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Photo-luminescence epoxies by Eosin Y dye with different concentrations for luminescent solar concentrators

Adnan Falih Hassan[1], Faris Mohammed Ali[2], Mohammedhasanain H.Aljassani[3,*]

[1]Department of Physics, University of Kufa, Najaf, Iraq
[2]Department Name, Al-Furat Al-AwsatTechnical University, Najaf, Iraq
[3]Department of Physics, University of Kufa, Najaf, Iraq

*Email: faris.m.n@etcn.edu.iq, aljassani86@gmail.com

Abstract

In this work photo-luminescence epoxies samples by eosin y dye were fabricated. Eosin Y used as substance in the treating of epoxy resin to form photo-luminescence epoxies of five different concentrations (4x10^-5, 8x10^-5, 2x10^-4, 6x10^-4,1x10^-3) moles/L. The absorbance spectra and the florescence intensities of the all fabricated photo-luminescence epoxy samples were measured with spectrometer and fluorescence spectrophotometer respectively. The fluorescence quantum efficiency, fluorescence life-time ,and radiative life-time from all photo-luminescence epoxies were reported. Optimal fluorescence quantum efficiencies are between the extent of the limits of concentrations (2x10^-4- 1x10^-3) moles/L .The quantum efficiencies of fluorescence for photo-luminescence samples are (75.5%, 77%, 84.8%, 93%, 85.8%) respectively with the five different concentrations above.

Keywords: Epoxy, Eosin Y, Photo-luminescence, Fluorescence quantum efficiency, Solar concentrator

1. Introduction

in 1936, Dr Pierre Castan in Switzerland managed to synthesising an epoxy resin when he hardened with phthalic acid anhydride.Today epoxies resin used in the world this Preferring of Dr S.O. Greenlee in the USA in In1939 when he developed epoxy resins of epichlorohydrin and bisphenol [1]. A good optical properties of the epoxy make it one of the most important materials used in optical applications such as coatings for light emitting diodes (LEDs) [2-5],and as a waveguide [6] or dispersion medium when it doped with luminescent pieces to composition of the luminescent solar concentrators (LSCs) [7].The concept of a luminescent solar concentrator (LSC) was offered In the late 1970s [8] by Goetzberger , Greubel to reduce the cost of solar cells by minimizing the area of the cells [9]. The luminescent pieces used in solar concentrator should have low re-absorbance and high fluorescence quantum efficiency, and the host materials should have high transmittance in the visible region [10], hardness, and UV stability which can have large sway on the solar concentrator ability to transporting light [11].In this an investigation, photo-luminescence epoxies by Eosin Y dye with five different concentrations, are fabricated and their absorbance, transmittance, and fluorescence properties (fluorescence quantum efficiency, Stokes shift, radiative life-time, and fluorescence life-time) calculated .

The absorbance , A, of the sample illustrates by:

$$A = -\log T = = -\log\frac{I}{I_0} = \log\frac{I_0}{I} \qquad (1)$$

where T is the transmittance, I_0, I are the incident and transmitted light, respectively. A of the medium is related with the optical path thickness of the sample, d (cm), concentration of the sample, C (mole/L), and molar absorptivity, ε (L/moles.cm), by the following [12]:

$$A = C\varepsilon d \qquad (2)$$

Absorbance and transmittance are not everything for incident light on the media, where there is a fraction of the light can be reflected from the interface. So the Absorbance, transmittance, and Reflectance, R, are relate together by the relation[13]:

$$A + T + R = 1 \qquad (3)$$

On the other hand, the reflectance of the media can be related with refractive index, n, of these media by Fresnel reflection as a fallows[14]:

$$R = \left(\frac{n-1}{n+1}\right)^2 \qquad (4)$$

In spectroscopy, the fluorescence depends on the radiative transformations that was produced by the transformations of the excited molecules from the highest to the lowest state, these transformations are, absorption, fluorescence, and phosphorescence [15]. The radiation life-time (τ_{FM}) can be calculated as follow :

$$\frac{1}{\tau_{FM}} = 2.88\times10^{-9} n^2 \bar{v}^2 \int \varepsilon(\bar{v})\, d\bar{v} \qquad (5)$$

