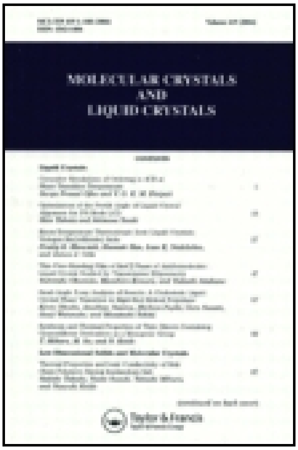

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MEASUREMENT OF ELECTRORHEOLOGY EFFECT OF FERROELECTRIC LIQUID CRYSTAL USING A SHEAR-HORIZONTAL WAVE DELAY LINE OSCILLATOR

Masaru Inoue [a], Hiroshi Moritake [b], Katsumi Yoshino [a] & Kohji Toda [b]

[a] Department of Electronic Engineering, Graduate School of Engineering, Osaka University, Yamadaoka, Suita, 565-0871, Japan

[b] Department of Electrical and Electronic Engineering, National Defense Academy, Hashirimizu, Yokosuka, 239-8686, Japan

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Measurement of Electrorheology Effect of Ferroelectric Liquid Crystal using a Shear-Horizontal Wave Delay Line Oscillator

MASARU INOUE[a], HIROSHI MORITAKE[b], KATSUMI YOSHINO[a] and KOHJI TODA[b]

[a]*Department of Electronic Engineering, Graduate School of Engineering, Osaka University, Yamadaoka, Suita 565–0871, Japan and* [b]*Department of Electrical and Electronic Engineering, National Defense Academy, Hashirimizu, Yokosuka 239–8686, Japan*

An electrorheology (ER) effect of a ferroelectric liquid crystal (FLC) is described on the basis in numerical analysis and experiment. Propagation characteristics of a shear-horizontal (SH) wave in a liquid crystal layer between a piezoelectric ceramic thin plate and a glass thin plate is numerically analyzed. The phase velocity of the SH wave depends predominantly on the viscosity of the FLC. The ER effect is measured using a SH wave device under the construction of delay line oscillator. The observed DC electric field dependence of oscillation frequency under the use of a helical structure of FLC is related to the observed microscopic result. This method has the advantage of simplicity and a small amount of liquid sample for evaluating the ER effect of the FLC.

Keywords: electrorheology effect; ferroelectric liquid crystal; shear-horizontal wave; delay line oscillator

INTRODUCTION

An electrorheology (ER) effect that the fluid viscosity changes with applied electric field [1] was first reported by Winslow in 1947 [2]. The phenomenon has been studied in colloidal suspensions, dielectric liquids and liquid crystals. The increase of the viscosity of a liquid crystal has been observed under the application of an electric field [3]. A rotational viscous meter is in general used to measure the viscosity of liquid crystal, which system needs a large amount of the liquid crystal sample. In the measurement system, a continuous shear flow in the liquid crystal, so that a well-aligned structure like a monodomain, is induced by both the shear stress and the electric field [4].

Various sensing devices were realized by the use of elastic waves [5]. A shear-horizontal (SH) wave at a solid/liquid interface has a low propagation loss which has a potential for the liquid-phase application [6].

In this study, an ER effect of a ferroelectric liquid crystal (FLC) is evaluated using by a SH wave delay line oscillator, which is related with the SH wave propagation in a cell structure containing the FLC. The relationship between the viscosity of the FLC and the SH wave velocities is essential for the measurement system.

NUMERICAL ANALYSIS RESULT

It is fundamentally important to analyze the propagation characteristics of the SH wave in the FLC cell from the viewpoint of the viscosity measurement in the form of detecting the velocity change of the SH wave propagation. In this section, the behavior of the SH wave propagation in a trilayer structure, having a viscous liquid layer sandwiched between a piezoelectric ceramic thin plate and a glass thin plate, is described in terms of the liquid viscosity and density.

