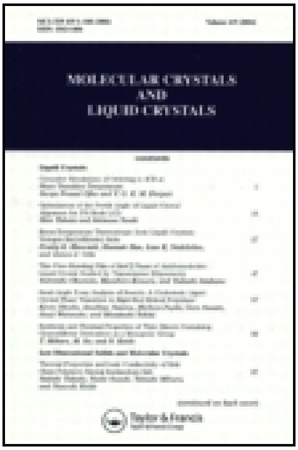

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Light Scattering of Short Helix Pitch Ferroelectric Liquid Crystal

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Light Scattering of Short Helix Pitch Ferroelectric Liquid Crystal

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Two new light scattering modes have been discovered in short helix pitch ($p_0 \cong 350\,nm$) ferroelectric liquid crystal (FLC). One of the modes arises because of a special kind of the FLC structure non-uniformity that originates inherently as a new phenomenon if the helix pitch is very small. Another mode relates to the helix twisting after the driving voltage switching off.

Keywords: ferroelectric liquid crystal; helical pitch; helix wave vector; light scattering

INTRODUCTION

Reorientation of the FLC director and the helix unwinding under the action of the applied electric field is accompanied always with so called transient light scattering. Origin of this phenomenon is a spatial non-uniformity of the FLC during the helix unwinding process when

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the light scattering helical state transforms to the uniform helix free structure that is practically transparent [1,2]. If the FLC layer thickness is 10 μm ÷ 75 μm then the electrically controlled light scattering with typical response time 0.5 ms ÷ 50 ms (dependently on the layer thickness and the applied voltage amplitude) can be observed even without any polarizer and analyzer [2,3]. So, the non-polarized light scattering occurs because of the FLC helix unwinding.

The polarized light scattering in FLC relates to ferroelectric domains [4] of the helix free FLC where the helix is suppressed in all the bulk due to interaction of chiral dopants with opposite handedness [5–7]. Modulation of the helix free FLC domains structure in electric field [8–10] is an origin of the electrically controlled polarized light scattering [11,12]. Any level of the polarized light scattering can be memorized in this case after the driving voltage switching off because of the multistability effect [8–10].

All helical ferroelectric liquid crystals, used before for investigations of the transient light scattering, have the helical pitch $p_0 > 400$ nm. That was a reason of the light scattering helical state. Recently a FLC mixture with the helix pitch $p_0 < 400$ nm was elaborated [13]. A shift of the p_0 magnitude down to the UV spectral range is desirable for suppression of the light scattering in the visible spectral range. In fact, our experiments show that both helical and unwound in electric field structures of the FLC exhibit practically no light scattering if $p_0 < 400$ nm. Nevertheless, we discovered two new light scattering modes in FLC such a kind under the action of applied voltage.

This paper is concerning with investigations and description of new light scattering modes of the FLC possessing the helix pitch $p_0 < 400$ nm.

EXPERIMENTAL

The helical pitch p_0 of mixtures of a new chiral dopant possessing very high twisting power [13] with a specially developed for this case achiral smectic C matrix was detected from the measurements of vertically aligned FLC layers transmittance. The matrix consists of phenyl- and biphenyl-pyrimidine derivatives. The measurements were done with the spectrometer “Ocean optics”.

A ferroelectric liquid crystal mixture FLC-576 developed in P. N. Lebedev Physical Institute of Russian Academy of Sciences with the helix pitch $p_0 \cong 350$ nm was chosen to study the light scattering.

Asymmetric boundary conditions described in [14] ware used for manufacturing of the FLC cells. At this approach only one ITO surface of FLC cells was covered with a photo-aligning substance – azobenzene sulfuric dye SD-1 layer, but another one was simply washed in

N,N-dimethylformamide (DMF) and covered with 1.7 μm, 10 μm or 21 μm calibrated spacers. The chemical structure of SD-1 dye is shown below in Figure 1.

The azo-dye solution was spin-coated onto ITO electrode and dried at 155°C. A polarized UV light was achieved by using a super-high pressure Hg lamp, an interference filter at 365 nm and a polarizing filter. The light with intensity of $6\,mW/cm^2$ and wavelength of 365 nm was irradiated normally onto SD-1 layers. We used the cells with the size of $13 \times 13\,mm^2$, the width patch area 2 mm, the thickness of the glass substrate 1.1 mm, electrodes area $5 \times 5\,mm^2$, and the cell gap 1.7 μm, 10 μm, 21 μm.