Where $\int \varepsilon(\bar{\nu})\, d\bar{\nu}$ is the area under the curve of molar absorptivity ε Vs. wavenumber, n is the refractive index, $\bar{\nu}$ is the wave-number at maximum intensity of the absorption spectrum. The radiation life-time relates to the fluorescence life-time (τ_F) as follow:

$$\tau_F = Q_F\, \tau_{FM} \qquad (6)$$

Where Q_F the fluorescence quantum yield of the molecules dye [15,16]. It was determined on the basis of the absorption and fluorescence spectra of dye. it is calculate by [17] :

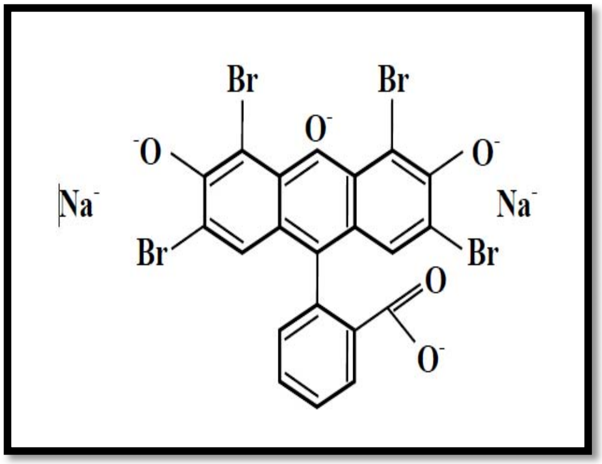
$$Q_F = \frac{Area\ under\ the\ fluorescenc\ spectrum}{Area\ under\ the\ absorbance\ spectrum} \qquad (7)$$

2. Experimental Work

2.1 Materials

In this work, the epoxy resin used as a solvent and as host matrix for Eosin Y dye which as a luminescent pieces, our epoxy resin was provided by the Henkel Polybit Industries Ltd. (UAE).While the eosin Y dye used as a luminescence pieces,which was provided by SCRC.

Eosin Y is a fluorescent red dye laser and it is form of eosin which consider as tetra-bromo fluorescein derivatives . Also it is known as Eosin yellowish or acid red 87. The chemical formula of eosin y is $C_{20}H_8Br_4Na_2O_5$ and its molecular weight is 691.9gm.mol^{-1}. Fig.(1) shows the structure formula of eosin y dye [18].



Figure(1): Structure formula of Eosin Y dye

2.2 Fabrication of samples

Before to the treating of the epoxy resin (hardener and resin) was whiskered at room temperature for 10 min to reduce the amount of air bubbles, second component (hardener) of our epoxy used as a solvent to preparation of dye solutions.

Different concentrations are prepared according to the following equations [19].

$$W = \frac{M_w \times C \times V}{1000} \qquad (8)$$

Where W weight of the dissolved dye (gm), M_w molecular weight of the dye (gm/mol), V the volume of the solvent (ml),and C the dye concentration (moles/L).

$$C_1V_1 = C_2V_2 \qquad (9)$$

Where $\boldsymbol{C_1}$ primary concentration, $\boldsymbol{C_2}$ new concentration, V_1 the volume before dilution, and V_2 the volume after dilution. Equ. (9) was used for dilution after preparing of primary concentration by equ.(8).In this present work, the concentrations that have been prepared are (4x10$^{\wedge -5}$, 8x10$^{\wedge -5}$, 2x10$^{\wedge -4}$, 6x10$^{\wedge -4}$,1x10$^{\wedge -3}$) moles/liter.

Mixing the first component (resin) of the epoxy with the second component, which has become the dye solution, with mixing ratio 2:1, mix it well for 3 min. Then cast the dye's epoxy into the molds that has been prepared before that. After 48 hours (time of drying samples depending on ambient temperature) the luminescent dye panels (LDPs) are produced, with fixed dimensions (l×w×t)=(10×8×0.1) cm^3 for all samples, where l,w, and t are length, width, and thickness of the samples respectively, as in the case of the pure epoxy panel was fabricated with the same dimensions of LDPs and with the same maxing ratio 2:1 for resin and hardener respectively .

