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Optical and dispersion properties of thermally deposited phenol red thin films

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ABSTRACT

Thin films of phenol red are prepared using thermal evaporation technique. X-ray diffraction patterns of the powder form, as-deposited and annealed thin films are examined. The crystal structure and Miller indices of phenol red are deduced. Optical properties of phenol red thin films are investigated using spectrophotometric measurements for transmittance and reflectance as a function of wavelength in the range of 200–2500 nm. The optical constants, optical transitions, dispersion parameters and third-order nonlinear susceptibility are determined for phenol red thin films. The influence of the annealing on as-deposited films at 373 for 2 h is investigated for both of structural and optical properties.

1. Introduction

Recent researchers have developed in using Organic materials for the fabrication of microelectronic devices. The performance of these devices is dependent on a variety of factors such as fabrication parameters, characteristics of the Organic materials used and their optical and electrical properties [1]. Thus, organic materials have grown due to the wide range of applications in photonic devices, such as sensors, light emitting diodes, solar cells, limiters, and optoelectronic devices [2]. During the last few years, interest in organic semiconductors and their thin films increased rapidly due to [3] the processing at low temperature, material variety, design flexibility, and environmental safety [4]. The organic molecules of interest for optoelectronic applications offer alternate σ and π bonds that form extended chains or rings. The construction of such alternate-bond structures produces π-electrons that are highly delocalized [5] and leading to the characteristic optical properties of these compounds.

The organic dye materials are highly desire for the optical applications due to their stellar optical properties [2,6]. The optical behavior of materials is important to determine its usage in optoelectronic devices [7]. In the present work, we report on the study of the optical and dispersion properties of phenol red thin films. Phenol red dye ($C_{19}H_{14}O_5S$) has the molecular structure that shown in Fig. 1. Thin films of phenol red are obtained by thermal evaporation technique onto quartz and glass substrates. The crystal structural of the powder of phenol red is indexed using X-ray diffraction (XRD) analysis. The optical constants (refractive and extinction indices), optical transition, dispersion parameters are deduced for phenol red films. Also, the influence of the annealing for as-deposited films at 373 for 2 h is investigated on the structural and optical properties of phenol red films.

2. Experimental procedures

The powder of phenol red purchased from sigma Aldrich company and used without additional purification. Phenol red thin films prepared using thermal vacuum evaporation technique with a high coating unit (E 306A, Edwards, England). The films deposited onto precleaned glass and quartz substrates for structural and optical measurements, respectively. The substrate temperature kept at room temperature. The deposition of phenol red films was carried out using a quartz crucible source heated slowly by a molybdenum boat in a vacuum of 3×10^{-4} Pa. The deposition rate was kept constant at about 2 nm/s using a quartz crystal thickness monitor (FTM4). Also, the thickness of films was determined was using a quartz crystal thickness monitor (FTM4) and checked after preparation by Tolansky's technique [8]. The phenol red films have thickness of 171 and 356 nm. Some phenol red films were annealed in air at 373 for 2 h.

The structural characterization of powder and thin films was carried out by X-ray diffraction (XRD) technique using a Philips X-ray diffractometer model X'pert, with CuK_α radiation that operated at

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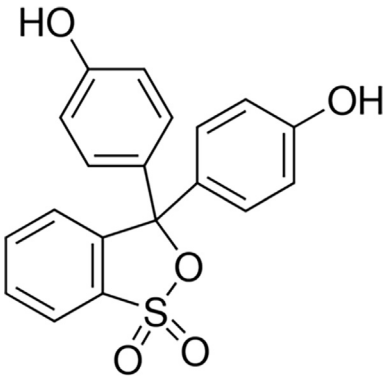

Fig. 1. Molecular structure of phenol red.

40 kV and 25 mA. The XRD patterns were measured in the range of (2θ°) 4° – 60°. The optical transmission (T) and reflection (R) spectra of as-deposited and annealed films of Phenol red were measured in the range of 200–2500 nm at normal incidence using a double beam spectrophotometer (JASCO model V-570 UV-Vis-NIR). The spectral data obtained directly from the spectrophotometer were transformed to absolute values by making a correction to eliminate the absorbance and reflectance of the substrate [9,10].

