The fluorescence spectrum is placed at lower energy (higher wavelengths) than the absorbance spectrum due to the loss of energy in the excited state because of vibrational relaxation. However, in most cases. The absorption and emission spectra partially overlap, meaning that some light is emitted at shorter wavelengths than the absorbed light [15, 16].

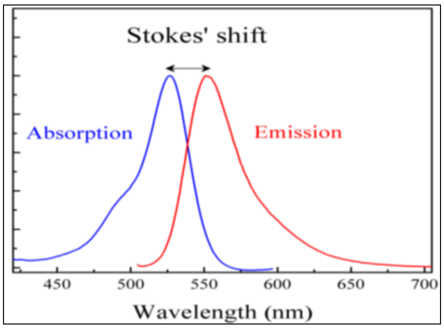
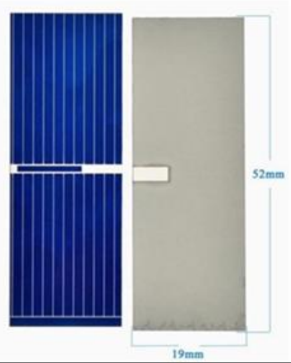


Fig 2: Stokes shift and overlap of the absorbance and fluorescence spectra [17]

The molecular fluorescence quantum efficiency (Q.E) can be defined as the ratio of the number of fluorescence photons emitted by a system of molecules to the number of absorbed photons. The molecular fluorescence spectrum is then defined as the relative fluorescence quantum intensity [18].

2. Experimental Part

In this research, dyes (turmeric, capsicum annuum) extracted from natural plants were prepared after converting these plants into powder [19] and dissolving a certain amount of it in absolute ethanol using the concentration law and mixing these dyes with zinc oxide (ZnO) nanoparticles. To serve as the luminescent core of the silicon solar cell, the absorption and fluorescence spectra were determined. the properties of solar cell which it use in this research is show in Fig (3).



Micro Solar cells	
Max Power	0.2W
Average Voltage	0.5V
Average Current	0.2A
Size	52x19mm/2 x 3/4"
Fetures	micro,super thin,high efficiency

Fig 3: Photovoltaic cell

3. Results and Discussion

3.1 The Absorbance and Fluorescence Spectra of the Curcuma Dye in Ethanol

The Curcuma Dye structure is shown in Fig (4).

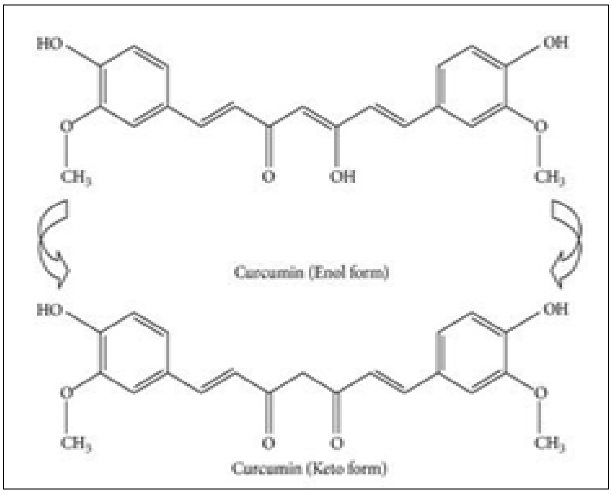


Fig 4: Curcuma Dye structure

The absorption and fluorescence spectra of the Curcuma dye were studied in three phases, the first for the Curcuma dye only, the second for the mixture of 75% Curcuma dye with 25% ZnO nanoparticles, and the third for the mixture of 50% Curcuma dye with 50% ZnO nanoparticles.as shown in Fig (5-7).

