Terafluidic Devices- Perspectives and Problems

Sergey V. Pasechnik[1,2] and Dina V. Shmeliova[1,2]
[1]Moscow State University of Instrument Engineering and Computer Science, Moscow, Russia
[2] Moscow State University of Information Technologies, Radioengineering and Electronics University, Moscow, Russia

Abstract—**The new approach to an elaboration of liquid crystals (LC) tuned THz devices, based on usage of shear flows, is proposed. Flows are considered as more universal tool of LC orientation in the comparison with the action of properly treated surfaces. In particular, they can be used for an orientation of both thin and thick (of order 1mm) LC layers. High sensitivity of LC to the flows makes possible to elaborate LC devices of new types – terafluidics.**

I. INTRODUCTION

The increasingly fast development of THz technique implies an elaboration of many elements (shutters, attenuators, phase retarders, polarization controllers etc.) similar to those used in a traditional optics. In the latter case liquid crystals (LC) are of a common usage as they provide effective control (usually via electric fields) of light beams. Basically it is determined by unique properties of these materials such as a strong anisotropy of optical (Δn), dielectric (Δε) and viscous-elastic parameters. As a result, a number of electrically controlled LC devices, characterized by high efficiency, low control voltages and suitable operating times were proposed and realized in practice.

Recently there were some attempts to elaborate the similar devices for THz range of wavelengths (λ = 30..300 μm). They were not as successful as in the case of optical range. The main reasons can be summarized as follows:

1. It is difficult or even impossible to provide (by traditional surface treatment) a perfect orientation of typical LC (Δn is of order 0.1 in THz range) in the relatively thick (d = 0.5..5 mm) layers, needed for essential change of phase delay ($\delta = 2\pi\Delta n(d/\lambda)$) (at least $\pi/2$) between the extraordinary (e) and ordinary (o) rays (n_e and n_o – corresponding refractive indexes) passing through the layer.

2. The electric control usually used in LC devices operating in visible or IR ranges of wavelength is of a limited application for THz range due to high energy losses in transparent ITO electrodes.

3. The “turn off” times of proposed THz elements based on usage of thick LC layers are typically of order of some minutes, which is drastically restricts a practical application of liquid crystals in THz devices.

Some of the problems mentioned above can be partly overcome by usage of magnetic fields, alternative (“in plain”) geometry of electric field application or stripped electrodes. Usage of composite materials like porous polymer films filled with liquid crystals [2] also seemed to be perspective for THz range.

In this report we present the new approach for elaboration of LC-THz devices for applications based on usage of shear flows as universal tool, which provides orientation of liquid crystals.

II. RESULTS

1. It is well know, that there are a number of possible orientational structures arising in flows of liquid crystals throw channels of different geometry, sizes and surface treatment under the action of a pressure gradient G = dP/dx (Poiseuille flows [1]). Our aim is to show that such flows can be effectively used instead of (or additionally to) electric fields for THz applications. In accordance with possible practical realization, we will consider a flow of LC through the plane and cylindrical capillaries.

In the simplest case of a linear flow of LC through the channel of a rectangular cross section with large aspect ratio and initial homeotropic orientation the velocity v_x, orientation θ, and also the flow induced phase delay δ are described by the next simple expressions:

$$V_x(z,t) = -\frac{G(t)}{2\eta_1}\cdot\left(z^2-\frac{d^2}{4}\right) \tag{1}$$

$$\theta(z,t) = -\frac{\alpha_2}{6K_{33}\eta_1}\cdot z\left(z^2-\frac{d^2}{4}\right)\cdot G \tag{2}$$

$$\delta(t) \cong \frac{2\pi d}{\lambda}\cdot\frac{n_o(n_e^2-n_o^2)}{2n_e^2}\cdot\left\langle\theta^2\right\rangle = \frac{1}{15120}\cdot\frac{\pi d}{\lambda}\cdot\frac{n_o(n_e^2-n_o^2)}{2n_e^2}\cdot\left(\frac{\alpha_2 G d^3}{K_{33}\eta_1}\right)^2 \tag{3}$$

where $\theta \ll \pi$ –is the angle of the director’s declination from the initial orientation, η_1 – the shear viscosity coefficient, α_2 and K_{33} – are the Leslie coefficient and the Frank module.

