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Birefringence of Nematic Liquid Crystal in Microwave and Light Wave Region

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The birefringence values of a nematic liquid crystal (NLC), $\Delta n'$ in the microwave region and Δn in the light wave region, were measured and compared. The value of $\Delta n'$ was found to be smaller than Δn, because the influence of a dielectric relaxation of the LC molecules still remained in the microwave region.

Keywords: birefringence Δn; light wave; microwave; nematic liquid crystal

INTRODUCTION

It is important to measure an accurate, dielectric property of the liquid crystal material as one indicator of the material selection when the nematic liquid crystal (NLC) is applied to an adaptive device in the microwave region.

The method of measuring the complex permittivity $\varepsilon_{\parallel}$ (when the long axis of liquid crystal (LC) molecules is parallel to the direction of the RF electric field **E**) and $\varepsilon_{\perp}$ (when the long axis is perpendicular) in the microwave frequency range was reported previously [1,2].

The value of the birefringence in NLC, $\Delta n'$ in the microwave region can be determined from the measured values of $\varepsilon'_{\parallel}$ (the real part of $\varepsilon_{\parallel}$) and $\varepsilon'_{\perp}$ (the real part of $\varepsilon_{\perp}$).

On the other hand, the birefringence Δn in the light wave region can be measured by optical power detection of the splay deformation of an oriented layer in a NLC.

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This paper presents experimental results showing that the value $\Delta n'$ measured by the microwave method is smaller than the value Δn measured by the optical method, and also discusses the physical meaning of those experimental results.

MEASUREMENT METHODS OF THE BIREFRINGENCE VALUES $\Delta n'$ AND Δn

1. Measurement of $\Delta n'$ in the Microwave Range

We obtained the values of $\varepsilon_{\parallel}(=\varepsilon'_{\parallel} - j\varepsilon''_{\parallel})$ and $\varepsilon_{\perp}(=\varepsilon'_{\perp} - j\varepsilon''_{\perp})$ by measuring capacitance and conductance of NLC cell in 10 kHz-13 MHz, and by using the cutback method in the range of 40 MHz-40 GHz [1].

The value of $\Delta n'$ can be calculated from Eq. (1) by using the measured results of $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$.

$$\Delta n' = \sqrt{\varepsilon'_{\parallel}} - \sqrt{\varepsilon'_{\perp}}. \tag{1}$$

2. Measurement of Δn in the Light Wave Region

We irradiated a wedge-shaped parallel nematic (PN) structure liquid crystal cell under the cross-Nicol's configuration, in which the direction of the polarizer is perpendicular to that of the analyzer, with a He-Ne laser ($\lambda = 632.8$ nm). The transmitted optical power was detected with a photodiode, and the value of Δn was determined as follows. As shown in Figure 1, we fabricated a wedge-shaped PN structure LC cell that is movable in the cell plane in order to detect variations in the liquid crystal layer's retardation ($\Delta n \cdot d$). The variation of the thickness (d) is related to the variation in the cell's retardation. The value of Δn could thus be calculated from Eq. (2):

$$\Delta n = \frac{\lambda}{d_2 - d_1} = \frac{x_0 \lambda}{\Delta x d_0}, \tag{2}$$

where λ is the wavelength (632.8 nm) of light, d_0, d_1, d_2 is the gap of wedge shaped LC cell at x_0, x_1, x_2, respectively. And d_0/x_0 is an inclination of the wedge. $\Delta x(=x_2 - x_1)$ is the observed strip gap under the cross-Nicol configuration.

EXPERIMENTAL RESULTS AND DISCUSSION

The dielectric properties of the five kinds of NLCs-BL006, BL011, BL048, BL005, and MLC11000-100 (made by MERCK) measured in this experiment are summarized in Table 1.

