Optical properties of parylene and its use as substrate in beam splitters

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The optical properties of a commercial parylene pellicle are obtained using a classical oscillator model with a single oscillator. Using a standard design antireflection stack and beam-splitter multilayer films coated on this pellicle, its performance is greatly improved, flattening the curve and increasing its useful spectral range.

I. Introduction

Pellicles made of organic components[1] have been widely used to split beams, polarize light, and reflect images with negligible lateral shift effects.[2,3] Unlike the more conventional cemented cube or glass plate beam splitter, pellicles tend to minimize or eliminate ghost images, refractive errors, energy absorption, and spherical and chromatic aberrations. Some interesting applications of parylene pellicles exploited their mechanical and electrical properties for electronic purposes.[4–8]

Optical applications of the pellicles have been commercially available for some time[9]; unfortunately, little has been reported on the use of the optical properties of these materials to improve or adapt the commercial product for some specific problem.

In this work we report on the optical properties of the parylene pellicles for the visible part of the spectrum. The modeling of the dielectric function in terms of wavelength uses the classical oscillator model reported elsewhere.[10] We also propose an improvement on a commercial beam splitter whose performance does not correspond to the advertised specifications.

II. Refractive Index Dispersion of Pellicles

Basically there are two materials with which to elaborate pellicles: a chlorine-substituted member of the family of polymers based on para-xylene is used by Union Carbide, whereas Du Pont uses nitrocellulose.

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Unsupported membranes are prepared by using the vapor phase deposition process as described by Gorham.[11] In the case of parylene, di-*p*-xylene is heated to the gas phase *in vacuo* and deposited as a polymer directly from the gas phase onto a substrate, e.g., glass plates. After the deposition of the polymer to the desired thickness, optically controlled by its reflectance extrema, it is properly glued to a metal frame and the supporting agent is then activated by solution in water. Free films, several centimeters in diameter, may have thicknesses as small as 18 nm but usually around several hundred nanometers.[3] Extrathin nitrocellulose pellicles permit the farthest penetration into the UV. The procedure described above is quite crude; in practice, the process is more sophisticated, proprietary, and a closely guarded art.

Transmission interference fringes of 10–20% amplitude are prominent throughout the UV–visible–near IR spectral regions and allow the calculation of the dispersion curve. Although this procedure is described in detail in Ref. 12, no dispersion curves are presented at all and an approximate formula is used instead, good only for small reflectances.

In our laboratory we used spectrophotometry in a wide spectral band at normal incidence and null ellipsometry at a single wavelength, $\lambda = 546.1$ nm, to verify the numerical values of the complex refractive index at λ.

The experimental transmittance curves are fitted using the classical oscillator model where the dielectric function is represented by a damped oscillator with a given peak frequency, intensity, and bandwidth, according to the following[10]:

$$\varepsilon = \varepsilon_1 + \varepsilon_2 = \varepsilon_\infty + \sum S_i/[(1 - \omega^2/\omega_i^2) - i\gamma_i\omega/\omega_i],$$

where S_i, ω_i, and γ_i represent, respectively, the strength, resonance frequency, and linewidth of the actuating oscillators. The term ε_∞ is the high frequen-

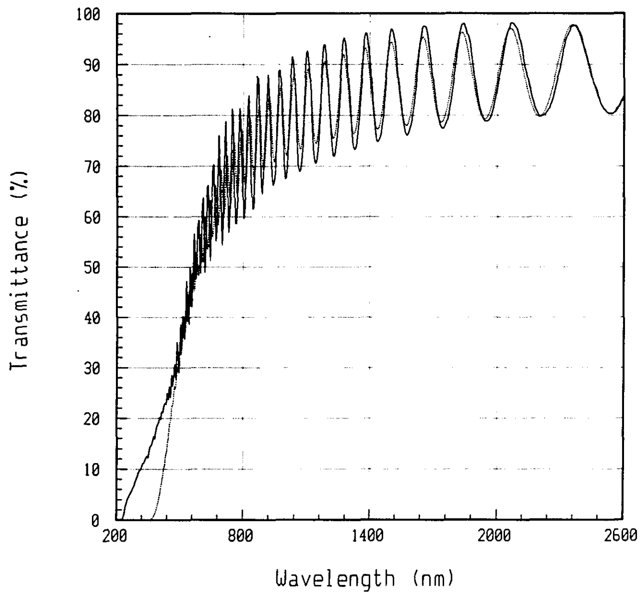

Fig. 1. Experimental transmittance spectrum of the parylene pellicle at normal incidence using a Perkin-Elmer 330 spectrophotometer (solid line) and theoretical fitting using the classical oscillator method (dotted line).