Chapter 1 3. Rustle and Discussion

3.1 Absorbance and Transmittance Spectra

The absorbance and transmittance spectra of the our samples were measured with UV/Vis spectrometer (SINCO Mega-2100). For our pure epoxy panel and eosin y dye panels (EDPs), the spectra were measured with the common thickness about (0.1 cm), and for EDPs at the

five different concentrations (4x10$^{\wedge -5}$, 8x10$^{\wedge -5}$, 2x10$^{\wedge -4}$, 6x10$^{\wedge -4}$,1x10$^{\wedge -3}$) moles/L.

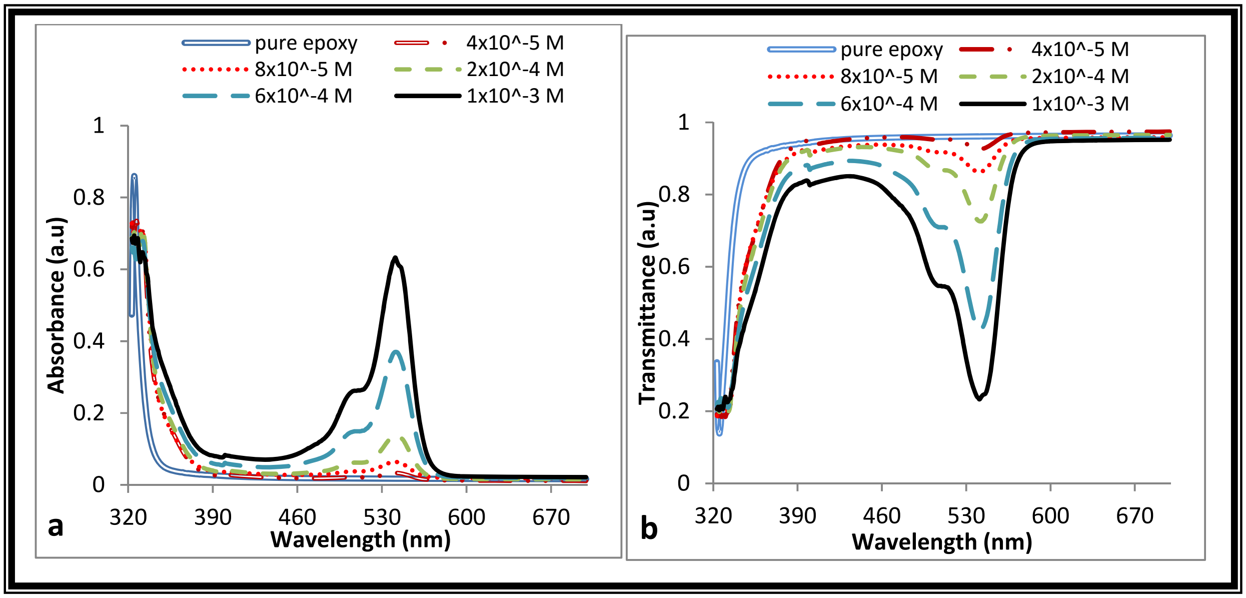


Figure (2): (a) Absorbance and (b) Transmittance spectra for pure panel with EDPs

