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Research Article

Effects of Luminous Solar Concentrator Parameters (Dyes Mixture, Host type and LSC Thickness) on the Si Solar Cell Performance Efficiency

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Abstract

Luminescent Solar Concentrator (LSC) plates have been prepared with different concentrations ($1*10^{-5}$, $2*10^{-5}$, $3*10^{-5}$, $5*10^{-5}$, $7*10^{-5}$, $1*10^{-4}$ Mol/L) of organic dye doped polymer. The optical properties of dye doped and un-doped polymer were measured and the solar to electric conversion efficiencies of several LSC modules based on R6G, and mixture of dyes (R6G & RB)doped in PMMA and Epoxy with different sample thickness were measured. It was found that the conversion efficiency depend on dye concentration in the LSC. The best conversion efficiency improvement for a modules Si-solar cell of dimensions of 10cm x 20cm covered with R6G ($3*10^{-5}$ mol/l concentration)doped PMMA LSC was6.927% (i.e. with efficiency incensement $\Delta\eta$=13.3% compared with the same module without LSC). Also it was found that LSC consists of mixture of dyes (R6G & RB with concentration 7E-5) doped PMMA had η=7.596%. This LSC exhibitsa potential to improve the Si solar cell performance efficiency, since a wide absorption and emission spectra will be used. The effect of epoxy as a host material for R6G in LSC was studied for the same concentration above. These results show that by using epoxy as a host for R6G ($2*10^{-5}$ concentration) had η=7.897% (i.e. efficiency increment $\Delta\eta$=14.4% compared with LSC for R6G doped PMMA). This is a promised results since epoxy resins can set at room temperature. However, epoxy resins have a poorer photostability compared with PMMA. Also the results include the effect of sample thickness on the conversion efficiency of Si solar cell.

Keywords: *Luminescent Solar Concentrator; Optical properties; Solar conversion efficiency; Epoxy; PMMA, Rhodamine 6G dye and Rhodamine B dye.*

1. Introduction

Solar cells were used to convert renewable sun energy to electrical energy. Until recently, the cost of polysilicon, the starting material for solar cell production, has shown to represent higher than 30% of total solar system cost. This has motivated researchers to attempt to economies on the amount used per peak watt of power production. A possible solution to the challenge of minimizing the amount of silicon required is to use a concentrating system to collect sunlight over a large area and direct it on to a small area of solar cells. This reduces the amount of silicon used, while still producing the same power output. Efficiencies can actually be higher, because of the increased illumination intensity that the cell experiences (JG. Fossum *et al*, 1977; A. Goetzberger *et al*, 1977). Imaging concentrators use lenses, mirrors or a combination of both to focus sunlight on to the cells. While capable of achieving extremely high concentrations (several hundred suns), these require precise tracking to follow the sun across the sky and keep the cells illuminated. Also, these are unable to make use of diffuse of diffuse solar radiation. An alternative is to use a non-imaging concentrator. There are several deferent ways of achieving this [A. Goetzberger *et al*, 1977; T.K. Mallick *et al,* 2007). We explore here one of these options – that of the luminescent solar concentrator (LSC)-which uses a sheet of luminescent material to trap both direct and diffuse solar radiation and transfer this energy to smaller areas of silicon cells to generate electricity(A. Goetzberger *et al*, 1977). The LSC was first proposed in the late 1970s as a means of concentrating solar radiation(W.H. Weber *et al* ,1976; A. Goetzberger 1978; A. Goetzberger *et al* , 1979). Extensive studies were made of LSC technology through the 1980s until the limitations of the fluorescent dyes available at that time hindered further development (P.S. Friedman, 1981; R. Reisfeld *et al*, 1988; M.G. El-Shaarawy etal,2003; JM. Drake *et al*, 1982).

The LSC is particularly suited to this application as it is relatively inexpensive, does not require solar tracking and works in both diffuse and direct sun

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light. The LSC can be designed such that the luminescence energy matches the PV cell by this way the light reaching the cell is converted more efficiently, because the down-conversion of the radiation happens in LSC, unwanted thermalisation losses in the cell are avoided (JM. Drake *et al*, 1982; M. Gratzel , 2003).

Organic dyes offer the simplest means of incorporating in a LSC, as they can easily be dissolved in a range of organic polymers, such as poly(methylmethacrylate) (PMMA), which are then cast into sheet form. Initial LSC research (A. Goetzberger etal,1977; A. Goetzberger,1978; M. Gratzel ,2003) used dyes originally developed for use in dye lasers, such as Rhodamine 6G, DCM and Coumarin, as they were widely available and had well-characterized properties. Many visible-emitting laser dyes have near-unity quantum yields (for example, η =98 % for Rhodamine 6G[M. Gratzel ,2003), making them ideally suited to LSC use, although they have limited photo-stability. Also dye stability can be enhanced by the host material.

