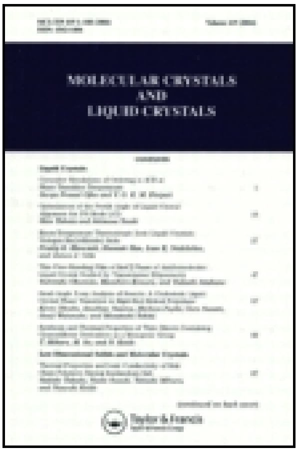


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Light Scattering Properties of Polymer Dispersed Liquid Crystals

S. Tahata [a], A. Tsumura [a], M. Mizunuma [a], H. Koyama [a], A. Tamatani [a] & T. Masumi [a]

[a] Materials and Electronic Devices Lab., Mitsubishi Electric Corp., 1-1 Tsukaguchi-honmachi 8-chome, Amagasaki, Hyogo, 661, JAPAN

Version of record first published: 24 Sep 2006.

To cite this article: S. Tahata, A. Tsumura, M. Mizunuma, H. Koyama, A. Tamatani & T. Masumi (1996): Light Scattering Properties of Polymer Dispersed Liquid Crystals, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 275:1, 99-106

To link to this article: http://dx.doi.org/10.1080/10587259608034065

Mol. Cryst. Liq. Cryst., 1996, Vol. 275, pp. 99–106
Reprints available directly from the publisher
Photocopying permitted by license only

Light Scattering Properties of Polymer Dispersed Liquid Crystals

S. TAHATA, A. TSUMURA, M. MIZUNUMA, H. KOYAMA,
A. TAMATANI and T. MASUMI

Materials and Electronic Devices Lab., Mitsubishi Electric Corp.,
1-1 Tsukaguchi-honmachi 8-chome, Amagasaki, Hyogo 661, JAPAN

(Received January 5, 1995; in final form April 28, 1995)

The Stein-Rhodes Model (SR model) which explains light scattering by anisotropic spheres is applied to the light scattering phenomenon in Polymer Dispersed Liquid Crystals (PDLC). Comparison of H_V light scattering capability obtained by both the experiment and the theoretical model reveals that, especially in a high temperature region, the experiment provides stronger light scattering intensities than the theoretical model.

Observation of PDLC under a polarized microscope shows that the region in which a liquid crystal is oriented expands with the increase of temperature. We assume from these results that the temperature dependence of the birefringence of a liquid crystal droplet is smaller than that of a bulk liquid crystal, which is mainly caused by the difference of liquid crystal orientation. For applying the SR model to PDLC, we must take into account the temperature dependence of liquid crystal orientation in the droplets.

Keywords: Polymer dispersed liquid crystal, PDLC, Stein-Rhodes model, H_V light scattering, V_V light scattering

1. INTRODUCTION

As Polymer Dispersed Liquid Crystals (PDLC) realize a display device that switches between opaque and transparent states by applying electric field, it requires no polarizers for display application. Thus, the PDLC, when applied to projection displays, is expected to provide a very bright projected image.[1,2]

The contrast ratio is one of the most important values for any type of display and, in case of the PDLC, the contrast ratio is mainly decided by the opaqueness of the off state which results from the scattering capability of the PDLC. The light scattering capability of the PDLC depends on the birefringence of the liquid crystal material and the larger the birefringence is, the stronger the scattering capability becomes. Nevertheless, a detailed understanding of the relationship between the refractive indices of PDLC components such as liquid crystals and the photo-curable resin matrix and the light scattering capability has been scarcely established.

The Stein-Rhodes model (SR model) is one of the theories that has established the relationship between the scattering effect and refractive indices of anisotropic spheres dispersed in polymer composites.[1,2] This theory reveals the correlation of scattering capability, refractive indices and the size of spheres, under the condition that the polarized light is scattered.

In this report, as a first step to discuss the light scattering properties of PDLC, the relationship between the refractive indices of the materials that constitute the PDLC and the light scattering capability was experimentally obtained and the results were compared with the SR model.

2. EXPERIMENTAL

The liquid crystal used in this experiment is E8, supplied by Merck. 2-Ethylhexyl acrylate monomer and urethane diacrylate oligomer were used as the polymer matrix precursor. The PDLC sample was made by the polymerization-induced phase separation technique.

E8/the monomer/the oligomer were mixed with the ratio of 75/20/5 and then a photo-initiator of 1 wt.% was added. This mixture was sandwiched between a pair of glass substrates with transparent ITO electrodes and was cured by irradiation of UV light.

