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Modification of the Optical Properties of Glass by Spin Coating with Novolac: Polyester Blend

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ABSTRACT

The novolac/polyester blend to coat the glass enhances the characteristics (transmittance, absorbance, reflectance, extinction coefficient, and energy gap of glass) by coating it with a polyester/novolac blend for use in the detector. Spin coating is utilized to coat the glass with novolac/polyester blend at various volume ratios of 1:1, 1:2, 1:3 of polyester. The optical properties of novolac: polyester blended film 10µm thickness have been considered depending on the wavelength of absorbance, transmittance, and reflectance spectra in the range 300-900 nm. The optical parameter includes calculation (absorption coefficient α, extinction coefficient, energy gap). The result showed that the absorption, extinction coefficient, and reflectance decrease with the increase in polyester content, while transparency and transmittance increase. The absorption coefficient increases with wavelength to 365 nm, then decreases. Transmittance decreases with wavelength increase. The reflectance increases with wavelength increase. The energy gap does not affect the increase in the polyester content, so the conductivity will not change with the change in the polyester concentration. Fourier transform infrared spectroscopy (FTIR) analysis was utilized to distinguish bond absorption around 2900-3550 cm^{-1}, and the aromatic C-H groups stretched due to vibration from medium to weak bands within 3090-3020 cm^{-1}. The intensity of the ester group bonds and other bonds increased in the samples due to increased polyester content. FTIR showed physical interaction between novolac and polyester due to Van der Waals bonds.

1. INTRODUCTION

Nanoparticles have been widely explored because of their high surface area-to-volume ratio and excellent reactivity by virtue of unique properties [1]. Nanoparticle is an efficient bridge from atomic or molecular world to the bulk material. The physical characteristics of a bulk material are independent of its shape or size. However, the morphological microstructure (dimensions and configurations) of material is dominant for controlling its physical properties at the nanoscale. The material science at nanoscale manifests itself in unique behaviors such as an increase in the explosive character, melting point depression, or growth of new properties [2].

Optical properties are important in different applications such as solar cells and the detectors of electro-optics [3-5]. The performance of the detectors starts growing quickly [6]. Meanwhile, the optical constant of materials will vary according to the properties of the optical material. Films are good specimens for reflectance and transmittance, they provide a fair reference for comparison [5, 7]. Recently, a family of miniaturized electro-optic devices comprising the diode lasers, detectors, materials, and fiber optics [4] was added to the line. Optical properties, dielectric constant, and shear absorption get fine attention when careful examination of the structure of electronic materials to describe what kind of conversion is going on in the gap is made through the optical absorption spectra [4, 8].

Nanoparticles show unique optical properties due to quantum confinement effect, existence of surface plasmon resonance and large surface-to-volume ratios, which result in excellent light absorption, tunable band gap, and superior photonic interaction [9-11]. These characteristics make them especially suited for use within optoelectronic devices, photovoltaic systems, and next-generation optical coatings [3]. The design of the optical band gap can provide accurate adjustment of light absorption and emission spectra, and high-absorption cross-sections for an efficient light-harvesting system [12]. Therefore, the addition of nanoparticles in glass or polymeric matrices makes it possible to achieve optical materials that are highly responsive, energy efficient, and functionally diverse [13].

Introducing nanoparticles directly into polymer matrices has been considered as a promising technique to further improve the performance of polymeric coatings, leading to nanocomposite materials with better optical, electrical, and mechanical properties [14]. For example, quantum confinement effect, tunable band gap, and surface plasmon resonance unique to the nanoparticles lead to excellent control of the light absorption or emission spectra as well as charge transport properties [15, 16]. When dispersed in polymers such as novolac and unsaturated polyesters systems, these nanomaterials are uniquely capable of enhancing the optical transparency, refractive response, and dielectric efficiency of host matrix [17-19]. Such a synergistic system not only produces high transparency and good photonic response but also achieves structural reinforcement as well as thermal stability, which endows these nanocomposites with potential applications in advanced optoelectronic devices such as solar energy harvesting, photo detector, light-emitting devices and bright windows [20, 21]. Therefore, the simultaneous development of polymer–nanoparticle systems represents a promising, multiple-enabled pathway to customize the optical response of glass substrates and access novel hybrid materials for high- performance electro-optical applications [22].

