



Study of Optical Properties of Phenol Red Dye Doped Polymer Films

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Abstract: The optical properties and the main optical constants of Phenol Red dye doped polymer films, for different concentrations, were studied. The polymer films were prepared by casting method using Polymethylmethacrylate (PMMA) polymer as a host and the chloroform as a solvent for both the dye and the polymer. The absorbance and the transmittance spectra of the polymer films were measured using visible-ultraviolet (Vis-UV) double-beam spectrophotometer in the wavelength range 190-1100 nm. The data obtained from the measurements were used to determine the optical constants of the dye doped polymer films, include the absorption coefficient (α), the extinction coefficient (κ), the refractive index (n), the real (ϵ_r) and the imaginary (ϵ_i) parts of the dielectric constant (ϵ) as a function of the incident photon energy ($h\nu$). The obtained results show that the optical properties of the Phenol Red dye doped polymer films are dependent on the optical parameter values of dye film and significantly modified with the variation of these values. This is quite useful for optical applications through controlling the light by changing the physical properties of the dye doped polymer films.

Key words: Optical properties; Optical constants; Phenol Red dye; Polymethylmethacrylate (PMMA) polymer; Dye doped polymer films.

I. Introduction

Linear and nonlinear optical properties of materials have been the subject of numerous investigations by many researchers during recent years. They have attracted extensive attention due to their various photonic applications such as, optical switchers, optical sensors, optical power limiters, optical communications, and optoelectronic and photonic devices [1-9]. Among optical materials that have been identified, organic dyes have attracted considerable research interest, because they have: large nonlinearities, fast response times, wide range of visible and ultraviolet spectral band, and good environmental photo-thermal stability [10-12]. In addition, these materials are of relatively low cost and ease of preparation.

The organic dye materials are greatly demand for the optical applications. The optical and the electrol properties of these materials can be significantly improved by embedding them as inclusions in proper polymers (with suitable solvents) to produce solid polymer films for suitable applications [11, 13]. One of the important polymeric materials is the Polymethylmethacrylate (PMMA). It is most widely used as a suitable host matrix for various dye materials due to its advantages: relatively low cost material, high optical transparency in the visible and ultraviolet light spectrum, high soluble in many solvents, good outdoor weather resistance, and has relatively high laser damage resistance [14, 15].

The aim of the present study is to investigate the optical properties of the prepared Phenol Red dye doped polymer films. Then the data obtained from the absorption and transmission measurements will be used to determine the main optical constants of the dye doped polymer films such as, reflectance, absorption coefficient, extinction coefficient, refractive index, and real and imaginary parts of the dielectric constant.

II. Theoretical

The absorbance of the polymer film can be measured by the spectrophotometer and it is defined by the relation [16, 17]:

$$A = \log_{10} \frac{I_0}{I} \quad (1)$$

where I_0 is the intensity of the incident light on the polymer film sample and I is the transmitted intensity from the sample.

The absorption coefficient (α) of the polymer film sample can be obtained from the Lambert-Beer law [16]:

$$I = I_0 e^{-\alpha t} \quad (2)$$

and is given by:

$$\alpha = 2.303 \frac{A}{t} \quad (3)$$

where t is the film sample thickness.

The reflectance of the polymer film sample can be determined from the relation [18-20]:

$$T = (1 - R)^2 e^{-\alpha t} \quad (4)$$

where T is the transmittance of the polymer film sample and is given by the relation:

$$T = \frac{I}{I_0} \quad (5)$$

The relationship between the absorbance (A), transmittance (T), and reflectance (R) of the polymer film sample is given by:

$$A + T + R = 1 \quad (6)$$

The refractive index (n) of the polymer film sample can be determined from reflectance (R) using the following relation [18, 20]:

$$n = \left(\frac{1 + R}{1 - R} \right) + \left(\frac{4R}{(1 - R)^2} - \kappa \right)^{1/2} \quad (7)$$

where κ is the extinction coefficient and is given by the relation [20]:

$$\kappa = \frac{\alpha \lambda}{4 \pi} \quad (8)$$

where λ is the wavelength of the incident light.

