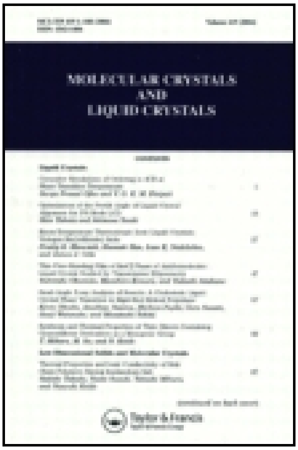

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Measurement of Refractive Indices of the Liquid Crystal Mixtures Merck 10400-000 and 10400-100 at the Infrared Wavelength λ = 1550 nm

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In this work the extraordinary and ordinary refractive indices of different commercial liquid crystal (LC) compounds have been measured at the wavelength $\lambda = 1550\,nm$. Four samples have been investigated. Two of them are LCs Merck 10400-000 and 10400-100. The other two have been obtained mixing the previous LCs in different proportions. The method used for the measurement is based on a refractometric technique that takes advantage of refraction of a narrow laser beam by a wedged shaped LC cell. The method allows the measurement of both the extraordinary and ordinary refractive indices of the LC. The measurement of the angle of the wedged cell is a very critical point and it has been performed by means of an optical method. The refractive indices have been measured at different temperatures.

Keywords: 61.30.-v (Liquid Crystals); 42.70.Df (Liquid Crystals as Optical Materials); 78.20.Ci (Refractive Index)

1. INTRODUCTION

One of the most important wavelengths used in optical fiber telecommunication systems is $\lambda = 1550\,\mathrm{nm}$, that is where optical fibers present the lowest transmission loss, i.e., 0.2 dB/Km [1]. This wavelength region is the most used today for long haul optical fiber telecommunication systems [1]. Liquid crystals (LCs) could find interesting applications in this field in designing various optical devices. For this

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reason it is important to enrich the knowledge about the optical properties of these materials at the wavelengths around 1550 nm. Among the many optical properties, the two refractive indices play the most important role. As a difference with the standard measurements obtained with spectrophotometers [2] the method presented in this paper gives not only the optical anisotropy of the LC, but also the two values of the refractive indices separately. This method represents a modification of the Pellet and Chatelain method [3]. It is also worthy to note that, on the contrary to the case of visible light, in the infrared spectral region commercial instruments, like the Abbe Refractometer are not available. This method has also been successfully used to measure the refractive indices of other LCs in the mid IR spectral region, i.e., $\lambda = 10.6\,\mu m$ [4], that is the main CO_2 laser emission line. It is important to remark here that also other methods have been reported in the literature [5,6] for the measurement of the refractive indices in the IR spectral region.

2. DESCRIPTION OF THE EXPERIMENTAL APPARATUS

The experimental setup is shown in Figure 1. We use a 1550 nm c.w. laser that operates on the fundamental Gaussian mode. The laser is especially designed to be injected into an optical fiber, so, in order to obtain a collimated free propagating laser beam, a beam collimator is connected to the fiber output. The laser beam is linearly polarized

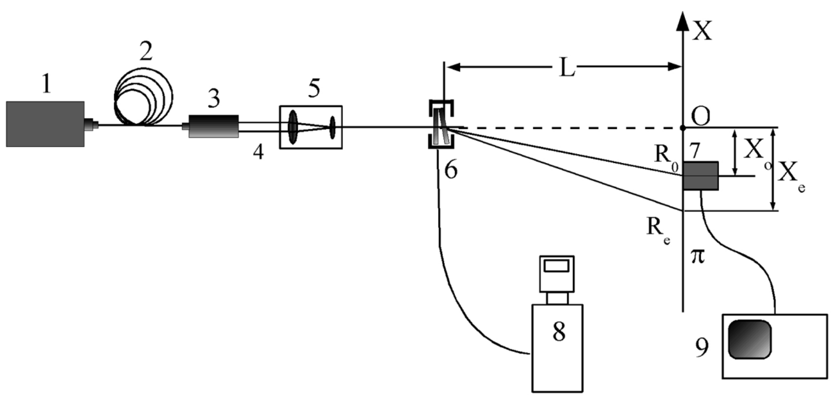

FIGURE 1 Experimental apparatus: 1) 1550 nm c.w. laser source. 2) Optical fiber. 3) Beam collimator. 4) collimated laser beam. 5) beam condenser. 6) Wedged liquid crystal cell and thermostat 7) 1550 nm point-like light detector. 8) temperature controller. 9) Digital oscilloscope.