Clear epoxy resins have been used which exhibited around 30 % lower absorption in the visible region than PMMA(S.J. Gallagher *et al* ,2007). This is certainly an advantage for fluorophores which may be sensitive to temperature. Unlike PMMA casting, which requires heat to cure the polymer, epoxy resins can set at room temperature. However, epoxy resins have a poorer photostability compared with PMMA. LSC affects the solar cell characteristics like,

(*i) Open circuit voltage* (V_{oc}) (X. Wang *et al* ,2003);

$$V_{oc}=\frac{K_BT}{q}\ln\left(\frac{Isc}{I_S}+1\right) \tag{1}$$

Where, Is: Saturation current ,Isc: Short circuit current وKB: Boltzmann constant and T: Room temperature

(ii) Short circuit current (Isc),

$$I_{SC}=I_S\left[\exp\left(\frac{qV_{oc}}{K_BT}\right)-1\right]+\frac{V_{OC}}{R_{sh}} \tag{2}$$

Where, R_{sh}=shunt resistance

(iii) Fill factor (FF)

$$FF=\frac{I_m.V_m}{I_{sc}.V_{oc}}=\frac{P_m}{I_{sc}V_{oc}} \tag{3}$$

Where V_m,I_m represent maximum voltage and current at maximum output. .

(iv) Conversion power efficiency η. Which represents the percentage of power converted (from absorbed light to electrical energy) and collected when a solar cell is connected to an electrical circuit. This term is calculated using the ratio of maximum power (pm) divided by the input light irradiance (Pin) under standard test condition in (W/m2) and the effective area of the solar cell a (in cm^2)

$$\eta=\frac{P_m}{P_{in}a}\times100\%=\frac{I_mV_m}{P_{in}.a}\times100\% \tag{4}$$

(Δη%) it's equal the different between conversion energy efficiency by using (LSC)plate (η%LSC) and bare solar cell (η%bare) divided by the (η%bare).

$$\Delta\eta=\frac{(\eta\%)_{LSC}-(\eta\%)_{bare}}{(\eta\%)_{bare}}\times100\% \tag{5}$$

2. Experimental work

2.1 Materials

Rhodamine 6G with molecular formula $C_{28}H_{31}N_2O_3Cl$, molar mass 479.02 g/mole and Rhodamine B with molecular formula C28H31N2O3Cl, molar mass 479.02 g/mole and their mixtures were used becauseR6G and RB has strong absorbance in visible region and also it has large cross section and that is what solar cells need. These dyes dissolved in chloroform Molecular Formula**:** $CHCl_3$, Molecular Weight**:** 119.4 g/mole, Density:1.483 g/cm^3, Melting point: 63.5 °C, 210 K, -82 °F, Boiling point: 61.2 °C, 334 K, 142 °F, Refractive index (n_D): 1.4459 (A. Goetzberger *et al* ,1979) were used in this work**.** All the materials from HIMEDIA company, India.

For thin film samples Epoxy and PMMA materials has been used in manufacturing LSC for solar cells, it is polymers material, transparency, it has low viscosity, resistance to shocks and pressure, it doesn't effected by humidity and chemical materials, also it is electrical insulator material.

In this study, epoxy was used for the reasons such as: It is good solvent for R6G dye; High technique doesn't need to make LSC; Availability and low cost materials; Rapid drying of LSC in laboratory without any assistance material; It has low refractive index (1.25) which gives a chance for fluorescent ray to transpire down from the critical angel toward the solar cell.

2.2 Instrument used in practical work

Absorption spectrum was measured by a UV-visible spectrophotometer-T60 PG instruments Limited. Fluorescence spectrum was measured by a (Spectrofluorometer SL174) by the processor (Elico). The current- voltage for Si solar cell ((10*20 cm) Carmanh Technology Inc.) and the effect of LSC by using solar module Analyzer (60V, 6A) ,PROVA 200 Co.

3. Results and discussion

The spectral optical properties for R6G, RB, RC,3GO, Fluorsen and their mixtures are discuss earlier in [Slafa I. Ibrahim ,2012; Ali H. Al-Hamdani *et al*, 2013;Ali H. Al-Hamdani,2014; Adnan F. Hassan etal,2014). Also the linear and nonlinear properties of dyes doped polymers are discussed in (Ali H. Al-Hamdani *et al* , 2010; Ali H. Al_Hamdani *et al* , 2013; Ali H. Al_Hamdani *et al* ,2014).