The measuring system of the polarized light scatteirng profile is shown in Figure 1. Light scattering profiles were taken for three different directions in relation to the angles of the polarizer-analyzer system with scattering angles as far as $\pm 30°$ using a He-Ne laser of 543.5 nm.

The measured directions were firstly parallel, secondly perpendicular to the polarization direction when the polarizer was located parallel to the analyzer (V_V mode), and thirdly 45° to the polarization direction when the polarizer was located perpendicular to the analyzer (H_V mode).

Light scatteirng intensities were defined as the integrated areas of each light scattering profile.

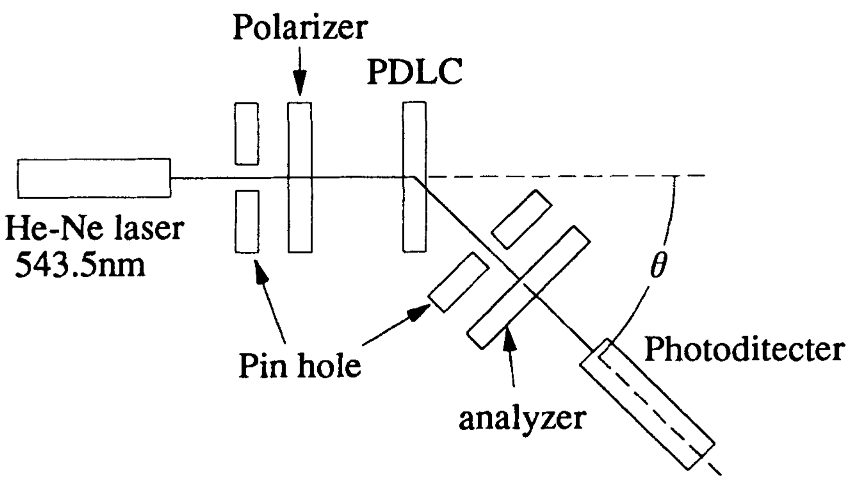


FIGURE 1 Measurement system of light scattering profiles.

3. RESULTS AND DISCUSSION

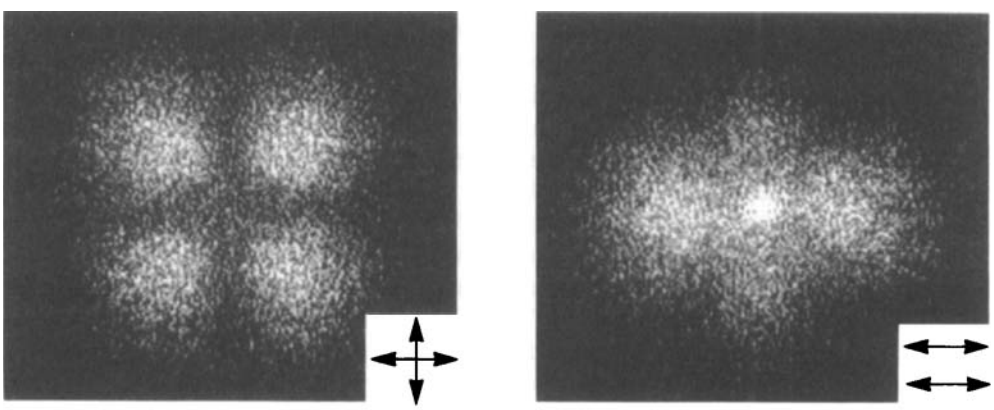
The H_V and V_V scattering patterns are shown in Figures 2(a) and (b), respectively. The directions of the polarizer-analyzer system are indicated in these figures.

The H_V scattering shows a four leaf pattern in the 45° directions to the polarizers, which originates from birefringence of liquid crystals, whereas the V_V scattering shows an oval pattern which expands to the polarized direction. The liquid crystal droplets of this sample were observed under a polarization microscope which is equipped with a birefringent gypsum plate. The first and third quadrants are colored yellow and the second and fourth quadrants are colored blue, which means that this liquid crystal possesses positive birefringence.[3,4] These results apparently show that the liquid crystals in the droplets are radially aligned.