There are several pointers can be achieved from fig.(2). First, the absorbance range of pure panel is within Ultra-Violet range, high absorbance about equal to 0.859 at wavelength of 325 nm with the average range of absorbance and transmittance between (400-700)nm about equal to 0.018 and 0.96 respectively . So no competition by epoxy (host matrix) with dyes molecules to absorb of radiation within the visible range. Second, the absorption spectra for our eosin y dye panels are within visible range (specifically between 400-600 nm). So the EDPs are useful as a LSCs devices. Third, for our EDPs as the concentration increases the intensity of absorbed light increases, these consistent with the Beer-Lambert law equ.(2). Fourth, Eosin Y dye panel at high concentration (specifically at $1\text{x}10^{\wedge-3}$ M), the profile of the absorbance spectrum peak is a little changing, because of at high concentrations the dye molecules will be as grouping form. Therefore, they are absorb the light as assemblages of dimers not as individual molecules(i.e. non-homogeneous distribution of the light), this leads to deviation in Beer-Lambert law. Final, too small absorbance (i.e. high transmittance) in the range between (600-700)nm for all samples. Table (1) shows the change of different parameters with absorbance spectra for EDPs with the five different concentrations ($4\text{x}10^{\wedge-5}$, $8\text{x}10^{\wedge-5}$, $2\text{x}10^{\wedge-4}$, $6\text{x}10^{\wedge-4}$, $1\text{x}10^{\wedge-3}$)moles/L.

Table(1): Maxima wavelengths of absorbance intensities for Eosin Y dye panels

Con. mol/L	λ_{abs} (nm)	Absorbance (a.u)
$4\text{x}10^{\wedge-5}$	542	0.0331
$8\text{x}10^{\wedge-5}$	541	0.0642
$2\text{x}10^{\wedge-4}$	541	0.139
$6\text{x}10^{\wedge-4}$	542	0.37
$1\text{x}10^{\wedge-3}$	542	0.633

The reflectance one of an important optical parameters that which gives the information about the lost energy of electromagnetic wave by reflection from top surface of a samples. In this present work, the reflectance data of pure panel and EDPs are calculated from absorbance and transmittance data through the equ.(3). This in turn gives a very important optical factor, is the refractive index, which is describe the ability of light to propagate through the samples. The refractive index in this work calculated as a function of reflectance by modify of Fresnel equ.(4). Table (2) shows the change of the average values of the reflectance and refractive index at absorbance band for each eosin y dye panel with different concentrations and for pure panel at the range (400-700)nm.

Table(2): Changing of the average value of the reflectance and refractive index at the absorbance band for EDPs and for pure panel at the range (400-700)nm

Con. mol/L	**pure panel**	
	$R_{ave(400nm-700nm)}$	$n_{ave(400nm-700nm)}$
-	0.022	1.35
Con. mol/L	**Eosin Y dye panels**	
	$R_{ave(400nm-600nm)}$	$n_{ave(400nm-600nm)}$
4x10^-5	0.025	1.379
8x10^-5	0.040	1.501
2x10^-4	0.055	1.607
6x10^-4	0.095	1.890
1x10^-3	0.116	2.039

Can be seen from Table(2), that each of the reflectance and refractive index of the samples are on the rise with increasing concentration of the dye molecules, where this behavior is considered normal due to increased optical density of the samples.

3.2 Fluorescence Spectra

In this work, the important next step in spectroscopic studies is measurements of the fluorescence spectra. The fluorescence spectra for our samples were recorded by fluorescence spectrophotometer F96 PRO. For our pure panel and EDPs, the samples were measured with common thickness about (0.1 cm), and for EDPs at the five different concentrations ($4\text{x}10^{\wedge-5}$, $8\text{x}10^{\wedge-5}$, $2\text{x}10^{\wedge-4}$, $6\text{x}10^{\wedge-4}$,$1\text{x}10^{\wedge-3}$) moles/L, fig.(3).