in a fixed direction. A beam condenser formed by two lenses placed in a confocal position allows to obtain a quite narrow laser spot of a diameter of approximately 1 mm. The laser radiation passes through a liquid crystal cell filled with the liquid crystal under investigation. The cell is composed of two glass windows, 3 mm thick, kept in a wedge-shaped configuration by means of two spacers of different thickness. The typical wedge angle is $\theta = 2\,\mathrm{Deg}$. This angle is measured on the empty wedge cell using an optical method that ensures an uncertainty lower than 5×10^{-3} Deg. The alignment of the NLC molecules is planar and is obtained by coating the inner surfaces of the glass plates by PVA (a polymer) and rubbing the surfaces with a soft velvet, in a unidirectional manner. The uniformity of the alignment has been checked by means of a polarizing microscope. The maximum extinction is found with crossed polarizers. This observation ensures that there is no appreciable director twist in the bulk of the sample. Furthermore, it is important to emphasize that the wedge cell method is virtually insensitive also to a relatively strong twist of the director (see the theoretical analysis reported in ref. [7]). A source of uncertainty in our experiment could be related to the presence of a non-vanishing pretilt angle θ_{t}. To measure the pretilt angle of our substrates, we have used the crystal rotation method [8] at the $\lambda = 632.8\,\mathrm{nm}$ wavelength. θ_{t} remains always lower than 0.05 rad in the whole investigated temperature range of our liquid crystal mixtures. The refractive index seen by the extraordinary beam does not coincides with the extraordinary index n_{e} but is $n \approx n_e - \Delta n \theta_t^2$ [9], where Δn is the anisotropy of refractive indices of the NLC. In our experiment Δn < 0.15 and, thus, the uncertainty on the measurement of the extraordinary index due to the finite pretilt is $\delta n = |n - n_{\mathrm{e}}| < 0.0004$ that is negligible with respect to the other error sources.

For every sample under investigation a different cell has been built by means of the same technique, with the only difference of a small change of the angle of the wedge, that has been measured accurately for every sample. All the alignment operations of the infrared laser beam have been made easier by superimposing a visible He-Ne laser beam to the infrared one (not shown in Fig. 1). One of the two cell windows (i.e., the first encountered by the laser beam) is placed perpendicular to the beam wave-vector. The infrared laser beam passes through the wedged cell and reaches a 1550 nm light detector. The detector is point like as the diameter of the detecting surface (20 µm) is much smaller than the beam diameter. The detector is mounted upon a micrometric translating stage in order to change its position in a very precise manner across the observation plane π along the X axis (see Fig. 1). The detector signal is monitored by means of a digital oscilloscope. The cell is enclosed inside a thermostat which temperature is controlled with an accuracy of $\Delta T = 0.1^{\circ}C$ and that can reach a maximum temperature of about 83°C, that is lower than the clearing points of the LC tested here. From Merck datasheet we find that the transition temperature of LC 10400-000 is 96°C, while that of LC 10400-100 is 95°C. The distance L (typical value is $L \approx 1.5\,m$) between the nematic film and the detector surface, which plays an important role in our measurements, has been evaluated with a precision of 0.06%.

Before starting the measurements we have always verified that the empty cells do not introduce appreciable spurious deflections of the laser beam. Note that, for perfect plane and parallel glass plates, only a lateral shift of the laser beam of about 50 μm should occur. This shift can be disregarded here because it is much smaller than the experimental accuracy (200 μm) on the determination of the position of the centre of the beam along the X axis in Figure 1. In fact, no appreciable displacement of the laser beam is observed when the empty cell is inserted or removed.

3. DESCRIPTION OF THE EXPERIMENT AND RESULTS

Since the laser beam is polarized at 45 degrees with respect to the LC sample director, it splits itself in two sub-beams, that we call the "ordinary ray" and the "extraordinary ray" [9]. By measuring the deviation angle of these two rays with respect to the situation where the NLC is absent, we retrieve the two refractive indices of the liquid crystal by means of the Snell's refractions laws. With reference to Figure 1, the point O where the ray, emerging from the empty wedge, encounters the observation plane π is determined experimentally by translating the detector along the X axis by means of the micrometric translator until the detector signal on the oscilloscope is maximum. This, of course, is the centre of the Gaussian shaped spot. After that, the cell is filled with the liquid crystal and the two refracted beams R_o and R_e appear (Fig. 1). The detector is now translated in order to bring the centre of the sensor exactly in coincidence with the peak corresponding to the ordinary beam. The displacement X_o from the point O is recorded. The same procedure is repeated for the extraordinary spot, recording the distance X_e from point O. The accuracy on the measurement of X_o and X_e is estimated to be 200 μm. From Snell's laws and from simple geometrical considerations we can retrieve the two indices of refraction following the subsequent formulas.

