Translational flow in the low-frequency regime of electroconvection in parallelepiped sandwich cell of planar liquid crystal

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The translational flow in the low-frequency regime of electroconvection in parallelepiped sandwich cell of planar nematic liquid crystal has been observed. The dark and bright stripe pattern was observed to be shifting toward the center of the parallelepiped sandwich cell from both sides because of the horizontal component of the electric fields, $E_x$ from indented (non-convection) area. The flow velocity, $\bar{v}$, linearly decreased as the flow reached the center of the cell. In addition, several control parameters were used to determine their relation with this flow. Increasing applied voltage and frequency monotonically decreased translational flow velocity. Whereas, increasing the temperature of the system caused an increase in flow velocity. © 2019 The Japan Society of Applied Physics

Electroconvection (EC) in liquid crystals (LCs) is a well-known and extensively investigated system for understanding pattern formation.1,2 Electroconvection can be observed by confining a negative dielectric anisotropic nematic LC between two parallel glass plates coated with transparent electrodes, treated to achieve a certain director $\hat{n}$ (average molecules orientation), and then subjected to electric fields. Two common orientations used are homeotropic2,3 ($\hat{n}$ normal to the electrode surface) and planar4–7 ($\hat{n}$ parallel to the electrode surface) orientations.

When a low-frequency electric field $\vec{E}$ normal to $\hat{n}$ ($E_x$) with a certain threshold was applied to a planar sample cell, a convective roll appeared, and a stationary dark and bright stripe pattern was optically observed because of the anisotropic LC.8 This EC pattern was called Williams domain pattern (grid pattern) was observed, followed by a pattern of convective roll appeared, and a slow shift of the pattern was also observed, indicating a translational flow pattern for every 120 s for the translational flow velocity. A rather similar pattern flow has been observed above Lifshitz frequency called propagating Williams domain3 or traveling wave.14–16 Furthermore, some parameters that could affect the flow velocity of this phenomenon were studied.

We used a standard setup for the planar EC observation.17 The LC used in this experiment was 4-methoxybenzylidene-4-butylaniline (MBBA) doped with 0.02% tetra-n-butyle-ammonium bromide (TBAB). It was filled between two parallel indium tin oxide coated glass (ITO) plates separated with a 50 μm mylar spacer. To achieve planar alignment, the glass was treated using a rubbing method with polyvinyl alcohol (PVA). On the x axis, the top and bottom ITO were made to be indented ($\Delta d$) to create a parallelepiped cell, as shown in Fig. 1(a). Two cells were created with $\Delta d = 1$ mm and $\Delta d = 2$ mm. The overlapped areas were then divided by seven segments (X) with lengths of $\sim 1.2$ mm each as the limit of the observation area.

AC voltage, $V(t) = \sqrt{2} V \cos(2\pi ft)$, was applied to the sample using a function synthesizer (WF1974; NF Corporation) and an amplifier (F10AD; FLC Electronics). Normalized voltage, $\varepsilon = (V/V_s)^2 - 1$, was used as a control parameter, where $V_s$ denotes the critical voltage for WD pattern. The experiment temperature was kept at $T = 30.0 \pm 0.2 ^{\circ} C$ using a proportional–integral–derivative controller (DB500; CHINO Works America Inc.), except in the last experiment. To measure the translational flow, the CCD camera (KPF30PLC; Hitachi Ltd.) mounted on the microscope (CST-15; Carton Optical Industry Inc.) was used to capture pattern images on the x–y planes for 20 min after waiting for 10 min. The images were then analyzed using the software ImageJ. Frequency $f$ and temperature $T$ were also used as other control parameters.

When the voltage applied to the cell surpassed the threshold voltage, the MBBA molecules started to move and created convective rolls indicated by dark and bright stripes in the order of $\sim 50 \mu m$. But, in addition to the conventional convective roll, a slow shift of the pattern was also observed, indicating a translational flow caused by $E_x$. Figure 1(b) (left) shows the movement of the EC pattern for every 120 s for the $X = 2$ segment of the 2 mm cell, with $\varepsilon = 0.5$ and $f = 100$ Hz. The red line was used to mark the dark stripe of the EC pattern, which shifted to the right with an average velocity of $0.178 \pm 0.015 \mu m \ s^{-1}$. The dashed black line was used as reference. Figure 2(b) (right) show the same phenomenon with different flow direction (from right toward the center of the cell). As it got further from the edge of the cell, the $E_x$ became weaker; thus, the translational flow velocity, $\bar{v}$, decreased linearly with gradient of $-0.0717 \pm 0.033 \ s^{-1}$, as shown in Fig. 2(a). The deceleration of the flow was $(9.62 \pm 1.01) \times 10^{-6} \mu m \ s^{-2}$. The negative velocity at $X = 6$ and $X = 7$ implies the EC pattern flowed to the left as shown in Fig. 2(b) (left). The cell with $\Delta d = 1$ mm showed a similar trend with a lower initial velocity. The flow velocity...
decreased with a rate of \(-0.0674 \pm 0.078 \text{ s}^{-1}\) with respect to the position before reaching the center of the cell and deceleration of \((7.95 \pm 1.42) \times 10^{-8} \text{ mm s}^{-2}\). At \(X = 4\) and \(X = 6\), the flow velocity was too low to be measured and became completely still at \(X = 5\).

To measure the dependence of the translational velocity on \(\varepsilon\), the \(X = 2\) segment of the 2 mm cell, with \(f = 100\) Hz, was used. The flow velocity was measured with \(\varepsilon = 0.05, 0.10\) and 0.15—as at the higher \(\varepsilon\) became, the more the flow fluctuated. This result is shown in Fig. 2(b), where the flow velocity decreases as \(\varepsilon\) increase. When the applied voltage increase, rotational flow velocity of convection roll increase\(^{18}\) then the translational flow velocity \(v\) due to \(E_x^*\) from indented (non-convection) area will be decreased. In other word, the translational flow velocity is resisted by convection roll.

Furthermore, the dependence of translational flow velocity on AC frequency and temperature was measured, as shown in Fig. 3. The flow velocity decreased as the frequency increased. As the frequency increase, the rotational velocity of convection increases so the translational flow velocity decrease. The dependence of flow velocity on temperature (in the nematic phase) at the \(X = 7\) segment of the 1 mm cell, with \(\varepsilon = 0.05\) and \(f = 100\) Hz, is shown in Fig. 3(b). Flow velocity linearly increase on temperature with a gradient of \(1.37 \pm 0.08 \text{ nm s}^{-1} \text{ °C}^{-1}\). When temperature increase, the viscosity at non-convection area decreased, then the translational flow velocity due to \(E_x^*\) increased. This result show that the translational flow velocity changes is more dominant than rotational flow velocity due to temperature.
In summary, the translational flow in the low-frequency regime of EC in a parallelepiped sandwich cell of planar LC has been observed due to the horizontal component of applied electric fields, $E_{\text{ac}}$. Flow velocity $v$ is initiated from both sides of the cell and decreases as the flow moves toward the center. Our study suggests that the larger the indented area ($\Delta l$) or the parallelepiped cell, the more the initial flow velocity. The dependence of some other parameters on flow velocity was also explored. An increase in the frequency and amplitude of voltage results in a decrease in velocity, whereas an increase in system temperature causes an increase in flow velocity.

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**Fig. 3.** (a) Translational flow velocity dependence on (a) AC frequency for $\Delta l = 1$ mm cell, with $\varepsilon = 0.1$ and $X = 2$ and (b) temperature on the $\Delta l = 1$ mm cell, with $f = 100$ Hz and $\varepsilon = 0.05$ at $X = 7$. 