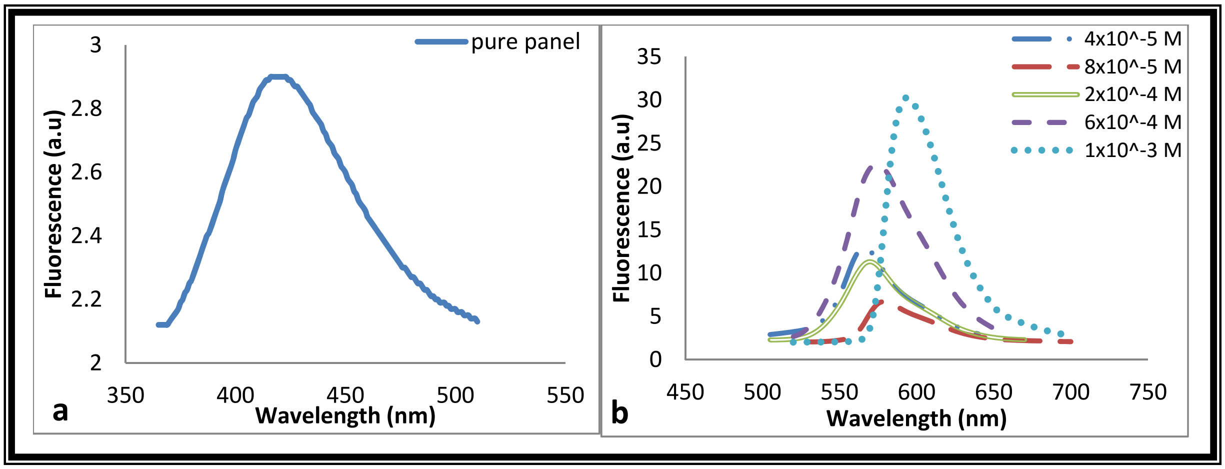


Figure (3):Fluorescence spectra for (a) pure panel, and (b) EDPs

From fig.(4 a) our epoxy has a maximum fluorescence intensity of approximately (2.9 a.u) at the wavelength (λ_{flu}= 420 nm). As was the case in the Absorption Spectra, several changes appear at different concentrations for our EDPs in the fig (4 b). at dilute concentration Fluorescence intensity increases linearly with increasing concentration, due to the dye resolve fully into monomer, where the average distance between the dye molecules in dilute concentration, is very large. Fluorescence intensity remains continues to increase at high concentrations may be because the small of the interaction-time due to the too small of the interaction path-lengths of samples (thickness of our samples 0.1 cm), is enough to reduce quenching of intensity through self-absorption by other dye molecules fig.(4).The change of different parameters of the florescence spectra with concentrations for our EDPs are present in the Table(3).

