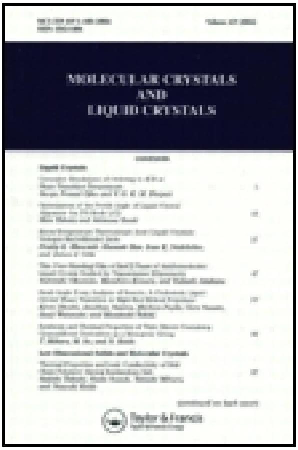

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Director Motion Measurement of Nematic Liquid Crystal in Vicinity of Substrate Under Voltage Application using Shear Horizontal Wave

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Nematic liquid crystal director motion in vicinity of a glass plate is evaluated in relation to acoustic phase delay change of shear horizontal (SH) wave propagating in a cell structure. The evaluated director angle of a nematic liquid crystal 4-cyano-4′-pentylbiphenyl (5CB) in a cell prepared by irradiating ultraviolet (UV) light is a little higher than that in a rubbing cell under low voltage application. Time response of director motion under the SH wave propagation is very shorter than that of transmitted light measurement. The present technique is promising for evaluating director motion in the vicinity of the substrate surface.

Keywords: cell structure; director orientation; nematic liquid crystal; shear horizontal wave

INTRODUCTION

Behavior of liquid crystal directors at the interface between a liquid crystal layer and a glass substrate has attracted from the view points of not only the fabrication of liquid crystal device but also the physics. Several optical methods were utilized for clarifying the behavior of liquid crystal directors [1–5]. Nematic liquid crystal with cylindrical

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shape is oriented on average with its long axis in a preferred direction, which is specified by the director, and exhibits various anisotropies such as dielectric constant, diffraction index and viscosity.

Among various elastic waves such as surface acoustic wave (SAW), Lamb wave and shear horizontal (SH) wave, the SH wave does not suffer from propagation loss at a liquid-loaded interface and thus the use of the SH wave is regarded to be effective for investigating the viscosity of liquid [6,7] and liquid crystal [8,9]. The orientation of the liquid crystal director can be related to the viscosity anisotropy and has been examined under the SH wave propagation in the liquid crystal cell [10,11].

In this study, the voltage dependences of the orientation of the liquid crystal directors are described using two types of cells, which are a rubbing cell and an ultraviolet (UV) cell. The response of the director motion under application and removal of the voltage using the SH wave method is also described in comparison with that obtained from transmitted light measurement.

EXPERIMENTAL SETUP

Figure 1 shows a schematic experimental setup of acoustic phase delay measurement used in this study. A liquid crystal cell is composed of two 400 μm thick glass plates (Cornig, 7059), whose surfaces were coated with polyimide (JSR, AL1254). For the rubbing cell, the polyimide surfaces were rubbed in one direction. For the UV cell, on the other hand, the polarized UV light was radiated on the polyimide surface. The orientation direction was perpendicular to the propagation direction of the SH wave in both cells. Two piezoelectric ceramic plates (TDK, 101A) with the thickness of 1.0 mm were cemented at both ends on the surface of one glass plate. Two interdigital transducers (IDTs) with the periodicity of 400 μm were mounted on both ceramic plates. One IDT, to which the sinusoidal voltage was applied using a function generator (Tektronix, AFG320), was used for exciting the SH wave and the other was for receiving. The acoustic phase delay was measured as a function of applied voltage to the liquid crystal layer using an RF lock-in amplifier (Stanford Research Systems, SR844). The applied voltage to the liquid crystal layer was rectangular voltage with the frequency of 2 kHz using a function generator (Tektronix, AFG320) and a power amplifier (NF, 4010). The liquid crystal material used in this study was 4-cyano-4′-pentylbiphenyl (5CB) and the thickness of the liquid crystal layer was 25 μm.

