Optically induced hydrodynamic reorientation of liquid crystals and its applications for infrared detection and information storage

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Absorption mediated effects provide the strongest mechanisms of optically induced reorientation of liquid crystals (LC's). The following mechanism of transformation of absorbed light energy into reorientation of LC's is theoretically discussed in the present paper: thermal expansion resulting from absorption induced heating causes inhomogeneous flow of the LC in the capillary which, due to the strong coupling of hydrodynamic and orientational degrees of freedom, leads to LC reorientation. With a plane capillary, this may allow detection of infrared radiation at a microwatt level. With microcapillaries in porous media, this may lead to chaotization of orientation and creation of scattering pixels allowing for high resolution optical information storage matrixes. Estimations done for so called "filled nematic liquid crystals" are in good accordance with existing experimental data.

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I. INTRODUCTION

Orientational effects in liquid crystals (LC's) under the action of quasistatic electric and magnetic fields are comprehensively investigated [1]. Presently, there are many contributions as well to the field of optically induced orientational phenomena; see, e.g., the review article [2]. As indicated in [2], an extremely small absorption would provide energy sufficient for remarkable director reorientation. The problem is to find mechanisms transforming the absorbed energy into director reorientation.

One of the most promising mechanisms turned out to be photoconformational reversible transitions in LC molecules [3]. More specific to LC's is hydrodynamically induced reorientation where the hydrodynamic motions are generated under the influence of light waves. These so called optohydrodynamic orientational effects were investigated in a number of articles and proved to provide perhaps the strongest mechanism for optical nonlinearity of LC's [4–6].

In the present paper, we will investigate in detail the following process. The absorbed light energy heats the LC causing its thermal expansion. A pressure gradient then results in a Poiseuille flow of the LC. The latter reorients molecules due to the strong coupling of hydrodynamic and orientational motions in the LC. The consequences of this reorientation are different for two general situations: flow in a plane capillary (Sec. III) and flow in microcapillaries (Sec. VII). In the first case, schemes may be designed where the reorientation modulates the phase of a signal beam allowing detection of an infrared radiation (Sec. V). As it was shown in [6], very high sensitivity there can be achieved. Consideration of thermal noise correlated with volume and director fluctuations carried out in Sec. VI of the present paper indicates registrable powers as low as 10^{-8} W/cm^2. This is already comparable with the sensitivity of complex structure metal-photosemiconductor-dielectric in LC light valves, but has the advantage of having no constraints in the red edge of the spectrum. A peculiarity of hydrodynamically induced effects is that the temporal variation of temperature (and not its absolute value) is the driving force just as in pyroelectrics.

In Sec. VII we discuss the effect of hydrodynamically mediated optical reorientation in microcapillaries modeling the situation with "filled nematic liquid crystals." Unique possibilities of these systems for optical information storage and projection applications were revealed in a number of recent papers [7]; however, the underlying mechanism was only partially understood. Good accordance of our numerical estimations with existing experimental data throws more light onto the problem.

II. EQUATIONS OF NEMATIC HYDRODYNAMICS

To introduce the main ideas in a simple form, it is convenient to consider the hydrodynamically mediated optical reorientation of LC's in the following scheme [6]. Consider a horizontally arranged plane capillary (cell) with a nematic LC (NLC) communicating with a volume of a liquid (which may be the same NLC) strongly absorbing light energy (Fig. 1). Let us choose a Cartesian coordinate system whose z axis is along the normal to the cell plates whereas the x axis is in the cell plane. The origin of the coordinates will be arranged on the bottom left edge of the capillary.

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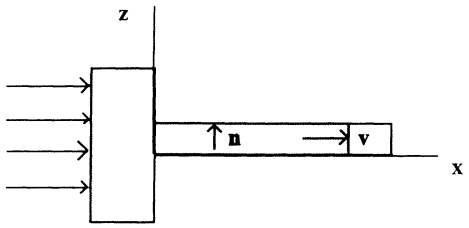

FIG. 1. Generation of Poiseuille flow in a capillary of NLC under the action of excess pressure due to the thermal expansion of the volume of a liquid absorbing the radiation: the x axis of the Cartesian coordinate system is along the flow; the z axis is perpendicular to the plates of the capillary; $\mathbf{n}$ is the NLC director unperturbed orientation; and $\mathbf{v}$ is the flow velocity.

