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Diffraction at a single domain of the "seesaw oscillation" structure in a nematic liquid crystal

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A series of observations of diffraction at a nematic liquid crystal structure above the threshold voltage of "seesaw oscillation" have been carried out. When the sample of the liquid crystal was placed in the beam waist position the diffraction at a single domain was observed. The period of "seesaw oscillation" was measured. The flow of the domain structure was deduced from the time dependence of intensity of the far-field diffraction pattern.

1. Introduction

The best known dissipative structure in the nematic liquid crystal with a negative dielectric anisotropy are the Williams domains, which occur when an a.c. electric field is applied across a layer [1]. The increasing of the a.c. applied voltage causes oscillatory motion of the Williams domains [2]. Recently a temporally ordered structure of nematic liquid crystal has been found in a d.c. electric field [3, 4]. This structure is called the "seesaw oscillation". The structures of the hydrodynamic motion and the molecular alignment of "seesaw oscillation" were investigated [5]. The parameters of nematic liquid crystal structure were usually measured with the use of a polarizing microscope. The oscillatory motion of the Williams domains was measured by applying the light diffraction experiment [2].

In this paper we report observations and measurements of diffraction at the "seesaw oscillation" structure in nematic liquid crystal. It is shown that if the sample is placed in the beam waist position the diffraction can be observed at a single domain of the "seesaw oscillation" structure. This approach is compared with the optically obtained Fourier spectrum method. An analysis of the phase of the diffraction pattern oscillating due to the "seesaw oscillation" permits us to deduce the flow of the domain structure.

2. Sample and experimental arrangement

The liquid crystal (the mixture of MBBA and EBBA) was sandwiched between glass plates pyrolytically covered with conducting layers [6] and orienting layers of SiO_x deposited under vacuum by using Janning's method [7]. The transparent electrodes were distanced with a 20 μm teflon spacer. The d.c. voltages were applied across the electrodes. The experiment was made at room temperature.

The Fourier spectrum of the liquid crystal structure was observed with the use of an optical system, in which the sample was placed in the front focal plane of the lens [8]. The illuminated area was equal to about 5 mm². The optically obtained Fourier spectrum was recorded photographically.

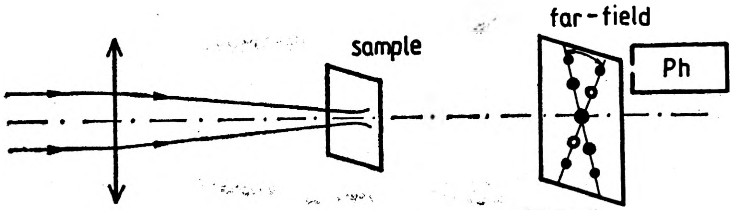

Fig. 1. Experimental arrangement

The basic experimental arrangement is shown in Fig. 1. Light emerging from a He-Ne laser was collimated and focused. In the beam waist position there was placed the sample of liquid crystal. The scattered light was detected by a photomultiplier in the far-field plane. The photomultiplier was followed by an $X(t)$ recorder. The far-field patterns were also recorded photographically.

3. Experiment

The liquid crystal sample with no applied electric field causes a weak scattering of the light. If an electric field ~ 4 V is applied the transparent sample becomes opaque. By means of a microscope we can see the image of a stable structure. On increasing the voltage, beyond 4 V, the number of this stable structure can be observed [3]. When the voltage goes up to ~8 V, the structure begins to oscillate. This oscillating structure, called the "seesaw oscillation", consists of local coherent domains. Each domain contains a number of rolls and resembles a diffraction grating. The axes of rolls of neighbouring domains are almost perpendicular. The transmittance function of the "seesaw oscillation" structure is shown schematically in Fig. 3.

To establish the properties of scattered light depending on the size of the illuminated area we compared an optically obtained Fourier spectrum with far-field patterns of the "seesaw oscillation" structure. The applied voltage was 11 V. The patterns were recorded photographically and the time of exposure was 1/60 s. First, we observed the optically obtained Fourier spectrum of the sample. The resulting pattern is presented in Fig. 2a. A series of isolated spectral components are associated with the uniform background. They are due to the internal structure of domains and the uniform background resulting from a random part of fluctuations. Figure 2b shows the far-field pattern obtained when the sample was placed in the beam waist position. The beam width in the beam waist position, defined by the intensity $1/e^2$ points, was about 300 μm. As can be seen, this pattern is similar to that shown in Fig. 2a. When the patterns were observed with the naked eye both the pattern of Fig. 2a and