The measurement of FLC cells light scattering needs high voltage and small response time registration. First requirement is the amplitude of driving signal must change in large dynamic range from 1 V (for measurement threshold voltage) to 100 V (for measurement saturation effect in liquid crystal) and sampling of signal with frequency 1 MHz.

The measurement must be performing in automatic regime. For this aim we built the measurement complex device, whose principal scheme is shown in Figure 2.

The basic element of this experimental set-up is computer data acquisition (DAQ) board NI PCI 6251 from National Instruments. This board has two analog outputs and 16 analog inputs. The operating voltage is ±10 V, the maximal registration speed is 1 μs. The board has independent output and input buffer for 4000 point. For our experiment the output signal 10 V isn't enough and the Wideband Power Amplifier KH model 7600 from Krohn-Hite Corporation with amplification coefficient ×5 and ×25 times was used. It gives possibility to have the output signal ±250 V. For the input signal this board has internal amplifier with coefficients ×1, ×2, ×4, ×8, ×16, ×32, ×64, ×128 times. A photo-detector was connected to input board plate for optical measurement.

The software for experimental set-up developed by us has built-in functions for analog output-input. The program has three functional

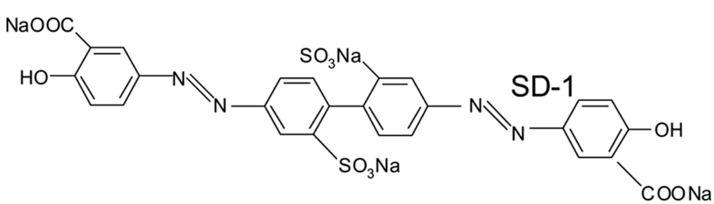

FIGURE 1 The chemical structure of azobenzene sulfuric dye SD-1.

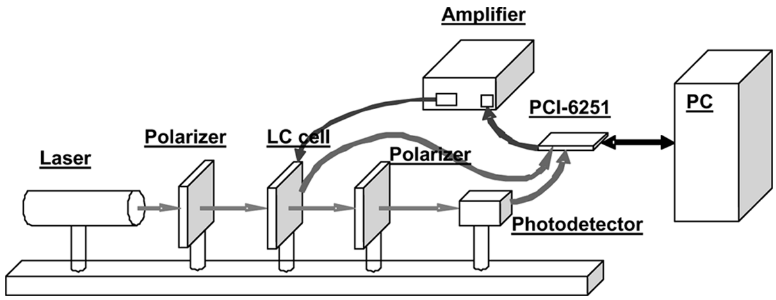

FIGURE 2 Experimental set-up for optical measurement.

blocks which do the operation with the set-up very effective. The first block is a programmable generator that realizes any form of signal with duration of 2000 points. The duration of one point can be set from 1 μs to 1 s. The second block is a measuring block, which save 4000 values of the input voltage with step from 1 μs to 1 s. The operation of the first and the second blocks is synchronized inside the DAQ board and cannot be disturbed by the computer interruptions. The third block is used to accumulate the experimental data during the working period.

Polarizers can be removed out of the set-up at measurements of the light scattering.

RESULTS AND DISCUSSION

All newly prepared FLC cells filled with the short helix pitch FLC-576 ($p_0 \cong 350$ nm) exhibit a special kind of textures between crossed polarizers if the applied voltage amplitude does not exceed a critical threshold. These textures depend on the applied voltage polarity; see Figure 3(a) and 3(b). The textures clearly indicate a spatial non-uniformity of the FLC layer whose typical dimensional characters are much larger than p_0 magnitude and its gauge varieties is from $3 \div 5$ μm up to $20 \div 30$ μm as it follows from Figure 3(a), and 3(b). A reason of the non-uniformity is absolutely not clear yet but it evidently exists being very steady and reproducible.

Keeping elucidation of the textures origin for a future research, we will consider them (corresponding FLC structures) as an entity and as a source and a reason of a new kind of the light scattering. Actually, just a sensitivity of the texture non-uniformity to the applied voltage polarity (Figs. 3(a), and 3(b) results in electrically controlled polarized light scattering, Figure 4.

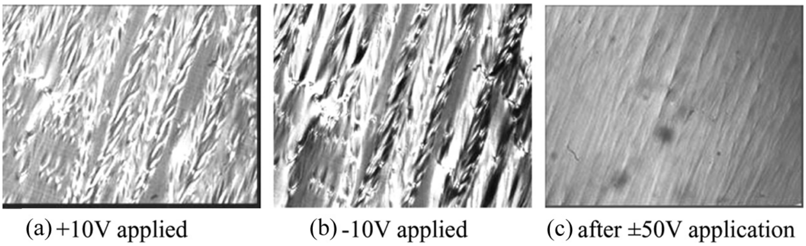

FIGURE 3 Textures of the short helix pitch 10 μm FLC layer placed between crossed polarizers. Micro-photos dimensions are $200 \times 140\,\mu m$.

