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► To cite this version:

G. Pandey, C. Boué, D. Fournier, A. Boccara. Thermal diffusivity and anisotropic effects in transparent polymers using colinear mirage detection. Journal de Physique IV Proceedings, 1994, 04 (C7), pp.C7-279-C7-281. 10.1051/jp4:1994766 . jpa-00253295

HAL Id: jpa-00253295

<https://hal.science/jpa-00253295>

Submitted on 1 Jan 1994

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Thermal diffusivity and anisotropic effects in transparent polymers using colinear mirage detection

G.C. Pandey, C. Boué*, D. Fournier* and A.C. Boccara**

Research Center, Indian Petrochemical Corpn. Ltd., Baroda 391346, India

* Lab. d'Instrumentation, UPMC, UPR A0005 du CNRS, ESPCI, 10 rue Vauquelin, 75005 Paris, France

** Lab. Optique Physique, UPR A0005 du CNRS, ESPCI, 10 rue Vauquelin, 75005 Paris, France

Abstract : Colinear mirage detection was found to be simple and efficient to solve the problem of thermal diffusivity measurements in transparent polymer foils. Both reliable values have been obtained and anisotropic effects revealed.

It is well known that measuring thermal diffusivity of polymers sample using the exploration of the heated field by mirage effect is rather difficult. Indeed in such experiment two heat diffusion processes competes one in the polymer itself and the one in the surrounding medium (e.g air) often dominates. [1]

A very deep and elegant analysis of such data allowing measurement of the polymers properties has been proposed recently [2] The basic idea being to work close to the sample surface and at various frequencies to discriminate the two competing diffusions.

Thus Mirage detection, in the surrounding fluid (air) bounding mode, does not allow direct surface or bulk temperature without the influence of the surrounding medium. In a colinear mirage experiment, performed on a thin transparent plate, many factors contribute to reveal mainly the polymer diffusivity characteristics rather than the surrounding air ones. In such scheme the probe beam experiences the temperature gradient in air over a length of the order of the thermal diffusion length (μ_{air} typically 250 μm at 100 Hz), whereas in the polymer over the sample thickness (typically 50 to 200 μm) (fig 1). The deflexion being proportional to dn/dT (n refractive index, T temperature, $dn/dT = 10^{-6} \text{ K}^{-1}$ in air and 10^{-4} in polymers) the polymer signal dominates by a factor of $100 \times \mu_{\text{air}}/\mu_{\text{polymer}}$ which is thus larger than 10^3 . This means that even with sample thicknesses of the order of 10 μm the polymer signal dominates.

Finally, one has to verify that the temperature distribution in the bulk of the polymer plate is not influenced by air diffusion under the conditions of our experiment. A computer simulation performed in the presence of air or in vacuum has proved that no large heat transfers spoiled the temperature field even for plates a few tens of microns thick.

FIGURE 1 Experimental setup

In our experiment transparent polymers were heated using the chopped CW light beam of a Nd^{3+} YAG laser ($1.064 \mu\text{m}$). This wavelength was found to produce heating without melting (beam waist $80 \mu\text{m}$). The probe beam (beam waist $50 \mu\text{m}$) was either HeNe ($0.63 \mu\text{m}$) or a laser diode ($0.78 \mu\text{m}$).

The measurement consists in measuring the amplitude and the phase of the deflexion as a function of the pump beam probe beam distance. When this distance is larger than the sum of the two beam waists the signal phase exhibits a variation close to r/μ_{polymer} . In order to measure the thermal diffusivity in various directions the sample is placed on a rotating platform and its orientation controlled by observation of the birefringent axis.

As an example, we have looked at a polyester sample drawn in two orthogonal direction which clearly show bi axial optical figure in converging light. Fig 2 shows the results obtained for the two orthogonal directions at a 20 Hz frequency modulation.

From the slope we have $D_{11} = 2.4 \cdot 10^{-3} \text{cm}^2/\text{s}$ $D_{\perp} = 7.4 \cdot 10^{-3} \text{cm}^2/\text{s}$.

We emphasize that very often when scanning the heat field we have found regions whose optical properties are close to the average ones but which exhibit higher values of the thermal conductivity (more than one order of magnitude). We think that these regions may contain a large density of polymer in crystalline form.

Other families of polymer samples for which it is very important to know the thermal diffusivity are dielectric materials. Indeed thermal wave probing is used to reveal the electric charge distribution across the sample thickness. Although the VDF75-TrFE25 copolymer we used was a little hazy we have obtained very clean data and the thermal parameters were found to be $D_{\perp} = 0.8 \cdot 10^{-3} \text{cm}^2/\text{s}$ $D_{\parallel} = 1.1 \cdot 10^{-3} \text{cm}^2/\text{s}$.

In conclusion the proposed technique provides one very simple way to characterize locally the thermal parameters of transparent polymers. By moving the pump and probe wavelength toward the infrared, we can also work with polymers have large optical scattering in the visible range.

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[3] B. Ploss, R. Emmerich, S. Bauer, J. Appl. Phys. **72**, (11) 5363, 1992

Figure 2. Thermal diffusivity measurement of an anisotropic polyester film by conlinear mirage detection