Figure 2 shows a schematic experimental setup of optical measurement used in this study. We used the same cell configurations as those

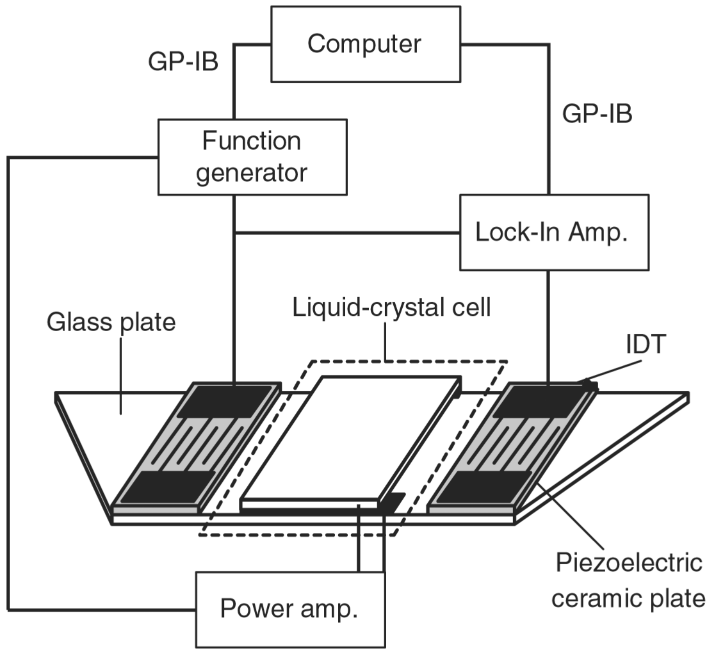

FIGURE 1 Schematic construction of SH wave device and experimental setup of acoustic phase delay measurement.

in the acoustic phase delay measurement, except the orientation was twisted nematic (TN). The liquid crystal cell was set between two parallel polarizers. A He-Ne (632.8 nm) laser was used as a light source

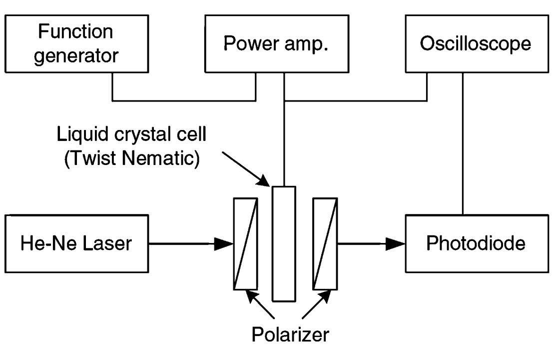

FIGURE 2 Schematic construction of experimental setup of transmitted light measurement.

and transmitted light intensity through the cell was detected by a photo-diode. For voltage application to the liquid crystal layer, the response time was measured using a digital oscilloscope (Tektronix, TDS5052).

RESULTS AND DISCUSSION

Figure 3 shows the measured frequency dependence of insertion loss of the SH wave device. We selected 8.9 MHz of frequency which corresponds to the center frequency of the peak with the lowest insertion loss. The phase velocity of the SH wave propagating in the liquid crystal cell can be calculated using the material constants of the glass substrate and the liquid crystal. Numerical calculation of the phase velocity of the SH wave was carried out by developing Farnell's and Campbell and Jones methods [12–14]. Figure 4 shows the fractional velocity change of the SH wave as a function of the liquid crystal director angle from the substrate surface at 8.9 MHz of frequency. The fractional velocity change takes the peak value at 45 degrees of the director angle. The peak value of the fractional velocity change depends on the frequency and the mode of the SH wave but the profile is the same [11].

Figure 5 shows the measured acoustic phase delay changes between two IDTs as a function of the applied voltage for various temperatures. The acoustic phase delay change was constant for applied voltage at 35°C in the isotropic phase. On the other hand, the phase delay increased under low applied voltage with lower temperature. The

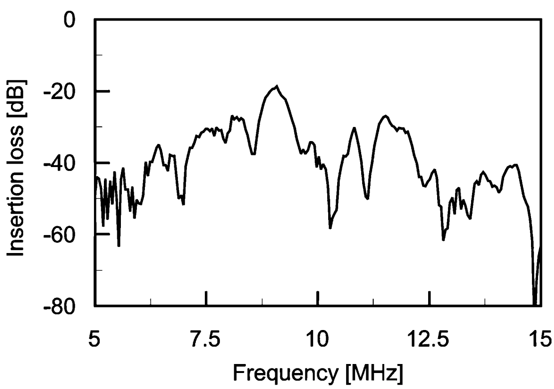

FIGURE 3 Measured frequency dependence of insertion loss between two IDTs on glass plate.

