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Citation	電気材料技術雑誌. 2001, 10(2), p. 181-184
Version Type	VoR
URL	https://hdl.handle.net/11094/81693
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Temperature Dependence of Electrorheology Effect in Nematic Liquid Crystal under SH Wave Propagation

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An electrorheology (ER) effect means that the fluid viscosity changes with an applied electric field [1]. It was first reported by Winslow in 1947 [2], and has been studied in colloidal suspensions, dielectric liquids. The ER effect has been reported in nematic liquid crystals [3-5] as well as the above liquids. A rotational viscous meter is in general used to measure the viscosity of liquid crystal, which induces a continuous shear flow in the liquid-crystal layer. The ER effect of the nematic liquid crystals is considered to be affected by the director orientation, which would request a viscosity measurement system without disturbing director orientation.

Elastic wave devices have been widely used for many applications including filters for various communication systems [6,7] and microsensors for detecting material properties [8,9]. A shear horizontal (SH) wave scarcely suffers from the propagation loss at the solid/liquid interface, which leads to the investigation of the liquid properties [10-12]. Recently, a viscosity sensor has been realized by using the SH wave propagation [13,14].

In this paper, temperature dependence of an electrorheology effect of a nematic liquid crystal is measured by a SH wave propagating in the liquid-crystal cell. The applied voltage dependences of the propagation loss and the acoustic phase-delay change at various temperatures are investigated. Those experimental results are related to the Leslie viscosity coefficients expressed by an order parameter.
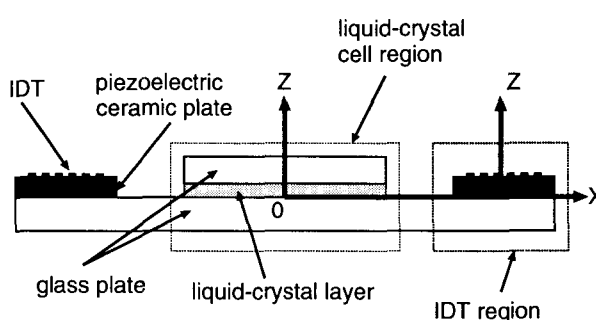

Fig.1 Schematic construction of a prepared device.

Figure 1 shows a schematic of a device construction in this study. This device has two kinds of regions: one is for generating and receiving the SH wave, which is called the IDT region. The IDT region is composed of a layered structure consisting of a piezoelectric ceramic thin plate (TDK, 101A) with a 200 μm-thickness and a glass thin plate (Corning, 7059) with a 400 μm-thickness. The piezoelectric ceramic thin plate is cemented to the glass thin plate with epoxy resin. Two interdigital transducers (IDTs) are formed on the piezoelectric ceramic thin plate, for input and output, each of which has an interdigital

periodicity of 400 μm and seven electrode-finger pairs. The other intermediate region is for the SH wave propagation in a liquid-crystal cell which is called the liquid-crystal cell region. The liquid-crystal layer is sandwiched between the two glass plates. The thickness of the liquid-crystal layer is adjusted by a polyethyleneterephthalate (PET) film as a spacer of 25 μm. The liquid crystal material prepared in this study is 4-cyano-4'-pentylbiphenyl (5CB) with positive dielectric anisotropy. The clearing point of 5CB is corresponded to the 35.5 °C. The SH wave excited in the IDT region propagates in the lower glass plate, and then is detected as a delayed electrical signal at the other IDT after propagating in the liquid-crystal cell region.

The operation performance of the IDT is fundamentally important for exciting the SH wave on the glass plate. Figure 2 shows the measured frequency dependences of the insertion loss of the SH wave device with and without the nematic liquid crystal, respectively. Multiple center frequencies are distinctly observed and their frequencies correspond to the respective modes. The real line in the figure is for the result in the case of the double-layer composed of the piezoelectric ceramic and glass plates without the liquid crystal. The predominant operation frequencies of the SH wave device are 8.13 and 13.7 MHz. The difference of insertion loss between the device construction with and without the liquid-crystal layer is substantially negligible. The SH wave propagation has low energy loss at the solid/liquid interface, which is supported by this experimental result.

