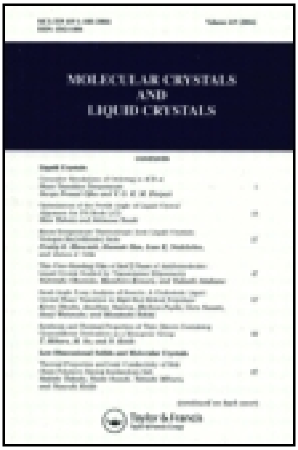

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A. R. Sampaio [a] , N. M. Kimura [a] , R. C. Viscovini [a] , P. R. G. Fernandes [a] & A. J. Palangana [a]
[a] Departamentos de Física e Ciências, Av. Colombo, Brazil

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DIGITAL IMAGE PROCESSING STUDY OF A REENTRANT ISOTROPIC-DISCOTIC NEMATIC PHASE TRANSITION

A. R. Sampaio, N. M. Kimura, R. C. Viscovini, P. R. G. Fernandes, and A. J. Palangana
Departamentos de Física e Ciências, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá (PR), Brazil

The structural change in the discotic nematic textures is investigated, by means of digital image processing, near the reentrant isotropic (I_{RE}) – discotic nematic (N_D) – isotropic (I) phase transitions in a lyotropic mixture of potassium laurate, decanol and D_2O. The N_D phase is characterized by extraordinary and ordinary refractive index measurements and discussed in terms of the mean square deviation parameter determined through a statistical method for the image data detected by the CCD camera.

Keywords: digital image processing; discotic nematic; reentrant isotropic

INTRODUCTION

The application of the digital image processing method is relevant not only from the fundamental point in scientific research but also for technological interest. In the field of liquid crystals [1], this investigation method has been employed, particularly, in thermotropic [2,3] systems to investigate topological texture configurations near the phase transitions. Recently it was applied in the evaluation of the change of the image frame textures near the uniaxial and biaxial nematic phase transitions in lyotropic liquid crystals [4]. These systems [5] are complex fluids formed by mixtures of amphiphilic molecules and a solvent (usually water), under convenient temperature and concentration conditions. The basic units of the lyotropic systems are anisotropic micelles [6]. In the temperature-concentration

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Address correspondence to R. C. Viscovini, Departamentos de Física e Ciências, Universidade Estadual de Maringá, Av. Colombo, 5790, Maringá, 87020-900, Brazil.

phase diagram, two uniaxial and one biaxial nematic phases have been observed [7]. The uniaxial nematic phases have been shown to be prolate (calamitic N_C) and oblate (discotic N_D) micellar aggregates dispersed in water [6]. The biaxial nematic phase (N_B) appears to be an intermediate phase along the border between the two uniaxial nematic ones. Therefore, the existence of this biaxial nematic lyotropic phase has been questioned in the literature [8]. This phase diagram, studied by Yu and Saupe [7], shows for a particular choice of temperature and concentration conditions for the ternary system potassium laurate, 1-decanol and D_2O, the occurrence of a sequence of phase transitions: reentrant isotropic $\leftrightarrow$ discotic nematic $\leftrightarrow$ isotropic.

Extraordinary ($n_{\|}$) and ordinary ($n_{\perp}$) refractive indices, near the I_{RE} – N_D and N_D – I phase transitions, are determined as a function of the temperature through an Abbe refractometer [9–11] to characterize the discotic nematic domain and its transitions to the isotropic phases. It is important to mention that the schlieren texture is not stable in discotic nematic phase. This texture changes slowly to the pseudoisotropic schlieren. The dynamic of the texture configuration in N_D range, using a colour CCD digital camera coupled to a polarizing microscope, is investigated in this work.

FUNDAMENTALS

The method of digital image processing discussed in this paper was origi nally applied to the termotropic liquid crystals by B. Montrucchio *et al.* [2,3]. In our case, the discotic nematic textures detected by the CCD camera is directly stored in a file driven by an IBM-PC compatible computer with a resolution of 640×480 pixels and a Delphi-program was utilized to analyze these image frames [4]. In this way, it is convenient to consider the 2-dimensional function $b(x, y)$, that represents the 24 bits true colour pixel, with ranges from 0 to 255 in red, green or blue colours. The green colour have been showed to be most sensitive [4] for the lyotropic nematic textures. The average statistical directional moments $M_0^i(x, y)$ and $M_k^i(x, y)$ of the image frame are defined by [2]:

$$M_0^i(x,y) = \frac{1}{l_{0i}} \int_0^{l_{0i}} b(x + r\sin\theta_i, y + r\cos\theta_i)dr, \tag{1}$$

$$M_k^i(x,y) = \frac{1}{l_{ki}} \int_0^{l_{ki}} \left[b(x + r\sin\theta_i, y + r\cos\theta_i) - M_0^i(x,y)\right]^k dr, \tag{2}$$

where k is the moment order, r is the radial distance from an arbitrary point $P(x, y)$ of the tone $b(x, y)$, along the eight radial directions at 45 degrees from each other, θ_i is the angle formed by the i-direction with the y-axis and l_{0i} and l_{ki} are local coherence lengths of the image frame [2,3]. These local coherence lengths are defined as the radial distances from point $P(x,y)$ at which the values of the directional moments given by Eqs. (1) and (2) saturate within a confidence level (δ). The parameters l_{0i} and l_{ki} are obtained taking in account the major natural number that satisfy the following condition: $\left|M_k^i(x,y) - M_0^i(x,y)\right| \leq \delta M_0^i(x,y)$, with $\delta = 5\%$. In this paper, we compute the mean square deviation (σ) of the mean values of the l_{0i} and of l_{ki}, in 640×480 squared pixels, with second moment order ($k = 2$), for eight radial directions ($i = 1, \ldots, 8$). Note that each pixel has 8 immediate neighbor pixels [4]. Further details about of the method of image processing, studied in this work, are given in Refs. [2,3].

The lyotropic mixture investigated in this work was prepared with the following concentrations in weight percent: potassium laurate (KL:24.80), decanol (DeOH:6.24) and D_2O(68.96). KL was synthesized from lauric acid (Sigma) via neutralization with potassium hydroxide (Merck) and was further purified by recrystallization with hot ethanol (Merck) several times in the laboratory, DeOH and D_2O (>99% purity from *Aldrich*). The phase sequence, determined by optical microscopy and refractive index measurements, is reentrant isotropic (I_{RE}) up to 13.3°C, discotic nematic (N_D) from 13.3°C to 33.3°C, and isotropic (I) again above 33.3°C. Temperature dependences of extraordinary and ordinary refractive indices, near the I_{RE}–N_D and N_D–I phase transitions, were performed through an Abbe refractometer [9,10]. The nematic sample is encapsulated in sealed planar microslides with 0.2 mm of light path from Vitro Dynamics. The laboratory frame axes are defined with the boundary surfaces parallel to the 1-2 plane and 3 is the axis normal to the biggest surface of the microslide. The optical investigation was carried out using a *Sony* colour *CCD* digital camera connected to a *Leica* polarizing microscope. The sample, not aligned, is placed in a hot stage (*MK*200) device. The sample temperature was controlled by a *Heto* circulating temperature bath stable within 0.01 K. The optical measurements were performed only when the temperature of the sample was stabilized to better than 0.1°C. A heating (cooling) rate of $\sim 0.8\,\mathrm{mKs}^{-1}$ was used during the acquisition of the experimental image frames.

RESULTS AND DISCUSSION

The extraordinary ($n_{\|}$) and ordinary ($n_{\perp}$) refractive indices as function of temperature, near the $I_{RE} - N_D$ and $N_D - I$ phase transitions, are presented in Figure 1. Full starts in this figure represent the values of $\langle n \rangle$ where $\langle n^2 \rangle = (n_{\|}^2 + 2n_{\perp}^2)/3$ is the averaged value of the refractive index in the