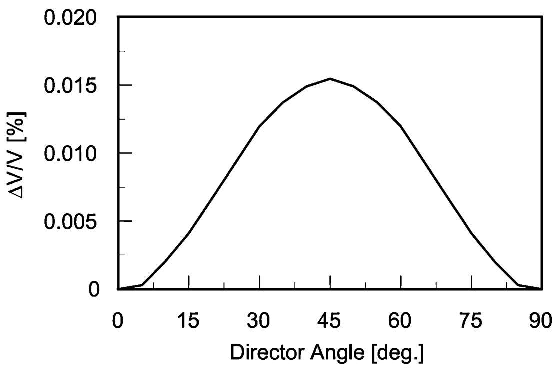

FIGURE 4 Calculated director angle dependence of fractional velocity change of SH wave (8.9 MHz).

measured phase change $\Delta\phi$ is related to the following equation,

$$\frac{\Delta\phi}{360 \times f} = \frac{L}{v} - \frac{L}{v_{ref}},$$

where v and v_{ref} are the phase velocities of the SH wave with and without the voltage application to the liquid crystal, respectively. f is the operating frequency of the SH wave device and L is the acoustic path length which corresponds to the liquid crystal cell length. Thus, we calculated the fractional velocity change from the measured acoustic phase delay change, shown in Figure 5.

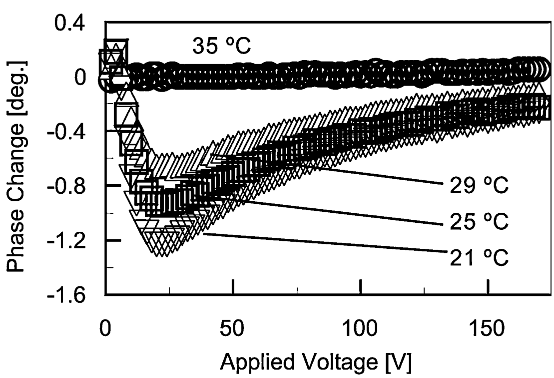

FIGURE 5 Measured applied voltage dependences of acoustic phase delay change of SH wave propagating in liquid crystal cell for various temperatures. Temperature of 35°C is in isotropic phase and other temperatures are in nematic phase.

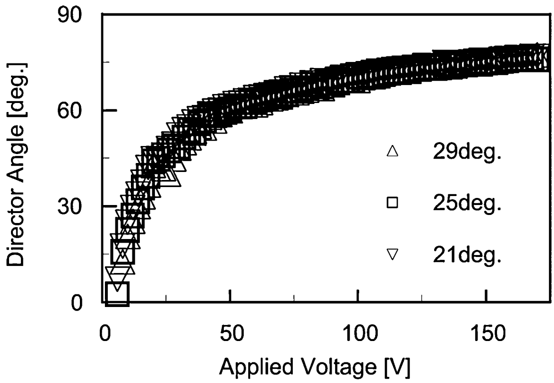

FIGURE 6 Evaluated applied voltage dependences of director angle for various temperatures.

We evaluated the applied voltage dependences of the director angle using the result in Figure 5, and director angle dependence of fractional velocity change, shown in Figure 4. Figure 6 shows the voltage dependences of evaluated director angle for various temperatures. The obtained results indicate that the director angle is independent of temperature in the nematic phase. The evaluated director angle under application of voltage of 100 V is about 65° which is not parallel to the direction of the electric field.

The mechanical displacement of the SH wave propagating in the liquid crystal cell structure is obvious in Figure 7 for the 8.9 MHz SH wave. The mechanical displacement exponentially decays in the liquid crystal layer and completely disappears at around 7 μm from the interface. The evaluated director angle in this measurement is regarded as the average angle of the directors existing in the region from the interface to the depth of a few micrometers. The liquid crystal directors in the vicinity of the substrate surface can hardly rotate in the direction of the electric field, because the liquid crystal molecules are anchored to the substrate surface. Therefore, the evaluated director angle under application of high voltage is smaller than 90°.

Figure 8 shows the applied voltage dependences of the evaluated director angle in the rubbing cell and the UV cell. The direction angle in the UV cell is a little higher than that in the rubbing cell under low voltage application. In general, the anchoring energy of the UV alignment is regarded to be weaker than that of the rubbing alignment. The difference of the director angle between the rubbing cell and the UV cell under low voltage application may be caused by the difference of the anchoring energy of both alignments.