In this work the absorbance and transmission spectrum for LSC plates at different concentration has been measured and depicted for R6G doped PMMA and R6G doped Epoxy in (Figuers,1and 2) respectively. From these results show that Clear epoxy resins have been used which exhibited around 30 % lower absorption in the visible region than PMMA (S.J. Gallagher *et al* ,2007). This is certainly an advantage for dye which may be sensitive to temperature. Unlike PMMA casting, which requires heat to cure the polymer, epoxy resins can set at room temperature. However, epoxy resins have a poorer photostability compared with PMMA. It is shown that the absorptions was decreased as the dye concentrations was increased also it was noticed a red shift in the position of the peak absorptions.

Table 2, shows that there is an increase in the conversion efficiency of Si solar cell if it is covered with LSC that consists of mixture of dyes (R6G and RB). This increment is depend on how large is the region of the solar radiation that contribute in Si conversion energy.

To study the effect of host materials on the LSC properties. The conversion power efficiency of bare solar cell has been measured indoor and compared with conversion power efficiency of solar cell covered with LSC consists of with R6G doped epoxy and R6G doped PMMA plates of different concentrations(table, respectively). The cause of the increasing of the conversion power efficiency is the red shift in the incident light concentrate by the LSC, in which the Si solar cell is of the more response. Transmittance of all LSC plates at different concentrations has been studied and noticed that at concentration ($1*10^{-5}$ mol/L) reach 78% as shown in table 2 and it decreased with increasing thickness and concentration of LSC plate.

The LSC plates have been designed to enhance the solar cell conversion power efficiency, it is shown an increasing in the conversion power efficiency of solar cell with increasing of the concentration dye. Modules with dimensions of 10*20 cm and LSC with dye concentration $2*10^{-5}$ mol/L had efficiency of 7.897% (i.e. with efficiency incensement $\Delta\eta$=12.3% compared with the same module without LSC).

The LSC sheet thicknesses effect on conversion efficiencies are studied in the range of 0.5-3 mm of R6G doped epoxy sheet thickness . The higher efficiency occur at LSC thickness equal to 2.5 mm and (concentration $2*10^{-5}$ mol/L). A thicker sheet can result in a higher efficiency, as the required dye concentration can be decreased, thus reducing re-absorption losses. However, this must be balanced against the increased embodied energy and material cost.

Conclusions

From the results of optical properties of liquid sample , it can be concluded that there is an increase in stock shift toward red region in the position of the maximum fluorescence intensity of for R6G with increasing in the concentration.while there is a reduction of quantum efficiency yield with increasing in the concentration. R6G dye dissolve directly in Epoxy resin. Epoxy material has been used at first time in form of plate doped and undoped with R6G dye to improve the efficiency of solar cell. The LSC plate at concentration ($2*10^{-5}$ mol/L)and thickness (1mm) gives the highest conversion power efficiency of solar cell.

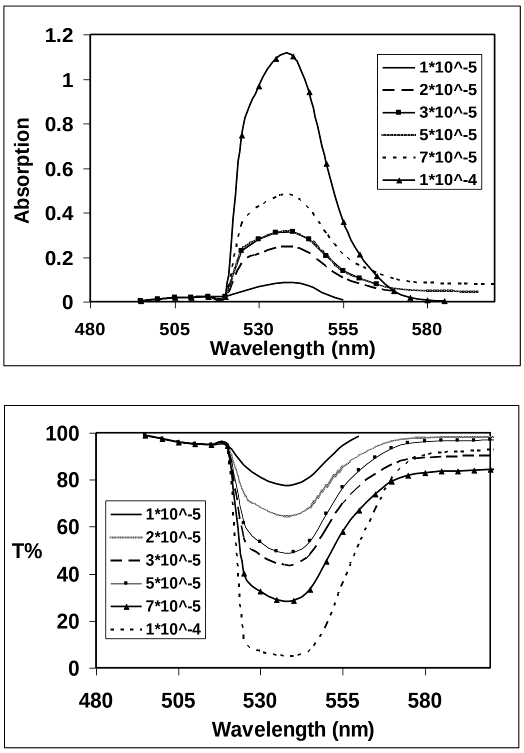
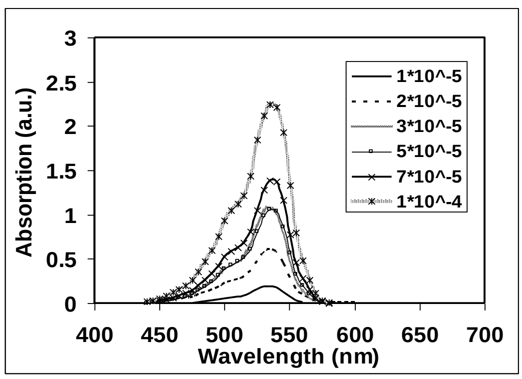