The dynamic responses of the acoustic phase-delay are measured at several applied electric fields of 0.8, 1.6, 3.2 and 4.0kV/mm, as shown in Fig. 3. The electric field is applied to the liquid-crystal cell. The acoustic phase-delay change decreases under the application of low electric field. It is caused by the secondary flow of the reorientation process of the liquid-crystal director, which couples to the SH wave propagation [15].
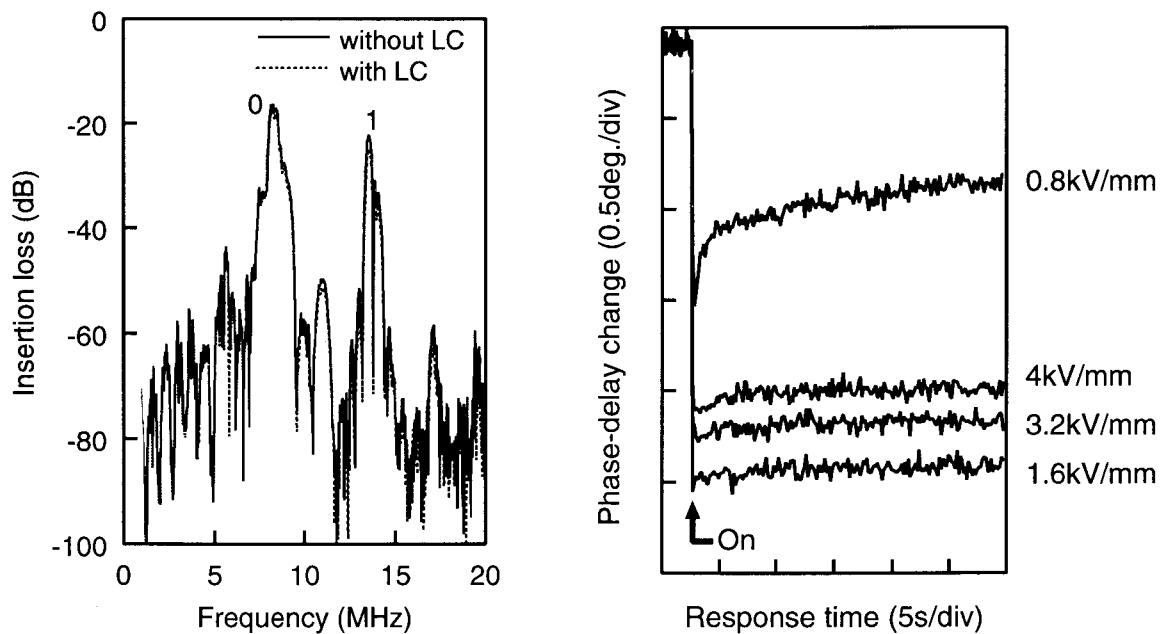

Fig.2 Frequency dependence of insertion loss.　Fig.3 Dynamic response of phase-delay.
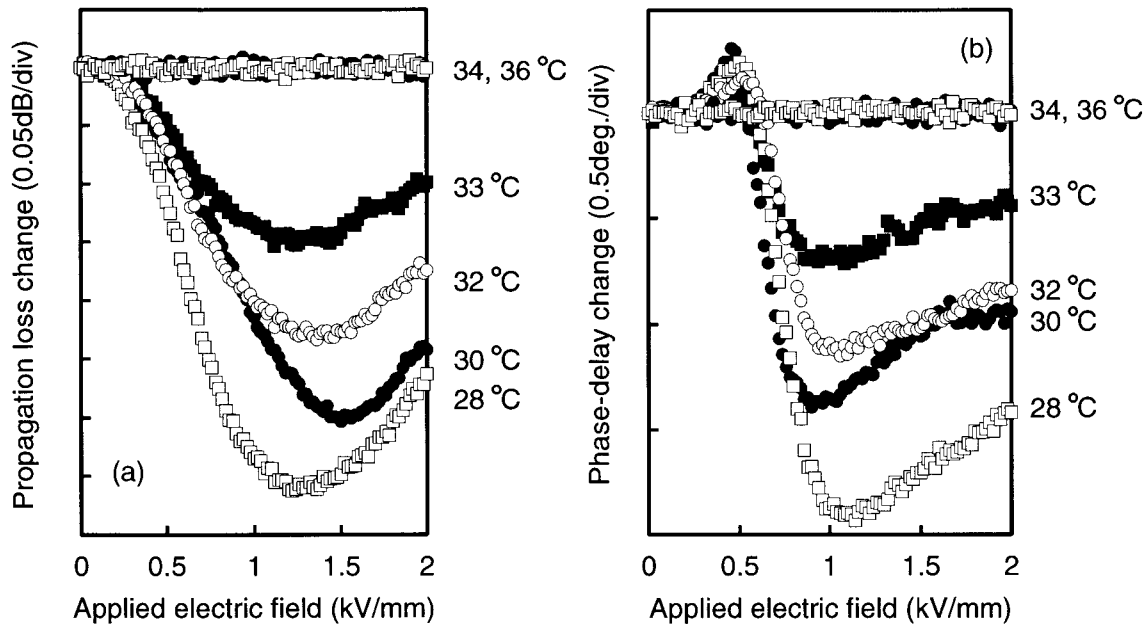
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Fig.4 Applied electric field dependences. (a) propagation loss change and
(b) phase-delay change of the SH wave at various temperature.