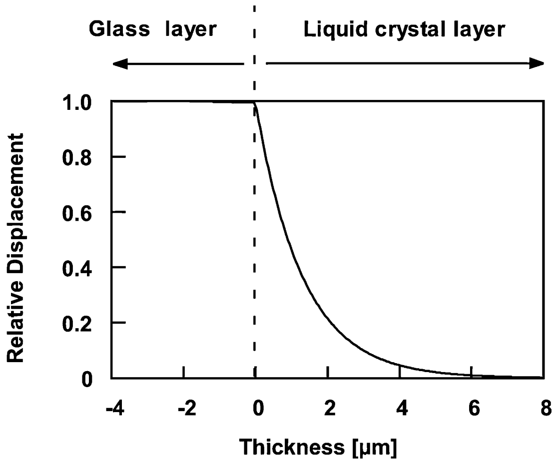

FIGURE 7 Calculated mechanical displacement distributions of 8.9 MHz SH wave in liquid crystal cell.

The time response of the director motion under voltage application and removal to the liquid crystal layer was measured. Figure 9 shows the waveforms of the applied voltage and the director angle in the rubbing cell. The time response corresponds to the director motion of the liquid crystal molecules in the vicinity of the interface with the glass plate. The response times under application and removal of the voltage are denoted as the rise time and the decay time, respectively. Figure 10 (a) and (b) show the rise time and the decay time of the

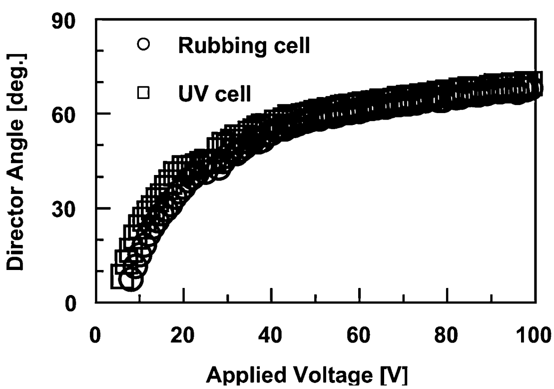

FIGURE 8 Evaluated applied voltage dependences of director angle in rubbing cell and UV cell.

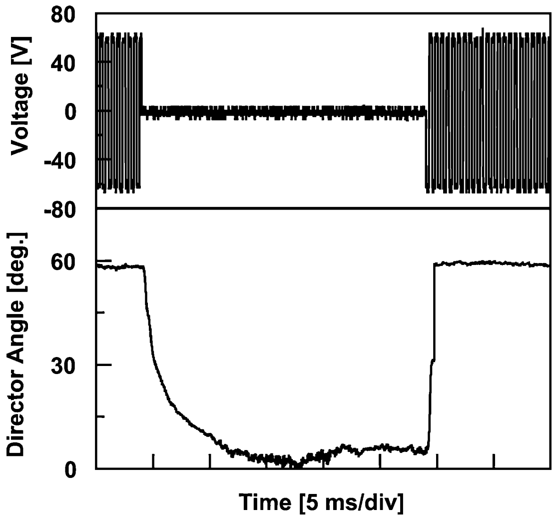

FIGURE 9 Waveforms of applied voltage and director angle under application and removal of rectangular voltage.

director motion as a function of the applied voltage in the rubbing and UV cell, respectively. The rise time decreased with the applied voltage and converged at around 0.3 ms beyond 40 V in both cells. The minimum time constant of the lock-in amplifier used in this study is 0.1 ms and the response time below 0.3 ms could not be measured in this setup, where the decay time is independent of the applied voltage.

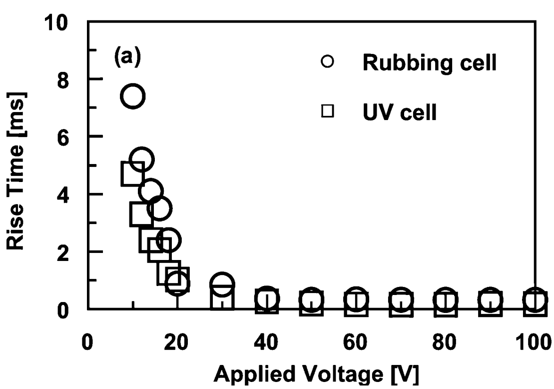

FIGURE 10 Applied voltage dependences of rise time (a) and decay time (b) of evaluated director angles in rubbing cell and UV cell.

