Refractive index of Polyvinyl Alcohol (PVA) Isotropic Foils, Measured by an Interferometric Method Based on Fabry – Perot Etalon

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Both the theoretic elements of an interferometric method for the refractive index determination based on a Fabry-Perot etalon and the procedure of the Fabry-Perot cell obtaining are described in this paper. The results obtained by this method for PVA isotropic foils and for PVA foils including small amounts of potassium iodide are given here.

Keywords: PVA, FPE, refractive index, isotropic materials

Poly (vinyl alcohol) (PVA) is a water-soluble polyhydroxy polymer and it is the largest volume synthetic resin produced in the world [1]. The excellent chemical resistance, physical properties, and complete biodegradability of PVA resins have led to their broad practical applications including: polymeric membranes, nanostructured composites materials, nanofibers [2 - 4] optoelectronic and photonic devices [5]. The knowledge about the values of the visible refractive index of isotropic layers made from PVA are very important for the optoelectronic applications such as in achieving hybrid polarization interference filters [6]. When isotropic foils based on PVA are stretched, they became anisotropic and could be used as retarders or special anisotropic plates, having the thickness estimated as it was shown in [7].

The study of the induced anisotropy in PVA foils containing rod-like molecules [8] represents another field in which the knowledge on the refractive index value is very important.

The Fabry-Perot Etalon (FPE) is an optical instrument which uses multiple-beam interference. The Fabry–Perot Etalons are applied in many areas such as metrology and laser technology [9], due to their high spectral resolution and sensitivity.

As a light source for a Fabry-Perot etalon can be used either an extended light source in the focal plane of a collimating lens (fig. 1) or a divergent point source (fig. 2). In both cases the Fabry–Perot Etalon produces concentric circular interference fringes due to the light inclination - dependent phase deference (fringes of equal inclination [10-11]).

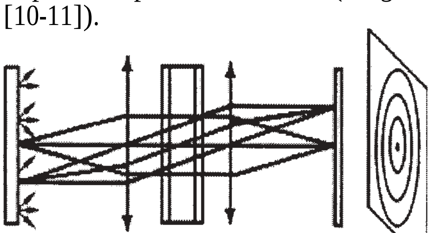

Fig. 1. EFP with an extended light source

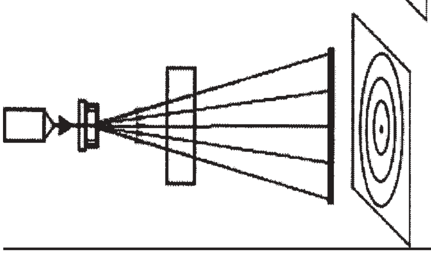

Fig. 2. EFP with a divergent point source

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Theoretical Notions

Let us consider a Fabry-Perot etalon where light of wavelength λ is incident on the parallel plates being many times reflected by the semi-transparent surfaces. The path way difference between two adjacent transmitted beams (fig. 3) is given by [9-11]:

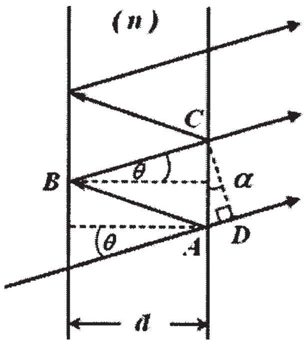

Fig. 3. Detail for the ray path way between Fabry /Perot mirrors

$$\delta = AB + BC - AD = 2nd\cos\theta \qquad (1)$$

Equation (1) indicates that, for a fixed distance *d*, the path way difference δ is a maximum value when θ=0. Constructive interference occurs between two given beams whenever their path way difference is an integer multiple of λ:

$$2nd\cos\theta = 2N\frac{\lambda}{2} \qquad (2)$$

For the destructive interference:

$$2nd\cos\theta = (2N+1)\frac{\lambda}{2} \qquad (3)$$

In order to determine the refractive index of the substance placed between two mirrors of Fabry-Perot etalon, two maxima of interference and the minimum placed between them (fig. 5) are selected. Let be θ_o the angle and N_o the interference order corresponding to the interference maximum placed towards the centre of the interference image.

Taking into account the conditions for maxims and minims appearance, it results the following:

- the first maxim, corresponding to the interference order N_o, satisfies the relation:

$$2nd\cos\theta_o = N_o\lambda \qquad (4)$$

- the neighbouring minim situated towards the exterior of the maxim satisfies the relation:

$$2nd\cos\theta_m = N_o\lambda - \frac{\lambda}{2} \quad (5)$$

- the interference maximum neighbouring the minim towards the exterior satisfies the relation:

$$2nd\cos\theta_M = (N_o - 1)\lambda \quad (6)$$

From the relations written above, it results that for the three considered fringes (two maxima and the minimum between them) the following relations can be written:

$$\begin{cases} \cos\theta_o - \cos\theta_m = \dfrac{\lambda}{4nd} \\ \cos\theta_m - \cos\theta_M = \dfrac{\lambda}{4nd} \end{cases} \quad (7)$$

Let us point out that the relations (4-6):

- are valuable for each interference order N_o;
- a similar result could be obtained if one considers two minima and the maximum between them, because the difference of optical pathway between a maxim and its neighbouring minima is always λ/2 .