The complex dielectric constant (ϵ) is related to the refractive index (n) and the extinction coefficient (κ) according to the relation [20]:

$$\epsilon = \epsilon_r + \epsilon_i \quad (9)$$

where ϵ_r and ϵ_i are, respectively, the real and the imaginary parts of the dielectric constant ϵ , and given by the following relations:

$$\epsilon_r = n^2 - \kappa \quad (10)$$

$$\epsilon_i = 2 n \kappa \quad (11)$$

III. Experimental

The chemical structure and the molecular formula of the Phenol Red dye is shown in Fig.1. The Phenol Red dye doped polymer films were prepared by casting method. Required amount of Phenol Red dye powder was dissolved in a mixed solution of chloroform and small amount of methanol (as additive solvent), suitable solvent solution for both the dye and the polymer. Then required amount of highly purity Poly(methylmethacrylate) (PMMA) granules was added. The mixture was filtered and then stirred at room temperature for one hour using a magnetic stirrer until homogenous solution was formed. A proper amount of the resulting solution was taken and casted on a thin glass slide. This procedure was repeated for preparing the other polymer films at different dye concentrations. The prepared polymer films were allowed to dry at room temperature. The obtained polymer films were examined and it was found that they are uniform with good optical quality. The thickness of each one of these polymer films was measured to be 1 mm. Five polymer film samples at different concentrations, 0.01, 0.02, 0.03, 0.04, 0.05 mM, were chosen for our present study.

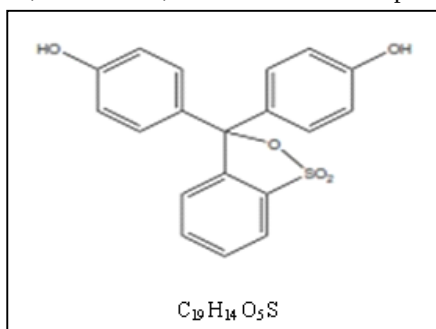


Fig. 1: Chemical structure and molecular formula of Phenol Red dye.

IV. Results and Discussion

The absorbance and transmittance spectra for the Phenol Red dye doped polymer film in the wavelength range 190-1100 nm were measured using Cecil Visible-Ultraviolet (Vis.-UV) double-beam spectrophotometer (Model

CE-7500, England). Fig. 2 shows the absorbance spectra of the Phenol Red dye doped polymer films at different concentrations. It is seen that there is a peak located at the wavelength 462 nm, within the visible spectrum region. The absorbance of the polymer film is low and increased slightly with increasing the Phenol Red dye concentrations. It can be seen also that there is another peak appeared around the wavelength 300 nm within the ultraviolet spectrum region with relatively high absorbance, increases slightly with increasing the dye concentration. This may be related to the unsaturated energy bands.

Fig. 3 shows the transmittance spectra of the Phenol Red dye doped polymer films. It is observed that the transmittance of the polymer film is high within the visible spectrum region; it is about 82-93 % of the value of the incident light beam on the sample film. Increasing the dye concentration leads to small reduction in the transmittance of the polymer film over the range 300-1100 nm.

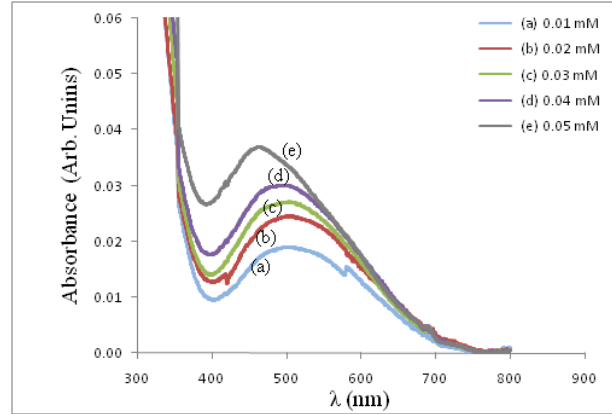


Fig. 2: UV-Vis absorbance spectra of Phenol Red dye doped polymer film at different concentrations.