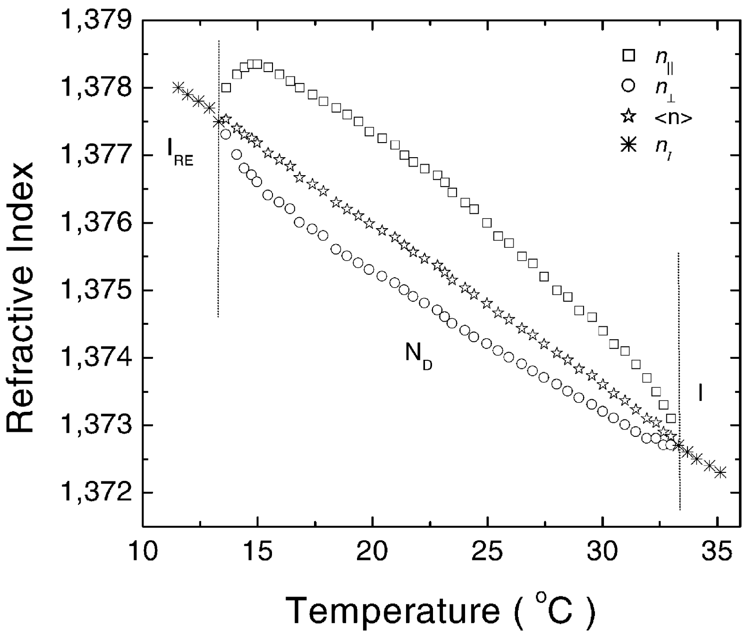

FIGURE 1 Extraordinary ($n_{||}$) and ordinary ($n_\perp$) refractive indices vs temperature of KL system, for sodium D line (589.3 nm). I_{RE}, N_D and I are the isotropic reentrant, discotic nematic and isotropic phases, respectively.

discotic nematic phase. Note that the optical birefringence $\triangle n = n_{||} - n_\perp$ is positive [12] in the discotic nematic phase and both refractive indices, as a function of temperature, trend to one index in the reentrant isotropic and isotropic phases. This result confirms the existence of the discotic nematic phase between the two isotropic phases in accordance to the phase diagrams reported in the literature [7,13].

The schlieren texture, characteristic of the nematic phase, is not stable in N_D phase. It transforms gradually, after the transition $I_{RE} - N_D$ is completed, to a pseudoisotropic texture [14] as exhibited in Figure 2. The surface alignment, induced only by the boundary conditions, of N_D phase is perpendicular to the biggest surface of the microslide. In this way, the discotic micelles tend to get an orientation partially homeotropic that dis appear at $N_D - I$ phase transition. The textures of this phase sequence, $I_{RE} - N_D - I$ phase transition, will be discussed here via digital image processing method.

Figure 3 shows the mean square deviation (σ) as a function of temperature near the $I_{RE} - N_D - I$ phase transitions for the heating cycle. The black texture, in I_{RE} phase, turns to the schlieren texture at $I_{RE} - N_D$ phase

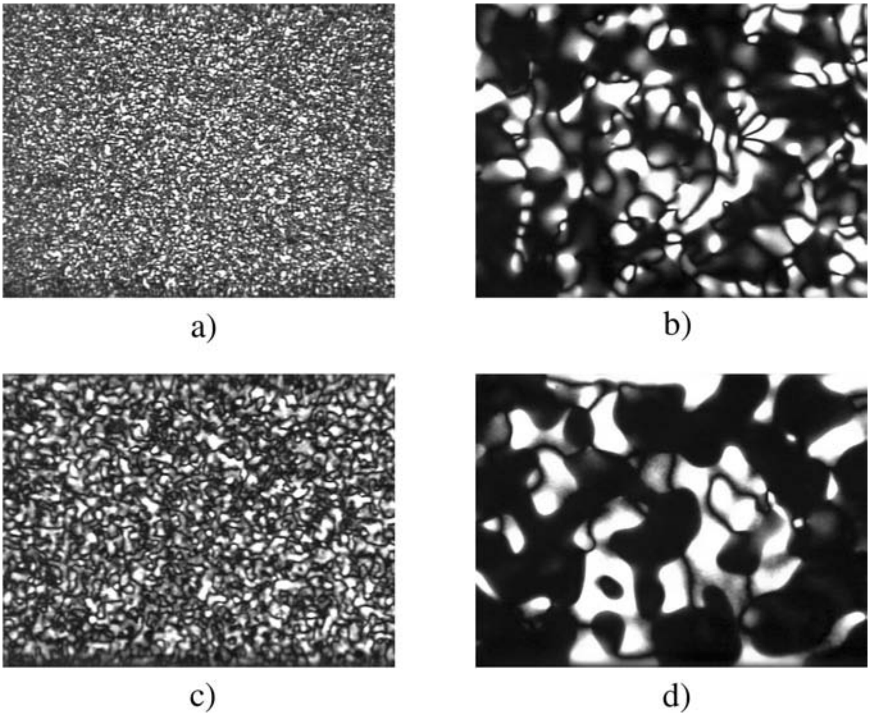

FIGURE 2 Lyotropic discotic nematic textures observed at the polarizing microscope along the 3 axis between crossed polarizers, magnification $\times 50$: (a) heating at 13.6°C; (b) heating at 18.5°C , where the mean square deviation (σ) reaches the maximum value; (c) cooling at 33.0°C, and (d) cooling at 27.5°C, where σ also reaches the maximum value.