The behavior of the system which we are going to investigate is described, in general, with a set of three nonlinear dynamic equations: for the director, for the hydrodynamic motions (Navier-Stokes equations), and for the thermal conductivity. Realizing that the nonlinear dynamics of this system is a highly worthy subject of investigation, we will leave it for the future, concentrating here on linearized equations valid for small light powers. Two different orientations of the director in the cell—planar and homeotropic—can be discussed in the framework of the same approach.

Thus the process starts with the change T in the temperature due to absorption, and the linearized thermal conductivity equation has the form

$$\frac{\partial T}{\partial t} = r\Delta T + \frac{W}{V\rho C_p}, \tag{1}$$

where r is the temperature conductivity coefficient (in cm^2/s), ρC_p is the specific volume thermal capacitance (in $\mathrm{erg/cm}^3\ \mathrm{K}$), and W is the power (in erg/s) released in the volume V of absorbing liquid.

The speed of the volume expansion due to the temperature increase is

$$\frac{\partial V}{\partial t} = \beta V \frac{\partial T}{\partial t}, \tag{2}$$

with β being the thermal expansion coefficient (in K^{-1}).

Expansion of the liquid creates a pressure gradient over the cell. To let the liquid flow under this gradient, we will have to assume the presence of a free volume in the cell (e.g., a bubble) where a constant (e.g., atmospheric) pressure is kept. To simplify the problem, let us assume the pressure gradient to be along the x axis, resulting in a Poiseuille flow with $v_x = v$, $v_y = v_z = 0$ and $\partial/\partial x = \partial/\partial y = 0$, where $\mathbf{v}$ is the velocity of hydrodynamic flows in the cell.

The velocity v and the pressure gradient can be determined from the linearized Navier-Stokes equation and the uncompressibility condition. In our case, the latter just means that the increase of the volume of the liquid in one part of the cell shall be compensated with the flow to the free volume:

$$l\int_0^L v(z)dz = \frac{\partial V}{\partial t}, \tag{3}$$

where L is the thickness of capillary and l its width.

Due to viscous stresses, the flow leads to the reorientation φ of the NLC described by the linearized equation for the torque balance:

$$\gamma\frac{\partial\varphi}{\partial t} - K\frac{\partial^2\varphi}{\partial z^2} - \alpha\frac{\partial v}{\partial z} = 0, \tag{4}$$

where $\gamma = \alpha_3 - \alpha_2$, $K = K_1$, and $\alpha = \alpha_2$ for homeotropic initial orientation, $K = K_3$ and $\alpha = \alpha_3$ for planar initial orientation, K_i are Frank elastic constants (in erg/cm), and α_i are Leslie coefficients (in poise).

We assume hard anchoring at the boundaries: $v(z = 0) = \varphi(z = 0) = 0$ and $v(z = L) = \varphi(z = L) = 0$. Equations (1)–(4) along with the boundary conditions determine all the perturbations T, v, and φ for the optohydrodynamic effect under consideration.

III. TIME-MODULATED REORIENTATION

Hydrodynamic motion takes place during the thermal relaxation time and stops when it is reached. In the case of incident cw radiation this time can become comparatively large if the cell is considered to be thermally isolated. Assume here that the radiation is time modulated. This kind of situation used to be realized in pyroelectrics in infrared detection schemes and is conventional also to enhance the signal to noise ratio. Having in mind infrared detection applications, we will discuss here a model scheme where absorption is taking place in a separate volume of thermally isolated cell connected with the capillary. Thus, suppose

$$W = W_0(1 + m\cos\Omega t), \tag{5}$$

with m being the modulation depth. Since we consider here absorption taking place in a separate volume of a liquid communicating with the capillary, the effects correlated with the spatial inhomogeneities of the temperature distribution are not principal. Hence we will assume homogeneous heating and neglect the term ΔT in Eq. (1).