The equation gives the connection between occurrence intensity and the bright light intensity:

$$I=Ioe-\alpha t \quad (1)$$

wherever the thickness is represented by t in cm, and α is the absorption coefficient in cm^{-1},

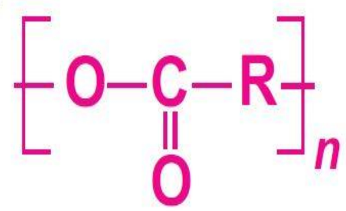
$$\alpha\ t = 2.303 \log I/Io \quad (2)$$

Anywhere, the log I/Io quantity denotes the absorbance (A) [23]. The absorption coefficient may be considered as:

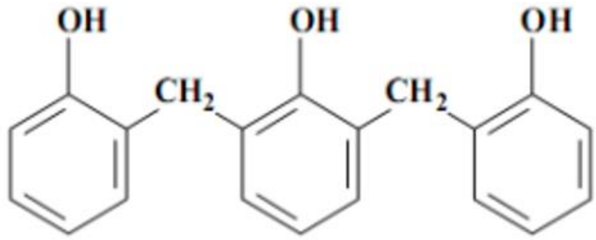
$$\alpha = 2.303\ (A/t) \quad (3)$$

The absorption amount is $\alpha \geq 10^4\ cm^{-1}$, and the electric changes in transition are direct [24-26]. Polymers are primarily utilized in electronic applications and optic devices like modulators, insulators, and sensors because of their high resistivity and dielectric properties [23, 27, 28]. The unsaturated polyester structure is indicated in Figure 1 (A). Novolac resin structure is demonstrated in Figure 1 (B). It has high-temperature resistance, easy processing, low cost, wear resistance, brittleness, high shaping pressure, and diverse colors. Phenolic resins are shaped by the reaction of phenol and formaldehyde and catalyzed by an acid [29, 30]. Unsaturated polyesters have abrasion resistance, heat resistance, excellent compressive strength, and high impact resistance; unsaturated polyesters are useful as fastening gouts with visible or ultraviolet light and insulation coating [3, 31]. Blending processes like polyester and novolac thermoset resins are categorized by utilizing two-component preparations to enhance the transparency characteristics of the polymer [27, 31].

Changing the optical characteristics of glass may have a deep influence on various technological areas, notably, for optoelectronics and photonic applications, solar energy technical fields. Enhanced transparency, adjustable absorbance and optimized reflectivity can enhance the performance of some devices including solar electric cells, photo detecting sensors, and smart windows. These glass substrates, with customized properties from the appropriate polymeric coatings (for example, those used here in novolac/polyester blends), can be designed for enhanced light manipulation, energy conversion, and environmental response. This functional improvement can assist in the development of new electro-optic systems, next generation devices and sustainable energy technologies.



(A) polyester



(B) Novolac

Figure 1. The structure of unsaturated polyester and novolac resin

Therefore, this study focused on the change of optical properties of glass substrates through spin coating and with different compositions of novolac/polyester polymer blend. This work facilitates a better comprehension of the power of polymeric matrices in modifying patented glass surfaces for enhancing photo-refractive properties, since optical behavior (transmittance spectrum, absorbance, reflectance, extinction coefficient, and energy gap) was characterized. The results provide some guidelines in the design of high-end polymer-based nanocomposites for optoelectronic and photonic devices, bringing forward that a better relationship with engineered nanoparticles, such as polymer blends, can be brought about in functional materials engineering.

2. EXPERIMENTAL

2.1 Materials

The novolac resin used in this work was a laboratory grade from the local market. Its ~purity is ≥ 98%, and the average molecular weight is 750 g/mol. For novolac dissolution, ethanol was employed (analytical grade and 99.5% pure). The ethanol was tightly sealed during storage at room temperature prior to use without additional purification or drying.

2.2 Sample preparation

Thin films were fabricated by a spin-coating process with a programmable spinner (Laurell WS 650MZ-23NPP, Laurell Technologies, USA). The coatings were deposited on microscope glass borosilicate substrates of size 25 mm × 25 mm ×1 mm (length, width, and thickness). Before deposition, all substrates were subjected to a standard surface pretreatment process for the improvement of film adhesion and uniformity including an ultrasonic cleaning with neutral detergent solution for 10 min and consecutive deionized water, acetone, and ethanol purification. A spin-coating was conducted at a final angular velocity of 2500 rpm with an acceleration rate of 1000 rpm/s, and the process time was 60 s. Following deposition, the coated films were thermally cured in a convection oven at 80°C for 60 minutes to drive solvent evaporation and further induce polymer cross-linking. All preparation procedures were performed in a normal laboratory environment free of dust particles.