transition (see Fig. 2a). In this case, σ increases and becomes maximum at around 18.5°C where the schlieren texture, at $I_{RE} - N_D$ phase transition, is transformed into a pseudoisotropic schlieren texture with the appearance of bright irregular and black domains. From this point, in the range of N_D phase, the partial homeotropic orientation of the micelles increases, followed by a decrease of σ until the $N_D - I$ phase transition. This fact reflects the transition between pseudoisotropic schlieren and black textures. On the other hand, the optical measurements were also performed for cooling near the $I - N_D - I_{RE}$ phase transitions (see Figs. 2c and 2d). The data of σ, as a function of temperature, are shown in Figure 3. Again σ increases, near the $I - N_D$ phase transition, with the appearance of pseudoisotropic schlieren texture and reaches a maximum value at about 27.5°C. In addition, as expected, σ decreases as temperature decreases towards the

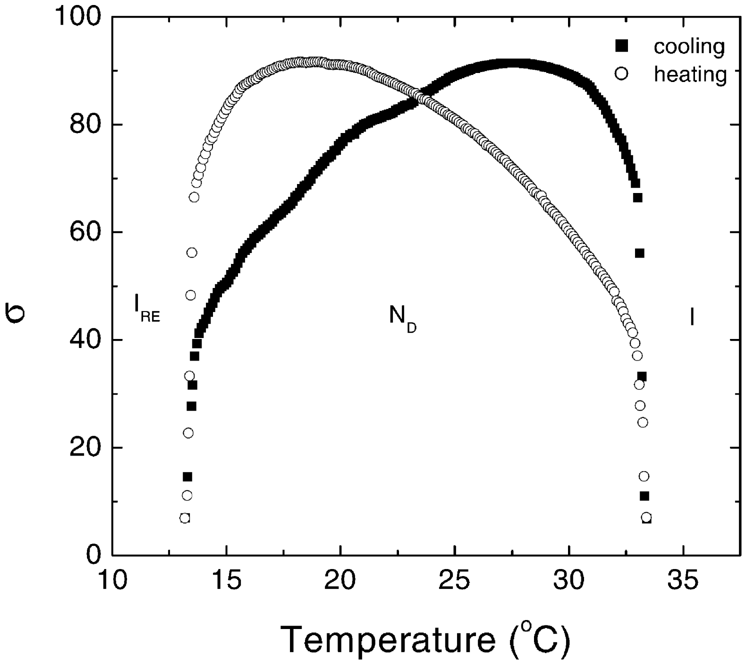

FIGURE 3 Temperature dependence on mean square deviation (σ) in KL/DeOH/D_2O system. I_{RE}, N_D and I phases, respectively.

$N_D - I_{RE}$ phase transition. Note that the $I - N_D - I_{RE}$ phase transitions are identified with the minimum values of σ determined in each phase transition [4]. Conversely, our results show yet a shift in the position of the maxima of σ, in the range of N_D phase, obtained during heating and cooling cycles. However, the magnitude of σ is approximately the same in both cycles as indicated in Figure 3. This result is agree with the changes in the partial homeotropic configuration of the director in the pseudoisotropic schlieren texture, induced by the boundary conditions, verified through optical microscopy (see Figs. 2b and 2d). To the best of our knowledge, there is no a study regarding this pseudoisotropic schlieren texture in a reentrant isotropic – discotic nematic lyotropic in literature.

In conclusion, the optical investigations of the topological configuration of lyotropic discotic nematic texture near the $I_{RE} - N_D - I$ phase transitions were carried out. The results presented here are consistent with the phase diagram proposed by several authors [7,13] and confirms the occurrence of a reentrant isotropic phase. The digital image processing method utilized in this work is sensitive and efficient enough to detect small changes in the dynamics of discotic nematic texture. It can be an important technique to investigate phase diagrams of lyotropics and their interfaces with biological systems.

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