Navier-Stokes equations and Eq. (4) provide estimations for the transient times showing then that the time of relaxation of hydrodynamic motion in the capillary $\tau_h = \rho L^2/\pi^2\eta$ is much shorter than the orientational relaxation time $\tau_r = \gamma L^2/\pi^2 K$. Obviously, the modulation frequency Ω has to be smaller or comparable to τ_r for the director to respond effectively to the hydrodynamic torque: $\Omega \leq \tau_h^{-1}$. With this condition, hydrodynamic motion follows adiabatically the temporal modulation of the radiation. Thus the velocity of hydrodynamic motion of the NLC can be represented in the form

$$v(z,t) = \frac{\pi\beta}{2lL\rho C_p} W \sin\frac{\pi z}{L}. \tag{6}$$

The expression (6) is the smoothest mode of perturbation fulfilling the boundary conditions.

The solution of Eq. (4) can be represented with the approximate formula

$$\varphi(z,t) = \varphi(t)\sin\frac{2\pi z}{L}, \tag{7}$$

though the exact expression can be straightforwardly written down in this particular case.

The antisymmetric character of the director perturbations over the center of the cell is a result of vanishing velocity gradient and hence vanishing hydrodynamic torque in the center of the cell. The director oscillates with the frequency Ω phase shifted with respect to hydrodynamic motion of the NLC and modulation of the radiation:

$$\varphi(t) = \varphi_0\left[1 + \frac{m}{\sqrt{1+\Omega^2\tau_r^2}}\cos(\Omega t - \nu) - e^{-\frac{t}{\tau_r}}\left(1 + \frac{m}{1+\Omega^2\tau_r^2}\right)\right], \tag{8}$$

$$\varphi_0 = \frac{W_0}{W_h}, \tag{9}$$

$$W_h = \frac{3\pi l K \rho C_p}{\alpha\beta}, \tag{10}$$

$$\tan\nu = \Omega\tau_r. \tag{11}$$

The results obtained here are related to a sharp switching of the radiation. Equation (8) shows that the modulation depth decreases with increasing Ω. This is related to the circumstance that the director reorientation is a viscous motion with a damping constant $\sim \tau_r^{-1}$. Therefore, at small frequencies of modulation $\Omega \leq \tau_r^{-1}$, the director is able to follow after the periodic external influence and the reorientation reaches its maximal value. On the contrary, for high modulation frequencies $\Omega \geq \tau_r^{-1}$, orientational viscousity is strongly damping the director oscillations.

Highly peculiar for the orientational interaction of NLC's with external fields is the decrease in the reorientation with increasing NLC layer. Namely, the density of elastic energy is proportional to L^{-2}, which makes the characteristic time of reorientation proportional to L^2. Therefore, at a fixed Ω, the director follows the oscillations of the external force less and less with increasing L. In other words, increasing thickness increases the relaxation time and thus leads to stronger damping of oscillations.

IV. PULSED RADIATION

As it was shown above, properties of optohydrodynamic reorientation are determined by the relation between the radiation modulation period and the characteristic time of director reorientation. With a pulsed radiation, the relation between pulse duration τ_p and τ_r will play the major role.

In the case of long pulses $\tau_p \gg \tau_r$, we deal actually with a cw radiation. The maximal reorientation angle in this case is determined by Eq. (8) with $m = 0$. It is interesting to note that the magnitude of the maximal reorientation in this case becomes independent on the cell thickness. This is a peculiarity of the mechanism under consideration related to the circumstance that both the energy of elastic deformation and the hydrodynamic torque — the gradient of the hydrodynamic motion— are proportional to L^{-2}.

One has to take into account that Eq. (8) is obtained in linear approximation for the volume expansion vs temperature increase, Eq. (2), valid for small variations in the temperature and hence for small variations in the volume $\beta\Delta T \ll 1$. Therefore, the following relation between the radiation intensity and absorption coefficient of the medium has to be fulfilled:

$$\frac{\beta W \tau_p}{V\rho C_p} \ll 1. \tag{12}$$

Thus the steady state optohydrodynamic reorientation described by Eq. (8) with $m = 0$ takes place when the condition

$$\tau_r \leq \tau_p \ll \frac{V\rho C_p}{W\beta} \tag{13}$$

is fulfilled. The condition (13) puts restriction on the maximal values of the radiation intensity when the process is still linear:

$$W \ll \frac{V\rho C_p}{\beta\tau_r} = \frac{\pi^2 V\rho C_p K}{\beta\gamma L^2}. \tag{14}$$

