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RESEARCH PAPER

Preparation and Characterization of Physical Properties of CMC: PVP-SiO_2 Nanocomposites

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ABSTRACT

In this study, we fabricated CMC-PVP films doped with diverse amounts of SiO_2 *via* casting method approach to examine their optical and structural characteristics. To create the samples, distilled water and a certain weight proportion of CMC and PVP polymers were first combined using a magnetic mixer and heated to 60°C for 1 h. The resulting homogenous solution was then poured into glass molds and allowed to evaporate. FTIR spectroscopy was used to examine the film structures and validate interactions between SiO_2 and the CMC-PVP blend. According to optical analysis, transmittance values decreased as the proportion of SiO_2 doping enhanced. Additionally, the refractive index, extinction coefficient, reflectance, absorbance, and absorption coefficient were enhanced. The optical energy gap values decreased with increasing SiO_2 doping percentages, which were varied from 3.96 eV to 3.73 eV.

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INTRODUCTION

Two popular polymers in the fabrication of optical materials, including films, coatings, and adhesives, are carboxymethylcellulose (CMC) and polyvinylpyrrolidone (PVP). These polymers have unique structural characteristics due to their strong internal bonding strength and chemical durability [1, 2]. The strong hydrogen bonding between the various components and easy formation are examples of structural characteristics of CMC-PVP samples. The CMC-PVP blend is a special kind of polymer with unusual optical characteristics [1, 3], which depend on the mixing ratios between CMC and PVP and the presence of additives like SiO_2. These compounds were extensively utilized in many different industries, including solar energy, glass, ceramics, chemistry, coatings, and electronics [4, 5], They can also be utilized to improve illumination and lessen the absorption of UV and IR rays in windows and glass surfaces. Furthermore, it is applicable to create color coatings, adhesives, paints, reflective surfaces, light signals, films and transparent membranes that need to have good light scattering [6, 7]. This research aims to investigate the effects of SiO_2 nanoparticle doping on the optical and structural properties of the CMC - PVP polymer matrix.

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MATERIALS AND METHODS

The CMC-PVP and CMC-PVP-SiO_2 samples were prepared by casting method. First, two polymers, namely, CMC (0.5 g) and PVP (0.5 g, MW=40,000) were mixed in 40 mL of distilled water at 60°C for 1h. After that, CMC-PVP mixture was further stirred for 2 h at 60°C to obtain CMC- PVP blend. Finally, diverse amounts of additive SiO_2 (0, 0.03, 0.05 and 0.07 wt%) were introduced into the solution of PVP-CMC to produce samples. The material supported by SiO_2 nanoparticles was employed due to their resistant to acids and alkali, well-developed pores, high surface area, low oil absorption, high temperature resistance, strong

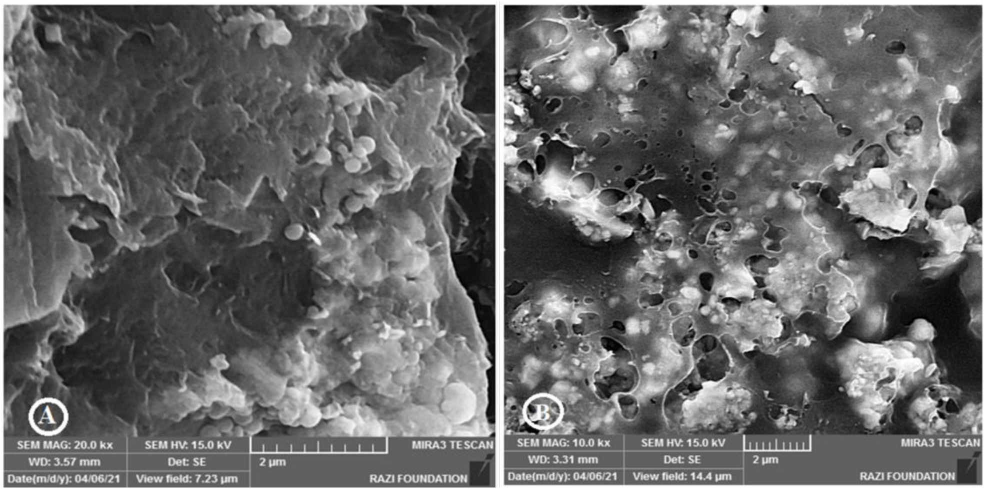

Fig. 1. FE-SEM images of (A) PVP-CMC and (B) PVP-CMC-SiO_2 nanocomposite.

