Modelling of static electric field effect on nematic liquid crystal director orientation in side-electrode cell

A.A. Ayriyan[1], E.A. Ayrjan[1], M. Dencheva-Zarkova[3], A.A. Egorov[2], G.B. Hadjichristov[3], Y.G. Marinov[3], I.A. Maslyanitsyn[2], A.G. Petrov[3], L. Popova[3], V.D. Shigorin[2], A. Strigazzi[4,5] and S.I. Torgova[6]

[1] *Laboratory of Information Technologies, Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Moscow region, 141980 Russia*

[2] *Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, Moscow, 119991 Russia*

[3] *Georgi Nadjakov Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko chaussee, Sofia 1784, Bulgaria*

[4] *Department of Applied Science and Technology (DISAT), Physics Institute of Condensed Matter and Complex Systems, CNISM, Politecnico di Torino, c. Duca degli Abruzzi 24, 10129 Torino, Italy*

[5] *National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe Ave. 31, Moscow, 115409 Russia*

[6] *Lebedev Physical Institute, Russian Academy of Sciences, Leninsky pr. 53, Moscow, 119991 Russia*

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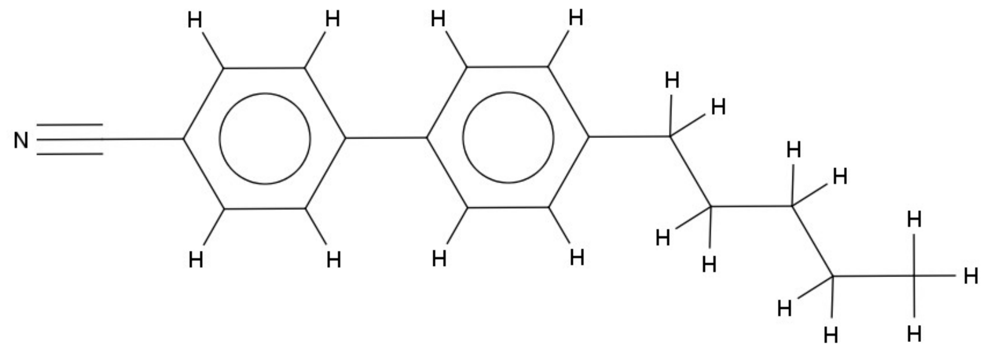
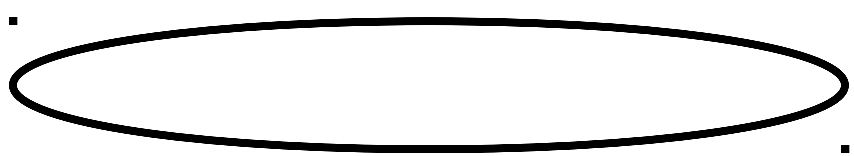
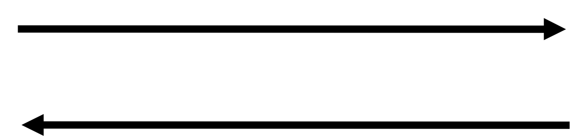
Nematic liquid crystal (NLC)