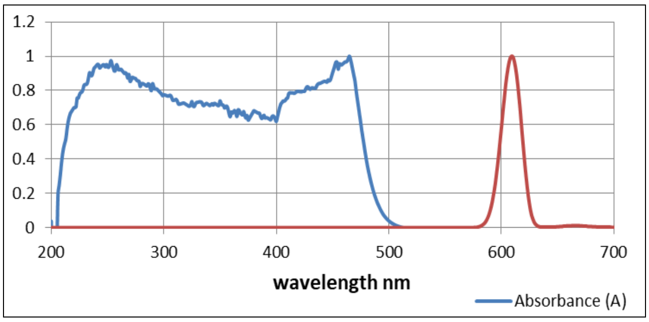


Fig 5: Absorbance and fluorescence spectra For Curcuma dye only

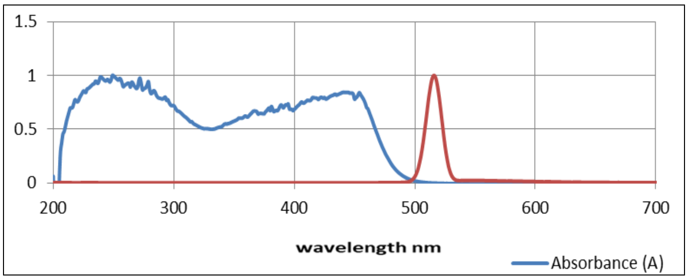


Fig 6: Absorbance and fluorescence spectra For 75% Curcuma dye with 25% Zno

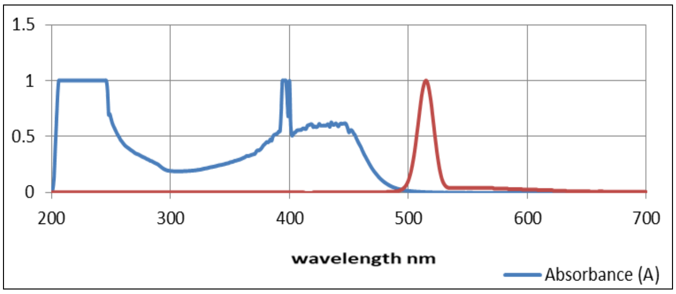


Fig 7: Absorbance and fluorescence spectra for 50% Curcuma dye with 50% ZnO

Additionally, the connection between wave number (cm^{-1}) and molar absorption coefficient ($L/mol^{-1}cm^{-1}$) has been demonstrated, in Fig (8), these are to calculate the area under the curve as well as nonradiative life time (τ_{fm}) to absorption and fluorescence life time (τ_f). and Table (1) illustrated this calculations.

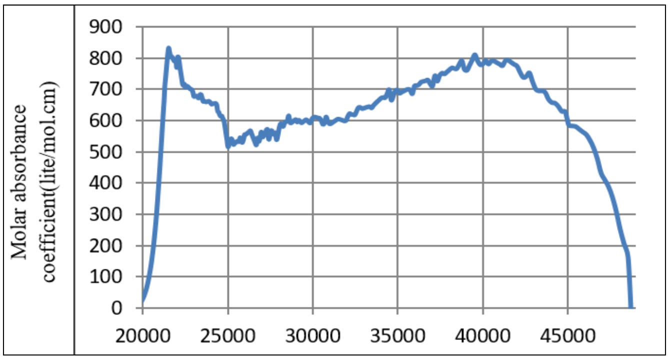


Fig 8A: (Curcuma dye only)

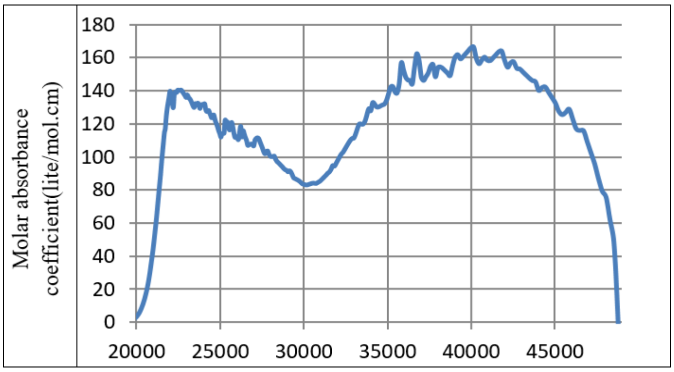


Fig 8B: (75% Curcuma dye with 25% ZnO)

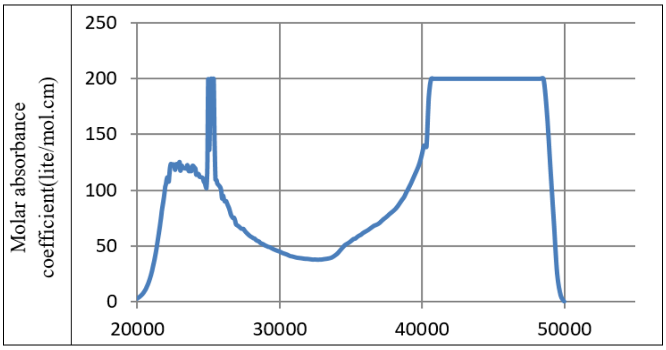


Fig 8C: (50% Curcuma dye with 50% Zno)

Table 1: Wavelength of maximum absorption and maximum fluorescence, radiant life, fluorescence lifetime, quantitative efficiency of the Curcuma dye, without ZnO nanoparticle, with ZnO nanoparticle

The samples (mol/L)	λ A_{max} (nm)	λ F_{max} (nm)	Stokes Shift $\Delta\lambda=\lambda_{flo}-\lambda_{abs}$ (nm)	The radiated Life time τ_{fm} n sec	The fluorescence Life time τ_f n sec	The quantum efficiency% Q_{fm}
Only Dye	465	609	144	3421.693	3123.322	0.9128
75% dye+25% ZnO	249	516	267	7676.653	7007.249	0.9128
50% dye+50% ZnO	206	515	309	6719.896	6133.921	0.9127

3.2 The Absorbance and Fluorescence Spectra of the Capsicum Annuum Dye in Ethanol

The Capsicum Annuum dye structure is illustrated in Fig (9).

