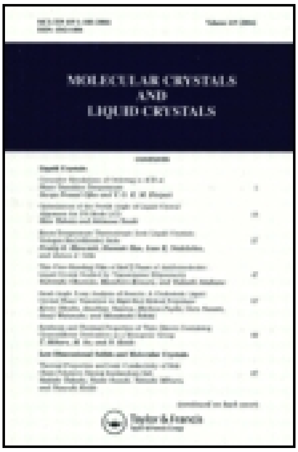

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Light Induced Thermocapillary Motion in Nematic Liquid Crystals

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Surface tension gradients can cause mass transfer (Marangoni effect). We investigated thermocapillary in homeotropic oriented nematic liquid crystals. The heating process was performed with a Gaussian laser profile. The upper surface of the cell is free and the bottom has hard anchoring conditions. Upon assuming the fluid is incompressible, the hydrodynamic equations that explain the system shifts can be derived from the balance of torques, Navier-Stokes and heat equation. The heat equation is written for anisotropic area. We investigated the problem of the existence of vertical magnetic field. We found that the magnetic field can affect the system.

Keywords Hydrodynamic; liquid crystal; marangoni effect; surface effect

Introduction

Liquid crystals (LCs) have attracted much interest in recent decades, especially since control of their flexible properties with light, magnetic or electrical fields make them a suitable candidate for many applications. A wide range of bulk or interfacial effects could be observed in LCs. One of the important surface effects is the Marangoni effect, which explains that mass moves due to force as a result of surface tension gradient. Mass moves from a higher surface tension to lower, thus causing variations in the fluid such as director reorientation. With respect to the agent of surface tension gradient, this effect is categorized in different ways. The surface tension gradient can be created by a change in the density of material, temperature gradient or electric field in polar materials. When the agent of surface tension gradient is the temperature gradient, this phenomenon is called thermocapillary. This phenomenon has been studied for many ordinary and isotropic materials but if the material is anisotropic, other aspects are added to the problem and making it complex and interesting.

Here, our goal is to investigate the surface effects due to absorption of normal incident laser light beam with Gaussian profile in a layer of nematic liquid crystal (NLC) with

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homeotropic orientation. With regard to conditions of the problem, it can be said that there is azimuthally symmetry and functions depend only on **r** and **z**.

The problem includes three coupled parts: heat production, velocity field and director reorientation.

Temperature Distribution

We consider a very thin layer of liquid crystal that is placed on glass and its upper surface to be free. Thickness of layer is in order of several hundred micrometers, so the Froude number is greater than one, showing the dominance of surface effects in comparison to bulk effects [1]. Because of the layer's thinness, all kinds of temperature differences along **z** are negated by the heat diffusion phenomenon [2].

If we want to explore differences due to heat production in anisotropic media more correctly, we should consider heat equation anisotropy [3]. Therefore, with respect to the aforementioned content, the heat equation is formed as:

$$k_{\perp}\left(\frac{1}{r}\frac{dT}{dr}+\frac{d^2T}{dr^2}\right)+\frac{P_0\alpha_{\perp}}{\pi\omega^2}\exp\left(-\frac{r^2}{\omega^2}\right)=0 \tag{1}$$

$k_{\perp}$ Is the vertical heat conduction coefficient of LCs, $P_{\perp}$ is the laser power, $\alpha_{\perp}$ is the vertical heat absorption coefficient, ω is the Gaussian profile spot size and T is the temperature function.

By using typical magnitudes of LC MBBA, the diagram of temperature change is as shown in Fig. 1.

The spot size of a laser beam is 0.3 mm and its power is 5 mw. The absorption coefficient of NLC is 1 cm^{-1}.