2.3 Mixing proportion

Three polymer blends were prepared to study the effect of polyester content on the optical properties of coated films. 0.1 g/mL (1 g novolac in 10 mL ethanol) of novolac resin was dissolved in the first part and was magnetically stirred for one hour at room temperature until the solution became homogeneous and clear. Unsaturated polyester resin was subsequently incorporated into the novolac solution at volume ratios of 1:1, 1:2, and 1:3 (novolac:polyester, v/v). Each mixture was stirred for an additional hour to obtain a homogenous polymer blend suitable for film deposition. These varying blend ratios enabled a systematic investigation of the effect of increasing polyester concentration on optical parameters such as absorbance, transmittance, reflectance, extinction coefficient, and energy band gap. The formulations used in this study are summarized in Table 1.

Table 1. Mixing proportion of the utilized samples

Sample Code	Novolac Volume (mL)	Polyester Volume (mL)	Novolac:Polyester Ratio (v/v)
Sample 1	5	5	1:1
Sample 2	5	10	1:2
Sample 3	5	15	1:3

3. RESULT AND DISCUSSION

Figure 2 represents Fourier transform infrared spectroscopy (FTIR) versus wavelength for the samples. The IR intense absorption of novolac around 3550-2900 cm^{-1} due to the OH-group vibration. The aromatic group is represented with a wave number 3000-2950 cm^{-1}, and the ester group (C=O) with a wave number 1600 cm^{-1}. The aromatic C-H group stretches from medium to weak bands within the 3090-3020 cm^{-1}. The intensity of the ester group bonds and other bonds increased in the samples due to the increase in polyester content; therefore, the transparency increased, and the bonds became weaker; therefore, the insulation properties decreased.

The absorption confidence (α) increases with wavelength, as demonstrated in Figure 3. The most significant absorption value occurs at the wavelength range 400-800 nm. Sample (1) has the most significant absorption. The absorption decreases with polyester content because the transparency increases with the polyester content increase due to defects in the crystalline lattice, which allow light to pass through the glass.

As demonstrated in Figure 4, transmittance decreases with wavelength increase due to covalent bonds between polymer chains, which change the polymer chains' form and decrease the incident light's transmission. The transmittance increases with the increase in polyester content in the coating film.

The reflectivity decreases with the increase in the polyester content, as demonstrated in Figure 5, due to the reflectivity theory of light used to evaluate the refractive index (n) and extinction coefficient (k). The values of n and k have been designed utilizing the following equations:

$$K = \alpha\lambda/4\pi \tag{4}$$

$$R = \frac{(n-1)^2+k^2}{(n+1)^2+k^2} \tag{5}$$

wherever the extinction coefficient is represented by k, the value (R + T < 1) at a specific wavelength indicates the existence of an absorbing region. The absorption coefficient increases when the wavelength increases, as demonstrated in Figure 6.

The equation can communicate the refractive index.

$$n = \sqrt{\frac{4R-k^2}{(R-1)^2}} - \frac{(R+1)}{(R-1)} \tag{6}$$

The extinction coefficient increases with wavelength because it is determined by the equation below:

$$k = \frac{\alpha\lambda}{4\pi} \tag{7}$$

where, λ is the wavelength, as demonstrated in Figure 7. The extinction coefficient reduces with polyester content growth because it depends on the wavelength effect and transparency. The optical energy gap quantity from this region can be assessed by exponential tail relation:

$$\alpha h\upsilon = A(h\upsilon - Eg)n \tag{8}$$

where, hυ is the photon energy, A is the proportional constant, and Eg is the allowable or prohibited energy gap, which is supposed to have values of ½, 3/2, 2, and 3 depending on the nature of the electronic transition in charge of the absorption. N=3 for the forbidden indirect transition of direct energy gap facilitates electron crossing from the valence band to the local levels to the conduction band. As demonstrated in Figure 8, the energy gap increases with energy photon. The increase in polyester content does not affect the energy gap; therefore, the conductivity does not change.

