DETERMINATION OF OPTICAL PROPERTIES OF COMMERCIAL THIN FILM POLYMERS USED FOR SOLAR PROTECTION APPLICATIONS

DETERMINACIÓN DE LAS PROPIEDADES ÓPTICAS EN PELÍCULAS DELGADAS POLIMÉRICAS COMERCIALES UTILIZADAS EN APLICACIONES DE PROTECCIÓN SOLAR

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ABSTRACT

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A procedure to determine the optical properties of commercial polymeric films used as solar control for building skins is proposed. The spectral variation (190-1100 nm) of the refractive index and extinction coefficient of the samples were obtained through the simulation of the experimental transmittance spectra of the samples. Films of polyvinyl chloride (PVC) and poly ethylene terephthalate (PET) were analyzed. Refractive index values between 1.1 and 2.5 at λ= 500 nm and extinction coefficient values of 104 cm-1 in the ultraviolet (UV) region were found. All these results show a good fit with those given in the literature for similar thin films. A new concept for the illumination and temperature control of buildings by the use of polymeric thin films as a transparent solar protection material is presented.

Keywords: Thin films; Polymers; Optical properties; Building skins

RESUMEN

Se propone un procedimiento para determinar las propiedades ópticas de películas poliméricas comerciales utilizadas como elementos de control solar en pieles de la edificación. La variación espectral (190-1100 nm) del índice de refracción y el coeficiente de extinción de las muestras se obtuvieron a través de la simulación de los espectros de Transmitancia de las muestras. Se analizaron películas de Cloruro de Polivinilo (PVC) y

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Poli Tereftalato de Etileno (PET). Los valores del índice de refracción están dados entre 1,1 y 2,5 para λ = 500 nm y los valores del coeficiente de extinción de 10^4 cm^{-1} se encontraron en la región ultravioleta (UV). Todos estos resultados muestran un buen ajuste con los datos que figuran en la literatura para películas delgadas similares. Es así que se presenta un nuevo concepto de iluminación y control de temperatura de los edificios mediante el uso de películas delgadas de polímeros como material de protección solar transparente.

Palabras clave: Películas delgadas; Polímeros; Propiedades ópticas; Piel de la edificación

1. Introduction

The window is the element mainly used to control the optical and thermal properties of spaces in modern architecture. For this kind of application, new materials such as polymeric thin films are being used to cover the window. Currently there is a considerable effort to optimize the optical properties of these coatings for applications of conservation of energy in buildings, facade embellishment, and greenhouses [1].

One such new material is the polymers, which are an excellent alternative not only as sun protection films for glass, but also for high-quality optics [2, 3]. The optical properties depend on the materials from which the films are made and also on the physical and chemical characteristics of the materials used as a substrate for supporting the polymeric films. Nowadays the selection of polymer films is done through the appearance of the film at first glance, but this is only a minimum necessity, because the films play a key role in the window in terms of light and thermal control of the area to be protected.

However, the optical performance of the film coatings is not well understood, due to the lack of models for obtaining and interpreting their optical properties. In the present paper, a model for determining the optical properties of polymeric thin films from transmittance measurements is proposed.

2. Experimental details

Commercial polymers were measured in the form of a thin film distributed by companies such as FilmTex. The references used were: 1) Cristal Commercial UV glass (CCial UV). This has excellent transparency and highly flexible PVC film, shine and is flexible with increased resistance to yellowing caused by sunlight. Thicknesses used: 100, 125 and 150 μm and 2) PET Film FP3 (FP3), which has good transparency, toughness, handling, low-temperature resistance, high energy conservation, and a good level of environmentally protective surfaces. Also, it shows good resistance to aging. Thicknesses used: 125 and 175μm.

The samples' thicknesses were measured with a mechanical profilometer Dektak 150 Veeco with a tip diameter of 12.5 μm. A pressure of 10 μN was applied over the samples' surface with a swept length of 3 μm for 80 seconds and a resolution of 0.083 μm.