This new kind of the light scattering shows two remarkable properties. First, a shape of the electro-optical response obtained due to the light scattering is practically the same as the applied voltage shape, Figure 4. Second, the electro-optical response time $\tau_{0.1-0.9}$ is rather fast: it is less than 100 μs at the applied electric field tension $(1.0 \div 2.5)V/\mu m$, Figure 5.

A shape of the $\tau_{0.1-0.9}(U)$ dependence is typical for the DHF effect [15] when the response time $\tau_{0.1-0.9}$ is practically independent on the

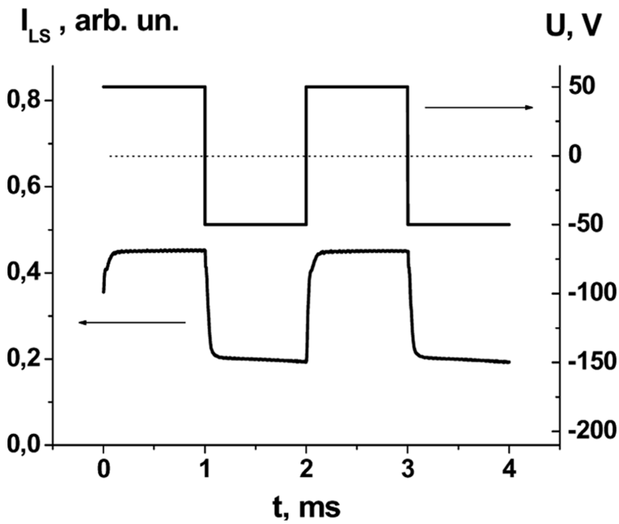

FIGURE 4 Top – the driving voltage ($f = 500\,Hz$) applied to the short helix pitch ($p_0 \cong 350\,nm$) FLC-576 layer; bottom – modulation due to the light scattering of He-Ne laser polarized light intensity I_{LS} passing through polarizer free liquid crystalline cell. The FLC layer thickness is 21 μm, a distance between the cell and the photo-detector is 15 cm.

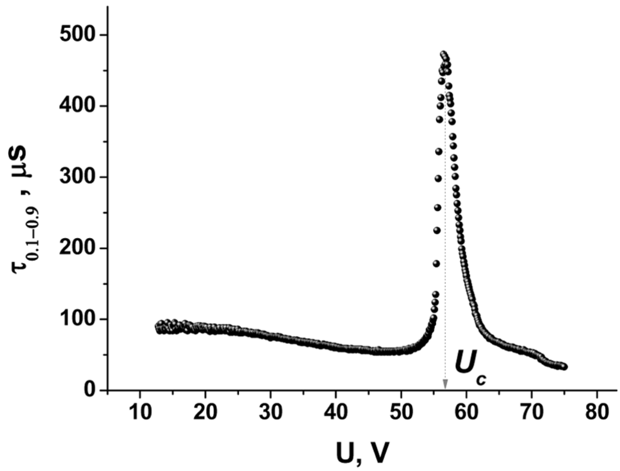

FIGURE 5 Dependence of the electro-optical response time on the applied voltage amplitude, the voltage waveform is the same as it is shown in Figure 4, top diagram; the driving voltage frequency is 500 Hz. Measurements have been carried out in light scattering mode of 21 μm FLC-576 based cell.

applied voltage amplitude U in the case if it is less than critical amplitude U_c of the helix unwinding that corresponds to the peak in Figure 5. Consequently, the light scattering that is under discussion, occurs if the helix is not unwound yet but simply deformed via the applied voltage, as it follows from comparison of diagrams in Figures 4 and 5. Therefore we will define this light scattering mode as the light scattering coupled with deformed helix ferroelectric liquid crystal or in abbreviated form as LSDHF mode.

If the voltage amplitude applied to the FLC cell exceeds some critical threshold, which depends on the frequency, then the textures shown in Figure 3(a), and 3(b) completely disappear and a texture shown in Figure 3(c) emerges instead. The FLC structure, which corresponds to this new texture, is rather uniform and do not scatter the visible light if $U<U_c$ because $p_0 < 400$ nm. Other words the LSDHF mode disappears in this case. A process of the FLC layer structure transformation results in disappearing of the light scattering in LSDHF mode as it is shown in Figure 6. After this transformation the texture presented in Figure 3(c) became steady even if the applied voltage is switched off.