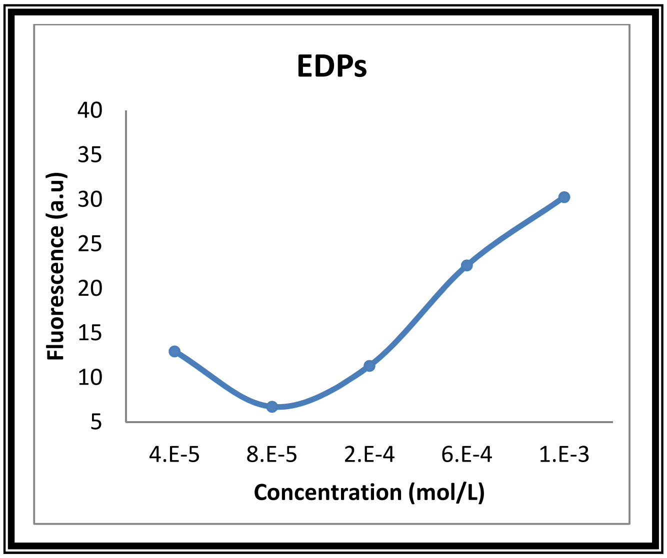


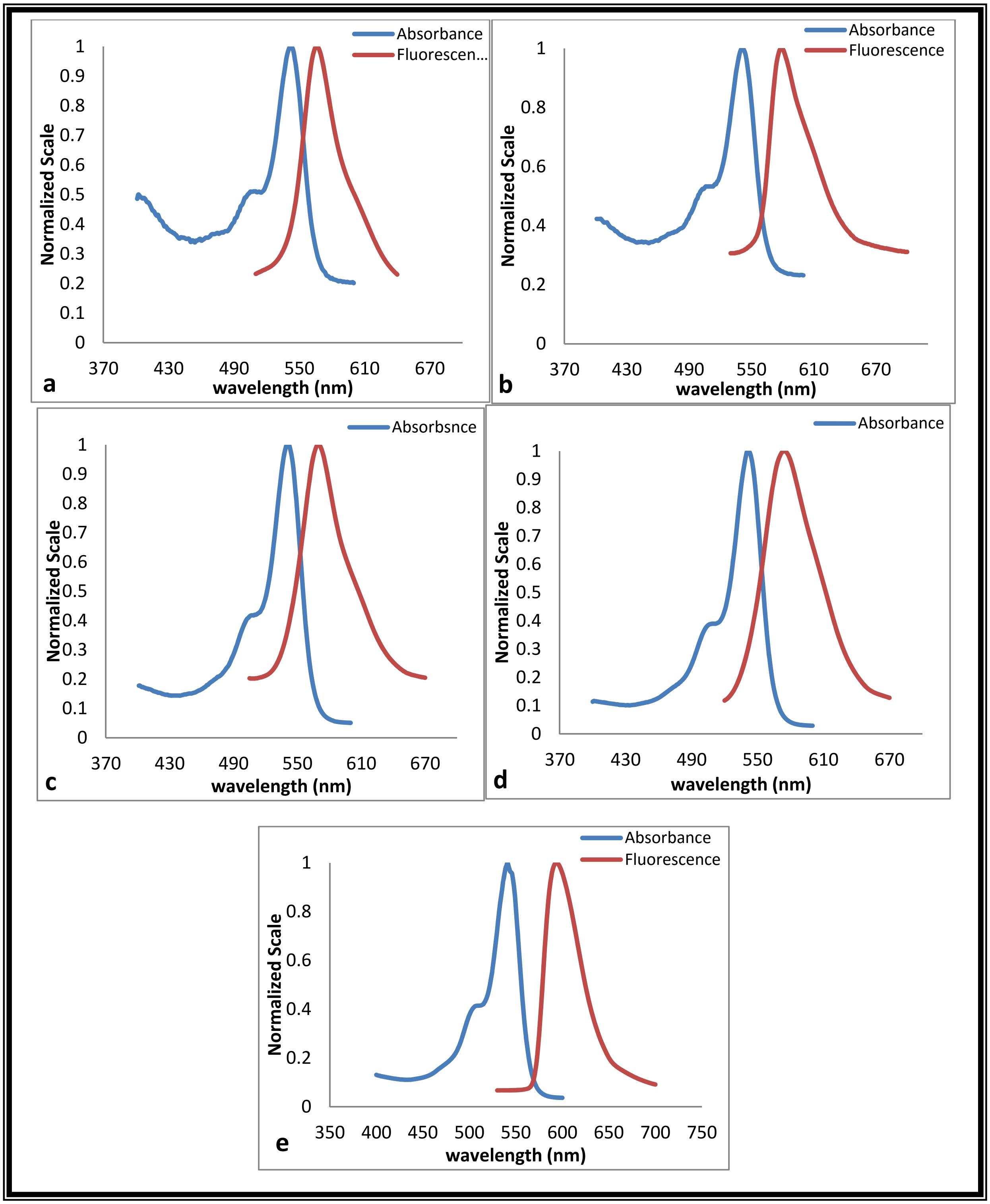
Figure (4):Fluorescence Intensity as a function of Concentration (moles/liter) for EDPs

Table(3): Maxima wavelengths of fluorescence intensities for Eosin Y dye panels

Con. mol/L	λ_{flu} (nm)	Fluorescence (a.u)
4x10^-5	566	12.94
8x10^-5	579	6.72
2x10^-4	570	11.32
6x10^-4	574	22.59
1x10^-3	594	30.27