Estimates made with using these expressions with material parameters of 5CB and thickness d= 0.5 mm show that maximal value θ_m of the angle θ is about 0.5 rad at very low pressure gradient (of order 1 Pa/m).

At the same time corresponding value of phase delay δ is very low (about $10^{-3}\pi$) for λ=d = 0.5 mm. The increasing of a pressure gradient breaks the linear approximation used above which leads to arising a number of specific instabilities. Nevertheless, it is well known, that intensive flow produced by large pressure gradient results in overall orientation of LC in the direction, close to the flow direction independently on the boundary conditions. This property makes possible to use flow induced orientation of LC for thick layers effective in THz range. In particular, for parameters mentioned above the maximal value of the phase delay is about 0.2 π and can be increased by the thickness increasing. In the last case the “turn off” times corresponding to the relaxation of LC to the chaotic distribution is of order of ten minutes, which was previously proved by independent ultrasonic investigations of bulk samples, oriented by flow [3]. The situation can be improved by additional usage of magnetic or electric fields [3]. Flow induced orientation of LC in thick layers can be used for elaboration of LC tuned THz devices such as polarization controllers, shutters and attenuators. High sensitivity of these devices to the pressure gradients provides a low power consumption and possibility to use microfluidics units for flow generation.

2. Flows of LC through cylindrical capillaries.

The maximal sensitivity of orientational structure to the flow takes place at homeotropic boundary orientation. On can use the dimensionless parameter [4]

$$\Lambda = \frac{1}{2}\left(\frac{dp}{dz}\right)\left(\frac{R^3}{K}\right) = \left[\frac{4\eta Q_i}{\pi R K}\right] \tag{4}$$

where R – a capillary radius, K – an effective Frank module. The flow effectively changes initial orientation in the case Λ>>1. It makes possible to define the range of the corresponding pressure gradient by the next expression:

$G \gg G_c = 2K\,R^{-3}$ (5)

So, liquid crystals can be used to control propagation of THz waves through such structures as hollow like photonic fibers (typical values of 2R are in the range 0.1..1 mm) or porous polymer films of thickness 10..20 μm with cylindrical pores of diameter D= 0.2..5 μm.

III. SUMMARY

The possibility for an elaboration of flow tuned LC devices, effective in THz range is considered. The made estimates show high sensitivity of thick layers of LC to the influence of shear flows, which makes possible to propose terafluidic devices on the base of microfluidic technologies.

This work was supported by the Ministry of Education and Science of the Russian Federation by grant No. 3.1921.2014/K.

REFERENCES

[1]. Pasechnik S.V. Chigrinov V.G., Shmeliova D.V. Liquid Crystals: Viscous and Elastic Properties. Wiley-VCH, 2009, 424p.

[2]. A. Chopik, S. Pasechnik, D. Semerenko, D. Shmeliova, A. Dubtsov, A. K. Srivastava, and V. Chigrinov Electro-optical effects in porous PET films filled with liquid crystal: new possibilities for fiber optics and THZ applications March 15, 2014 / Vol. 39, No. 6 / OPTICS LETTERS, 1453-1456.

[3]. A.S. Lagunov, V.F. Nozdrev, S.V. Pasechnik Anisotropy of ultrasonic absorption in flowing nematic liquid crystals. Sov. Phys.- Acoust. (USA), 1981, v.27, no.4, p.304-308.

[4]. Mendoza CI, Corella Madueño A, Reyes JA. Electrorheological effect and directional non-Newtonian behavior in a nematic capillary subjected to a pressure gradient. Phys Rev E.2008; 77:011706. doi:10.1103/PhysRevE.77.011706.