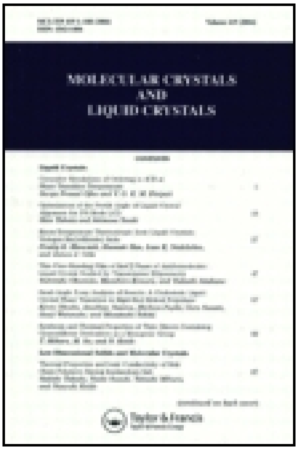

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Dynamic Image Analysis for Electro-Hydrodynamic Convection in Nematic Liquid Crystal

Tomoyuki Nagaya [a], Yoshinobu Satou [b], Yoshiki Hidaka [c], Hiroshi Orihara [b] & Yoshihiro Ishibashi [b]

[a] Faculty of Education, Okayama University, Okayama, 700-8530, Japan

[b] Department of Applied Physics, Nagoya University, Nagoya, 464-8603, Japan

[c] Department of Applied Science, Kyushu University, Fukuoka, 812-8581, Japan

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Dynamic Image Analysis for Electro-Hydrodynamic Convection in Nematic Liquid Crystal

TOMOYUKI NAGAYA[a], YOSHINOBU SATOU[b], YOSHIKI HIDAKA[c], HIROSHI ORIHARA[b] and YOSHIHIRO ISHIBASHI[b]

[a]*Faculty of Education, Okayama University, Okayama, 700–8530, Japan,* [b]*Department of Applied Physics, Nagoya University, Nagoya, 464–8603, Japan and* [c]*Department of Applied Science, Kyushu University, Fukuoka, 812–8581, Japan*

We have investigated the fluctuation in the electro-hydrodynamic convection(EHC) by developing a method for dynamic image analyses. The fluctuation of images is characterized by the two-time correlation function of the spatial Fourier coefficients of images. We measured the time correlation function of patterns in the two turbulent states of EHC:(i) the dynamic scattering mode(DSM) 1 and (ii)DSM2 states. It was found that in the DSM2 state, the correlation time, defined by the time at which the correlation function becomes a half of the initial value, decreases monotonically as the increase of the wave number. In the DSM1 state, on the other hand, the correlation time along the direction perpendicular to the rubbing direction has a peak at the wave number corresponding to the thickness of the cell. The peak value decreases as the applied electric field is raised, and vanishes entirely when the system undergoes the transition from DSM1 to DSM2.

Keywords: fluctuation; pattern formation; dissipative structure

INTRODUCTION

In recent years EHC has received considerable interest in connection with the study of the dissipative structure[1-6]. It is known that the pattern of EHC changes variously depending on the voltage and the frequency of the applied electric field, and that there are several kinds of fluctuating patterns in the phase diagram of EHC, such as the fluctuating Williams domain, the grid pattern and the dynamic scattering mode(DSM). Since the DSM has no periodic structure, the analysis of fluctuation of convective pattern in DSM may be more simple than that of other fluctuating patterns of EHC. As the first step of the analysis of the fluctuation in EHC, we have investigated the fluctuation of DSM.

DSM has been investigated extensively by Kai *et al.*[7-10] According to their studies[7-10], there are two different kinds of DSM states, so called the DSM1 and the DSM2 states[7-10]. The DSM2 state occurs at higher voltages above a threshold voltage V_{th}. Though considerable data on the DSM1 and the DSM2 states have been accumulated by their studies[7-10], there has been only a little amount of information about the fluctuation of convective pattern in the both states. In the present paper, then, we will investigate the fluctuation of convective pattern in both states by developing an image processing method which extracts the dynamical feature of fluctuation from the time sequence of observed images.

EXPERIMENTAL SETUP

The liquid crystal, *p*-methoxybenzilidene-*p*'-*n*-butylaniline (MBBA) doped with 0.05wt.% of tetra-*n*-butylammonium bromide, was sandwiched between two parallel glass plates coated with transparent electrode. To align the molecule of liquid crystal, the polyimide-coating and rubbing treatment were adopted on the surface of the glass plates. The axes of convective rolls in the Williams domain are perpendicular to the rubbing direction. Hereafter, the rubbing direction is taken as the x axis so that the axes of rolls are parallel to the y axis. The thickness of the cell was d=25μm. The size of each cell was about 1.5cm×1.5cm. In all experiments, the focus of objective lens was adjusted on the virtual image of the Williams domain[11].