For a pulsed radiation, the process of reorientation stops with the attenuation of hydrodynamic flow after the pulse is absorbed. The reorientation magnitude for short pulses $\tau_p < \tau_r$ can easily be obtained from Eqs. (1)–(4):

$$\varphi \sim \frac{Q}{\tau_r W_h}, \tag{15}$$

where Q is the absorbed pulse energy. Thus, for short pulses ($\tau_p \ll \tau_r$) the reorientation magnitude is determined by the pulse energy. Comparing Eq. (15) with the steady-state reorientation value (8),

$$\frac{\varphi_{\text{pulse}}}{\varphi_0} \sim \frac{Q}{4W_0\tau_r} \tag{16}$$

we see that, for the same powers ($Q = W_0\tau_p$), the effect turns out to be smaller in the pulsed regime by the factor of τ_p/τ_r.

V. INFRARED DETECTION

Let us discuss a simple scheme of registration of optohydrodynamically induced NLC reorientation: the capillary is sandwiched between polarizers and a monochromatic visible wave is incident on it perpendicularly. With crossed polarizers making a $\pm\pi/4$ angle with respect of the flow direction, the transmission coefficient of the system becomes

$$\rho = \sin^2\frac{\Phi}{2}, \tag{17}$$

where Φ is the additional phase shift induced by the reorientation of the NLC:

$$\Phi = \xi\frac{\omega\varepsilon_a}{2c}\int_0^L \varphi^2(z',t)dz'. \tag{18}$$

In expression (18), $\varepsilon_a = \varepsilon_{\parallel} - \varepsilon_{\perp}$ is the dielectric

anisotropy of the NLC at the optical frequency and c is the light speed in vacuum. The parameter $\xi = -\sqrt{\varepsilon_{\parallel}}/\varepsilon_{\perp}$ for planar orientation and $\xi = \sqrt{\varepsilon_{\perp}}/\varepsilon_{\parallel}$ for homeotropic orientation of the NLC.

Thus, with account of expression (8) and for observation time $t > \tau_r$, we obtain

$$\Phi = \xi \frac{\varepsilon_a \omega L}{2c} \varphi_0^2 \left[1 + \frac{m^2}{2(1+\Omega^2\tau_r^2)} + \frac{2m}{\sqrt{1+\Omega^2\tau_r^2}} \cos(\Omega t - \nu) + \frac{m^2}{2(1+\Omega^2\tau_r^2)} \cos(2\Omega t - 2\nu) \right]. \quad (19)$$

The phase shift consists of three parts: time invariable, modulated with frequency Ω, and modulated with frequency 2Ω. Time modulated as well as invariable parts decrease with increasing modulation frequency Ω at fixed cell thickness.

Consider the dependence of the phase shift from the cell thickness for a given Ω. Time invariable part of the phase shift increases monotonically with increasing L while time modulated parts become maximum for optimal thicknesses: $L = L_1 = \pi\sqrt{K/\gamma\Omega}$ for the term on the frequency Ω and $L = L_2 = \pi\sqrt{K/\sqrt{3}\gamma\Omega}$ for the term on the frequency 2Ω.

To understand the existence of optima let us note that the reorientation angle, and hence the change in the refractive index, stays finite in the limit case $L \to 0$ for a given Ω. Therefore, $\Phi \to 0$ proportionally to L. The director reorientation is, however, exponentially small for large values of L ($\Omega\tau_r \gg 1$) for our mechanism of reorientation. Since the optical path is just the first power of L, the induced phase becomes vanishing for large thicknesses. Thus an optimal thickness arises where the phase is maximum for the given frequency of modulation.

VI. NOISE

Sensitivity of ir detectors is limited by noise. In our case noise is correlated with the fluctuations of the volume of absorbing liquid and the fluctuations of the director orientation in the capillary.

The volume fluctuations can be estimated as (see, e.g., [8])

$$\sqrt{\langle (\Delta V)^2 \rangle} = \sqrt{k_B T V \chi}, \quad (20)$$

where $\chi = -(\partial V/\partial P)_T/V$ is the compression coefficient. Comparing this value with the volume of thermal expansion due to absorption of radiation, we get that the energy corresponding to the threshold sensitivity is equal to

$$Q' \sim \frac{\rho C_p}{\beta} \sqrt{k_B T \chi V}. \quad (21)$$

Director fluctuations can be estimated as follows:

$$\sqrt{\langle \varphi^2 \rangle} \sim \frac{k_B T}{KL}. \quad (22)$$

Comparing this expression with the optohydrodynamically induced reorientaiton, we find the threshold energy to be of the order of

$$Q'' \sim \frac{k_B T \gamma \rho C_p l L}{\alpha \beta K}. \quad (23)$$

There will be also noise characteristic to a particular electro-optical registration scheme. However, it is well investigated and we will not discuss it here.