FIGURE 1 Material constants of piezoelectric thin plate, glass plate and liquid crystal.

property	ceramic plate	glass plate	FLC	units
c_{44}	2.53	2.64		$\times10^{10}$[N/m^2]
e_{34}	11.58			[C/m^2]
ϵ_{11}	719	5.60		
ρ	7700	2760	1020.0	kg/m^3

Figure 1 shows the coordinate system used for the numerical analysis. The origin of Z axis is fixed at the interface between a piezoelectric ceramic thin plate with a thickness d and a liquid layer with a thickness $r_1 d (0 \leq r_1 \leq 1)$. One of the glass thin plate is contacted with the liquid layer at the $Z = -r_1 d$. The material constants of the prepared piezoelectric ceramic plate (101A, TDK) with its poling axis parallel to the free surface and perpendicular to the SH wave propagation direction, the FLC (CS1014, Chisso) as the liquid layer and the glass plate (7059, Corning) are listed in Table 1. The liquid-crystalline medium is assumed to be an isotropic viscous liquid in the case of the SH wave propagation. Numerical calculation of the phase velocity of the SH wave in the trilayer structure is carried out by developing Farnell's method [7].

Figure 2 shows the numerical analysis results of the fractional velocity change as a function of the liquid viscosity and the density for the zeroth order symmetrical (S_0) mode of the SH wave, where both surfaces of the piezoelectric ceramic thin plate are electrically shorted. This calculation is executed at the frequency of 5.56 MHz, corresponding to the center frequency of S_0 mode SH wave. Solid and dotted lines are for the liquid viscosity and the density dependences of the fractional velocity change, respectively. It is noted that the fractional velocity of the S_0 mode is monotonically change with the liquid density, and the liquid density dependence is negligible compared with the liquid viscosity dependence.

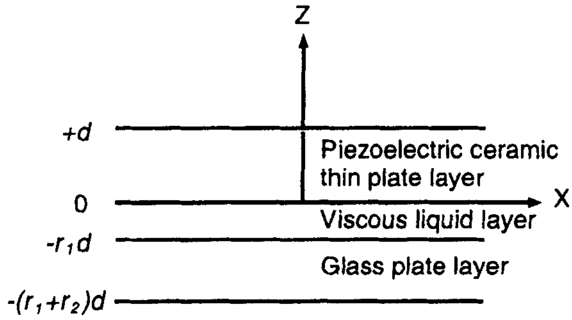

FIGURE 1 Coordinate system for numerical analysis.

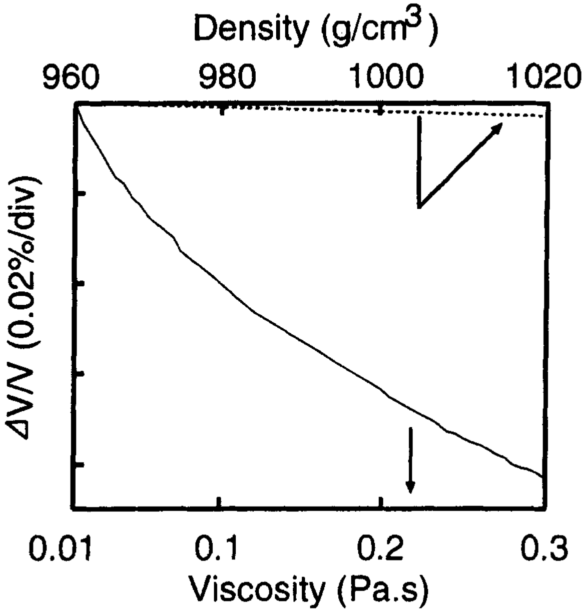

FIGURE 2 Fractional velocity change of S_0 mode of SH wave as functions of viscosity and density.

EXPERIMENT AND RESULTS

A schematic construction of a SH wave delay line oscillator prepared for the experimental study is shown in Fig. 3. The FLC (CS1014, Chisso) is sandwiched between a 200 μm-thick piezoelectric ceramic thin plate(101A, TDK) and a 400 μm-thick glass plate (7059, Corning). The thickness of the FLC layer is 25μm, adjusted by a PET film as the spacer. This cell structure needs a small amount of liquid sample with the capacity of about 0.003 ml. Two interdigital transducers (IDTs) are mounted on the piezoelectric ceramic thin plate, for input and output, each of which has seven electrode-finger pairs and 400 μm-interdigital periodicity. The liquid crystal cell area on the piezoelectric ceramic thin plate is coated by an aluminum thin film, which is used for applying to the liquid crystal layer between the piezoelectric ceramic thin plate and the ITO-coated glass plate. The two IDTs are connected via an amplifier for constructing for a delay line oscillator. An oscillator output signal is measured by a frequency counter.