The visible light scattering exists in this case only as a result of the helix unwinding or twisting but it is not exactly the same as the already known transient light scattering [1,2], because in our case both helical and unwound structures do not scatter the light. The

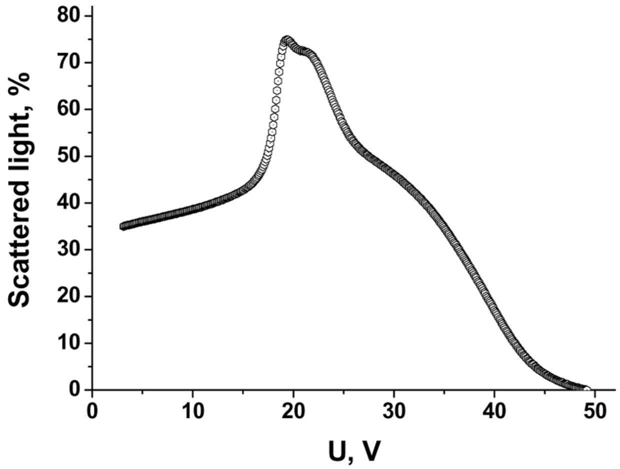

FIGURE 6 Percentage of the scattered polarized light intensity ($\lambda = 0.63\,\mu m$) dependently on the applied 5 Hz rectangular a c voltage. Measurements have been carried out with 10 μm FLC-576 based polarizer free cell.

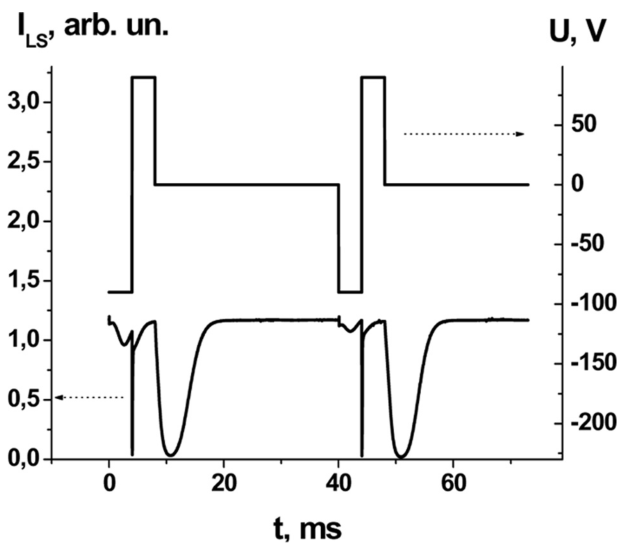

FIGURE 7 Top – the driving voltage applied to the short helix pitch ($p_0 \cong 350\,nm$) FLC-576 layer; bottom – modulation due to the light scattering of He-Ne laser polarized light intensity I_{LS} passing through polarizer free liquid crystalline cell. The FLC layer thickness is 21 μm, a distance between the cell and the photo-detector is 15 cm.

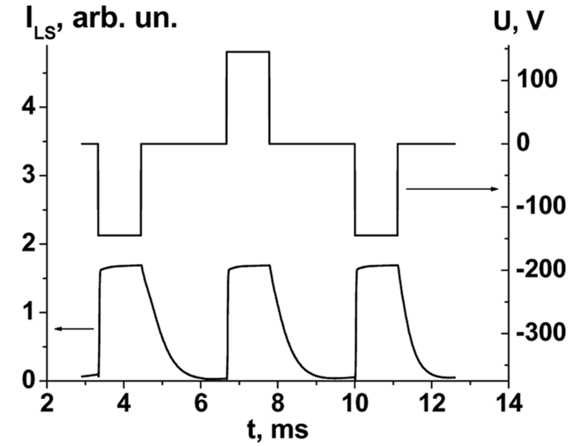

FIGURE 8 Top – the driving voltage applied to the short helix pitch ($p_0 \cong 350$ nm) FLC-576 layer; bottom – modulation due to the light scattering of He-Ne laser light passing through polarizer free liquid crystalline cell. The FLC layer thickness is 21 μm.

scattering arise just as pulses at the unwinding or twisting process only as it illustrates Figure 7.

A selection of an appropriate driving voltage waveform allows to camouflage the light scattering pulse corresponding to the helix unwinding, Figure 8. The electrically controlled light scattering with $\tau^{on}_{0.1-09} \cong 1$ ms and $\tau^{off}_{0.1-09} \cong 0.1$ ms can be obtained (Fig. 8) that provide the modulation frequency more than 100 Hz.