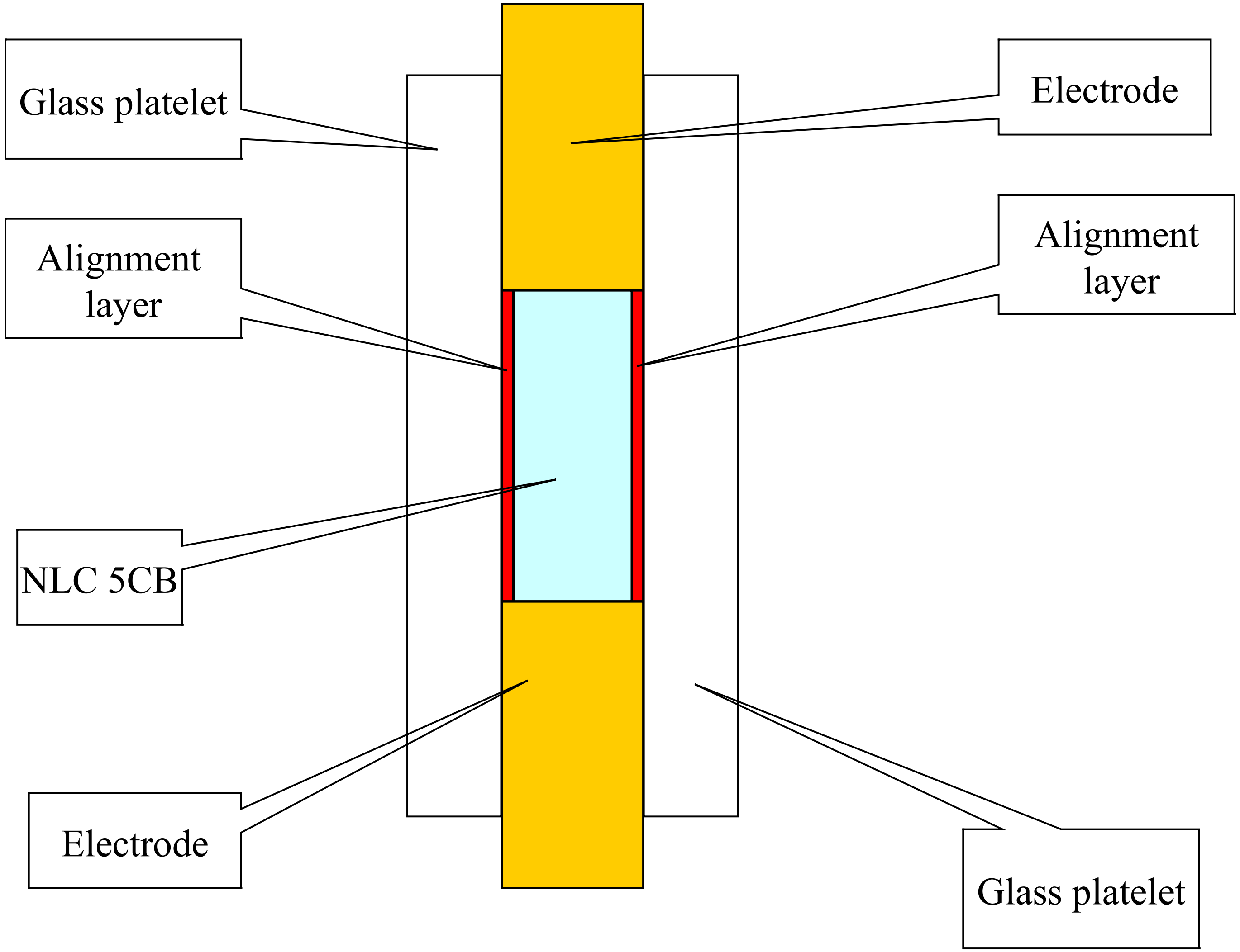
4-Cyano-4'-pentylbiphenyl (5CB)