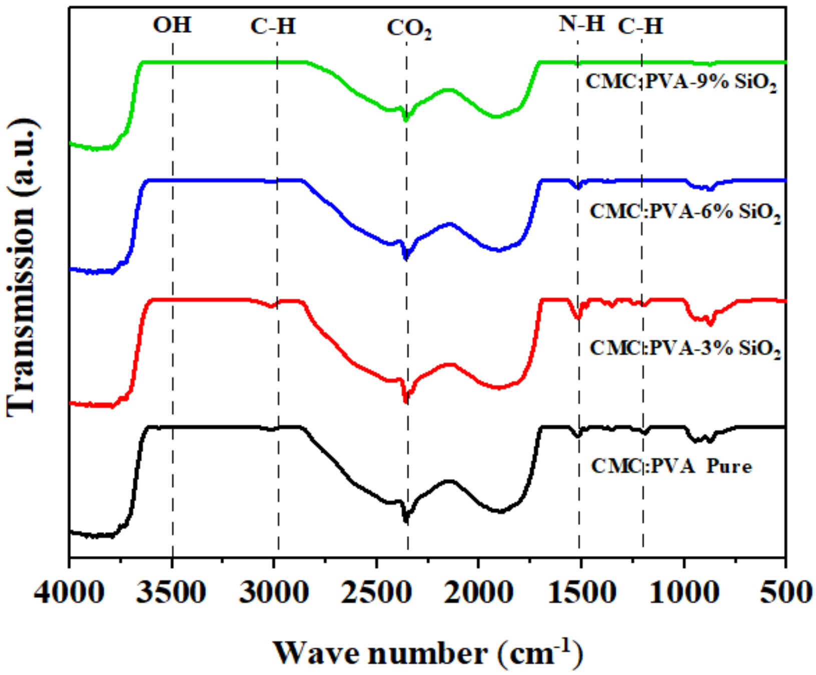

Fig. 2. FTIR spectra of resulting CMC-PVP and CMC-PVP-SiO_2 samples.

thickness, UV resistance, and good electrical insulation. With these properties, they can improve traditional materials and produce new materials.

RESULTS AND DISCUSSION

Fig. 1 depicts the field-emission scanning electron microscope (FE-SEM) images of the CMC-PVP films before and after the introduction of SiO_2 nanopowder at the specified ratios. The films composed of CMC-PVP exhibit a surface with notable roughness. Upon the incorporation of SiO_2 nanoparticles, the observations indicate that the reinforced polymeric films with heightened irregularity, increased roughness, and amplified surface porosity in comparison to the CMC-PVP films. This phenomenon can be attributed to the formation of hydrogen bonds facilitated by the active carboxyl and hydroxyl functional groups [8, 9]. The enhanced irregularity, roughness, and heightened porosity of the surface play a significant role in augmenting the adsorption chemistry of the overlaid films [10, 11].

Fig. 2 shows the FTIR spectra of resulting CMC-PVP and CMC-PVP-SiO_2 samples. The peaks at 825 cm^{-1} and 875 cm^{-1} are related to the bending vibrations of C-O and C-C bonds in the CMC-PVP film, respectively [12, 13]. The peak at 1187 cm^{-1} results from the stretching vibrations of C-O [12]. The band at 1244 cm^{-1} is described as asymmetric twisting vibration mode and CH_2 wagging [14]. C=N vibration-related absorption band is seen at 1518 cm^{-1}, and C–H bending is visible at about 921 cm^{-1} [8]. The peak at 1353 cm^{-1} is related to OH bending vibration [15]. Also, the peak at 1481 cm^{-1} is associated with the vibration of C=N [13]. The appeared peaks in the range of 2360–2330 cm^{-1} might be due to adsorbed CO_2 [16]. The peak at 3012 cm^{-1} is due to the C–H stretching [12]. We observe that doping procedure with SiO_2 decrease the intensity of the peaks.