The temperature of the cell was kept at 30°C during the experiment by a hot stage (Linkam TH-600PR). The applied ac electric field was supplied by a synthesizer (NF Electric Instruments 1940) and an amplifier (NF Electric Instruments 4005). The frequency of the ac field was set at 50Hz. A CCD camera (SONY XC-77CE) mounted on a polarizing microscope sent the image signal to an image processing computer (Carl Zeiss, Vidus Plus), where the image was digitized into 256 gray levels. The sequence of 96 images were captured with the time interval Δt=4msec and the Fourier coefficient of each image, $a_k(t)$, was calculated. Then the time correlation function of a_k, defined as $C_k(t) = \langle a_k(t) a_k^*(0) \rangle$, was evaluated. To estimate the characteristic time of the fluctuation of the mode k, moreover, the correlation time ξ_k, at which the correlation function becomes one half of the value of t=0, was calculated. The time correlation function and the correlation time were obtained by averaging over 20 runs.

RESULTS AND DISCUSSION

The time correlation function in the DSM1 state, under the applied voltage of 22.5V, along the x and y directions are presented in Fig. 1, and the correlations times along the both directions are shown in Fig. 2.

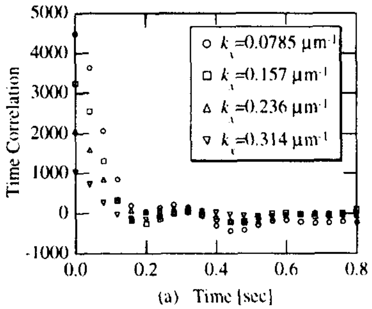

FIGURE 1 Time correlation function in the DSM1 state under the applied voltage of 22.5V. (a)along the x direction, (b)along the y direction.

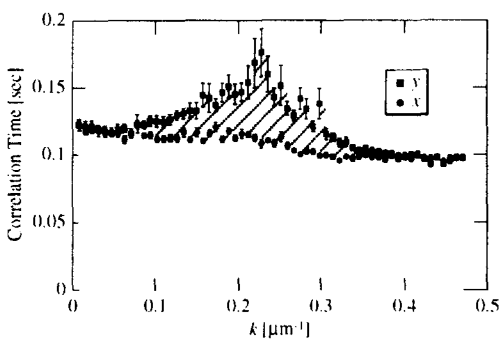

FIGURE 2 The correlation time in the DSM1 state.

It is clear from Fig. 1 that the time correlation function in the DSM1 state shows the spatial anisotropy. As seen from Fig. 2, the correlation time along the x direction has no characteristic dependency to the wave number except for showing the gradual decrease with the increase of k_x. On the other hand, it should be remarked that the correlation time along the y direction has a characteristic peak at $k_{max,y}$=0.24μm^{-1}. It means that the relaxation times of the modes around k_y=$k_{max,y}$ are longer than that of other modes. Except for around the peak, the correlation times along the both directions have almost the same values. Though the anisotropy of the space in the DSM1 state was not so remarkably as seen in the power spectra shown in Ref.[7], it could be recognized clearly by the time correlation function shown in Fig. 2.

The time correlation function in the DSM2 state, under the applied voltage of 45V, along the x and y directions are shown in Fig. 3, and the correlation times along the both directions are shown in Fig. 4. In the DSM2 state, the time correlation function along the both directions show similar dependence on the wave number, which indicates the spatial isotropy of the DSM2 state. Since there was no characteristic peak in the correlation time shown in Fig. 4, it was expected that the peak of correlation time disappears in accordance with the transition from DSM1 to DSM2.

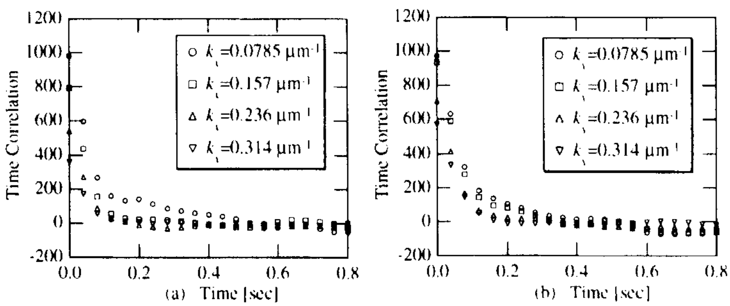

FIGURE 3 Time correlation function in the DSM2 state under the applied voltage of 45V. (a)along the x direction, (b)along the y direction.

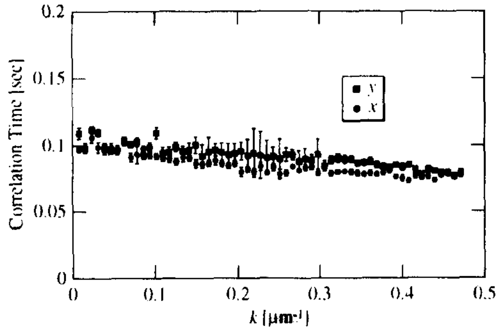

FIGURE 4 The correlation time in the DSM2 state.

