Rotational viscosity of induced smectic C* phase of liquid crystal

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The rotational viscosity and the molecular tilt angle θ have been determined in smectic layers of induced ferroelectric liquid crystal systems containing some $1R,4R$−2-(4-phenyl-benzylidene)-p-menthane-3-one derivatives as chiral dopants. The correlation between the rotational viscosity and the angle θ has been studied. The temperature dependence of rotational viscosity has been shown to be influenced by the temperature dependence of the smectic tilt angle.

Определены вращательная вязкость и угол наклона молекул θ в смектических слоях (θ) в индуцированных сегнетоэлектрических системах, содержащих производные $1R,4R$−2(4-фенилбензилиден)-n-ментан-3-онов в качестве хиральных добавок. Исследована корреляция между вращательной вязкостью и углом θ. Показано, что температурная зависимость угла наклона молекул в смектических слоях влияет на температурную зависимость вращательной вязкости.

There is a common opinion today that it is most suitable to use ferroelectric compositions consisting of two ingredients, namely, an optically active matrix providing formation of the smectic C mesophase within a required temperature range and a chiral component that induced a helical structure and the spontaneous polarization [1]. Thus, it seems to be an actual task to develop the physical materials science principles for ferroelectric liquid crystals (FELC) making it possible to elaborate purposefully the FELC materials for various applications in the data imaging systems and light modulating devices. When developing novel FELC materials, it is of a great importance to know in advance the behavior of various macroscale mixture parameters depending on composition of the latter.

The rotational viscosity coefficient of FELC that defines the time characteristics of electrooptical devices is a parameter of primary importance in the equations of the liquid crystal director dynamics. According to theory [2], the rotational viscosity coefficient γ_φ is expressed as

$$\gamma_\varphi = \gamma_\perp \sin^2\theta. \qquad (1)$$

It has been shown in experiment that the parameter γ is not a constant for a specific liquid crystal, since it depends heavily on the ordering parameter. Using the approach developed in [3], the following expression has been obtained for the viscosity coefficient [4]:

$$\gamma_\varphi = a_\varphi \sin^2\theta \cdot \exp(U_\varphi/kT), \qquad (2)$$

where a_φ and U_φ are constants.

The most widespread way to FELC is to induce the spontaneous polarization in an non-chiral smectic C by adding a chiral dopant (CD). It is known that at high CD concentrations (>20 %), the potential barrier U_φ rises sharply, thus increasing γ_φ. The introduction of chiral molecules, however, may cause also a change in θ value [1], both towards its increase and decrease.

Thus, it follows from the theory that, introducing the CDs that diminish the angle θ, it is possible to compensate the U_φ increase at the CD concentrations lower than 20 %, when the U_φ increases still not too much. In this work, the study results of the CD effect on the rotational viscosity of FELC mixtures.

The eutectic mixture (1:1) of two phenyl benzoate derivatives

$C_mH_{2m+1}OC_6H_4COOC_6H_4OC_6H_{13}$ ($m = 8$ and $m = 10$) was used as a smectic C LC matrix (Matrix **1**). The matrix shows the following sequence and temperatures of phase transitions: I 89.5 N 76.0 SmA 70.0 SmC 42.5 Cr [5]. The matrix components were obtained using a procedure similar to that described in [6]. A mixture of laterally fluorinated terphenyls was also used (Matrix **2**). The components of that matrix was prepared using the procedure [7]. The mixture shows the following sequence and temperatures of phase transitions: I 121.7 N 97 SmA 89 SmC 13 Cr.
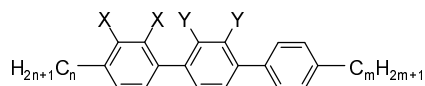
$n = 5, m = 7, X = F, Y = H$ 25%
$n = 5, m = 7, X = H, Y = F$ 50%
$n = 7, m = 5, X = F, Y = H$ 25%

As CDs, 2-arylidene derivatives of 1R,4R-*p*-menthane-3-one were used being typical second type CDs according to [8].

$n = 5(3a), 6 (3b)$
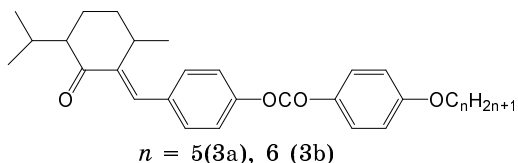
The LC compositions to be studied were placed into glued glass cells provided with transparent SnO_2 electrodes. The cells were 5 to 10 μm thick. Planar boundary conditions were provided in the cells. To obtain a single-domain sample, the cell was cooled slowly from the smectic A to the smectic C phase in an external electric field. The angle θ was measured using the electro-optical method [9]. The rotational viscosity was calculated using the known relationship [10] proceeding from the measured values of the repolarization time ($\Delta\tau$), spontaneous polarization (P_S) and the electric field strength (E) used to measure the repolarization time. The repolarization current study method under triangular voltage pulses [11] was
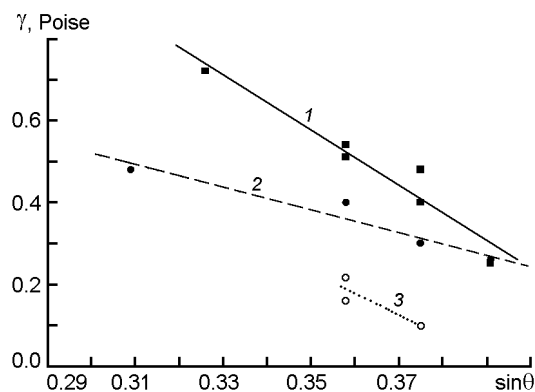