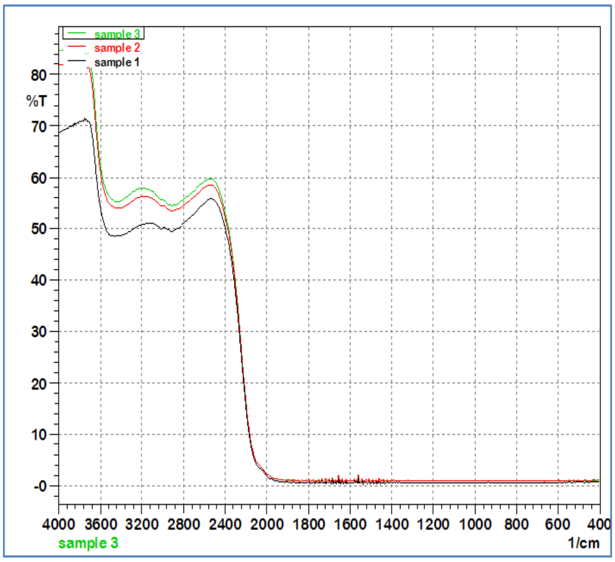


Figure 2. The FTIR versus wavelength for the samples

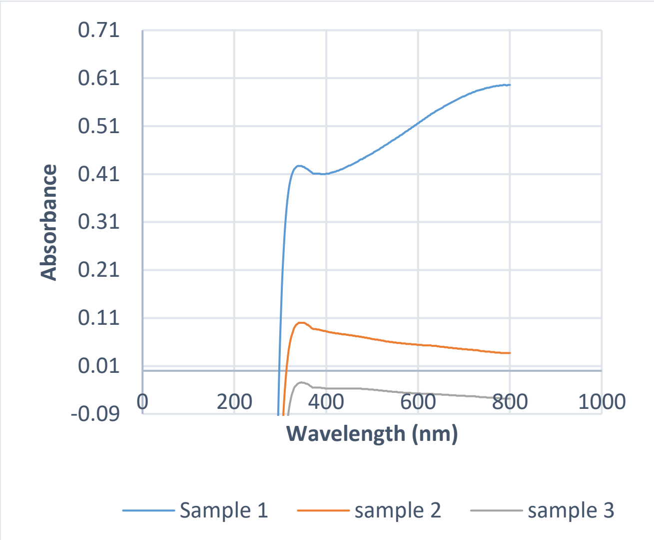


Figure 3. The absorption versus wavelength for the samples

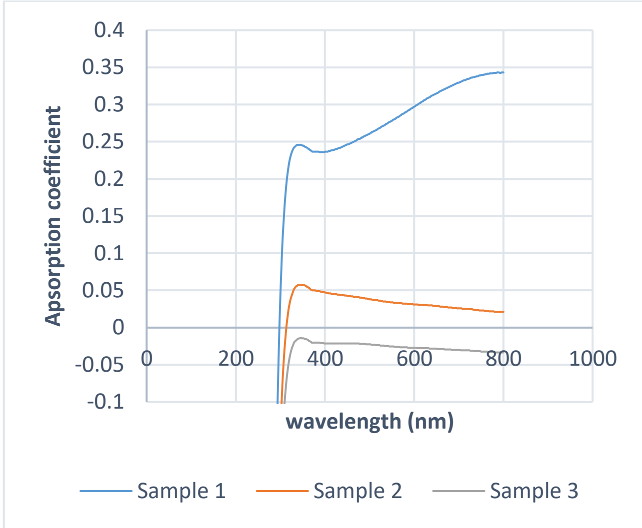


Figure 6. The absorption coefficient versus wavelength for the samples

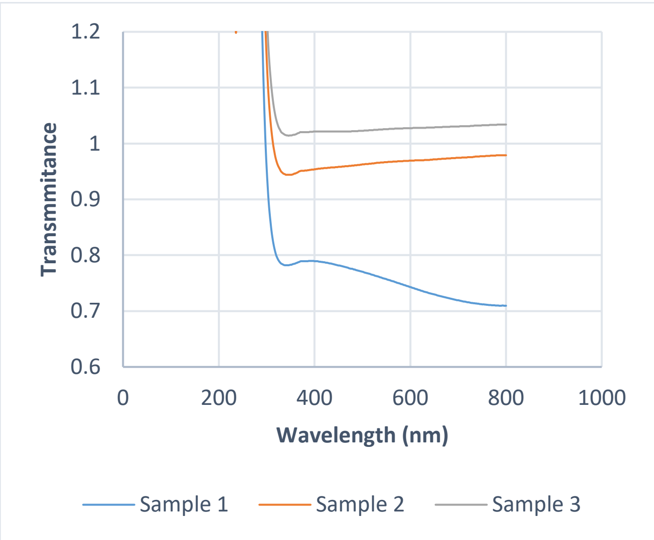


Figure 4. The transmittance against wavelength for the samples

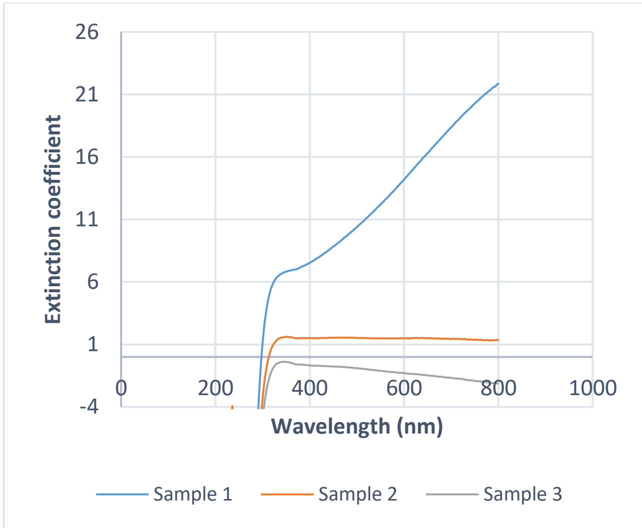


Figure 7. The extinction coefficient against wavelength for the samples

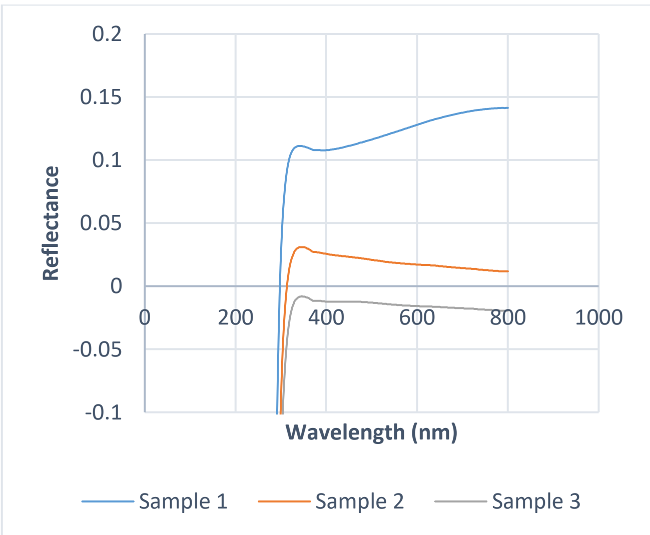


Figure 5. The reflectance against wavelength for the samples

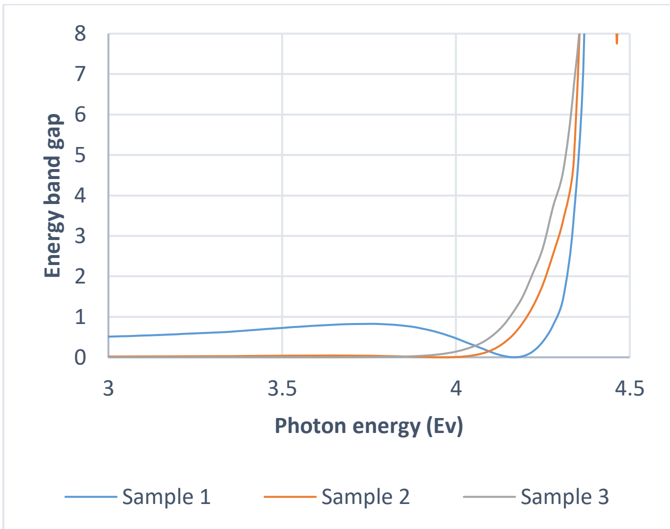


Figure 8. The energy band gap against wavelength for the samples

4. CONCLUSIONS

This study has demonstrated the effectiveness of spin coating as a viable technique for modifying and enhancing the optical properties of glass substrates utilizing a novolac/polyester blend. Through systematic variation of polyester volume ratios in the blend (1:1, 1:2, 1:3), significant changes in key optical parameters, including absorbance, transmittance, reflectance, extinction coefficient, and energy band gap, were observed.

The findings reveal that increasing polyester content in the blend leads to a notable enhancement in optical transparency and transmittance, accompanied by a reduction in absorbance, reflectivity, and extinction coefficient. These effects are attributed to increased light penetration through the material and the weakening of intermolecular bonds as the polyester concentration rises. Additionally, the study confirms that the energy gap remains unaffected by the variation in polyester content, indicating that the electrical conductivity of the coated films remains stable regardless of compositional changes.

FTIR analysis provided further insight into the molecular interactions within the blend, identifying characteristic absorptions associated with OH groups, aromatic structures, and ester functionalities. The results suggest that physical interactions—Van der Waals forces—govern the compatibility between novolac and polyester, with no evidence of chemical cross-linking.

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