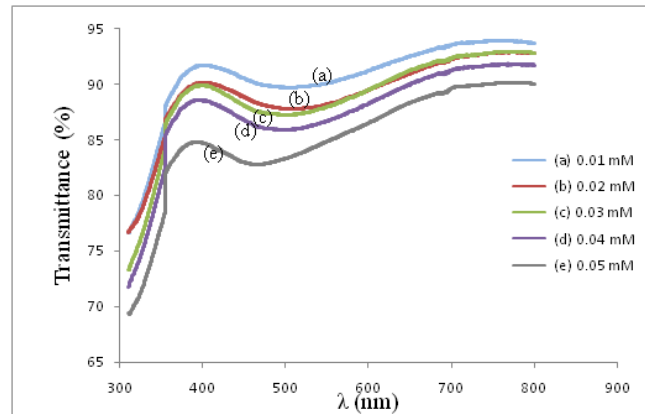


Fig. 3: UV-Vis transmittance spectra of Phenol Red dye doped polymer film at different concentrations.

The linear absorption coefficient (α) of the Phenol Red dye doped film was calculated using the relation (3). Fig. 4 shows the dependence of the absorption coefficient (α) on the incident photon energy ($h\nu$), for different dye concentrations. It is clearly seen that α exhibits relatively low values over the visible spectrum region, and its value is slightly increased with the increase in the dye concentration. But the value of α is increased over the ultra-violet spectrum region and it reaches to $\approx 3 \text{ cm}^{-1}$ for incident photon energy of $\approx 4 \text{ eV}$.

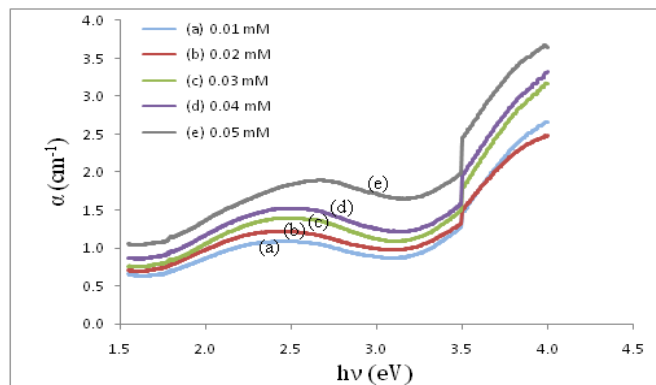


Fig. 4: The absorption coefficient (α) of the Phenol Red dye doped polymer film versus the incident photon energy ($h\nu$), for different dye concentrations.

The reflectance (R) of the Phenol Red dye doped polymer film at different concentrations is determined from the relation (4). Fig. 5 shows the reflectance (R) as a function of the incident photon energy ($h\nu$). The Results in this figure reveal that polymer film has low reflectance within the visible spectrum region (around 3-8 %) because the dye concentrations are low and the PMMA polymer is a transparent material. Increasing the dye concentration causes slight increase in the value of the polymer film reflectance, but this value significantly increases when the energy of the incident photons increases. We can also deduce from Fig. 5 that the polymer film exhibits high reflectance within the ultra-violet spectrum region, and increases with increasing the dye concentration.

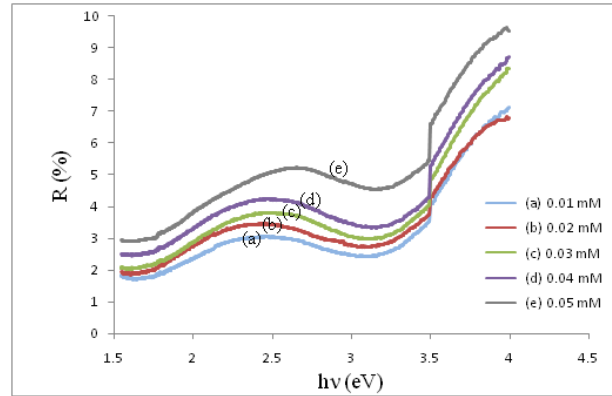


Fig. 5: The reflectance (R) of the Phenol Red dye doped polymer film versus the incident photon energy ($h\nu$), for different dye concentrations.

