Absorption current spectroscopy study in inorganic/organic interface containing Au nano-island film and LC layers

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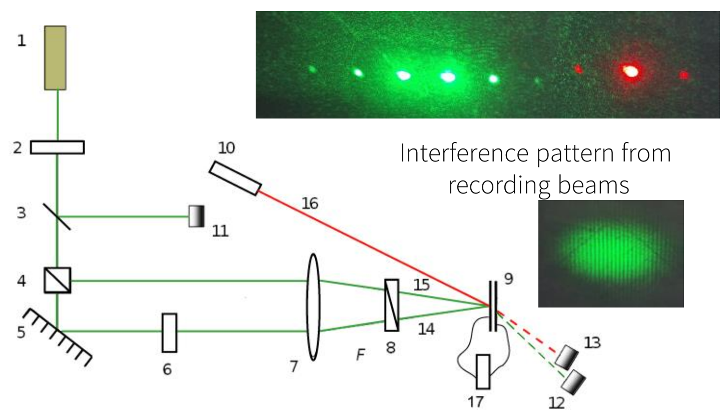
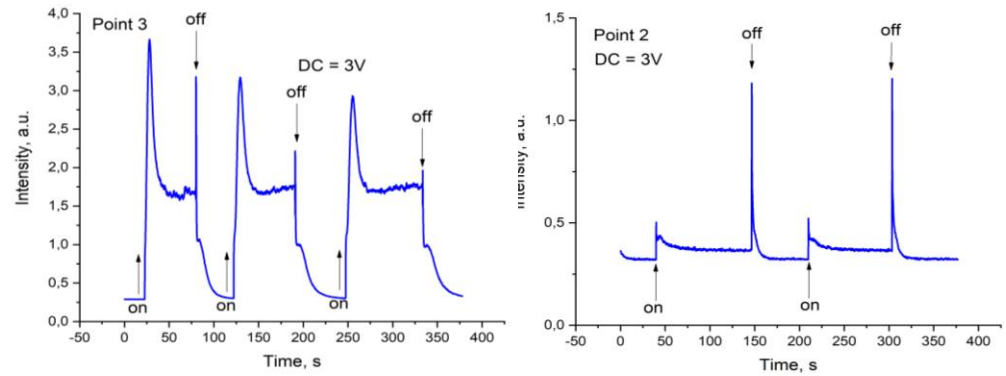
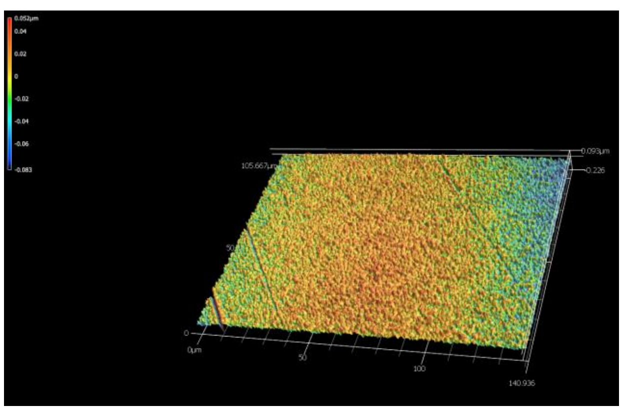
Diffraction orders



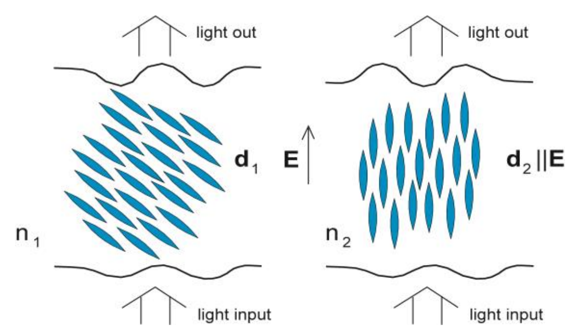
1 – continuous laser (λ=532 nm); 2 – λ/2-waveplates; 3 – beam-splitter plate; 4 – beam splitter cube; 5 – mirror; 6, 8 – polarizers; 7 – lens; 9 – sample; 10 – He-Ne laser (λ=632.8 nm); 11, 12, 13 – photodiodes, 14, 15 – recording beams for self-diffraction; 16 – a probe beam; 17 – power supply.



Experimental kinetics of the dynamic gratings received for the hybrid LC cell with Au film prepared with thermal annealing at 650^0C.



3D image from KEYENCE 3D Laser Scanning Microscope for sample with Au film thickness
d = 50 nm



Under the influence of an electric field, the optical transmission and refractive index in the LC cell change due to the reorientation of LC molecules.