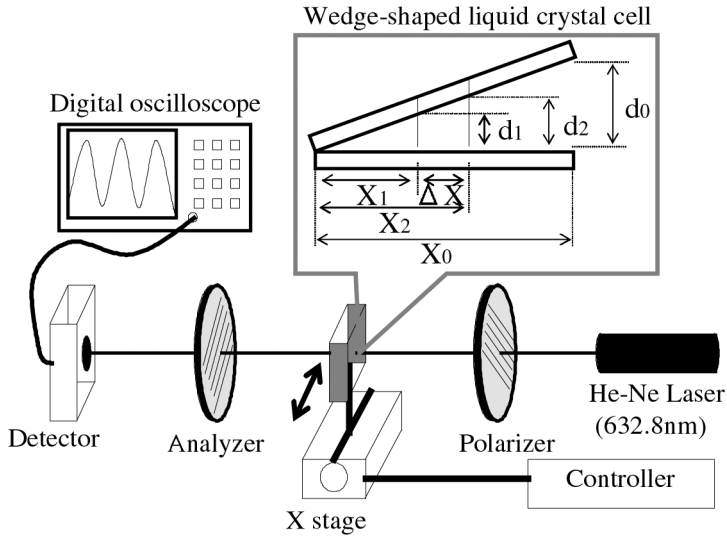

FIGURE 1 Experimental setup for measurement of the birefringence Δn in the light wave region.

We selected three kinds of NLC materials from among the materials shown in Table 1, and measured the dielectric relaxation property. The measured results of $\varepsilon'_{\parallel}$, $\varepsilon''_{\parallel}$, $\varepsilon'_{\perp}$ and $\varepsilon''_{\perp}$ for MLC11000-100, BL005, BL011 are shown in Figures 2, 3, 4, respectively.

The frequency performance of complex permittivity of MLC11000-100 is shown in Figure 2. The small discontinuity in the dielectric performance is recognized near the boundary of two measurement methods. It is understood the evident peak exists near 2.5 MHz in the frequency performance of $\varepsilon''_{\parallel}$. The value of $\varepsilon'_{\parallel}$ is 10 approximately, decreases to about 3 above several ten MHz, and coincides with the value of the microwave and millimeter-wave region. According to these experimental results, the dielectric relaxation of $\varepsilon'_{\parallel}(\varepsilon''_{\parallel})$ near

TABLE 1 Dielectric Properties of the NLC(MERCK) Used for our Measurements

	BL006	BL011	BL048	BL005	MLC11000-100
N-I (°c)	+113	+62	+100	+64	+75
$\Delta\varepsilon'$ (1 kHz, 20°c)	+17.3	+16.2	+16.8	+15.4	+7.4
$\varepsilon_{\parallel}$ (1 kHz, 20°c)	22.8	22.4	22.0	21.4	11.6
Viscosity (mm^2/sec., 20°c)	71	63	47	32	17

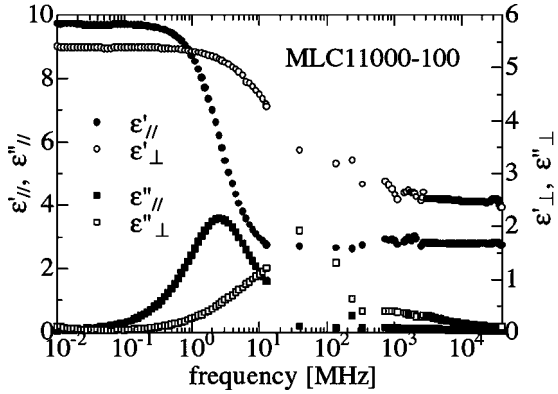

FIGURE 2 Complex permittivity of MLC11000-100.

2.5 MHz is confirmed. The value of $\varepsilon'_{\perp}$ decreases from near 10 MHz, and $\varepsilon''_{\perp}$ increases from near 100 kHz, and can be expected to have a peak at about 70 MHz. According to these results, the dielectric relaxation of $\varepsilon'_{\perp}(\varepsilon''_{\perp})$ near 70 MHz is confirmed.

Figure 3 shows the frequency performance of complex permittivity of BL005. Dielectric relaxation can be recognized at 2 MHz for $\varepsilon'_{\parallel}$ and 80 MHz for $\varepsilon'_{\perp}$.

Figure 4 shows the frequency performance of complex permittivity of BL011. Dielectric relaxation can be recognized at 1 MHz for $\varepsilon'_{\parallel}$ and 100 MHz for $\varepsilon'_{\perp}$.