The temperature dependence of the H_V and V_V scattering intensities was measured and compared with the theoretical calculation result by the SR model, the scattering theory for anisotropic spheres, which is expressed by the following equations.[5]

$$I_{V_V} = A V_0^2 \cos^2 \rho_1 (3/U^3)^2 \{(n_r - n_s)(\mathrm{Si}U - \sin U) + (n_t - n_s)(2\sin U - U\cos U - \mathrm{Si}U) + (n_r - n_t)[\cos^2(\theta/2)/\cos\theta] \cos^2\mu(4\sin U - U\cos U - 3\mathrm{Si}U)\}^2 \quad (1)$$

$$I_{H_V} = A V_0^2 \cos^2 \rho_2 (3/U^3)^2 \{(n_r - n_t)[\cos^2(\theta/2)/\cos\theta] \times \sin\mu\cos\mu(4\sin U - U\cos U - 3\mathrm{Si}U)\}^2 \quad (2)$$



(a) (b)

FIGURE 2 H_V (a) and V_V (b) scattering patterns of PDLC. The arrows in these photographs indicate the directions of the polarizers. See Color Plate I.

where

$$\cos\rho_1 = \cos\theta/[\cos^2\theta + \sin^2\theta\cos^2\mu]^{1/2}$$

$$\cos\rho_2 = \cos\theta/[\cos^2\theta + \sin^2\theta\sin^2\mu]^{1/2}$$

and

$$U = (4\pi a/\lambda)\sin(\theta/2), \quad \mathrm{Si}U = \int_0^U \sin x/x\,dx$$

where I_{V_V} and I_{H_V} denote scattering intensities of V_V and H_V scattering, respectively. A is a proportionality factor; V_0 and a are the volume and diameter of a liquid crystal droplet; *nr*, *nt* and *ns* are the refractive indices of radial and tangential directions of a liquid crystal droplet and polymer matrix, respectively; θ and μ are the polar angle and azimuthal angle of light scattering, respectively.

In H_V scattering, μ was set to be 45° and in V_V scattering, μ was set to be either 0° or 90°. Then the Equations (1) and (2) give the following characteristics: the H_V scattering intensity depends only on the birefringence of liquid crystal material (*nr-nt*) and the V_V scatteirng intensity, when $\mu = 0°$, depends on the difference of refractive indices between the liquid crystal and polymer matrix (*nr-ns*, *nt-ns*). And the V_V scattering, when $\mu = 90°$, depends on three kinds of refractive indices differences which are described above.

As it is impossible to directly measure the refractive indices of liquid crystals in droplets, the values measured for bulk liquid crystal material were employed in Equations (1) and (2).

Figure 3 shows the temperature dependence of refractive indices (*ne* and *no*) of the raw liquid crystal material and the polymer matrix. As is well known, *ne* tends to decrease and *no* tends to increase with an increase of temperature and *ne* and *no* values are astringent to a certain value at clearing temperature of the liquid crystal material. The refractive index of the polymer matrix slightly decreases with the increase of temperature. These values were obtained by experiments and introduced to the Equations (1) and (2) to calculate the scattering intensities by using the SR model at various temperatures. Figures 4, 5 and 6 show the temperature dependence of the light scattering intensity with different azimuthal angles, namely Figure 4 with $\mu = 45°$, Figure 5 with $\mu = 0°$ and Figure 6 with $\mu = 90°$. In these figures, the scattering intensity represents relative values which are normalized by the light scattering intensity at room temperature, which is defined to be 100.

Figures 5 and 6 show that the two kinds of V_V light scattering intensities, $\mu = 0°$ and 90°, obtained by the experiments agree well with those of the calculated values by the SR model in all the temperature regions. But Figure 4 shows that the measured H_V light scattering intensities with $\mu = 45°$ are higher than those intensities calculated by the model, especially in a higher temperature region. As has been mentioned earlier, the H_V light scattering intensity is dependent only on the birefringence and not on the difference of refractive indices between polymer matrix and liquid crystal. Thus, it is natural to anticipate that the extent of birefringence decrease of the liquid crystal contained in the droplet is smaller than that of the bulk liquid crystals in the higher temperature region.