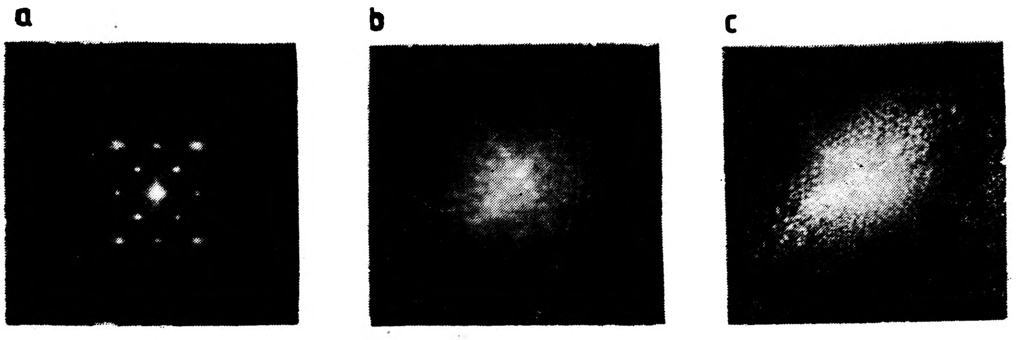

Fig. 2. Fourier spectrum of the sample (**a**), far-field diffraction patterns at the beam width of 300 μm (**b**) and 8 μm (**c**). Applied voltage $U = 11$ V

the one of Fig. 2b were stable. When the beam width in the beam waist position was 8 μm the oscillating pattern could be observed instead of a stable one. In Fig. 2c one of phases of this oscillation is shown. It should be noted here that the time of exposure 1/60 s is much shorter than the period of oscillation. The features of the last pattern confirm that the light was scattered by a single domain. The isolated spectral components in Fig. 2c are a result of diffracting by rolls inside the actually illuminated domain. The weak resolution of spectral components is due to the fact, that the beam width in the beam waist position (8 μm) is less than the diameter of the rolls (12 μm). The regular structure of speckle pattern suggests that the correlation length of random fluctuations is less than the beam width in the beam waist position.

The short-exposure photographs in Fig. 3 show phases of the oscillating pattern due to the diffraction at a single domain of the "seesaw oscillation" structure. The time dependence of the intensity of light detected by the photomultiplier in a fixed point of the far-field, shown in Fig. 3, manifests the oscillation of the rolls in the actually illuminated single domain. The schemes of instantaneous transmittances of the "seesaw oscillation" structure shown in Fig. 3 correspond to photographs of the far-field pattern and to intensity variation. Figure 4 shows the oscillation of the intensity at a given point of the far-field plane recorded during ~ 100 s. The dependence of the frequency f of the "seesaw

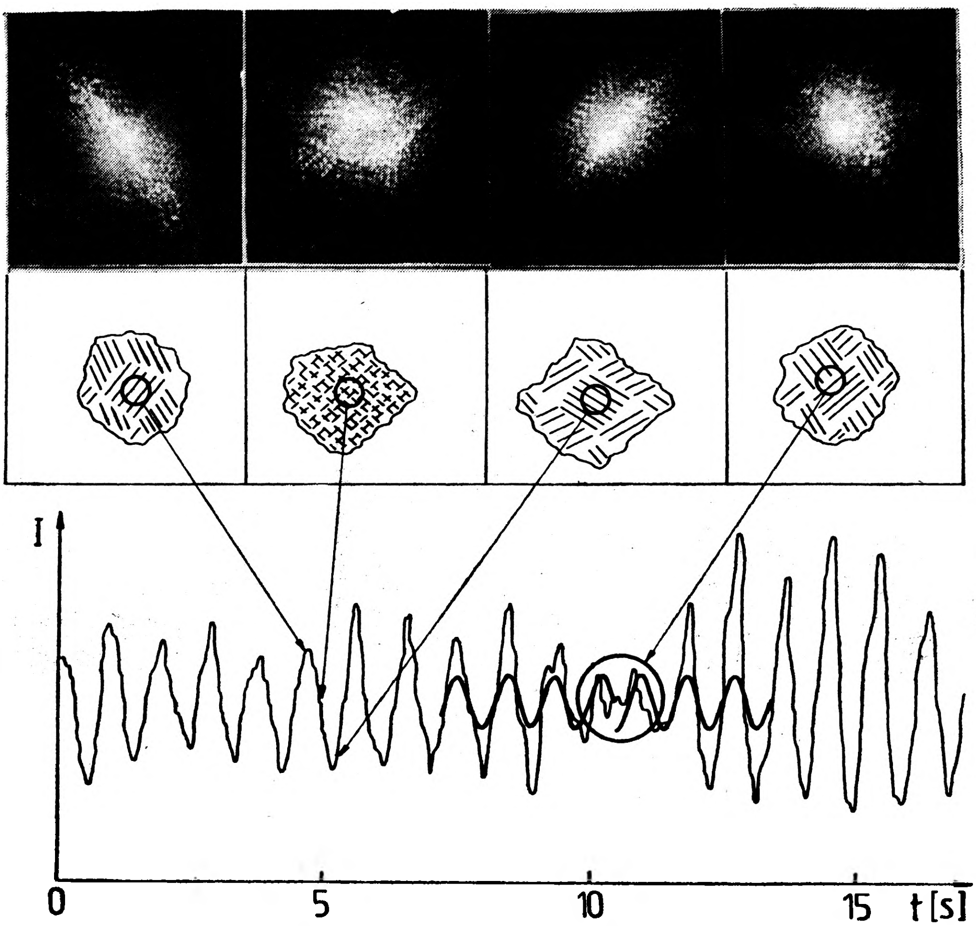

Fig. 3. Diffraction at a single domain of the "seesaw oscillation". Applied voltage $U = 11$ V