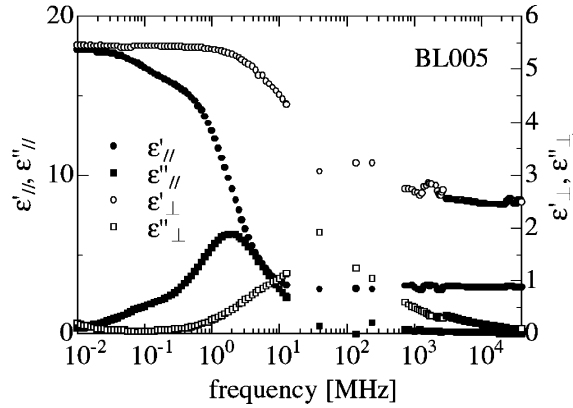

FIGURE 3 Complex permittivity of BL005.

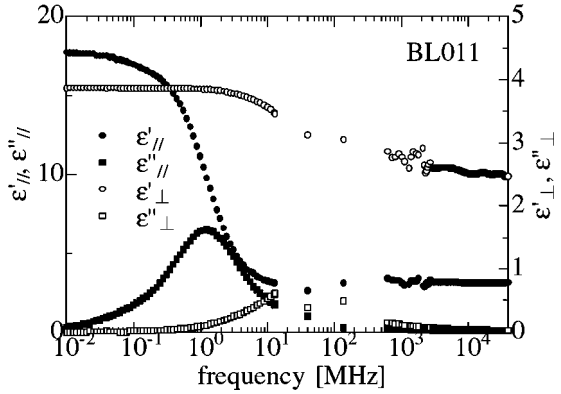

FIGURE 4 Complex permittivity of BL011.

The measured dielectric relaxation frequencies for three kinds of NLC are shown in Table 2. As shown in Table 2, the relaxation frequencies of $\varepsilon'_{\perp}$ are several ten times bigger than the ones of $\varepsilon'_{\parallel}$. Therefore it is evident the dielectric property for $\varepsilon'_{\perp}$ is more significantly affected than the one for $\varepsilon'_{\parallel}$ by the dielectric relaxation.

The values of $\Delta n'$ can be obtained by substituting the measured values of $\varepsilon'_{\parallel}$ and $\varepsilon'_{\perp}$ into Eq. (1), and those of Δn can be decided by Eq. (2). The $\Delta n'$ and Δn frequency performance for five kinds of NLCs are shown in Figure 5.

In the frequency range below 1 GHz, the values of $\Delta n'$ keep big values because of the difference of the relaxation strength and the difference of the relaxation frequency between $\varepsilon'_{\parallel}$ and $\varepsilon'_{\perp}$ in the dielectric relaxation as shown in Figures 2, 3, 4 and 5.

In 1–10 GHz, $\varepsilon'_{\perp}$ maintained a rather larger value because the effect of the dielectric relaxation still remained. On the other hand, the value of $\varepsilon'_{\parallel}$ decreases rapidly because this effect did not remain for the most part, and $\varepsilon'_{\parallel}$ maintained a constant value in this frequency range.

From 10 to 40 GHz, the effect of relaxation on $\varepsilon'_{\perp}$ also became smaller, and the value of $\varepsilon'_{\perp}$ decreased as shown in Figures 2, 3, and 4.

TABLE 2 Measured Dielectric Relaxation Frequencies for Three Kinds of Nematic Liquid Crystals

	MLC11000-100	BL005	BL011
$\varepsilon'_{\parallel}$	2.5 MHz	2 MHz	1 MHz
$\varepsilon'_{\perp}$	70 MHz	80 MHz	100 MHz