Figure 4 shows the measured frequency dependences of the insertion losses of the SH wave devices with and without the existence of the FLC when the peak frequency around 5.6 MHz corresponds to the S_0 mode. The slight difference of the insertion losses between the devices with and without the FLC is recognized, which indicates that the SH wave propagation involves low propagation loss at the solid/liquid interface.

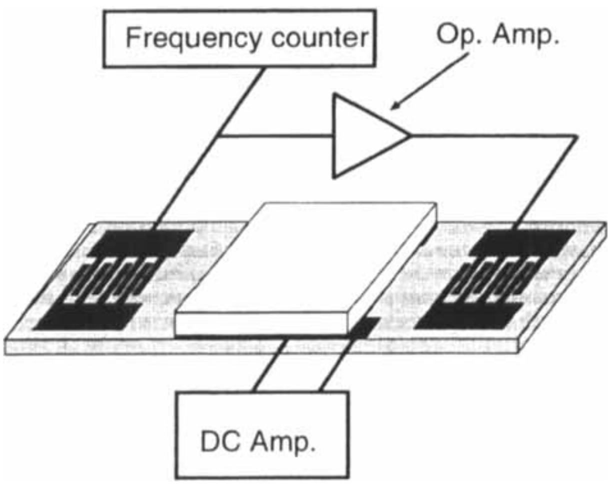

FIGURE 3 Schematic construction of delay line oscillator used in this study.

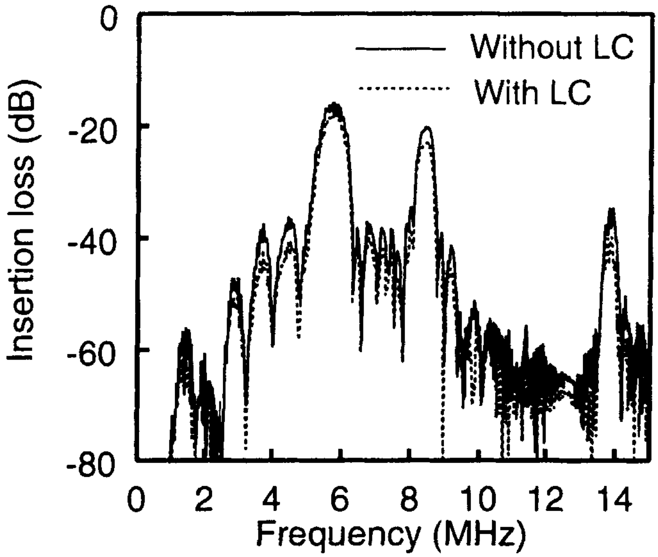

FIGURE 4 Frequency dependences of insertion loss of SH wave device.

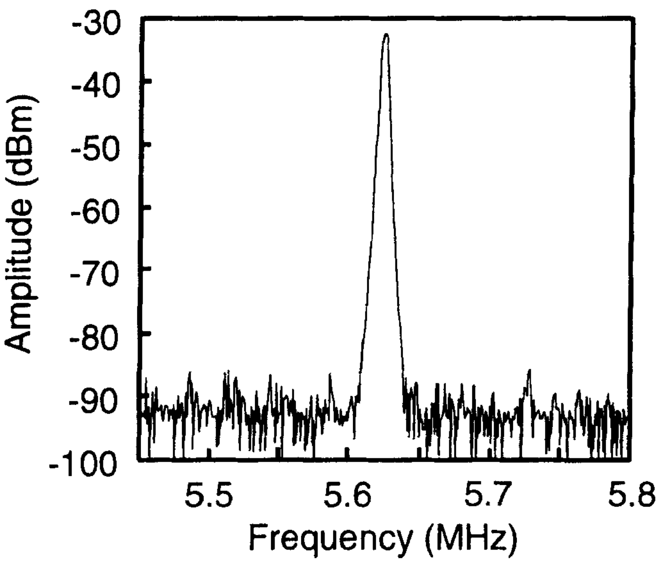

FIGURE 5 Observed spectrum of S_0 mode SH wave delay line oscillator.