VII. REORIENTATION IN MICROCAPILLARIES

As mentioned in the Introduction, NLC's filled in porous media exhibit fascinating optical properties allowing optical data storage, and high information content displays applications with bistability [7]. Investigations carried out in [7] revealed many important properties of so called filled nematic liquid crystals. However, understanding the underlying mechanism of the laser addressing process and its theoretical description are correlated with many difficulties because of the complexity of the system.

From [7] and preceding papers, it is already known that filled nematic liquid crystals consist of aggregates of small particles of pirogenic silica dispersed in a NLC. They create an extremely large specific surface in the NLC with characteristic size $l_m \sim 10^{-5}$ cm. A very low percentage of the silica in volume (1–2 vol %) ensures that it has no influence on the optical properties of the system which is thus determined only by the orientational state of the NLC.

According to the model of [7], the laser writing process consists in breaking hydrogen bonds due to thermal shock and reorientation of aggregates due to orientational coupling of molecules with surfaces on aggregates. However, this leaves open the question about the mechanism of reorientation under the action of the light wave. Though the energy of elastic deformations of the NLC inside a cavity, $F \sim KV/l_m^2 \sim Kl_m \sim 10^{-12}$ erg, turns out to be comparable with the energy of hydrogen bonds for strong deformations and may be enough to break them, it is less likely that the director reorientation is able to move the large aggregates. Strong orientation of molecules on the surfaces of aggregates is itself another physical assumption requiring more experimental data to be proven.

As is already clear from the above discussions, laser induced hydrodynamic motions and an accompanying reorientation process in randomly oriented microcapillaries (Fig. 2) can underlie a more realistic model.

Actually, the change in the temperature due to absorption of the radiation energy $\Delta T \sim W\tau_T/V\rho C_p$ creates excess pressure ΔP, which can be estimated through the van der Waals equation. With an accuracy meeting our purposes, however, one can make use of a simpler equation $\Delta P = \rho R \Delta T/M$, where R is the universal thermodynamic constant $R = 8.31$ J/K mol and M is the molar

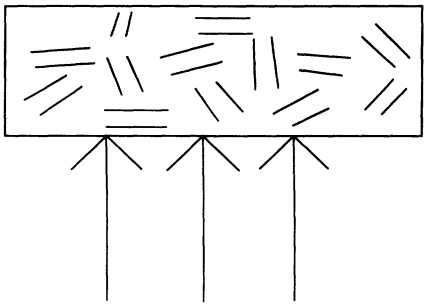

FIG. 2. Microcapillaries modeling filled nematics.

mass of the NLC.

The excess pressure induces Poiseuille flow in microcapillaries described by Navier-Stokes equation:

$$\frac{\Delta P}{a} \sim \eta \frac{v}{l_m^2}, \tag{24}$$

with characteristic size of the pressure gradient a coinciding with the transverse size of the light beam. Thus, for the velocity of the hydrodynamic flow, we obtain an estimation

$$v \sim \frac{R\tau_T l_m^2}{MVC_p\eta a} W. \tag{25}$$

Combining Eq. (25) with Eq. (4) and noting that the absorbed power W is related to the incident radiation intensity I as $W = V\sigma I$, we eventually arrive at the following value for the reorientation magnitude:

$$\varphi \sim \sigma L f(a) \frac{I}{I_c}, \tag{26}$$

where

$$f(a) = \frac{a/L}{1 + (a/L)^2} \tag{27}$$

describes the effect of the beam size and

$$I_c = \frac{rK}{l_m^3} \frac{\eta}{\alpha} \frac{MC_p}{R} \tag{28}$$

is a characteristic intensity determined by material parameters. In obtaining formula (26) we made use of the following evaluation for the thermal relaxation time:

$$\tau_T^{-1} = r\left(\frac{1}{a^2} + \frac{1}{L^2}\right). \tag{29}$$

Thus the beam size becomes involved in the problem in two ways determining, first, the pressure gradient and, second, thermal relaxation. As a result, there appears to be an optimal beam size just equal to the thickness of the filled nematic layer: for narrower beams $a \ll L$, the reorientation decreases because of very fast relaxation and for larger beams $a \gg L$, because of decreasing pressure gradient. It is easy to understand physically as well the other dependences in Eq. (26). For short pulses, the reorientation magnitude becomes modified by a factor τ_p/τ_r, where τ_p is the pulse duration and τ_r is the reorientation time in a microcapillary.