Figure 1: Absorption and Transmission spectrum of R6G doped epoxy with different concentrations



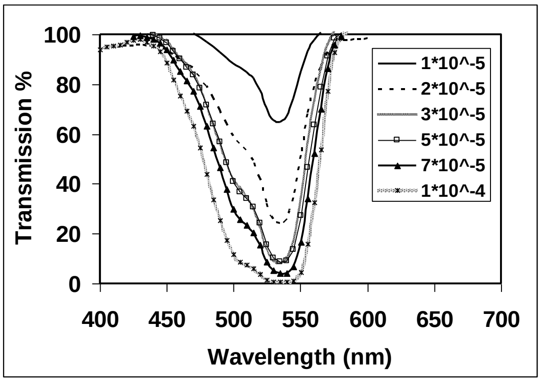


Figure 2: Absorption and Transmission spectrum for R6G doped PMMA with different concentrations

Table 1: Characteristic properties of Silicon solar cell (10*20 cm) Covered with luminous concentrator (LSC) consists of R6G doped PMMA. (LSC thickness 186μm), solar irradiance 250 mW/cm^2)

Dye Concentration	$P_{max.}$ (mW)	$V_{max.}$ (V)	$I_{max.}$ (mA)	EFF%	FF
0.0	152.9	6.070	25.2	6.118	0.718
$1*10^{-5}$	163.1	5.787	28.2	6.527	0.718
$2*10^{-5}$	167.6	6.030	27.8	6.705	0.787
$3*10^{-5}$	173.1	6.765	25.6	6.927	0.643
$5*10^{-5}$	165.3	6.669	24.8	6.615	0.703
$7*10^{-5}$	160.1	6.590	24.3	6.405	0.803
$1*10^{-4}$	156.4	6.547	23.9	6.258	0.788

Table 2: Characteristic properties of Silicon solar cell (10*20 cm) Covered with luminous concentrator (LSC) consists of mixture of (R6G &RB) doped PMMA. (LSC thickness 186μm, solar irradiance 250 mW/cm^2)

Dye Concentration	$P_{max.}$ (mW)	$V_{max.}$ (V)	$I_{max.}$ (mA)	EFF%	FF
0.0	154.1	5.951	25.9	6.165	0.690
$1*10^{-5}$	161.6	5.793	27.9	6.464	0.671
$2*10^{-5}$	170.8	5.305	32.2	6.832	0.662
$3*10^{-5}$	185.9	6.347	29.3	7.438	0.760
$5*10^{-5}$	186.9	6.446	29.0	7.477	0.736
$7*10^{-5}$	189.9	6.268	30.3	7.596	0.721
$1*10^{-4}$	170.8	5.732	29.8	6.832	0.676

Table 3: Characteristics properties si solar cell with LSC consist of R6G dye doped epoxy

Sample Concentration M/L	$P_{max.}$ (mW)	$V_{max.}$ (V)	$I_{max.}$ (mA)	EFF%	FF
0.0	355.6	6.610	53.8	7.112	0.874
Epoxy	350.2	6.608	53.0	7.004	0.891
$1*10^{-5}$	363.8	6.892	52.8	7.277	0.885
$2*10^{-5}$	394.8	6.940	56.9	7.897	0.895
$3*10^{-5}$	377.6	6.719	56.2	7.552	0.830
$5*10^{-5}$	375.9	6.737	55.8	7.518	0.849
$7*10^{-5}$	363.6	6.746	53.9	7.272	0.851
$1*10^{-4}$	360.2	7.063	51.0	7.204	0.912

Table 4: Effect of samle thickness on the characteristics properties of Si solar cell with LSC consist of R6G dye doped epoxy (concentration $2*10^{-5}$ mol/l)

Sample Thickness (mm)	P_{max} mW	V_{max} V	I_{max} mA	Eff%	FF
0.0	175.3	6.376	27.50	7.013	0.873
0.5	178.9	6.579	27.20	7.157	0.866
1	183.0	6.560	27.90	7.320	0.805
1.5	192.3	6.678	28.80	7.693	0.922
2	169.8	6.519	30.2	7.874	0.852
2.5	201.4	6.356	31.70	8.059	0.832
3	195.6	6.611	29.6	7.827	0.900

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