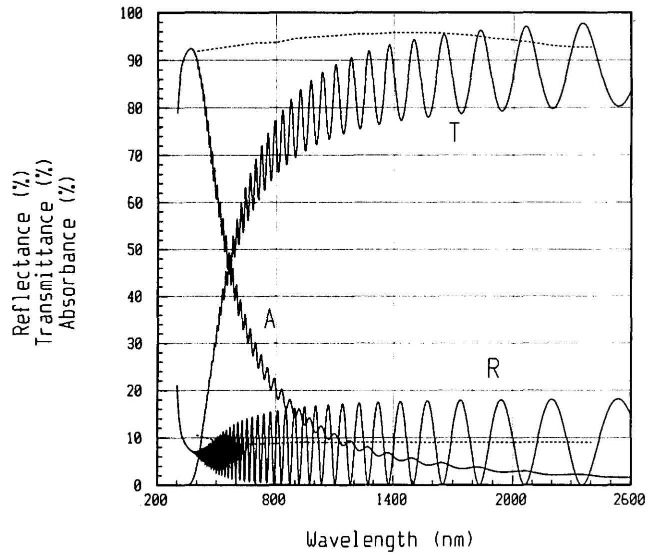

Fig. 3. Commercial data of an uncoated parylene pellicle reported by Ealing (dotted line) and computed data at normal incidence after the classical oscillator fit for a commercially available 521.0-nm thick parylene pellicle. Transmittance, reflectance, and absorptance curves are shown (solid lines).

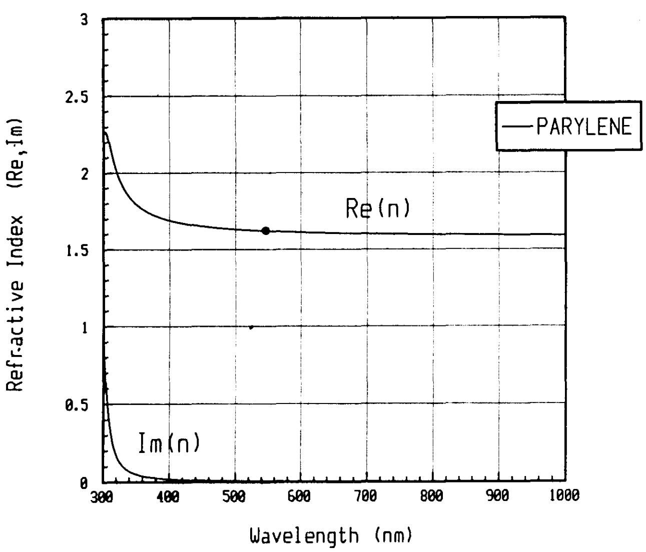

Fig. 2. Dispersion curve for the refractive index obtained from the classical oscillator model. The single oscillator parameters are given in the text. The dots represent experimental ellipsometric measurements.

cy contribution to ε. In our case, one oscillator was enough for the fitting in the interval from 400 to 2600 nm. It is evident that for UV frequencies, the fitting is not satisfactory; this situation could be resolved with the addition of a higher frequency oscillator, but we restricted the fitting to the range where the pellicle has practical applications.

Figure 1 shows the experimental T vs λ curve for the parylene pellicle and the theoretical fit using a single oscillator with the following parameters:

parylene

$$S = 0.3, \quad \omega = 4.2 \text{ eV}, \quad \gamma = 0.06 \text{ eV}.$$

$$\varepsilon_\infty = 2.2$$

Using these parameters, the complex refractive index is computed for every wavelength in the experimental range and the resulting dispersion relation is shown in Fig. 2. The ellipsometric measurements were performed on the sample to determine the refractive index for $\lambda = 546.1$ nm and the resulting values, $\tilde{n} = (1.66, 0.0001)$, agree with the ones predicted by the classical oscillator method.

The values of the refractive index (n,k) were used to recalculate the corresponding curves for transmittance $T(\lambda)$, reflectance $R(\lambda)$, and absorptance $A(\lambda) = (1 - R - T)$ of the parylene pellicle; the results are shown in Fig. 3, together with the data reported for a commercial uncoated pellicle[9]; in our experimental data, large oscillations are observed, as well as a non-negligible absorption.

The experimental transmittance curve measured in our laboratory (Fig. 1), differs drastically from that expected according to the supplier. The catalog provides either the average values for both the transmittance and the reflectance of the pellicle or the single interface performance, assuming a semi-infinite parylene medium and neglecting the interference effects associated with the second interface to air, which are important here because the coherence length is larger than the physical thickness of the film (8 μm according to Ealing; in our oscillator model fitting and our ellipsometric measurements, we obtained a 5.21-μm thickness).