VIII. DISCUSSION AND NUMERICAL ESTIMATIONS

Let us estimate the order of magnitude of the irradiation necessary to induce a phase shift of the probe beam $\Phi \sim 1$. Consider a NLC 4-methoxi-benzylidene-4-butylaniline (MBBA) in a cell with strong anchoring: $\varepsilon_a = 0.7, \sqrt{\varepsilon_\parallel} = 1.61, \sqrt{\varepsilon_\perp} = 1.54, \beta = 10^{-3}$ K^{-1}, $\rho C_p = 1$ J/cm^3 K, $L = 10^{-2}$ cm, and $l = 0.1$ cm and let $\omega/c = 10^5$ cm^{-1}. For a homeotropic orientation $K = K_3 = 7.5 \times 10^{-7}$ erg/cm and $\alpha = \alpha_2 = -0.8$ P and we get that $W_0 = 10^{-4}$ W for an unmodulated radiation ($m = 0$). For a planar orientation $K = K_1 = 6 \times 10^{-7}$ erg/cm, $\alpha = \alpha_3 = -0.012$ P, and $W_0 = 5 \times 10^{-3}$ W.

Thus, the situation with homeotropic orientation turns out to be more advantageous due to stronger coupling of hydrodynamic motion with the director orientation. Note that even more advantageous situations are realizable if special care is taken so that the phase shift is proportional to the first power of the director reorientation. Violating the antisymmetric distribution of the director is possible, for example, by ensuring weak anchoring on one of the boundaries. Another possibility is in the utilizaiton of NLC cells with inhomogeneous (say, hybrid) initial orientation.

To estimate orders of magnitudes of the quantities Q' and Q'' determining the sensitivity of the schemes under consideration, let us assume the following values of the additional parameters involved: $\chi \sim 10^{-10}$ cm^3/erg, $V \sim 1$ cm^3 and $k_BT \sim 4 \times 10^{-14}$ erg. Then (21) and (23) yield $Q' \sim 2 \times 10^{-2}$ erg and $Q'' \sim 0.4$ erg. Taking into account that the reorientation time is usually of the order of 1 s, we find eventually that the sensitivity of the scheme can be better than 10^{-6} W.

In a preliminary experiment carried out with a homeotropically oriented NLC pentylcyanobiphenyl (5CB) of the thickness 50 μm, a broadband irradiation was registered at the power level 10^{-4} W. The area of the absorbing liquid was 1 cm^2.

Let us now carry out estimations for the reorientation in microcapillaries. We have to estimate the radiation power sufficient to induce large reorientation $\varphi \sim 1$. It is important to note that large reorientation does not necessarily require turbulence or flow with high velocity. The reason why the reorientation is chaotic is the mere circumstance of having many chaotically oriented microcapillaries. Thus, for parameter values $M = 10^2$ g/mol, $\rho C_p = 10^7$ erg/cm^3 K, $r = 10^{-3}$ cm^2/s, $\eta = 1$ P, $\alpha = 0.1$ P (an average value for homeotropic and planar orientations), $K = 10^{-6}$ erg/cm, $l_m = 10^{-5}$ cm, $L = 10^{-3}$ cm, $a = 10^{-3}$ cm, and $\sigma = 10^2$ cm^{-1} we obtain that the reorientation takes place during a very short time $\tau_r \sim 10^{-4}$ s, requiring intensity 1 kW/cm^2 and corresponding to the sensitivity 0.1 nJ/μm^2. All these figures are in excellent accordance with the experimental observations indicating towards a correct understanding of the phenomenon.