Figures 4 (a) and (b) show the measured applied voltage dependences of the propagation loss and acoustic phase-delay change of the SH wave in the vicinity of the isotropic-nematic (Iso-N) phase transition temperature, respectively. The initial orientation of the liquid crystal director become parallel to the vibration-displacement direction of the SH wave. The propagation loss and acoustic phase-delay once decrease with voltage and then increase. With applying voltage to the liquid-crystal cell, the liquid-crystal director is parallel to the direction of the applied electric field because of the positive dielectric anisotropy. This result also corresponds to the temperature dependence of the acoustic phase-delay of the SH wave. The change of the acoustic phase-delay decreases with increasing temperature. The acoustic phase-delay change is negligible at $34°C$ near the Iso-N phase transition temperature. In the isotropic phase, no acoustic phase-delay change of the SH wave is observed at $36°C$ independent of applied electric field. This result indicates that the viscosity anisotropy of the nematic liquid crystal disappears in the isotropic phase.

The acoustic phase-delay is related to the effective viscosity of nematic liquid crystal [16]. On the other hand, the relationships between the Leslie viscosity coefficients and the order parameter have been discussed theoretically and experimentally [17,18]. The Leslie viscosity coefficients (α_i: $i = 1 \sim 6$) are expressed by the following equations:$\alpha_1 = A_1 S^2$, $\alpha_2 = -(B_1 + C_1)S - (B_2 + C_2)S^2$, $\alpha_3 = -(B_1 - C_1)S - (B_2 - C_2)S^2$, $\alpha_4 = \eta - aS + A_3 S^2$, $\alpha_5 = (\frac{3}{2}a + B_1)S + (A_2 + B_2)S^2$, $\alpha_6 = (\frac{3}{2}a + B_1)S + (A_2 - B_2)S^2$, where a, A_i, B_i and C_i ($i = 1, 2, \cdots$) are constants. η is the viscosity coefficient in the isotropic phase and S is the order parameter. $S = 1$ and 0 correspond to the completely ordered and disordered states of the molecular orientation, respectively. In the case of the state of $S = 0$ being the isotropic phase, the viscosity anisotropy disappears, which is given by $\alpha_4 = \eta$. On the other hand, in the nematic phase, the viscosity anisotropy of the liquid crystal is characterized by

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non-zero S. The temperature dependence of the order parameter, especially in the vicinity of the Iso-N phase transition temperature, drastically appears under the applied electric field, as shown in Fig. 4. These experimental results support that the molecular orientation is related to the acoustic phase-delay of the SH wave via the order parameter.

The temperature dependences of the electrorheology effect of the nematic liquid crystal were measured under the existence of the SH wave propagating in the liquid-crystal cell. The applied voltage dependences of the acoustic phase-delay change at various temperatures in the vicinity of the Iso-N phase transition temperature, are related to the Leslie viscosity coefficients expressed by the order parameter.

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