The absorption and fluorescence spectra of the Capsicum Annuum dye were studied in three phases, the first for the Capsicum Annuum dye only, the second for the mixture of 75% Capsicum Annuum dye with 25% ZnO nanoparticles, and the third for the mixture of 50% Capsicum Annuum dye with 50% ZnO nanoparticles as shown in Fig (10–12).

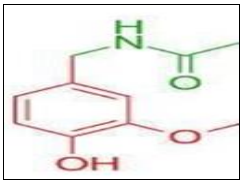


Fig 9: Capsicum Annuum dye structure

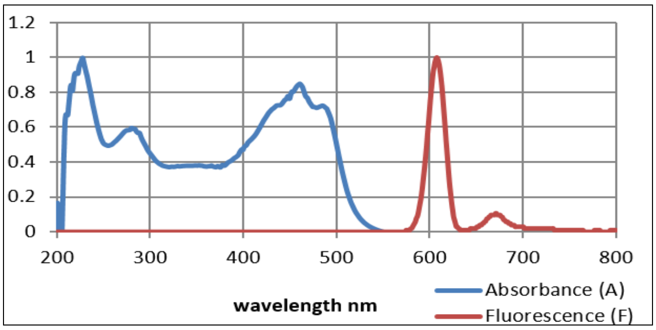


Fig 10: Absorbance and fluorescence spectra for Capsicum Annuum dye only

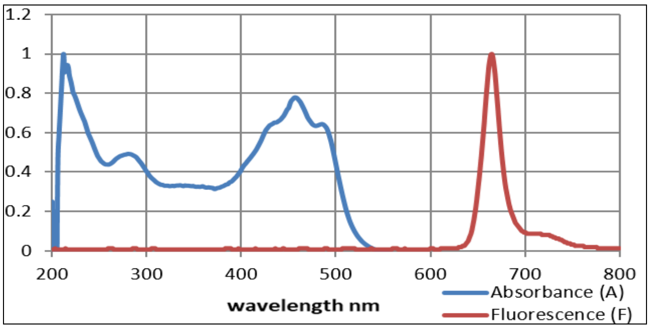


Fig 11: Absorbance and fluorescence spectra for 75% Capsicum Annuum dye with 25% ZnO

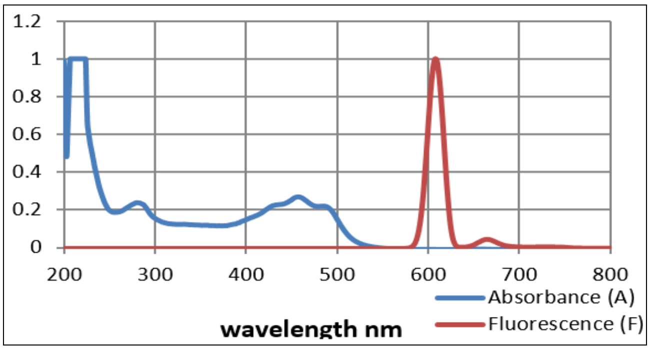


Fig 12: Absorbance and fluorescence spectra for 50% Capsicum Annuum dye with 50% ZnO

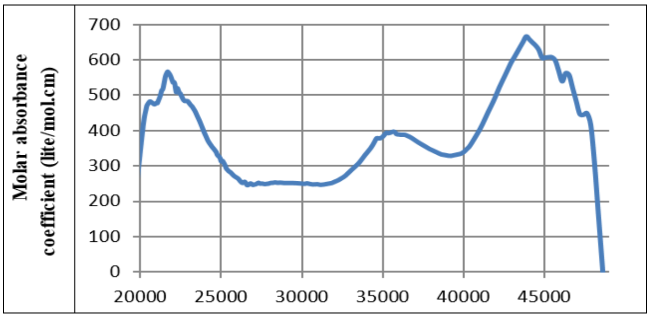


Fig 13A: (Capsicum Annuum dye only)