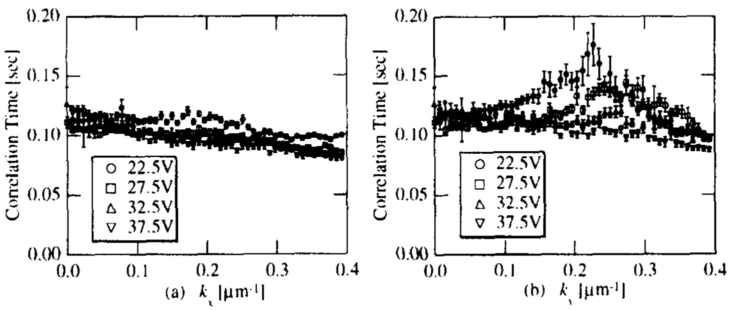

FIGURE 5 Applied voltage dependence of the correlation time. (a)along the x direction, (b)along the y direction.

This is confirmed from Fig. 5, where the wave number dependence of the correlation time along the x and y directions under the applied voltage of 22.5V, 27.5V, 32.5V and 37.5V are shown. Concerning about the x direction, no drastic change of the correlation time is observed. On the other hand, the peak value of the correlation time along the y direction decreases with increasing the applied voltage. To characterize this feature more quantitatively, we measured the area $S(V)$ enclosed by the curves of the correlation time along the x and y directions(see the shaded region in Fig. 2) and plotted it in Fig. 6. $S(V)$, namely the spatial anisotropy, decreases almost linearly up to 40V. It can be concluded that the threshold voltage between the the DSM1 and the DSM2 states is about 40V in our experiment. Strictly speaking, however, the DSM1 and the DSM2 states coexist in a certain range of the threshold voltage[7-10].

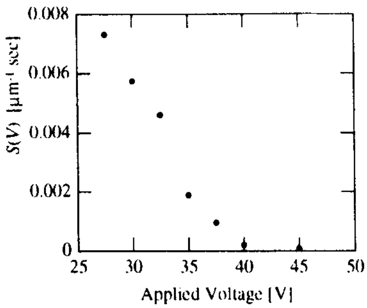

FIGURE 6 Applied voltage dependence of $S(V)$.

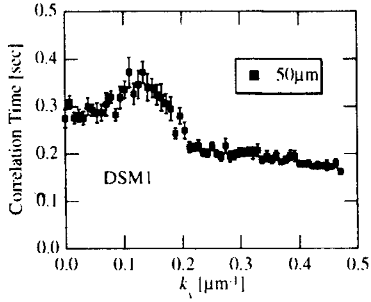

FIGURE 7 The correlation time of the fluctuation along the y direction in the cell with a thickness of 50μm.

Finally let us discuss the value of $k_{max,y}$. As is mentioned above, under the applied voltage of 22.5V the correlation time along the y direction has a peak around $k_{max,y}$=0.24μm^{-1} and the power spectra along the y direction also has a peak in the vicinity of $k_{max,y}$. Now it should be noted that the wave length corresponding to $k_{max,y}$=0.24μm^{-1} is 26.2μm, which is very close to the thickness of the cell. Then, we prepared the cell of 50μm in thickness and measured the correlation time under the applied voltage of 22.5V. As shown in Fig. 7 the correlation time along the y direction has a peak around k_y=0.12μm^{-1}, which corresponds to the wave length of 52.4μm. It is remarkable that the wave length of the characteristic fluctuation is very close to the cell thickness in both cells. However, we do not know the clear reason for it. Further investigation on the origin of the characteristic peak is required.

SUMMARY

In the present paper, the fluctuation of convective pattern in the DSM1 and the DSM2 states are investigated by measuring the two time correlation function.

In the DSM1 state, the time correlation function shows the spatial anisotropy: only the correlation time along the y direction has a characteristic peak at the wave number corresponding to the thickness of the cell. It is still an open question why the time function has the characteristic peak. With increasing the applied voltage, the peak value decreases. In the DSM2 state, no anisotropic feature in the time correlation function is observed. To estimate the anisotropy of the turbulence quantitatively, we measured the quantity $S(V)$ which is defined by the enclosed area between the curves of correlation time along the x and y directions and found that $S(V)$ decreases almost linearly up to 40V. It is found that the time correlation function is more sensitive than the power spectrum in investigating the anisotropic feature of the DSM1 state.

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