Fig. 1. Dependence of rotational viscosity on the tilt angle sine at various chiral dopant concentrations: **3a** in Matrix **1** (*1*); **3b** in the same (*2*); **3b** in the Matrix **2** (*3*).

used to measure P_S. The repolarization time was determined as the repolarization peak width at half-height using the pulse method of the repolarization current study [10].

The concentration dependences of γ_φ and θ have been obtained and the correlation between those quantities considered. The consideration results are presented in Fig. 1. It is seen that a reverse correlation is observed, in contrast to the theoretical expectations, that is, the viscosity decreases rather than increases as the angle θ rises. Before, we have studied other induced ferroelectrics where the CD addition resulted in increased θ or did not effect the tilt angle [12]. No correlation between γ_φ and θ was found in that case. Thus, it follows from all the above that it is impossible to use the relationship (1) to estimate the expected γ_φ values when ferroelectrics is induced in liquid crystals.

The relationship (2) should describe the temperature dependence of the viscosity coefficient. To check that relation, temperature dependences of γ_φ and θ have been studied. The study results are shown in Fig. 2. Substituting the experimental values of θ, temperature T and optimizing the parameters a_φ and U_φ, we have get the calculated temperature dependences of γ_φ (shown by lines in Fig. 2b). The calculated dependences are seen to coincide with experimental ones within a wide temperature range. However, the farther from the phase transition the experimental data were obtained, the larger they differ from the theoretical dependence.

Thus, the theory [2] does not provide an estimation of the viscosity coefficient in the
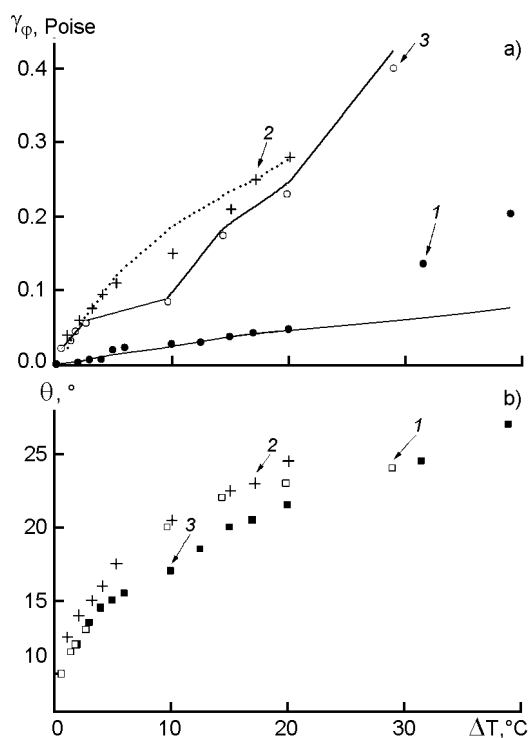
Fig. 2. Temperature dependences of rotational viscosity (a) and tilt angle (b) in smectic layers ($\Delta T = T_{SmA^* \to SmC^*} - T_{meas.}$): CD *3b* (15.59 mol.%) in the Matrix **2** (*1*); CD *3b* (7.5 mol.%) in the Matrix **2** (*2*); CD *3a* (7.75 mol.%) in the Matrix **1** (*3*).

ferroelectric under study basing on the parameters of achiral smectic C and chiral dopant. This is to be accounted for when

developing novel FELC compositions for practical applications. The rotational viscosity of a ferroelectric cannot be decreased by introducing a chiral dopant, as it would be expected basing on the theory. The experiments have shown that the temperature dependence of the viscosity coefficient is defined by the temperature dependence of the molecular tilt angle in the smectic layer, that is consistent with the theory [4].

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Обертальна в'язкість індукованої смектичної С* фази рідких кристалів

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Визначено обертальну в'язкість та кут нахилу молекул у смектичних шарах в індукованих сегнетоелектричних системах, що містять похідні 1R,4R–2(4-фенилбензиліден)-ментан-3-онів у якості хіральних домішок. Досліджено кореляцію між обертальною в'язкістю та кутом θ. Показано, що температурна залежність кута нахилу молекул у смектичних шарах впливає на температурну залежність обертальної в'язкості.