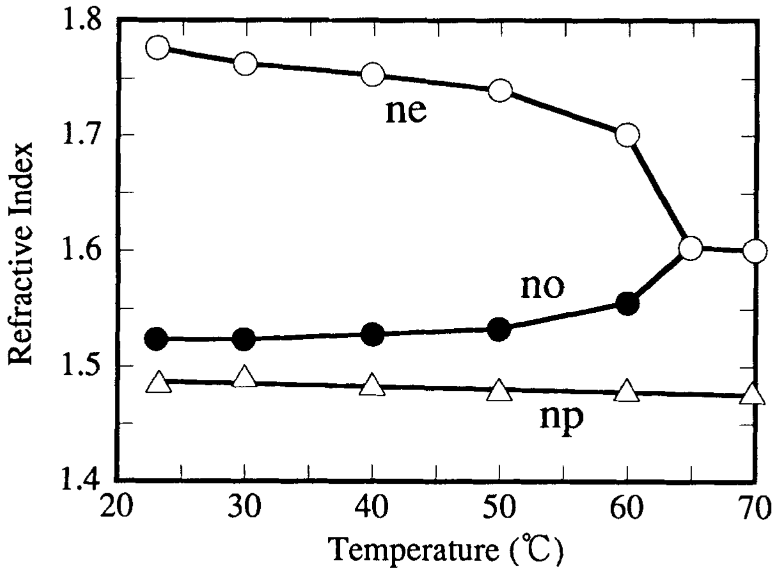


FIGURE 3 Temperature dependence of refractive indices of liquid crystal and polymer matrix. ○, ● indicate *ne*, *no* of liquid crystal, respectively. △ indicates refractive index of polymer matrix (*np*).

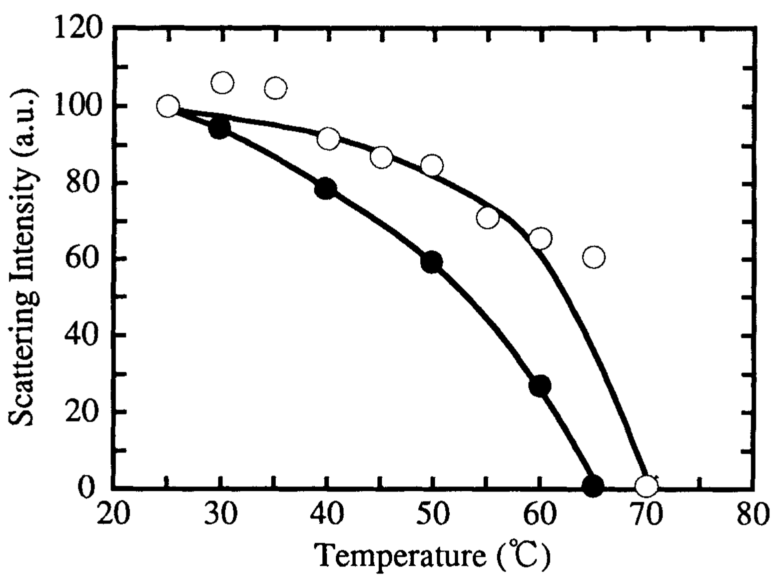


FIGURE 4 Temperature dependence of scattering intensities. Polarized direction was H_V and $\mu = 45°$. ○ and ● indicate measured data and calculated data, respecively.

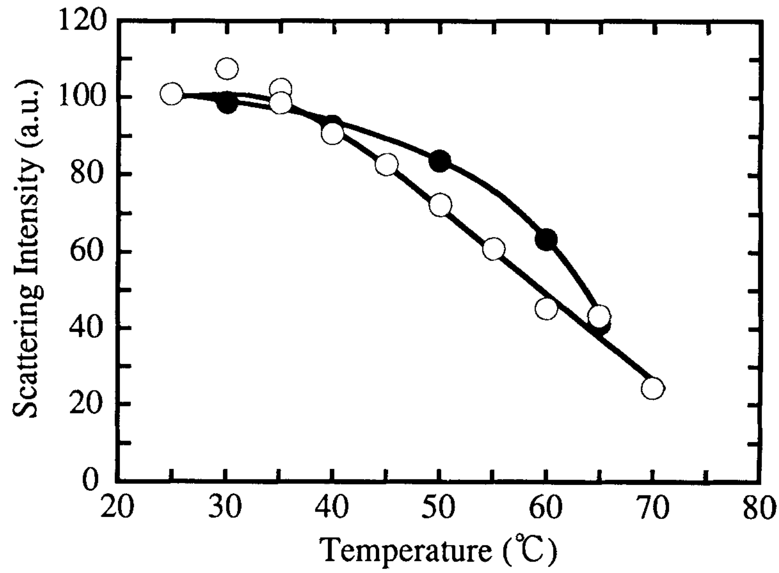


FIGURE 5 Temperature dependence of scatteirng intensities. Polarized direction was V_V and $\mu = 0°$. ○ and ● indicate measured data and calculated data, respectively.