The transmittance spectra were obtained using a T80 UV-VIS Spectrophotometer PG Instruments. The experimental data were collected in the ultraviolet, visible, and near-infrared ranges (λ = 190 to 1100 nm), with a step width of 5 nm. The computer program UV WIN 5.0 was used for data collection, using air as the standard.

2.1Theoretical Model

The physical model used for the calculation is shown in Figure 1. The polymeric film was immersed between two mediums of refractive index $\mathbf{n_0}$. A complex refractive index $\tilde{\mathbf{n}}$ is assigned to the film, and the light impinges perpendicularly to the polymeric surface.

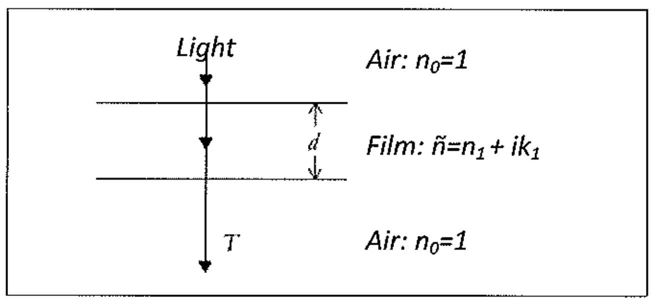

Figure 1. Physical system used to calculate the optical properties of polymeric films

The transmission coefficient T for normal incidence is given by [4]:

$$T = \frac{n_2}{n_0}\frac{[(1+g_1)^2+h_1{}^2]+[(1+g_2)^2+h_2{}^2]}{e^{2\alpha_1}+(g_1{}^2+h_1{}^2)(g_2{}^2+h_2{}^2)e^{-2\alpha_1}+C\cos 2\gamma_1+D\sin 2\gamma_1} \quad (1)$$

where

$$g_1 = \frac{n_0{}^2-n_1{}^2-k_1{}^2}{(n_0+n_1)^2+k_1{}^2}$$

$$h_1 = \frac{2n_0k_1}{(n_0+n_1)^2+k_1{}^2}$$

$$g_2 = \frac{{n_1}^2 - {n_2}^2 + {k_1}^2 - {k_2}^2}{(n_1 + n_2)^2 + (k_1 + k_2)^2}$$

$$h_2 = \frac{2(n_1 k_2 - n_2 k_1)}{(n_1 + n_2)^2 + (k_1 + k_2)^2}$$

$$A = 2(g_1 g_2 + h_1 h_2) \qquad B = 2(g_1 h_2 - g_2 h_1)$$

$$C = 2(g_1 g_2 - h_1 h_2) \qquad D = 2(g_1 h_2 + g_2 h_1)$$

The theoretical expression for the transmittance T of the film-air system is given as a function of λ, the wavelength, $\mathbf{n_0}$ the air refractive index, $\mathbf{n_1}$ and $\mathbf{k_1}$ the refractive index and extinction coefficient of the film, $\mathbf{d_1}$ the thickness. $\mathbf{n_2}$ and $\mathbf{k_2}$ are used when the polymeric film is supported by a substrate. In this experiment, the assigned values are $\mathbf{n_2=1}$ and $\mathbf{k_2=0}$. The thicknesses of the samples were measured using a profilometer Dektak 150 Veeco.

The procedure followed to calculate the optical properties is described by the following equation:

$$|T_{Exp} - T_{Theo}| \leq 0{,}001 \qquad (2)$$

where T_{Exp} is the experimental spectrum and T_{Theo} is theoretically obtained from Equation 1.

The theoretical values involved in Equation 2 were found by iteration using Equation 1. When Equation 2 is satisfied, the computer stops and the optical constants values are extracted.

Initially, the sample is supposed to be transparent between 500 and 1100 nm. In this region, approximate values of $\mathbf{n_1}$ are obtained, using Equation 2 and the **Wemple – DiDomenico** model [5]:

$$n = \sqrt{1 + \frac{E_0 E_d}{{E_0}^2 + \left(\frac{1237.4}{\lambda}\right)^2}} \qquad (3)$$

where $\mathbf{E_0}$ is the energy of the oscillator and $\mathbf{E_d}$ the dispersion energy, and $\mathbf{n_1}$ values are obtained over the whole spectrum. Finally, the extinction coefficient, **k(λ)**, was theoretically determined, again using Equation 2.