The optical properties were studied using UV-Vis spectroscopy, as illustrated in Fig. 3a, b. It can be seen that the transmittance decreases with an enhancement in amount of additive (Fig. 3a). Also, it is evident that the reflectance values increase as the doping percentage of SiO_2 enhances. The film modified with 9% of SiO_2 showed the highest reflectance values. Reflectance values was calculated as below [17]:

$$R = 1 - T - A \tag{1}$$

where, R, T, and A shows reflectance, transmittance, and absorbance factors, respectively.

The absorption coefficient was also determined [18]. The values of the absorption coefficient ($\alpha < 10^4$ cm^{-1}) indicate a high probability of indirect transition allowed.

$$\alpha = \frac{2.303A}{t} \tag{2}$$

where, α represents absorption coefficient. A

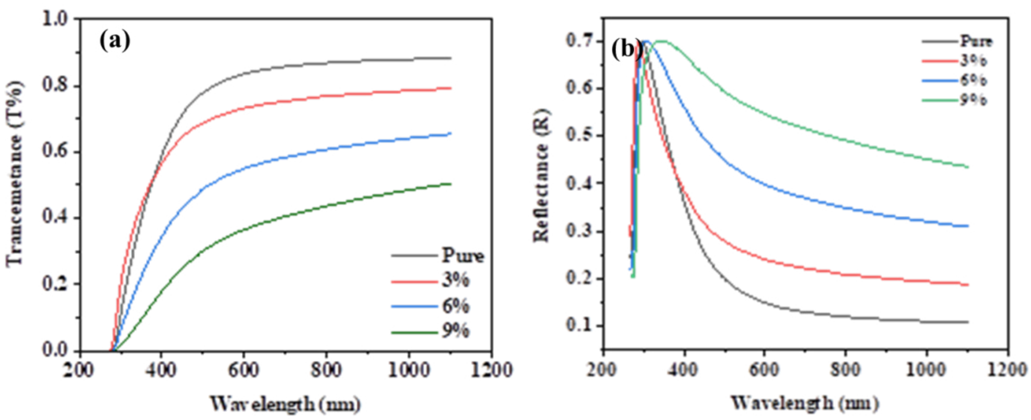

Fig. 3. (a) Transmission and (b) Reflectance spectra of resulting CMC-PVP and CMC-PVP-SiO_2 samples.

and t represent absorbance and film thickness, respectively.

Fig. 4 illustrates the energy gap values for the allowed indirect transition, where we observe a decrease in the energy gap values upon doping with SiO_2 particles at 6% and 9%, except for sample having 3% SiO_2. The reason for the decrease in the energy gap value could be due to formation of new localized states in the polymer. The nanosized SiO_2 particles have a large surface area that allows them to interact significantly with the polymer (CMC-PVP). As a result, new energy states are formed inside the energy gap of the polymer (CMC- PVP), which are located near the conduction band. These states create bridges for electron transfer from the energy gap to the conduction band. Consequently, a change in the Fermi level position of the conductor occurs as the number of electron transfers increases [19, 20].

Fig. 5a displays the refractive index values of the prepared films against the energy of the incident photon. It is noteworthy that the refractive index rises as the percentage of SiO_2 increases. This behavior is attributed to an enhancement in packing density [21, 22]. Refractive index was calculated as following [23, 24].