$$n_0 = \frac{\sin[\vartheta + \tan^{-1}(X_0/L)]}{\sin\vartheta} \tag{1}$$

$$n_e = \frac{\sin[\vartheta + \tan^{-1}(X_e/L)]}{\sin\vartheta} \tag{2}$$

where θ is the angle of the wedge formed by the two glass plates, L is the distance between the LC film and the π plane (see Fig. 1).

For each sample tested, the measurement has been repeated changing its temperature in order to reconstruct the temperature dependence of the refractive indices. Every time the temperature was changed, we waited 30 minutes, in order to have a good thermalization of the sample. In Figure 2 we report the measured extraordinary refractive indices (upper points) and the ordinary refractive indices (lower points) as a function of the temperature. The uncertainty in the estimation of each value of the refractive indices is mainly due to the uncertainties of θ ($<0.25\%$), of X_o and X_e (0.8%), and of L (0.06%). Substituting these uncertainties in Equations (1) and (2)

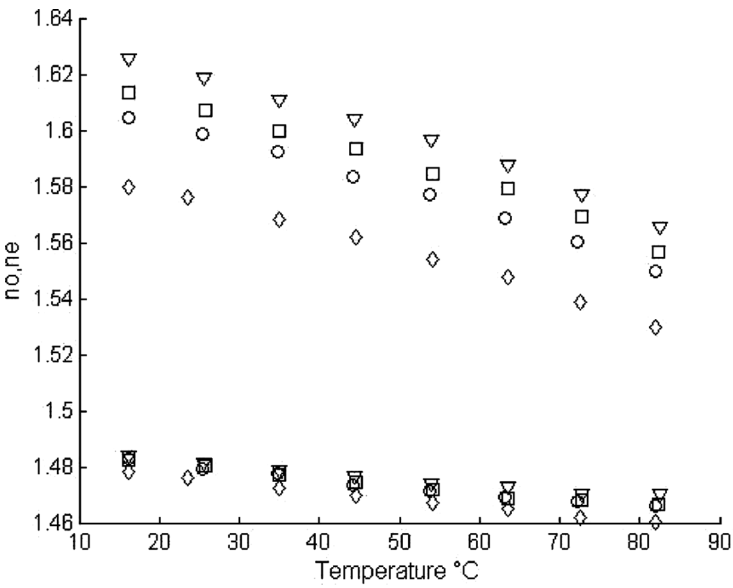

FIGURE 2 Refractive indices of the LC Merck 10400-000 (diamonds) and of LC 10400-100 (down triangles). 50% of LC 10400-000 and 50% of LC 10400-100 (circles). 25% of LC 10400-000 and 75% of LC 10400-100 (squares). Both the ordinary (lower points) and extraordinary refractive indices (upper points) are reported.

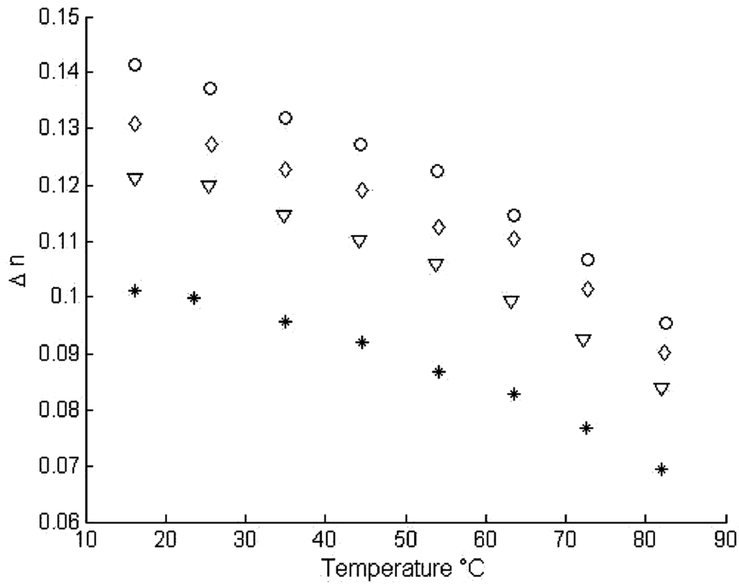

FIGURE 3 Optical anisotropy $\Delta_n = n_e - n_o$ of the measured samples. LC 10400-000 (stars) and LC 10400-100 (circles). 50% of LC 10400-000 and 50% of LC 10400-100 (down triangles). 25% of LC 10400-000 and 75% of LC 10400-100 (diamonds).

we estimate $\delta n < 0.007$ for both the ordinary and extraordinary indices. For more details on the uncertainties related to our method, the reader can see also ref. [4].