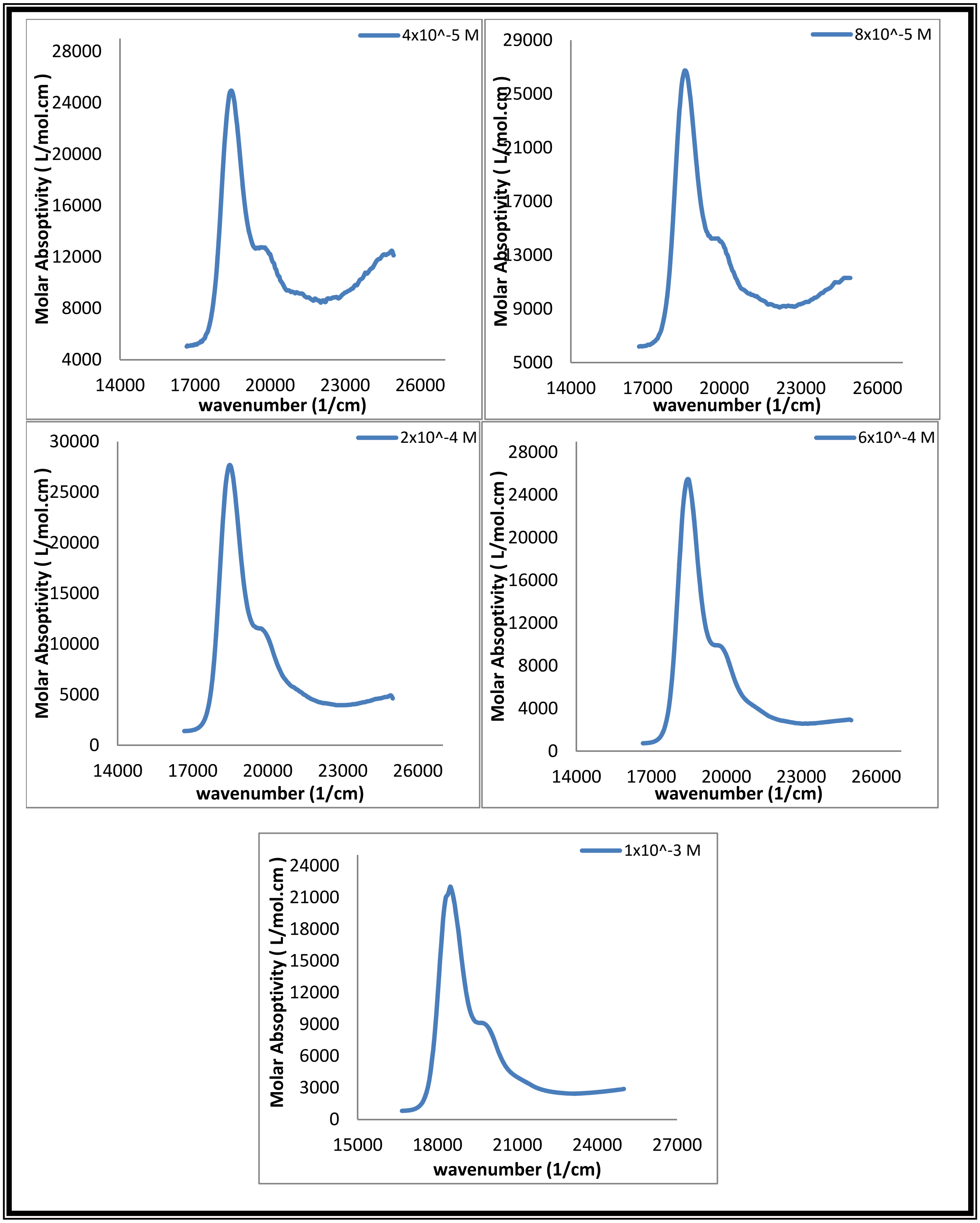
3.3 Normalization of absorbance and fluorescence spectra

This is a very important step to find and discuss the parameters (quantum efficiency ($\mathbf{Q}_F$) ,Stokes shift, fluorescence life-time ($\boldsymbol{\tau}_F$), and Radiative life-time ($\boldsymbol{\tau}_{FM}$)) for our samples . Where, these parameters are very important (specifically the $\mathbf{Q}_F$) for LSC device, which have deduction in many applications such as the enhancement of the photovoltaic cell efficiency. Fig.(5), illustrate the normalized scale of the absorbance and fluorescence intensity for EDPs.