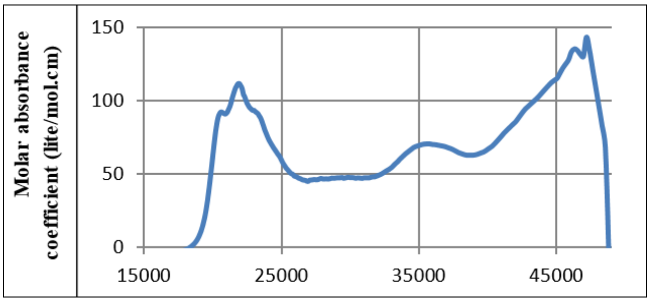


Fig 13B: (75% Capsicum Annuum dye with 25% ZnO)

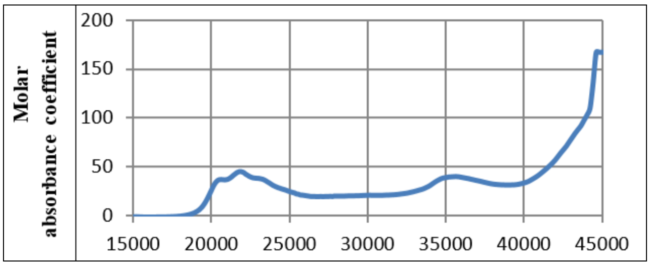


Fig 13C: (50% Capsicum Annuum dye with 50% ZnO)

Additionally, the connection between wave number (cm^{-1}) and molar absorption coefficient ($L/mol^{-1}cm^{-1}$) has been demonstrated, in Fig (13), these are to calculate the area under the curve as well as nonradiative life time (τ_{fm}) to absorption and fluorescence life time(τ_f).

Fig 13: Molar modulus spectra ($L/mol^{-1}cm^{-1}$) vs. wave number (cm^{-1}) in three phases, the first for the Capsicum Annuum dye only, the second for the mixture of 75% Capsicum Annuum dye with 25% ZnO nanoparticles, and the third for the mixture of 50% Capsicum Annuum dye with 50% ZnO nanoparticles.

Table 2: Wavelength of maximum absorption and maximum fluorescence, radiant life, fluorescence lifetime, and quantitative efficiency of the Capsicum Annuum dye, without ZnO nanoparticle, with ZnO nanoparticle

The samples (mol/L)	λ A_{max} (nm)	λ F_{max} (nm)	Stokes Shift $\Delta\lambda=\lambda_{flo}-\lambda_{abs}$ (nm)	The radiated Life time τ_{fm} n sec	The fluorescence Life time τ_f n sec	The quantum efficiency% Q_{fm}
Only dye	228	608	380	4530.579	4135.512	0.9127
75% dye+25% ZnO	212	665	453	18681.8	16052.74	0.8592
50% dye+50% ZnO	102	608	506	50940.21	46498.23	0.9128

It measures the appearance of the solar analyzer module and gives the maximum value of current (I_{max}), maximum value of voltage (V_{max}), efficiency of solar cell values (η), fill factor (FF). Before using natural dyes with (LSC), which was produced in this research, as shown in Table (3).

Table 3: Efficiency evaluation of pure solar cells

The samples (mol/L)	I_{max} (mA)	V_{max} (volt)	FF	%η
Single cell	329.9	0.422	0.764	0.892

Table 4: Solar cell efficiency (η) by using (LSC) panels of Curcuma dye

The samples (mol/L)	I_{max} (mA)	V_{max} (volt)	FF	η%	Δη%
Only dye	322.8	0.478	0.797	0.989	10.8
75% dye+25% ZnO	653.0	0.534	0.728	2.235	145.3
50% dye+50% ZnO	722.5	0.499	0.815	2.311	153.7

Table 5: Solar cell efficiency (η) by using (LSC) panels of Capsicum Annuum dye

The samples (mol/L)	I_{max} (mA)	V_{max} (volt)	FF	η%	Δη%
Only dye	327.0	0.477	0.804	0.999	11.9
75% dye +25% ZnO	762.3	0.475	0.722	2.321	154.8
50% dye+50% ZnO	742.2	0.517	0.851	2.459	170

Through Table (5, 4) We detect an improvement in solar cell efficiency (η) compared to solar cell efficiency prior to addition, in addition to the fluorescence spectra after addition of zinc oxide nanoparticles.

The reason for increasing the efficiency of solar cell can be attributed to the presence of the nanoparticles ZnO molecules, which is working on scattering the light beams that incident on the LSC. They would result in the latter scattering which direct the photons of incident ray to the solar cell which is fixed in all direction of LSC. Then, the number of photons reach the solar cell become very large when compared with the case of no LSC using.

4. Conclusion

When zinc oxide nanoparticles are added to natural dyes (Curcuma dye, Capsicum Annuum dye.), they contribute to improving the efficiency of the solar cell. The best result obtained when mixing (50% Capsicum Annuum dye with 50% ZnO nanoparticles).

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