To complete our discussion of reorientation in microcapillaries, let us estimate also the temperature and excess pressure at the laser recording process. It is easy to see that $\Delta T \sim 10$ K and $\Delta P \sim 1$ J/cm^3. This pressure proves to be high enough to move (reorient) the aggre-

gates. Namely, supposing a disk with a specific weight per area $\rho_s \sim 10^{-6}$ g/cm^2 as for the materials used in filled nematic liquid crystals, we find that the motion of the aggregate during the reorientation time 10^{-4} s can be considered as established with its velocity v_a determined just by the balance of friction force and the excess pressure: thus, even for motion perpendicular to the disk, we have

$$v_a = \frac{\pi}{16}\frac{l_m}{\eta}\Delta P. \tag{30}$$

For the above adopted data this leads to $v_a \sim 1$ cm/s. Thus the aggregate will be moved to a distance of about its size during the writing process. Note that we would have the same orders of magnitude independent of the suggested form of the aggregate surfaces.

Consider the role of finite anchoring energy at the boundaries of microcapillaries. One obvious consequence of weak anchoring is a larger reorientation angle for the given flow gradient as a result of smoother spatial perturbations of the director; maximum reorientation of the director is about five times larger in the limit case of "free" boundary conditions. This is easy to find solving Eq. (4) with account of Eq. (6) for finite polar anchoring energy. Thus a smaller velocity of hydrodynamic flow and weaker light intensity are required to create the same contrast in the case of weak anhoring. However, the slower the hydrodynamic flow, the smaller the influence on the network of microcapillaries.

There is experimental evidence that the rearrangement of the microcapillary network during laser writing process is the reason for the bistability of the system (transparent and scattering states) having a stabilizing effect on the director chaotic orientation [9]. Then, in the case of weak anchoring, an alternative effect may become possible. Namely, in a certain range of light intensity, the reorientation may be enough for a large reorientation of the director while the hydrodynamic pressure may still be too small to influence the network remarkably. In that range of light intensity, a high contrast may be achieved dynamically, with no long term storage of the optical information. We emphasize that realization of this kind of behavior is correlated with the availability of materials with a small weight per area and small anchoring energy.

The problem of surface conditions and their role on the processes under discussion is even more complicated. First of all, orienting properties and mechanisms are not well understood even for materials utilized traditionally for liquid crystal display manufacturing. In particular, a memory alignment effect was reported very recently [10] that may play an important role in the storage process in filled nematics liquid crystals. Another origin of complication lies in the three dimensional character of the microcapillary network. What is the role of azimuthal anchoring energy and a more complex flow profile? The nonplanar character of microcapillaries is a source of additional flow gradients with additional influence on the director.

Thus, to be precise, the real problem is three dimensional and extremely difficult to solve or simulate. However, at present, the problem is to understand basic mechanisms and features rather than to provide a quantitative description of the optically induced processes in filled nematic liquid crystals. All our simplifying assumptions prove to serve this purpose.

Thus we may suggest the following picture of the processes going on in filled nematic liquid crystals. At the first stage of preparation of transparent films, a quasistatic electric field induces homogeneous orientation in the whole volume of the cell which is supported then by the homeotropic anchoring at the cell plates. Laser heating results in a flow in microcapillaries which strongly perturbs the orientation of NLC molecules, possibly creating defect structures. Note that it is enough to have a lamellar flow with small Reynolds numbers to induce large reorientation of molecules. The sizes of local perturbations are determined by the sizes of microcapillaries ensuring very high resolution. Local perturbations are stabilized then by defect structures and by the interaction with aggregates forming the microcapillary network.

The main advantages of the effects in filled nematic liquid crystals compared to similar effects considered earlier for pure cholesteric and smectic LC's [11,12] are the following. Small sizes of microcapillaries, first ensure higher resolution, second ensure faster switching time, and third allow an alternative mechanism of laser recording which does not require heating to the isotropic state and hence is less energy consuming. We can expect that similar features will be realized also with polymer stabilized cholesteric textures [13] and even with other dispersions of NLC's.

There are still many questions to be answered to develop a quantitative model of the processes under discussion. In particular, orienting properties of surfaces of the aggregates for NLC's and effects correlated with the motion of the aggregates and their deformation under the direct action of the hydrodynamic pressure are not yet clarified. The investigation of spatial and temporal localization effects seems to be important to improve the model.

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