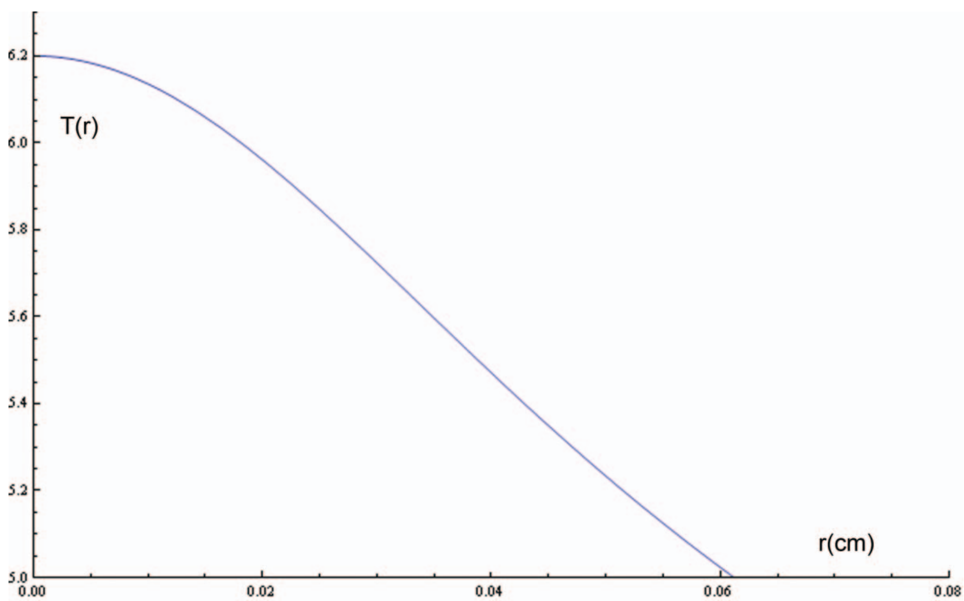

Figure 1. Temprature distribution with **r** that has Gaussian shape profile.

Velocity Field

Since the thickness of the selected layer is very thin, in comparison to the spot size of the laser beam, we can neglect the change of velocity and director along the r-axis, and we consider only their changes along z-direction, which is normal to the layer surface. The pressure change for media is given by below equation:

$$P = P_0 + \rho g(\xi(r) - z) \tag{2}$$

where $\xi(r)$, ρ are the surface function and the density of LC, respectively. In addition, the Navier-Stokes equation is:

$$\frac{\partial^2 v_r}{\partial_Z^2} = \frac{\rho g}{\eta}\frac{d\xi\,(r)}{dr} \tag{3}$$

where v_r is velocity in the r-direction and η is the Miesowitz coefficient of viscosity. Moreover, regarding surface tension gradient balanced by tangential tension of viscosity [4], the boundary condition in free surface is:

$$\frac{\partial v_r}{\partial Z} = \frac{1}{\eta}\frac{d\sigma}{dT}\frac{dT}{dr} \tag{4}$$

where σ is the surface tension index of LC.
On the other hand, it should not be a net current in constant radius [2], so we have:

$$\int_0^{\xi} v_r dZ = 0 \tag{5}$$

With respect to boundary conditions, velocity function yielded:

$$v = \frac{\xi}{\eta}\frac{d\sigma}{dT}\frac{dT}{dr}\left(\frac{Z^2}{2} - \frac{Z}{3}\right); Z = \frac{z}{\xi} \tag{6}$$

And its diagram is as follows:

Figure 2 shows the velocity changes with respect to the r- and z-dimensions in μm/s. It can be seen the velocity follows the temperature gradient in the r-direction, meanwhile

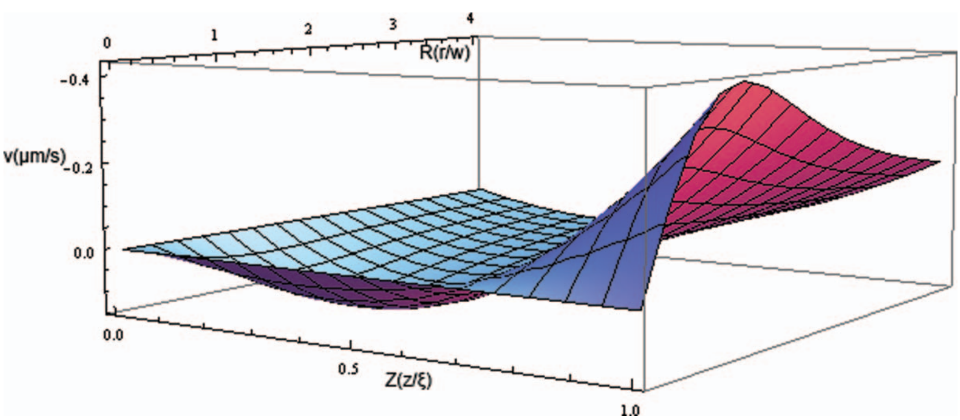

Figure 2. Velocity changes in $\frac{\mu m}{s}$, R and Z show $\frac{r}{\omega}$, $\frac{z}{\xi}$ respectively and are dimensionless.

there is variation from negative to positive in the z-direction with its maximum at the upper free surface. This variation is a result of Eq. 5.