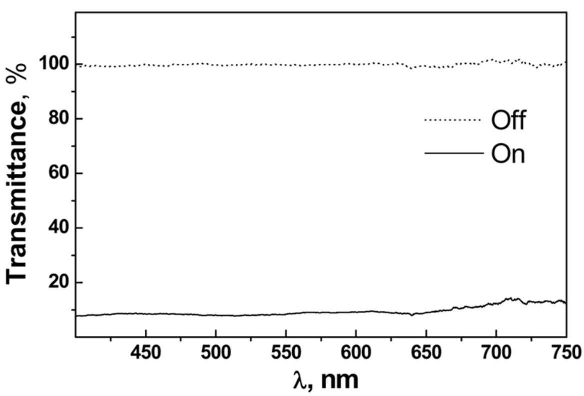

FIGURE 9 The light transmission spectra of the polarizer free cell filled with the short helix pitch FLC-576 ($p_0 \cong 350$ nm). The FLC layer thickness is 21 μm; off – no voltage applied, on −135 V is applied to the cell.

We will define this operation mode as the pulse transient light scattering or in abbreviated form as PTLS. The PTLS mode provides the electrically controlled light scattering of non-polarized light which is spectral insensitive, Figure 9.

CONCLUSIONS

Two new light scattering modes of the short helical pitch FLC ($p_0 < 400\,\mathrm{nm}$) have been discovered and characterized in this paper.

REFERENCES

[1] Yoshino, K. & Ozaki, M. (1984). *Jpn. J. Appl. Phys.*, *23*(4), L385.
[2] Kishio, S., Ozaki, M., Yoshino, K., Sakurai, T., Mikami, N., & Higuchi, R. (1987). *Jpn. J. Appl. Phys.*, *26*(5), L513.
[3] Haase, W., Podgornov, F., & Pozhidaev, E. (2002). *Proc. SPIE*, *4481*, 17.
[4] Beresnev, L. A., Loseva, M. V., Chernova, N. I., Kononov, S. G., Adomenas, P. V., & Pozhidaev, E. P. (1990). *JETP Letters*, *51*(9), 516.
[5] Beresnev, L. A., Baikalov, V. A., Blinov, L. M., Pozhidaev, E. P., & Purvanetskas, G. V. (1981). *JETP Letters*, *33*(10), 533.
[6] Rabinovich, A. Z., Loseva, M. V., Chernova, N. I., Pozhidaev, E. P., Petrachevich, O. S., & Narkevich, J. S. (1989). *Liquid Crystals*, *6*(5), 533.
[7] Loseva, M. V., Chernova, N. I., Rabinovich, A. Z., Pozhidaev, E. P., Narkevich, J. S., Petrachevich, O. S., Kazachkov, E. M., Korotkova, N. I., Shadt, M., & Bucheker, R. (1991). *Ferroelectrics*, *114*, 357.
[8] Andreev, A. L., Kompanets, I. N., & Pozhidaev, E. P. (1996). *Proc. SPIE*, 2771, 289.
[9] Pozhidaev, E. P., Andreev, A. L., & Kompanets, I. N. (1999). *Proc. of 7th Int. Conf. on FLC'*, 164.
[10] Pozhidaev, E. P. & Chigrinov, V. G. (2006). *Crystallography Reports*, *51*(6), 1030.
[11] Andreev, A. L., Bobylev, Yu. P., Gubasaryan, N. A., Kompanets, I. N., Pozhidaev, E. P., Fedosenkova, T. B., Shoshin, V. M., & Shumkina, Ju. P. (2005). *Journal of Optical Technology*, *72*(9), 701.
[12] Andreev, A. L., Bobylev, Yu. P., Fedosenkova, T. B., Yambaev, I. B., Kompanets, I. N., Pozhidaev, E. P., Shoshin, V. M., & Shumkina, Yu. P. (2006). *Journal of the SID*, *14*(7), 643.
[13] Pozhidaev, E. P., Vashchenko, V. V., Torgova, S. I., & Kompanets, I. N. (2008). *Proc. ILCC 2008 Conference*, MA 3002.
[14] Pozhidaev, E. P., Chigrinov, V. G., Huang, D. D., & Kwok, H. S. (2002). *EURODISPLAY'02 Digest*, 137.
[15] Beresnev, L. A., Chigrinov, V. G., Dergachev, D. I., Pozhidaev, E. P., Funfshilling, J., & Shadt, M. (1989). *Liquid Crystals*, *5*(4), 1171.