3. Results and discussion

Figure 2 shows the transmittance spectra of a commercial thin film and the simulated spectrum obtained theoretically. The spectrum obtained from the simulation fit well with the experimental spectra, indicating that the mathematical model could be used to obtain the optical properties of the films. In Figure 3, the experimental spectra of the investigated samples are shown. As can be seen in the transmittances curves, (Figure 3), for wavelengths below 400 nm there is a strong absorption region, indicating that these films are excellent for UV protection applications. The samples allowed 85% transmittance of visible light between 400 to 1100 nm.

In Figure 4 the refractive index values obtained for the samples are shown. The values obtained are comparable to those found in the literature [6].

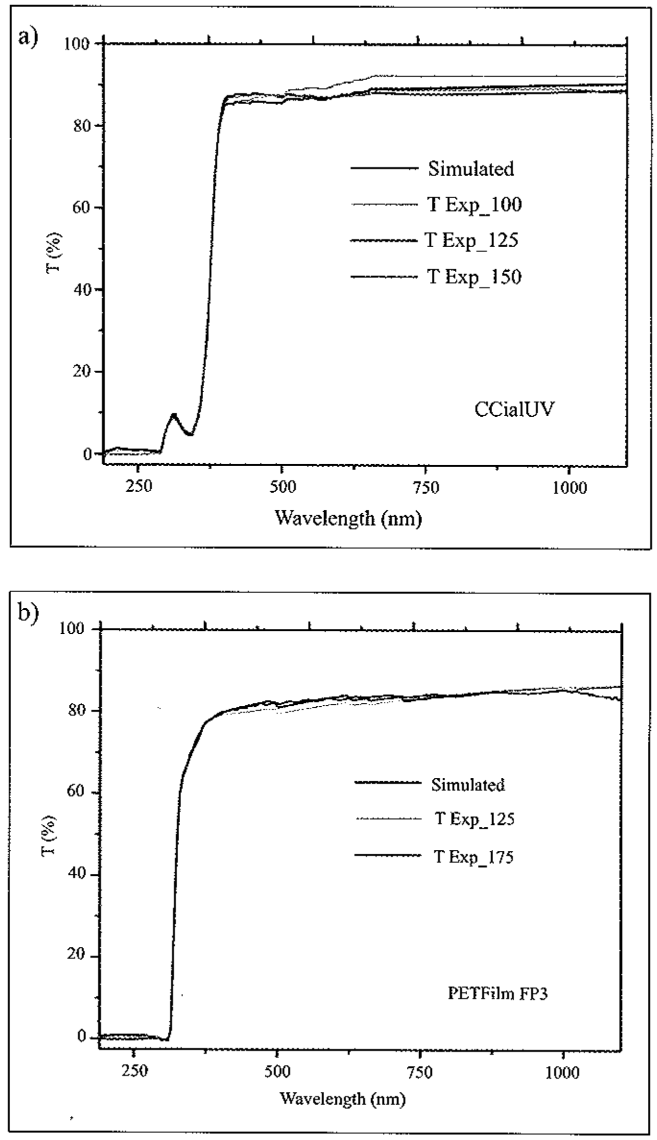

Figure 2. Simulated and experimental spectra of a FilmTex CristalCcial UV (a) and FilmTex PETFilm FP3 (b)