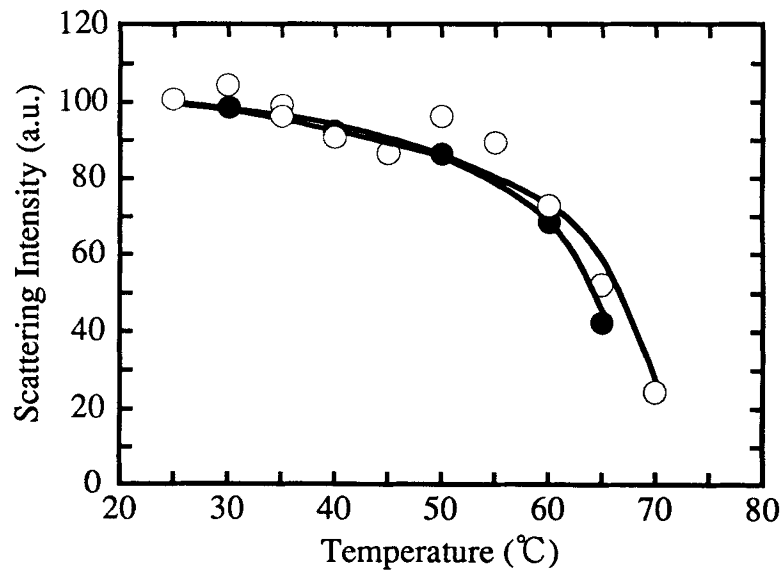


FIGURE 6 Temperature dependence of scattering intensities. Polarized direction was V_V and $\mu = 90°$. ○ and ● indicate measured data and calculated data, respectively.

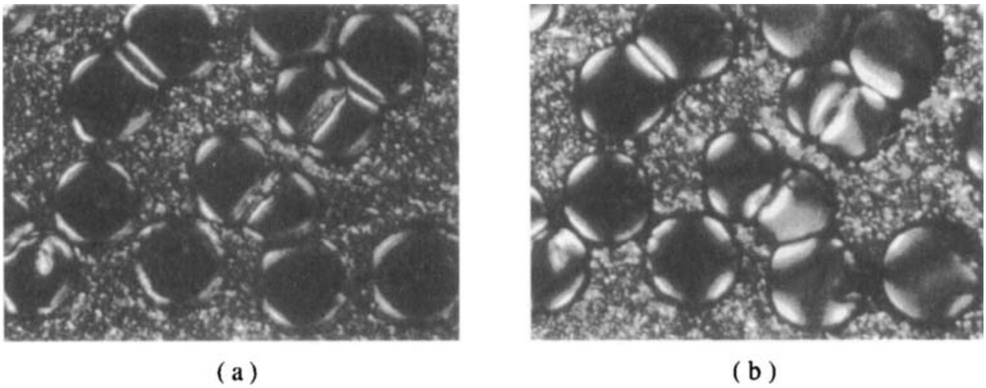


FIGURE 7 The liquid crystal droplets under polarized microscope. (a) room temperature, (b) 50 C. See Color Plate II.

In order to confirm this anticipation, we observed the orientation of liquid crystals in the droplet by means of polarized microscope. Figure 7 shows the photographs of liquid crystal droplets at (a) room temperature and (b) 50°C. Comparing these two photographs, we know that the oriented region, the so-called domain, expands with the increase of temperature. We assume that, in the high temperature region, a decrease of the birefirngence and an increase of the oriented region occur simultaneously, giving the effect of maintaining the over all birefringence value of the liquid crystal contained in the droplet constant.

4. CONCLUSION

The temperature dependence of light scattering properties of PDLC in which liquid crystal were radially aligned was measured by the polarized light scatteirng method. This experimentally obtained result was compared with the calculated one by the Stein-Rhodes model.

V_V light scattering intensities with two different azimuthal angles agree well with the calculated scattering intensities, but H_V light scattering intensities are stronger than the calculated results, especially in the high temperature region. It is observed that domains in which liquid crystals are oriented become larger at high temperatures. This gives the effect of compensating for the decrease in birefringence of bulk liquid crystals. As a result, the H_V light scattering intensities become stronger than the calculated intensities applying the SR model.

The liquid crystal orientation in the droplet must be taken into account when we try to introduce the SR model to the PDLC light scattering analysis.

References

1. J. L. Fergason, *SID'85 Digest*, **68** (1985).
2. J. W. Doane, N. A. Vaz, B.-G. Wu, S. Zumer, *Appl. Phys. Lett.*, **48**, 269 (1986).

3. R. J. Samuels, *J. Polymer Sci.*, A2, **9**, 2165 (1971).
4. J. M. Haudin, -Optical Studies of Polymer Morphology- in *Optical Properties of Polymers*, edited by G. H. Meeten, (Elsevier Applied Science 1986), Chap. 4, pp. 167–264.
5. R. S. Stein, M. B. Rhodes, *J. Appl. Phys.*, **31**, 1873 (1960).