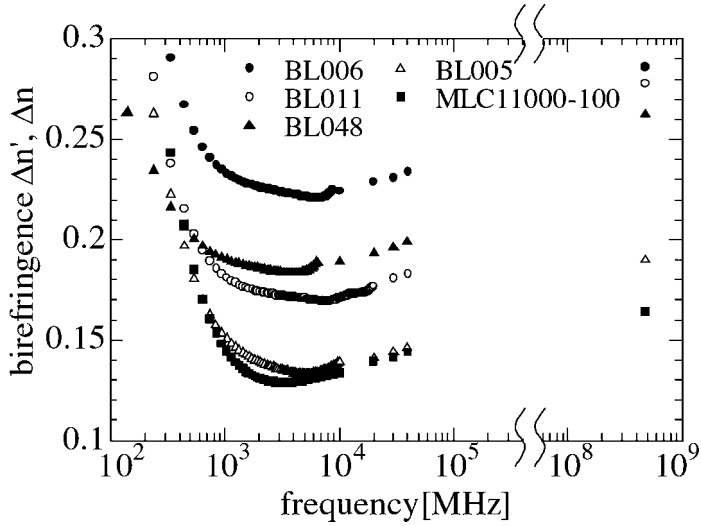

FIGURE 5 Frequency performance of birefringence $\Delta n'$ and Δn.

Therefore the value of Δn was greater at the higher measured frequencies, as shown in Figure 5.

Therefore the calculation by Eq. (1) shows the minimum values of $\Delta n'$ was between 3 and 10 GHz because of the dielectric relaxation.

In the light wave region, the effect of the relaxation vanished completely and the value of Δn was greater than $\Delta n'$ in the microwave range.

The effect of the swayed alignment of NLC's molecules should be considered as another reason for $\Delta n' < \Delta n$. In measuring the values of $\varepsilon'_{\parallel}$ and the extraordinary refractive index n_e, we set the direction of the NLC molecules parallel to the direction of the RF electric field by applying the binding force of DC electric field.

Even in this case, however, the NLC molecules were only aligned in the direction of the induced DC electric field, on average. A swayed alignment of molecules remained, in which the NLC molecules were swayed spatially with time.

When the absolute value k of the wave vector $\mathbf{k}$ ($k = 2\pi/\lambda$) is small, the amplitude of the swayed alignment became large. This indicates that NLC molecules are more strongly subject to the swayed alignment in the microwave region than in the light wave region. Therefore the value of $\Delta n'$ can be considered to be smaller than that of Δn.

The frequency performances of $\Delta n'/\Delta n$ in the microwave region are shown in Figure 6.

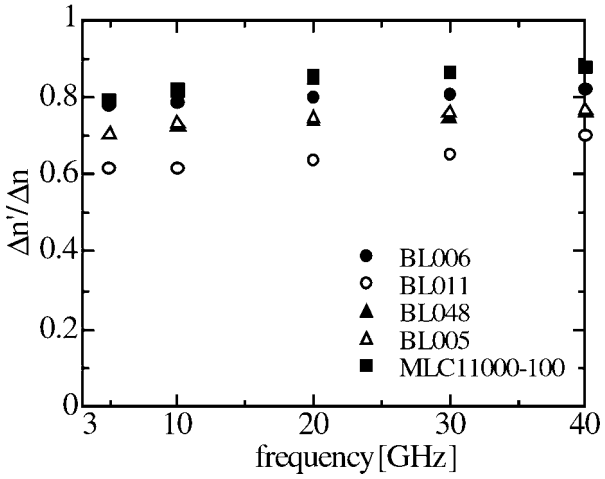

FIGURE 6 Frequency performance of $\Delta n'/\Delta n$ in microwave region.

These results indicate that the smaller values of $\Delta n'/\Delta n$ in the lower frequency range were because of the bigger influence of the dielectric relaxation of $\varepsilon'_{\perp}$, and the values of $\Delta n'/\Delta n$ were larger in the higher frequency region because of the smaller influence of the relaxation.

CONCLUSION

The measured value of the birefringence, $\Delta n'$ in microwave region and Δn in light wave region, of five kinds of NLC were compared and discussed. The value of $\Delta n'$ was found to be smaller than Δn, because the influence of a dielectric relaxation is to still remain in the microwave region as for $\varepsilon'_{\perp}$.

REFERENCES

[1] Kamei, T., Utsumi, Y., Moritake, H., Toda, K., & Suzuki, H. (2003). *Electronics and Communications in Japan*, *2*, 86, 8, 49.
[2] Kamei, T., Utsumi, Y., Moritake, H., & Toda, K. (2002). *19th International Liquid Crystal Conference*, P72.