The refractive index (n) is an important parameter related to the material density. This parameter was calculated for the Phenol Red dye doped polymer film using the relation (7). The obtained values of n were plotted as a function of the incident photon energy ($h\nu$), for different concentrations, as shown in Fig. 6. From this figure, we can see that there is a significant change in the value of the refractive index (n) over the visible spectrum region when the dye concentration increases. In the ultraviolet spectrum region, noticeable increase in the value of n is observed, but with small change in the value of n as the dye concentration increases.

The extinction coefficient (κ) is calculated using the relation (8). Fig.7 shows the variation in κ with the incident photon energy ($h\nu$). It is obvious from this figure that the behavior of κ with incident photon energy ($h\nu$) is nearly similar to that of the corresponding absorption coefficient (α) at different concentrations. It can be seen from this figure that the value of κ for the Phenol Red dye doped polymer film is varied with increase in incident photon energy over the visible spectrum region, it initially increases after that decreases then increases exponentially with increasing incident photon energy. The value of κ increases slightly with increasing the dye concentration.

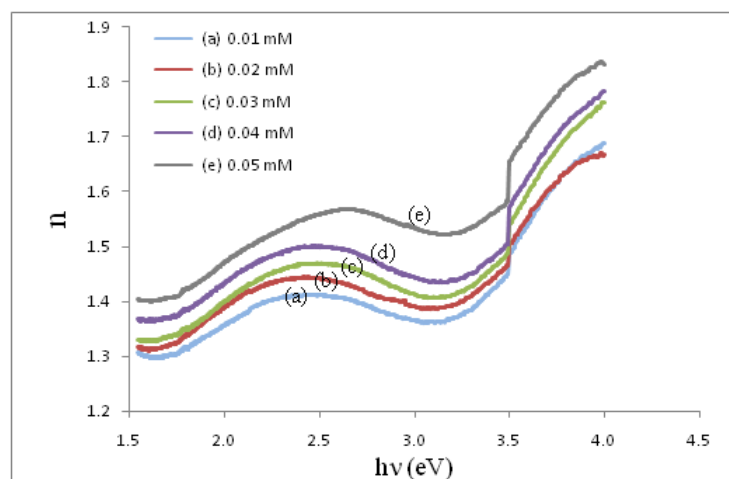


Fig. 6: The refractive index (n) of the Phenol Red dye doped polymer film versus the incident photon energy ($h\nu$), for different dye concentrations.

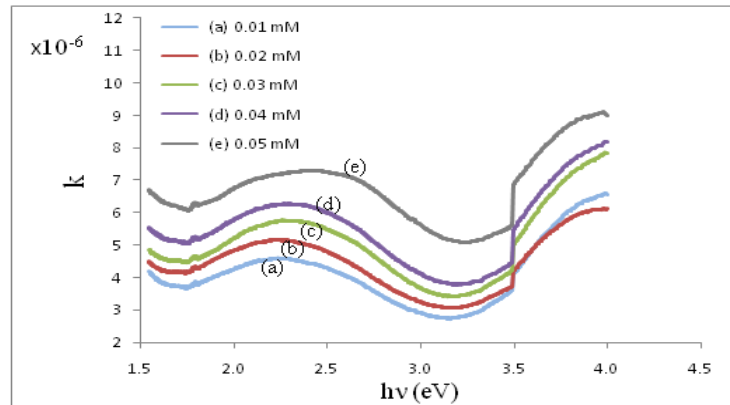


Fig. 7: The extinction coefficient (κ) of the Phenol Red dye doped polymer film versus the incident photon energy ($h\nu$), for different dye concentrations.