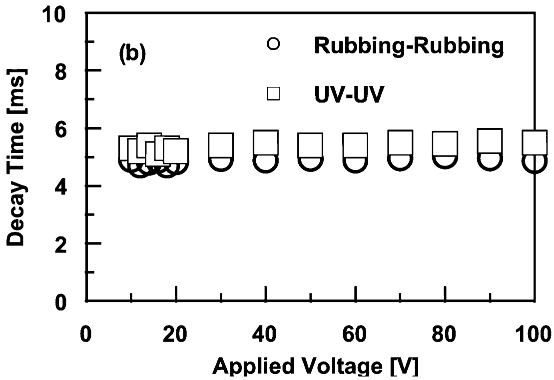

FIGURE 10 Continued.

The response times in both cells are the almost same as shown in Figure 10.

The response time of the optical measurement using the TN cell were also performed. Figure 11 (a) and (b) show the rise and decay times of the light intensity as a function of the applied voltage in the rubbing and UV cells, respectively. The rise time decreased with voltage and the decay time is independent of the applied voltage. In this measurement, the decay time of the rubbing cell is shorter than that of the UV cell. This result arises from the difference of the anchoring energy between the rubbing cell and the UV cell.

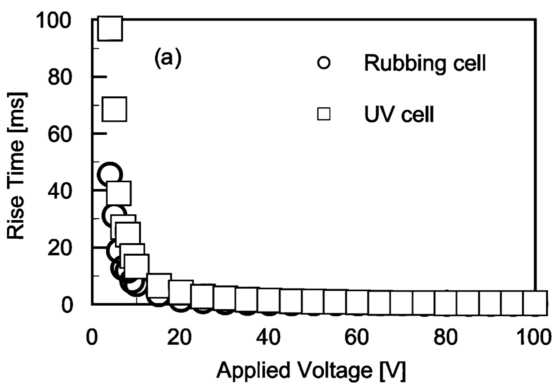

FIGURE 11 Applied voltage dependences of rise time (a) and decay time (b) of transmitted light intensity measurement in rubbing cell and UV cell.

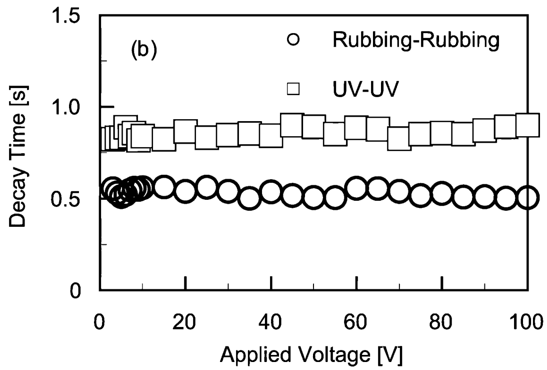

FIGURE 11 Continued.

The rise time of the optical measurement is several times longer than that of the SH wave measurement, while the decay time of the optical measurement is about a hundred times longer than that of the director angle measurement. The decay time corresponds to the response time for the voltage removal. When the voltage is removed, the molecule aligned along the direction of the electric field starts to rotate to the initial direction because the molecule at the surface of the glass substrate remains the initial direction by anchoring. Therefore, the molecule in the vicinity of the glass substrate quickly returns to the initial direction.

CONCLUSIONS

The nematic liquid crystal director orientation in the vicinity of the glass plate was evaluated from the acoustic phase delay change of the SH wave propagating in two types of cell structures. The applied voltage dependence of director angle was independent of the temperature in the nematic phase. The evaluated director angle in the UV cell was a little higher than that in the rubbing cell for low voltage application. The response times of the molecular reorientation under application and removal of the voltage were almost same in both cells. The response times measured using the SH wave propagation were very shorter than those of the transmitted light measurement because the SH phase change detected the director motion in the vicinity of the substrate. The present method using the SH wave propagation in a liquid crystal cell is promising for evaluating the director motion in the vicinity of the glass substrate.

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