The Fabry-Perot etalon is used in air (n_o =1). In these conditions the α_o, α_m, α_M and angles, measured in the exterior of the etalon (figs. 4 and 5), corresponding to the θ_o, θ_m and θ_M respectively angles, measured in the interior of the etalon, have values given by the refraction law:

$$\sin\alpha = n\cdot\sin\theta \quad (8)$$

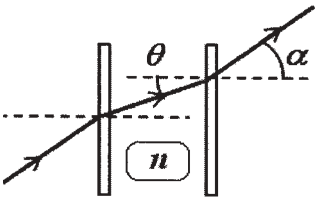

Fig. 4. The ray path through the FPE

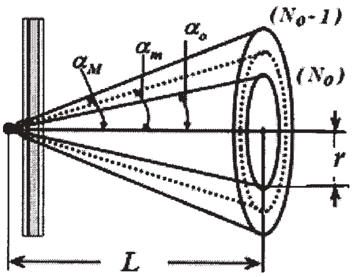

Fig. 5. The distribution of light intensity for two maxima separated by a minimum

From relations (7) and (8) it results that:

$$\begin{cases} \sqrt{n^2 - \sin^2\alpha_o} - \sqrt{n^2 - \sin^2\alpha_m} = \dfrac{\lambda}{4d} \\ \sqrt{n^2 - \sin^2\alpha_m} - \sqrt{n^2 - \sin^2\alpha_M} = \dfrac{\lambda}{4d} \end{cases} \quad (9)$$

Relations (9) lead to the equation (10).

$$\sqrt{n^2 - \sin^2\alpha_o} + \sqrt{n^2 - \sin^2\alpha_M} = 2\sqrt{n^2 - \sin^2\alpha_m} \quad (10)$$

Equation (10) shows that the refractive index depends only on the external angles α_o, α_m, and α_M, respectively, and it could be used in the case when the distance *d* between the etalon mirrors is unknown. The expression of the equation (10) roots is enough complex and it complicates the experimental data processing without a significant increasing in the precision of the proposed method. The precision is dependent on the precision in the α_o, α_m, and α_M angles determination.

In the cases in which the distance *d* between the Fabry-Perot etalon' mirrors and the angles θ and λ have small values, it becomes convenient to express relations (9) in an approximate form, by using the approximation:

$$\cos\theta = \sqrt{1 - \sin^2\theta} \cong 1 - \frac{1}{2}\sin^2\theta \quad (11)$$

On the basis of relations (11), relations (9) can be re-written as it follows:

$$\begin{cases} \sin^2\alpha_m - \sin^2\alpha_o \cong \dfrac{n\lambda}{2d} \\ \sin^2\alpha_M - \sin^2\alpha_m \cong \dfrac{n\lambda}{2d} \end{cases} \quad (9')$$

The relations (9') show that, if the interference fringes corresponding to the maxima and minima are indexed by using an integer number $k \in N$, then the values of $\sin^2\alpha$, which correspond to a sequence of consecutive maxima and minima, increase with a constant value nλ / 2d, so, they show linear dependence versus the order *k* of the considered ring.

Sample preparing

The PVA samples were prepared as gels by solving PVA in distilled water and boiling the resulted solution into a marine bath for a long time (about 10 h).

Many samples were prepared; a sample of pure PVA (sample P_0) and five samples (sample P_2, P_4, P_6, P_8, and P_{10}) in which small amounts of KI were introduced (table 1).

Table 1

KI AMOUNTS IN THE STUDIED PVA FOILS

Sample	PVA amount [grams]	KI amount [millilitres, solution 1N]
P2	20	2
P4	20	4
P6	20	6
P8	20	8
P10	20	10

Each sample has been introduced in a cell made from two parallel usual glass plates with the thickness 4mm, having metallized surface towards the interior of the cell (fig. 6).

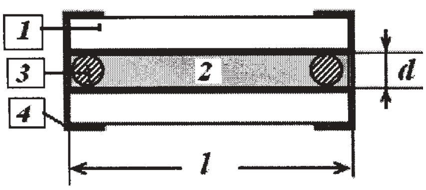

Fig. 6. Fabry - Perot cell

The glass plates used for Fabry – Perot cells were cut as squares with sides of 70mm from a large glass plate initially metallized by the industrial method for the semitransparent windows achieving.

The obtained semitransparent mirrors were cleaned by boiling in water with detergent and then were washed many times with distilled water in order to remove the detergent traces.

In order to realise and fill the cells with PVA, two glass plates were used with their reflecting surfaces towards the interior. A big enough quantity of PVA gel was deposed in the centre of one from the plates.