Theoretical model for dynamic grating kinetics in nematic LC: We investigate the change in the liquid crystal (LC) molecular director within the cell volume, considering the elastic and viscous forces of the LC system while neglecting the forces acting near and on the surface. For this purpose, the Ericksen-Leslie model, developed for bulk LC, is used in the single-constant approximation for the elastic moduli, where $K_{33} = K_{11} = K$.

$$\frac{\partial\theta}{\partial t} = \frac{K_{33}}{\gamma_1}\cdot\frac{\partial\theta}{\partial t} + \frac{\varepsilon_0\Delta\varepsilon}{\gamma_1}\cdot\sin(\theta)\cos(\theta)\cdot E^2$$

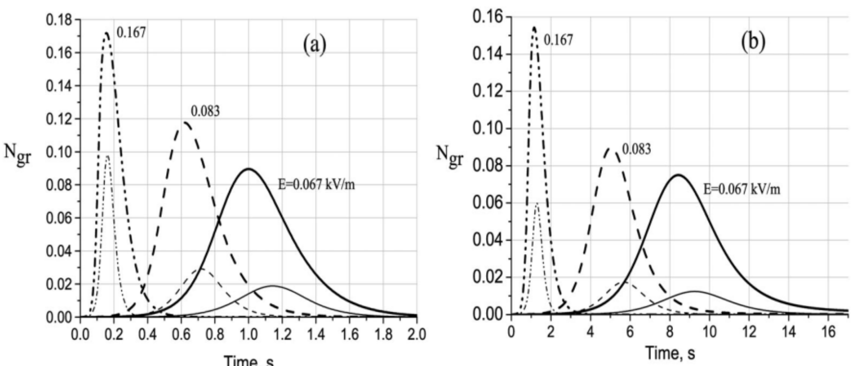
Nematic LCs exhibit a linear electro-optical effect (Pockels effect). The Pockels effect in LCs has the peculiarity that it is associated with the reorientation of the optical axis. In this case, if the angle of LC direction changes in the plane *(x, z)*, only the value of the extraordinary refractive index undergoes changes. The change over time $n_e(t)$ can be related to changes in *θ(t, z)* and the values of $n_{\parallel}$ and $n_{\perp}$ using the formula:

$$n_e(t) = \frac{n_{\parallel} n_{\perp}}{\sqrt{n_{\parallel}^2\cos^2\theta(t,z) + n_{\perp}^2\sin^2\theta(t,z)}}$$

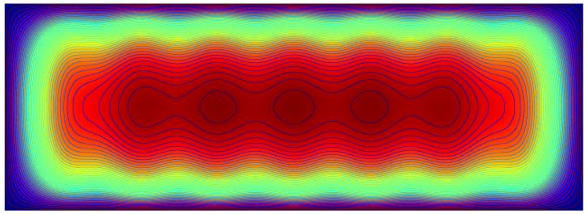
Spatially periodic electric field: $E = E_z\sin(x\cdot 2\pi/\Lambda)$

Grating modulation depth: $N_{gr} = n_e(E_{min}) - n_e(E_{max})$

In the developed theory for the Fredericks transition based on minimizing the free energy in a nematic LC, it was found that the reorientation time is directly proportional to the value of the rotation viscosity γ_1. The results of our calculations for recording a dynamic grating are shown in the Fig.:



Kinetics of the dynamic grating Ngr, which is formed in the bulk of the LC cell under the action of a constant electric field with a periodic sinusoidal structure along the x axis, for LC 5CB (a), and LC mixture LC1264 (b).



Parameters:
E_0 = 0.167 kV/m (U = 5 V)
Spatial period Λ = 30 µm
Grating recording time t = 10.1s
Cell thickness L = 30 µm
LC material: 5CB.

A dynamic grating with low modulation depth—defined by the difference between the maximum and minimum refractive index values. Such a grating forms when the spatial period of the interference pattern is small (compared to the cell thickness), at high applied voltage, or when the electric field is applied for a prolonged duration.

S. Bugaychuk, L. Viduta, A. Gridyakina, H. Bordyuh, V. Styopkin, L. Tarakhan, V. Nechytaylo, Faster nonlinear optical response in liquid crystal cells containing gold nano-island films, Applied Nanoscience (Switzerland), 10:4965-4970, (2020).

Conclusions:

1. The reorientation time depends on LC elasticity, viscosity, electric field strength, and spatial confinement parameters, such as cell thickness and the spatial period of the sinusoidal field. Spatial confinement significantly reduces the reorientation time.
2. For the first time, the kinetics of refractive index dynamic grating formation under a spatially modulated electric field have been studied. A short-lived dynamic grating forms under a constant field, while increased rotational viscosity prolongs reorientation time, leading to quasi-stationary gratings. However, fast dynamic gratings were not observed in two-wave interaction experiments with bulk LC cells.
3. The study provides insights into photorefractive mechanisms in LCs, where an optical interference pattern generates unstable electric charge, creating an internal field that modulates the LC director. Our modeling estimates threshold field values for dynamic phase grating formation. These gratings have applications in signal and image processing.