Figure 5 shows a typical oscillator output, of which the oscillation frequency is 5.632 MHz. The oscillation frequency f_0 satisfies the following equation [8]:

$$f_0 = \frac{V_{SH}}{L}(2n\pi - \phi_E), \tag{1}$$

where n is an integer, ϕ_E is an electrical phase shift, V_{SH} is the SH wave velocity and L is an acoustic path length between two IDTs. In the present device construction, ϕ_E and L are constant [9]. The change of oscillation frequency Δf is represented by the fractional velocity change of the SH wave:

$$\frac{\Delta f}{f_0} = \frac{\Delta V_{SH}}{V_{SH}}. \tag{2}$$

The measured DC field dependence of the oscillation frequency change of the SH wave delay line oscillator is shown in Fig. 6, corresponding to the S_0 mode propagation. Beyond 0.6 kV/mm, the oscillation frequency decreases the electric field, which might be considered in a relation with th viscosity of the FLC. A little increase of oscillation frequency is recognized when applying the electric field below 0.6 kV/mm. To investigate the relationship between the structure of the FLC and the SH wave propagation, the texture of the FLC cell was observed by a microscope. The FLC texture, shown in Fig. 7(a), is a result in the case of no existence of the SH wave and no applied voltage to the liquid crystal cell, when the helical structure of the FLC is observed. Under no applied electric field to the cell, it is noted that the existence of the SH wave excited by one of the IDTs gives no change of the helical structure. It is advantageous that the structure of the FLC is not disturbed by a continuous shearing force arisen in a rotational viscous meter [4]. The observed texture under the existence of the S_0 mode SH wave and an applied electric field of 0.5 kV/m is given Fig. 7(b), where the helical structure of the FLC disappears. The applied electric field of 0.5 kV/m corresponds to the DC field for the nearly maximum value of the oscillation frequency. It is considered that the increase of the oscillation frequency below 1.0 kV/mm is related to the disappearance of the helical structure of the FLC.

CONCLUSION

A measurement technique of an electrorheology effect of a ferroelectric liquid crystal using a SH wave delay line oscillator was described. Propagation characteristics of the SH wave in the trilayer structure as a liquid crystal cell was numerically analyzed. The experimental results indicate that the change of the FLC viscosity is induced by applying an electric field. The present technique is an effective method for measuring the electrorheology effect and has the advantages of the requirement of only a small amount of liquid sample and no disturbance of the FLC structure.

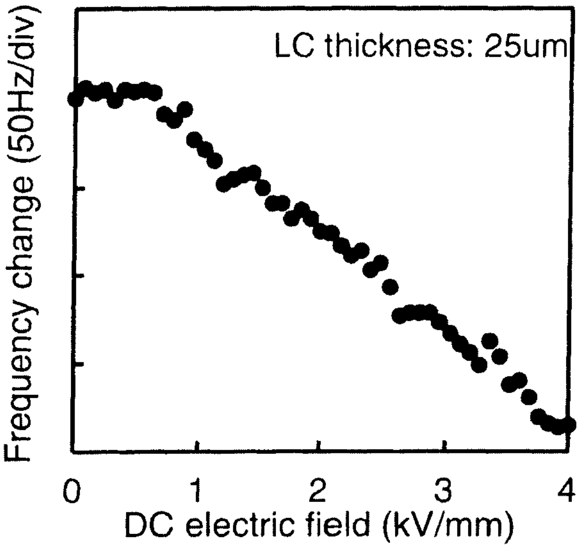

FIGURE 6 DC electric field dependence of change of oscillation frequency.

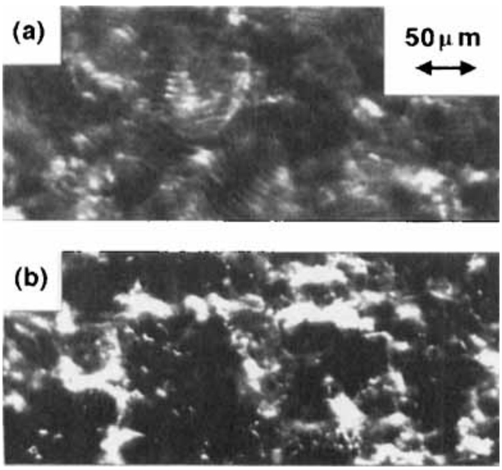

FIGURE 7 Observed texture of FLC cell. (a) without SH wave and applying voltage in FLC cell, (b) with SH wave and applying voltage ($10V_{pp}$).

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