Reorientation of Director

A magnetic field can reorient liquid crystal molecules, and this effect is called Fredericks transition [5]. Temperature gradient and viscosity induced torques on molecules force them to rotate. If we write the equilibrium of all applied torques and elasticity force, the amount of reorientation of molecules can be obtained. The torque balance equation is as follows:

$$\frac{k_3}{k_1}\frac{\partial^2 n_r}{\partial z^2} + \left(-\frac{1}{k_1\left(\frac{\chi_a}{\mu_0}B_z\right)}\right)n_r + \frac{\partial v_r}{\partial z} = 0 \tag{7}$$

where k_3, k_1 are Frank elastic constants, α_2 is the Leslie coefficient, χ_a is the magnetic susceptibility anisotropy, B_z is magnetic field and μ_0 permeability of free space.

From the equilibrium of surface torques [5], the boundary condition on the free surface is:

$$\frac{k_3}{k_1}\frac{\partial n_r(r, z=\xi)}{\partial z} + \left(-\frac{1}{k_1}\left(\frac{\chi_a}{\mu_0}B_z\right)\right)n_r(r, z=\xi) + \frac{\partial v_r(r, z=\xi)}{\partial z} = 0 \tag{8}$$

and from hard anchoring condition on interface of glass-NLC we have:

$$n_r(r, z=0) = 0, \quad v_r(r, z=0) = 0 \tag{9}$$

With these boundary conditions, we will have the following diagram for n_r:

Figure 3 shows the director reorientation with respect to the r- and z-directions. This figure shows that the director reorientation follows the gradient of the temperature. The

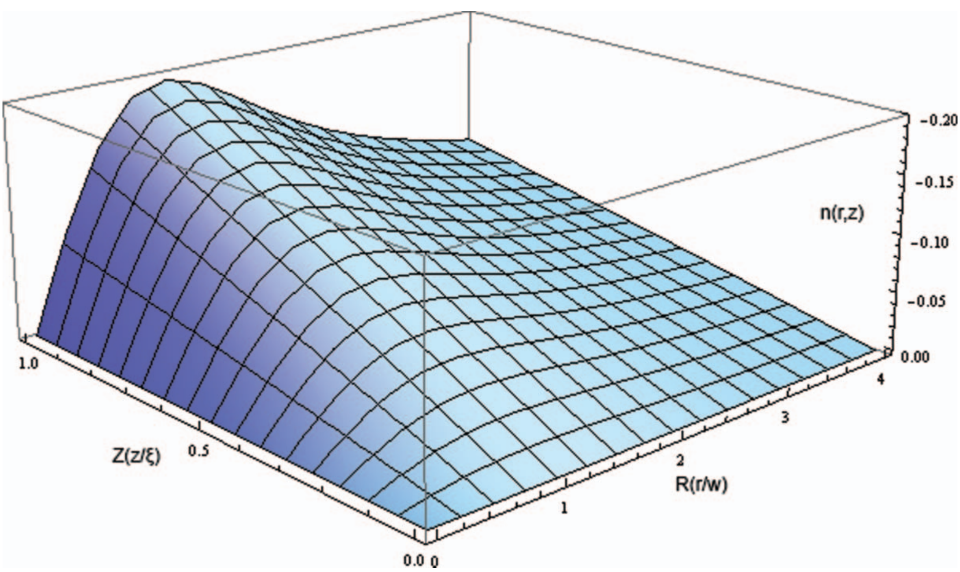

Figure 3. Reorientation of director in Radian, R and Z show $\frac{r}{\omega}$, $\frac{z}{\xi}$ respectively and are dimensionless.

maximum of the director reorientation is on the free surface. The figure also shows that the magnetic field in the z-direction acts as a stabilizer for the director and lowers the reorientation more than two orders of magnitude.

Conclusion

We calculated the flow and reorientation due to the Marangoni effect as a result of the absorption of normal incident laser Gaussian beam for homeotropic NLC with a magnetic field parallel to the molecular director. We found that the velocity follows the induced temperature gradient in the r-direction, where there is a variation for the velocity along the z-direction with its maximum at the free surface without any affect from the magnetic field. But the magnetic field affects the director reorientation and stabilizes it. The director reorientation follows the temperature gradient profile in the r-direction, also, where it's maximum is on the free surface, such as the maximum of the velocity.

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