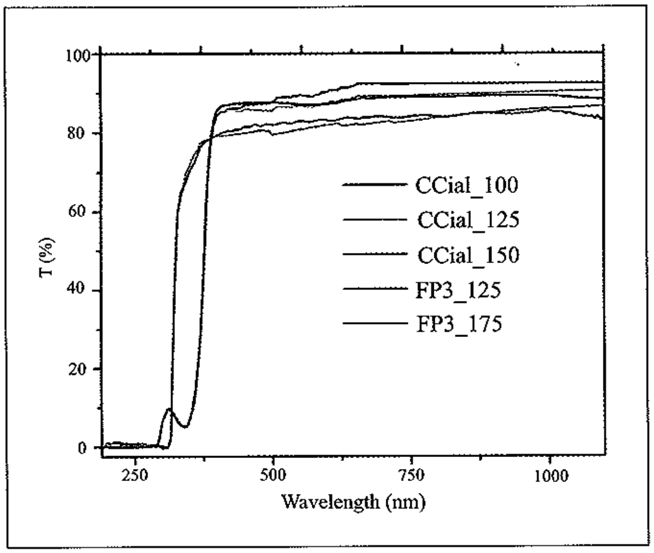

Figure 3. All transmittance spectra of polymeric films

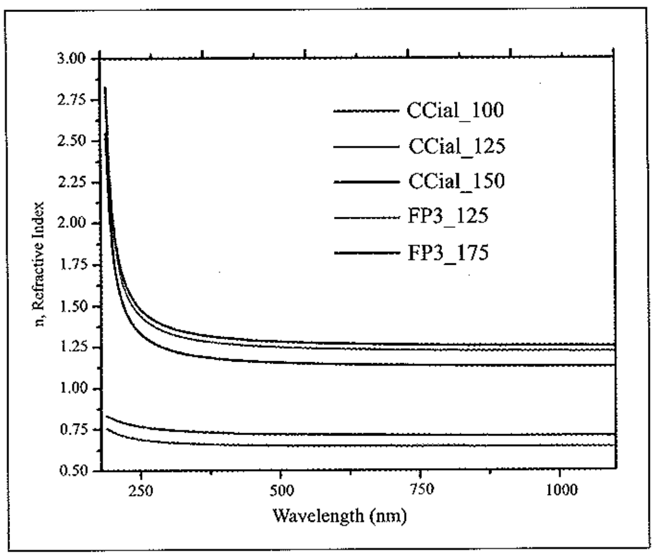

Figure 4. All refractive indexes of polymeric films

Figure 5 shows the **k** values obtained for the analyzed samples. As is shown in the figure, all the samples exhibit the same behavior in the analyzed spectral region. The samples CristalCcial 100 and PET FP3 175 have a strong absorption region for UV radiation up to 275 nm, while the other samples absorb the UV up to 274 nm. The height of the curves in the UV region is different for all the samples. This behavior could be associated with the different thicknesses of the samples.

Thicker samples allow the passage of a small percentage of short wavelengths of the UV light. From UV to NIR (1100)

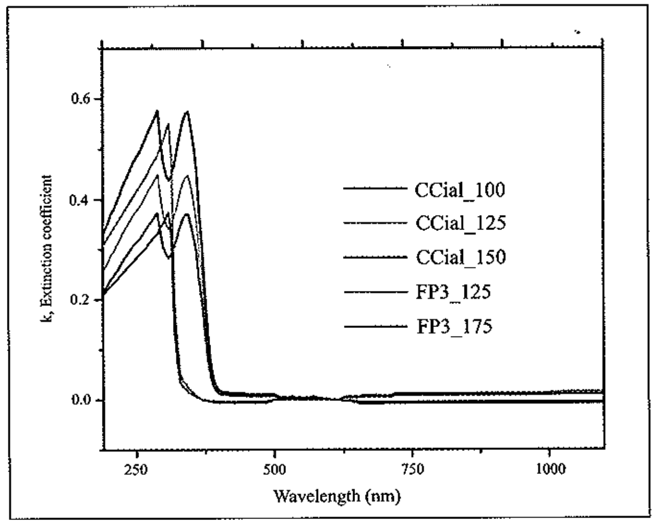

Figure 5. All extinction coeffient values of polymeric films

nm, all the samples are nearly transparent, with small absorption regions near 520 nm. If the sample is deposited on a substrate, the optical properties change, due to the presence of the substrate. This kind of system could also be analyzed using the theoretical model.

The model allows an easy determination of the optical constants of polymeric films used for the solar protection of windows.

4. Conclusions

A theoretical model was proposed for obtaining the optical properties of commercial films used as window protection. This model allows determining the spectral variation of the refractive index and absorption coefficient of polymeric films. The model could be applied to single samples, deposited on crystal substrates and multilayer systems.

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