In Figure 3 we report the optical anisotropy $\Delta n = n_e - n_o$ as a function of temperature for each sample measured.

The extraordinary refractive indices and the optical anisotropy versus the concentration of the LC 10400-100 and for two different temperatures are shown in Figures 4 and 5. Note that, within the experimental uncertainty $\delta_n \approx 0.007$, the experimental results in Figures 4 and 5 are well represented by a linear dependence in the concentration. This is in a satisfactory agreement with the typical behaviour observed in other liquid crystals in the visible region of the spectrum [10].

4. CONCLUSIONS

In this article we have reported the measurements of the ordinary and the extraordinary refractive indices of mixtures of the Merck liquid

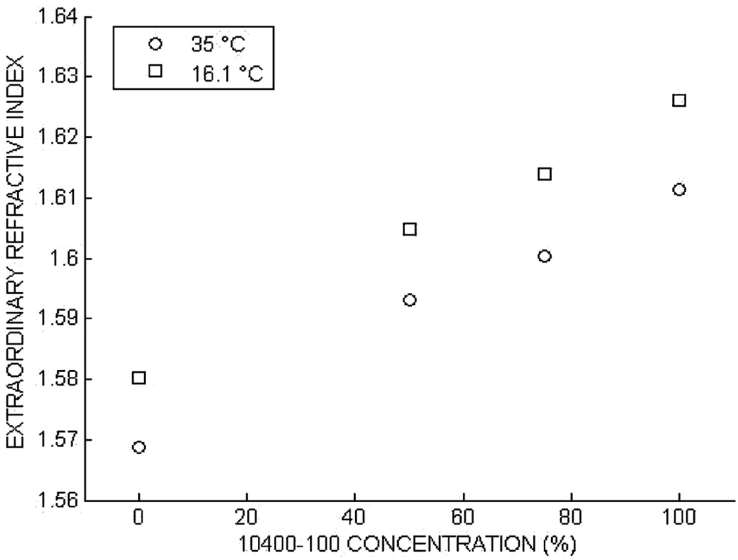

FIGURE 4 Extraordinary refractive indices as a function of concentration of LC 10400-100 for two different temperatures, i.e., 35°C (circles) and 16.1°C (squares).

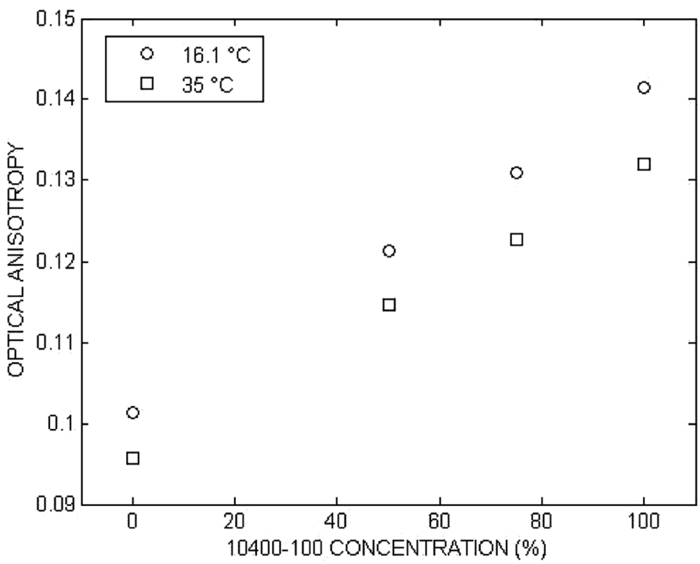

FIGURE 5 Optical anisotropy as a function of concentration of 10400-100 for two temperatures, i.e., 16.1°C (circles) and 35°C (squares).

crystals 10400-000 and 10400-100 at the wavelength $\lambda = 1550\,\text{nm}$. This is a very important wavelength for optical fiber telecommunication systems. The optical anisotropies that are measured in the present experiment are comparable with the values reported for the same materials with visible light. The temperature dependence of the refractive indices has been measured for some different concentrations of the components. The dependence of the refractive indices on the concentration is well represented by a linear law.

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