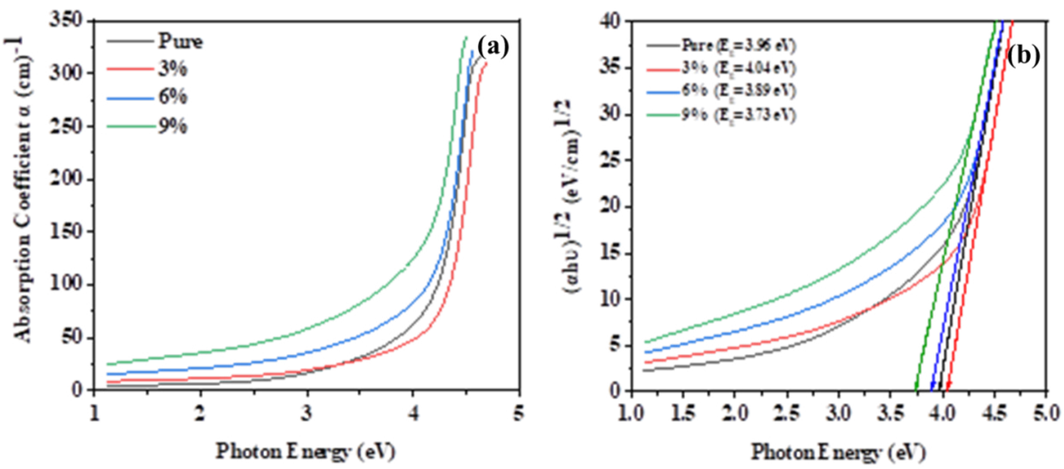

Fig. 4. (a) Absorption coefficient and (b) Energy gap of resulting CMC-PVP and CMC-PVP-SiO_2 samples.

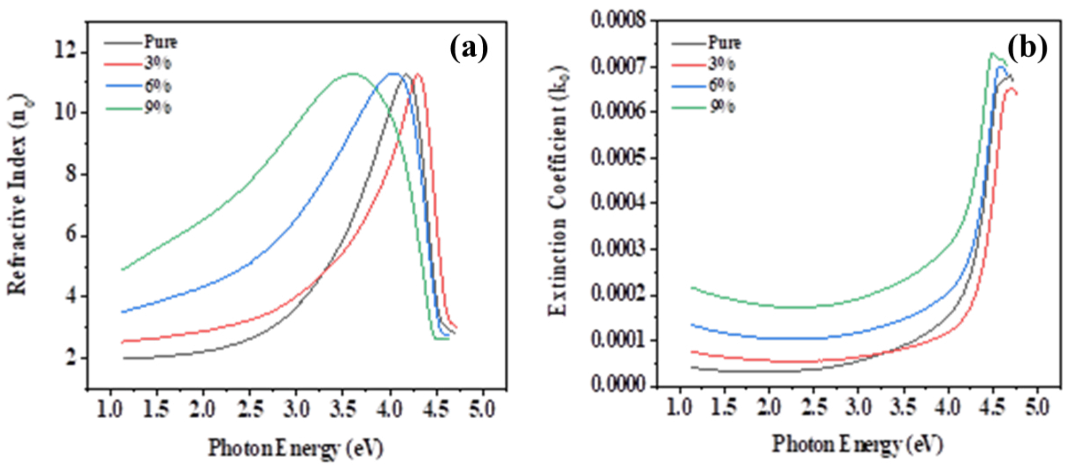

Fig. 5. (a) Refractive index and (b) Extinction coefficient of resulting CMC-PVP and CMC-PVP-SiO_2 samples.

$$n_o = \frac{1+R}{1-R} + \sqrt{\frac{4R}{(1-R)^2} - {k_o}^2} \qquad (3)$$

where, the refractive index, reflectance, and extinction coefficient are denoted by n_o, R, and k_o, respectively.

Also, Fig. 5b shows the extinction coefficient of the prepared films as a function of the incident photon energy. This behavior is similar to the behavior of the absorption coefficient, and the reason for this increase is the density of donor levels formed by the impurity material within the energy gap, which leads to enhanced quenching coefficient [25]. The extinction coefficient was calculated as [26],

$$k_o = \frac{\alpha\,\lambda}{4\pi} \qquad (4)$$

where, k_o represents extinction coefficient. α is absorption coefficient. λ introduces wavelength of the incident photon.

CONCLUSION

CMC-PVP films modified with SiO$_2$ were successfully fabricated and their structural and optical properties were investigated. FTIR spectroscopy indicated an interaction between the mixture of CMC-PVP and SiO$_2$, as the peaks decreased after doping with SiO$_2$. The transmittance value also decreased after doping with SiO$_2$. The energy gap for the CMC - PVP film was found to be approximately 3.96 eV, which decreased to 3.73 eV for the film having 9% SiO$_2$.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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