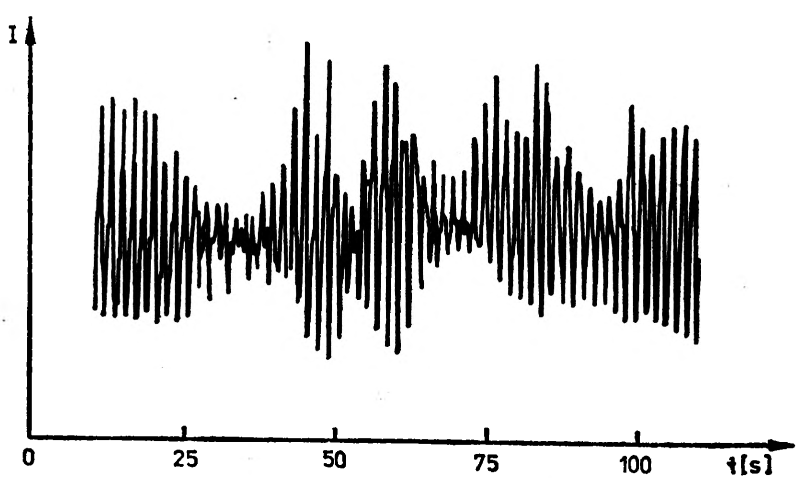

Fig. 4. Time dependent intensity variation of the far-field diffraction pattern at the applied voltage of 11 V

oscillation" on the applied voltage is shown in Fig. 5. The linear increasing of the frequency with the applied voltage corresponds to the results obtained by HIRATA and TAKO [3, 4].

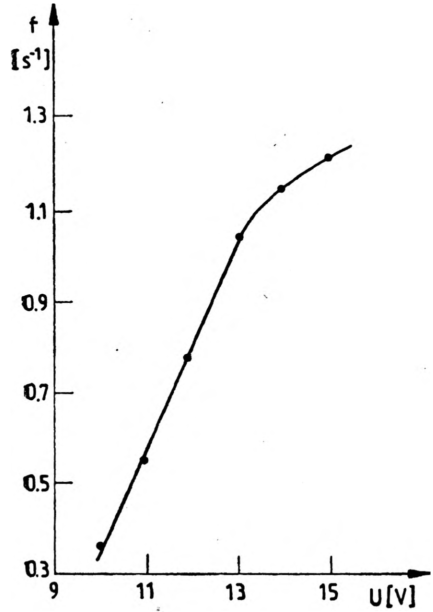

Fig. 5. Dependence of the frequency of the "seesaw oscillation" on the applied voltage

Both in Fig. 3 and in Fig. 4 we can see that the oscillation of the intensity is perturbed. The light intensity variation at a given point of the far-field plane can be described by a simple formula

$$I(t) = I_0(t)\sin\left[\frac{2\pi t}{T} + \Phi(t)\right]$$

where $I_0(t)$ is the time varying amplitude, $T = 1/f$ is the period of oscillation, and $\Phi(t)$ is the time varying phase. In the region of perturbation of the intensity oscillation the phase $\Phi(t)$ was changed by $\sim\pi/2$. To explain this effect, we consider the oscillation of rolls of the neighbouring domains. Both the microscopic observation and the features of the Fourier spectrum of the sample permit us to confirm that the instantaneous directions of axes of rolls of the neighbouring domains are almost perpendicular. Thus, the phase difference of oscillation of rolls of the neighbouring domains is $\sim\pi/2$. Therefore, the far-field intensity oscillation before and after perturbation can be caused by the neighbouring domains. The perturbation of the intensity oscillation indicates that the illuminated light occupies the boundary region of the neighbouring domains, this effect is shown schematically in Fig. 3. From the above discussion it follows that the existence of the perturbation of the intensity oscillation associated with the change of the phase is connected with the flow of the domain structure. The effect of the perturbation of intensity oscillation could also be caused by the random vibration of the experimental arrangement but in the case considered these vibrations were negligible.

4. Conclusions

The results show a possibility of applying the method to study dissipative structures of liquid crystals. Compared with the microscopic observations the presented approach, which permits us to select the single domain contribution to the scattered light, can be more sensitive to various phenomena associated with the structure of a liquid crystal.

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Дифракция на отдельной домене структуры „seesaw oscillation“ в нематическом жидком кристалле

Проведен ряд обследований дифракции на структуре нематического жидкого кристалла выше порога напряжения „seesaw oscillation”. В случае, когда образец жидкого кристалла был помещен в фокусе лазерного пучка, наблюдалась дифракция на отдельной домене. Измерен период „seesaw oscillation”. На основании зависимости интенсивности света от времени, в дифракционной фигуре дальней зоны, доказано течение доменовой фигуры.