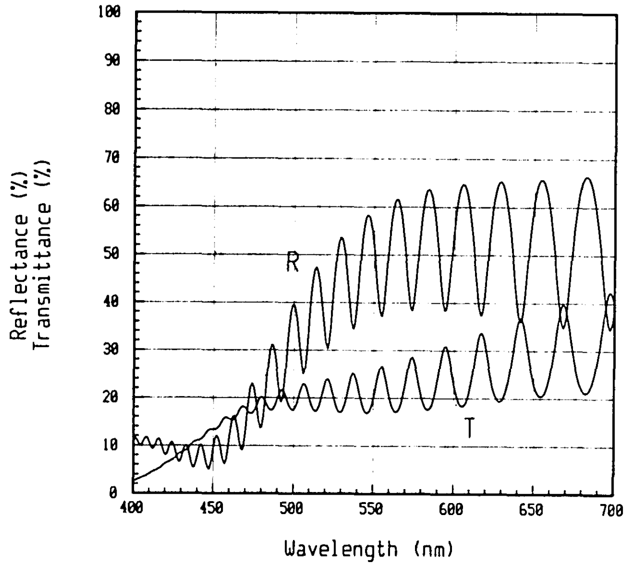

Fig. 4. Transmittance and reflectance of the commercial parylene pellicle under study at oblique incidence (45°) showing an enlargement of the oscillations for S-polarization light.

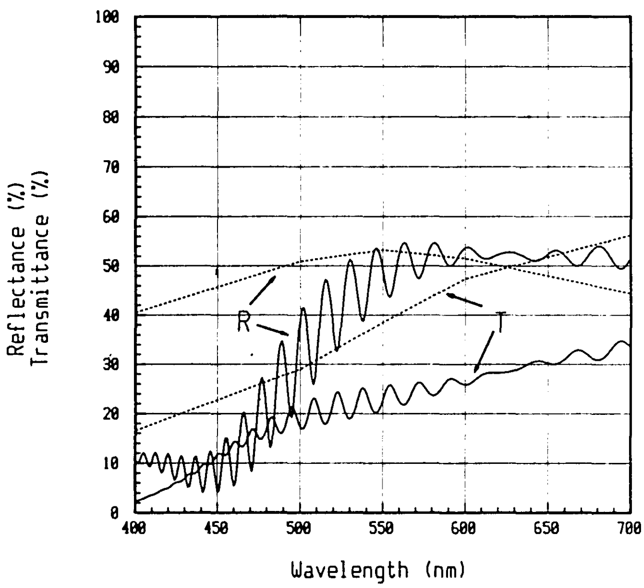

Fig. 5. Commercial data of a coated parylene beam splitter reported by Ealing with no angle of incidence indicated (dotted line), and the designed AR/parylene/BS performance at 45° after the experimental data. The oscillations at the designed wavelength $\lambda = 632.8$ nm are smoothed.

III. Beam Splitter Design

As an example, let us consider a commercial beam splitter advertised by Ealing,[9] in a typical application of optical deflectometry, commonly used for optical testing of components.[13] The reflectance and phase shift under reflection are crucial parameters in the testing.[14]

Our calculations show that, when the pellicle is used at oblique incidence, the oscillation problem becomes more important, i.e., oscillations for S-polarized light are ~30%, as shown in Fig. 4.

To eliminate the second interface effect, we coated the pellicle with an antireflection (AR) stack, reported first by Cox *et al.*,[15] whose main characteristic is a wideband performance. It is designed at $\lambda = 632.8$ nm at an angle of incidence of 45°.

On the other side of the film a standard wideband beam splitter (BS) designed by Costich[16] was deposited. This filter has a flat response with respect to wavelength when coated on a glass slab. Both AR and BS have quarterwave thickness, making the control of the deposit simple.

The composite performance of the AR/parylene/BS system is shown in Fig. 5, as well as the data obtained from the Ealing catalog for a 50/50% coated parylene beam splitter. It can be seen that the fluctuations of the reflectivity around the mean value are drastically reduced, but they are not zero. The intrinsic absorptance of the parylene pellicle cannot be avoided and it disqualifies the filter for any practical use below 450 nm.

In our system, the data at the selected $\lambda = 632.8$ nm are

$$R_P = 38 \pm 3\%, \quad R_S = 53 \pm 1\%, \quad R_{Av} \cong 45.5\%,$$

$$T_P = 35 \pm 5\%, \quad T_S = 28 \pm 0.5\%, \quad T_{Av} \cong 35.5\%,$$

$$A_P \cong 25\%, \quad A_S \cong 18\%, \quad A_{Av} \cong 21\%.$$

Evidently it is difficult to get a 50/50% R/T ratio because of the absorptance, even though the oscillations in the R and T curves from the interference in the uncoated parylene alone are drastically reduced with the aid of the AR coating, using the first surface as support of the beam splitter.

IV. Conclusions

The optical properties of a commercial parylene pellicle have been obtained using a classical oscillator model with a single oscillator. Using a standard design antireflection stack and beam splitter multilayer film coated on this pellicle, its performance is greatly improved, flatttening the curve and increasing its useful spectral range.

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