The values of the real (ϵ_r) and the imaginary (ϵ_i) parts of the dielectric constant (ϵ) were calculated using the relations (10) and (11), respectively. The obtained values of these two parameters were plotted versus the incident photon energy ($h\nu$) in Figs. 8 and 9, for different dye concentrations. It is obvious from Fig.8 that the behavior of ϵ_r as a function of the incident photon energy ($h\nu$), is similar to that of the refractive index (n) due to the relation between them according to the relation (10) (where $n > \kappa$). While the behavior of ϵ_i as a function of the incident photon energy ($h\nu$), is similar to that of the extinction coefficient (κ) due to the relation between them according to the relation (11). It is clear that the values of both parameters, ϵ_r and ϵ_i , increase when the dye concentration increases, but the values of ϵ_r are higher than that for ϵ_i . The difference in these values is due to the difference in the definitions of the two parameters according to the relations (10) and (11).

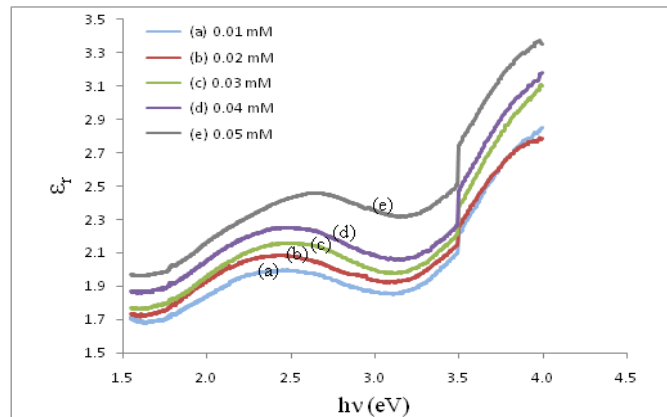


Fig. 8: The real part (ϵ_r) of the dielectric constant (ϵ) of the Phenol Red dye doped polymer film as a function of the incident photon energy ($h\nu$), for different dye concentrations.

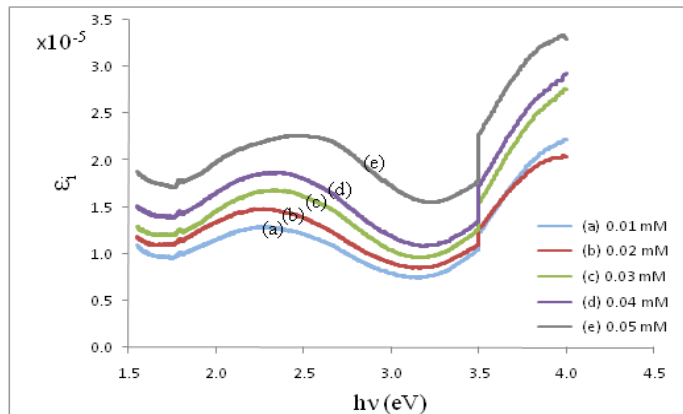


Fig. 9: The imaginary part (ϵ_i) of the dielectric constant (ϵ) of the Phenol Red dye doped polymer film as a function of the incident photon energy ($h\nu$), for different dye concentrations.

V. Conclusions

The optical properties and optical constants of the Phenol Red dye doped polymer films for different concentrations have been investigated. The optical constants of the polymer film as a function of the incident photon energy ($h\nu$) were determined by using the obtained data from the absorption and transmission spectra measurements. These include; the absorption coefficient (α), the reflectance (R), the extinction coefficient (κ), the refractive index (n), the real (ϵ_r) and the imaginary (ϵ_i) parts of the dielectric constant (ϵ). The results show that the optical properties of the Phenol Red dye doped polymer film are significantly affected by varying the values of the optical parameters of the polymer film. This may be useful for controlling the optical behaviors of the doped polymer films and then can be used in the photonic applications.

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