Figures (5): Absorbance and Fluorescence normalized scale against wavelength(nm) for Eosin Y dye Panels at the concentrations ((a) 4x10$^{\wedge-5}$,(b) 8x10$^{\wedge-5}$,(c) 2x10$^{\wedge-4}$,(d) 6x10$^{\wedge-4}$,and (e)10$^{\wedge-3}$)moles/liter

From fig.(5) The absorbance spectra are located in the lower wavelengths band Compared with the location of the emission spectra, in the higher wavelengths band, this because of non-radiative processes (internal conversion and vibrational relaxation) in the excited state. Therefore ,the energy is lost**.** As can be seen, there are partial overlap between the absorbance spectra and the emission spectra, where a large fraction for emission light will be re-absorbed by other molecules, which is unsolicited for LSCs. Figures (6) plot the molar absorptivity (molar absorption coefficient) versus the wavenumber for EDPs.



Figures (6):The Molar Absorptivity (L/mol.cm) as a function of the Wavenumber (1/cm) for EDP at five different Concentrations

Figures(6) were plotted to find the areas under the curves and by average values of refractive indices in the previous table (2), the radiative life-time can be calculated according to the equ.(5). Also by the areas under the curves of absorbance and fluorescence spectra in the fig.(5), fluorescence quantum efficiency according to equ. (7), is calculated. In this paper the areas under the curves were calculated by trapezoidal rule through the easy way is to employ Microsoft Excel of our data with band width equal to (1nm) of the points on the x-axes.Taking the difference between the absorption and emission spectra peaks, this gives Stokes shift. In addition to, according to equ.(6) fluorescence life-time can be calculated.

Table (4) The quantum efficiency (Q_F), Stokes shift($\Delta\lambda$),
fluorescence life-time(τ_F), and radiative life-time(τ_{Fm}) for EDPs

Con. mol/L	$\Delta\lambda = (\lambda_{flu} - \lambda_{abs})$nm	τ_{Fm} (ns)	τ_F (ns)	Q_F %
$4\text{x}10^{\wedge-5}$	24	10.54	7.69	75.5
$8\text{x}10^{\wedge-5}$	38	9.51	7.33	77
$2\text{x}10^{\wedge-4}$	29	7.33	6.22	84.8
$6\text{x}10^{\wedge-4}$	32	6.09	5.68	93
$1\text{x}10^{\wedge-3}$	52	7.06	6.06	85.8

There are many indications can be observed in the table (4). In general for all EDPs, the quantum efficiency are mostly less than unity (< 100%), this dependent on the radiative and non-radiative processes, where as a radiative process overcome on a non-radiative process, the quantum efficiency will be near of unity.For our samples, at low concentrations the fluorescence quantum efficiency increases linearly to reach the highest value at the best concentration, then begin to decline as increasing concentration. Where at high concentrations the loss of energy due to, the probability of the non-radiative processes increases compared with the radiative processes leads to the quantum efficiency decreases. This for internal losses of the panels , while there are external losses as in the case of the reflectance from top surface of the panels that which changing with the concentration of the dye molecules in the panels as it noted in the previous table(2).

Chapter 2 Conclusion

1- Epoxy resins in the form of a good host matrix of the fluorophore for solar concentrating applications, because it has a high transmittance of visible wavelengths (400nm-700nm), equivalent to 96%.
2- Eosin Y dye was good to improving the emission spectrum of the pure epoxy, through shifted toward the long wavelengths.
3- High concentrations are successful with the little thicknesses for luminescencent panels, this through:
    A- A small deviation to the Bear-Lambert law for Eosin Y dye panel at high concentration $1\text{x}10^{\wedge-3}$ moles/liter.
    B- Increase the intensity of fluorescence at high concentrations for Eosin Y dye panels, due to lower phenomenon of self-absorption.
    C- High fluorescence quantum efficiencies Eosin Y dye panels, as a result of reducing of the non-radiative processes, due to the small of the path-length interaction of light.

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