Two parallel enameled copper wires of a diameter d=0.13mm (130μm) were used as spacers. They were put near the edges of the glass plate (fig. 6). The correct arrangement of the second glass plate was obtained by a progressive approach towards the first plate and by a very slow lateral movement in order to avoid and /or to remove the air from the space between the mirrors.

When the imposed by spacers' diameter minimum distance d was reached, the lateral alternate movements are continued with magnitudes of about 1mm, in a direction perpendicular on the wires' axis, in order to verify if the spacers have a clear tendency to roll on the glass plates' surface. When the rolling tendency becomes evident, the gel traces between the wires and the plate' surface are completely eliminated and the distance between the two mirrors equalizes to the wires diameter. After this adjustment, the cell is sealed on the external side with adhesive paper and it is put in a press for drying, in order to avoid the accidental displacement of the glass plates.

Experimental device

The experimental device is schematically drawn in figure 7. The light divergent source is a laser diode (LD) followed by a microscope objective (Ob). The wavelength of the emitted radiation is λ=635 nm. The Fabry-Perot etalon (FPE), having in its interior the studied sample, is placed at a distance L=300 mm in front of the focal plane of the lens.

The measurements of the radii of the rings corresponding to interference maxima and minima were made by using a calibrated polar paper, produced by Graph Paper Printer [12]. The calibrated polar paper was fixed on the projection Screen (fig.7).

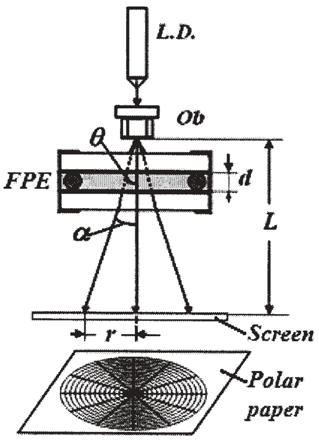

Fig. 7. Schematic representation of the experimental device

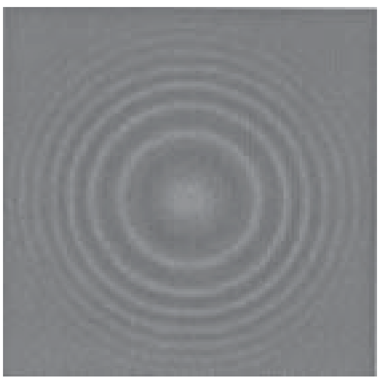

Fig. 8. Typical form of the interference field

The typical aspect of the obtained interference fringes is shown in figure 8.

Results and discussions

The plots of the square sinus of α angle versus the interference order k are shown in figures 9.a. and 9.b. for the sample P_o and P_{10}, respectively.

A linear dependence between $\sin^2\alpha$ and the interference order k was evidenced for the all studied samples, according to relation (9'). By passing from sample P_o to sample P_{10}, the increase of the KI concentration does not produce a significant modification in the slope values of the plots corresponding to the studied samples P_o and P_{10} (figs. 9a and 9b).

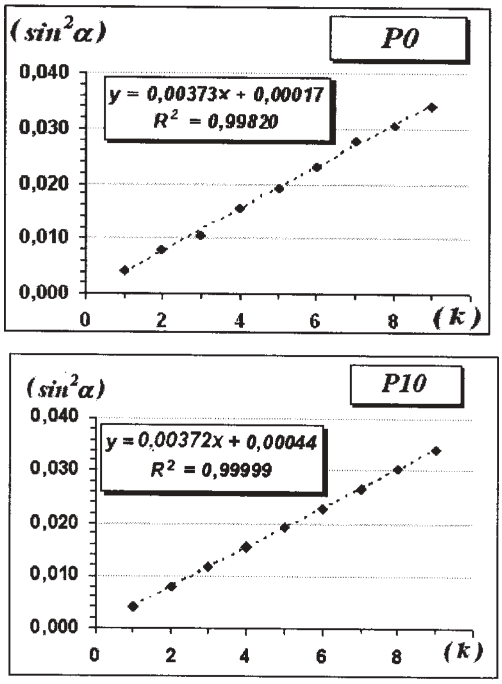

Fig. 9. Experimental results for P_{10} sample

From relation (9') and the line slopes in figures 9.a and 9.b it results the refractive index value of the pure PVA: n_{po} =1.5288. For the samples containing KI, a small decrease of the refractive index from the sample P_2 and P_{10} was noticed, this reaching the value n_{p10} =1.5231 for the sample with the highest concentration in KI.

Conclusions

The value of the pure PVA refractive index is 1.526. The presence of KI in the amounts from table 1 does not determine important modifications in the refractive index values of the PVA sample.

The described method can be improved in precision, if the screen with graph paper is replaced by a scanner having the role of date acquisition device. The scanner must possess a transparency copying option. Adequate software must be developed for processing the interference fringes.

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