The absorption coefficient (α) extinction index (k) and the refractive index (n) were calculated for the as deposited and annealed films at different wavelengths (λ) using the following equations as [11,12]:

$$\alpha = \frac{1}{d}\ln\left[\frac{(1-R)^2}{2T} + \sqrt{\frac{(1-R)^4}{4T^2} + R^2}\right] \quad (1)$$

$$k = \frac{\alpha\lambda}{4\pi} \quad (2)$$

$$n = \left(\frac{1+R}{1-R}\right) + \sqrt{\frac{4R}{(1-R)^2} - k^2} \quad (3)$$

3. Results and discussion

3.1. Structural characterization

Fig. 2 represents XRD pattern of phenol red in the powder form in 2θ° range of 4° – 60°. Many diffraction peaks appeared in the XRD pattern, indicating that a polycrystalline nature for the phenol red. The crystal structural of phenol red is examined from the obtained XRD data using the CRYSFIRE program [13]. The result showed that phenol red is a triclinic crystal system with lattice parameters; a = 8.377 Å, b = 11.277 Å, c = 13.214 Å, α = 67.73°, β = 77.51°, γ = 78.54° and the space group is (P-1). The corresponding Miller indices (*h k l*) for each diffraction peak in Fig. 2 are calculated using Check cell program [14] and listed in Table 1.

XRD pattern of thermally deposited phenol red thin films with different thicknesses is shown in Fig. 3a. It noticed that phenol red films exhibit a typical of an amorphous structure with a broad amorphous hump, where there is no significant reflection peaks in the pattern. The phenol red film of thickness 356 nm is annealed at 373 K for 2 h. The annealed film has an amorphous structure as observed from Fig. 3b.

3.2. Optical characterizations

The UV–VIS spectra of the material provide important information about the details related with optical band [15] that is characteristic for each material. The spectral distribution of the transmittance, T(λ), and reflectance, R(λ) for phenol red films, of thickness 356 nm, are investigated in the wavelength range of 200–2500 nm. Fig. 4 represents the variation of transmittance and reflectance as a function of wavelength for as-deposited and annealed phenol red films. As observed, the transmittance spectra show the absorption region for lower wavelengths (λ < 8 0 0), where T + R < 1 and the phenol red films are a good absorber for light. The electronic transitions are possible in this region as noticed from Fig. 4. For higher wavelengths (λ>800), T + R = 1 and the phenol red films are a transparent for light.

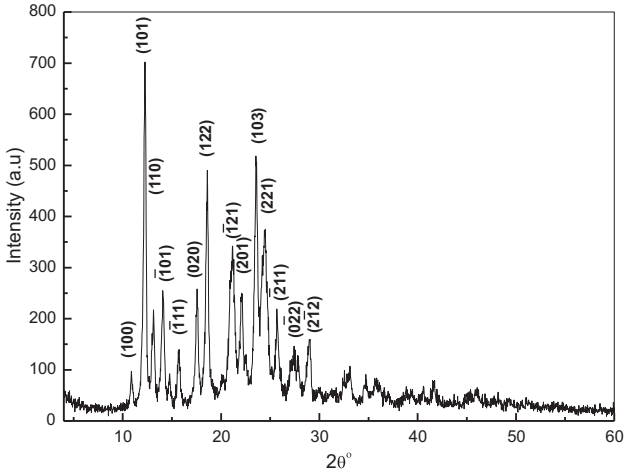

Fig. 2. XRD pattern of phenol red in the powder form.

Table 1
Results of indexing XRD pattern of phenol red in the powder form.

No.	$d_{exp.}$ (Å)	$d_{cal.}$ (Å)	|Δd|(Å)	*hkl*
1	8.12789	8.119	0.0088	100
2	7.21400	7.21	0.0040	101
3	6.73827	6.743	0.0047	110
4	6.27249	6.272	0.0005	$\bar{1}01$
5	5.98949	5.991	0.0015	$1\bar{1}0$
6	5.64330	5.643	0.0003	$\bar{1}11$
7	5.04326	5.062	0.0187	020
8	4.76791	4.769	0.0011	122
9	4.39344	4.393	0.0004	$0\bar{1}2$
10	4.19374	4.192	0.0017	$\bar{1}21$
11	4.01872	4.027	0.0083	201
12	3.77037	3.77	0.0004	103
13	3.63679	3.638	0.0012	221
14	3.46334	3.472	0.0087	$\bar{2}11$
15	3.24879	3.253	0.0042	$0\bar{2}2$
16	3.20229	3.203	0.0007	014
17	3.07600	3.072	0.0040	$\bar{2}12$

3.2.1. Optical constants (n, k)

The ability of a medium to interact with light is determined by its optical properties [16] and the refractive index of that medium is a measure of the propagation properties of light in it. The complex refractive index $\tilde{n}(\lambda)$ is depending on wavelength as: $\tilde{n}(\lambda) = n(\lambda) + ik$, where the real part (n) is refractive index and is related with the light propagation speed. The imaginary part (k) is the extinction index, that characterizes the absorption by the medium. Fig. 5 shows variation of the refractive index n as a function of incident photon wavelength for as-deposited and annealed