Director (***n*, *L*, *d***) - direction of preferentional alignment



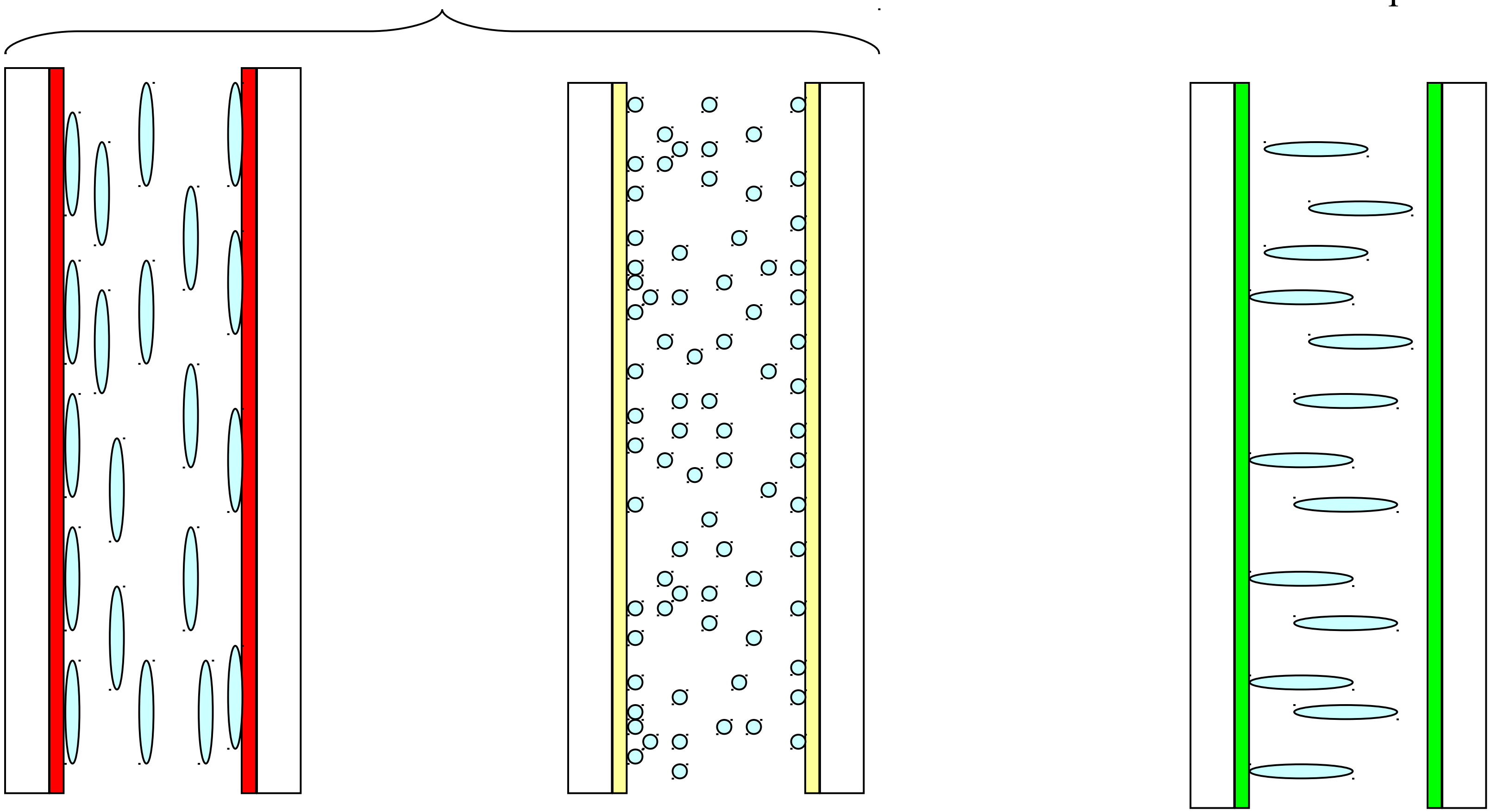
Cross-section of LC cell



Types of alignment in LC cell (without electric field *E*)

planar

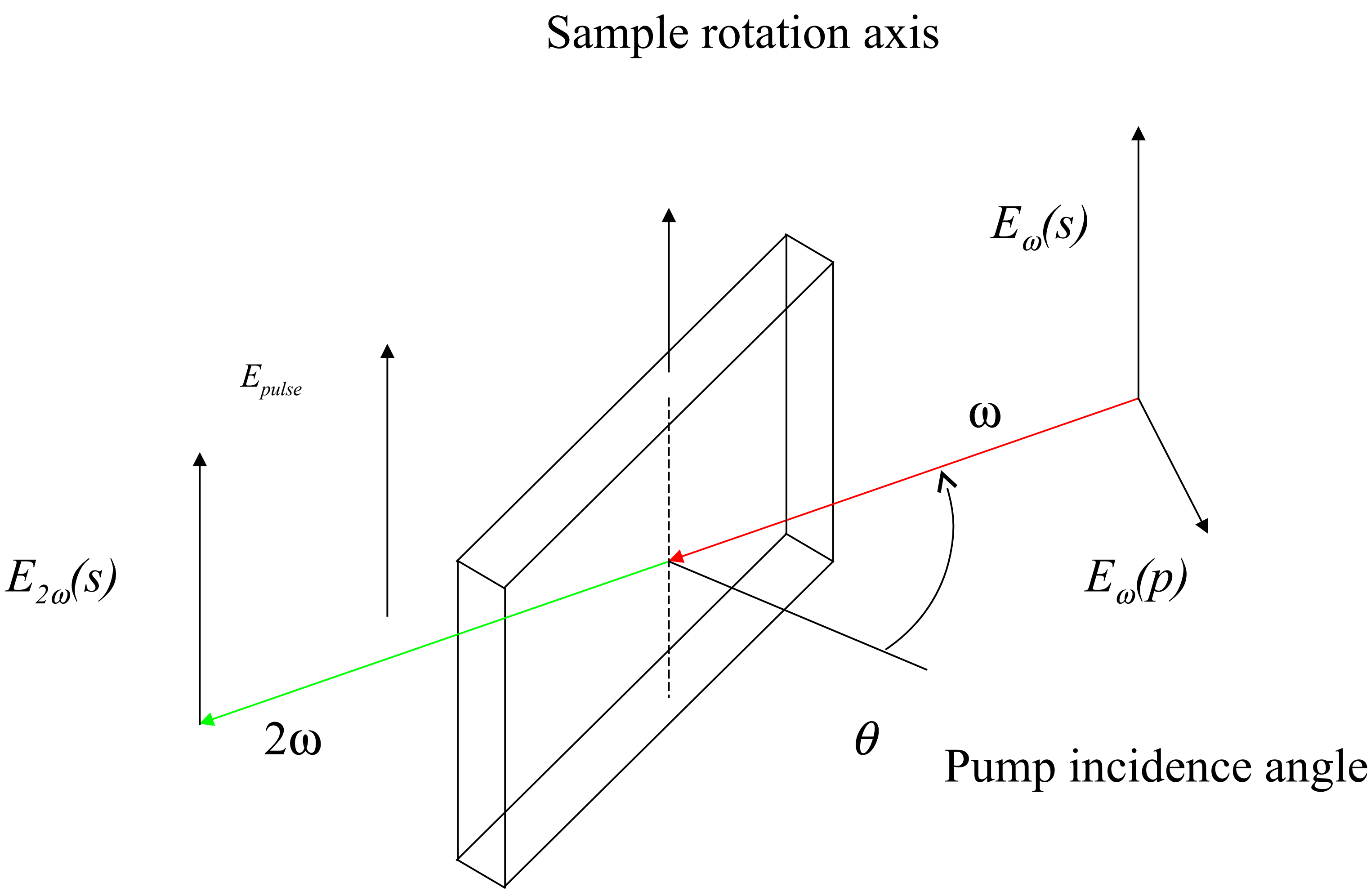
homeotropic

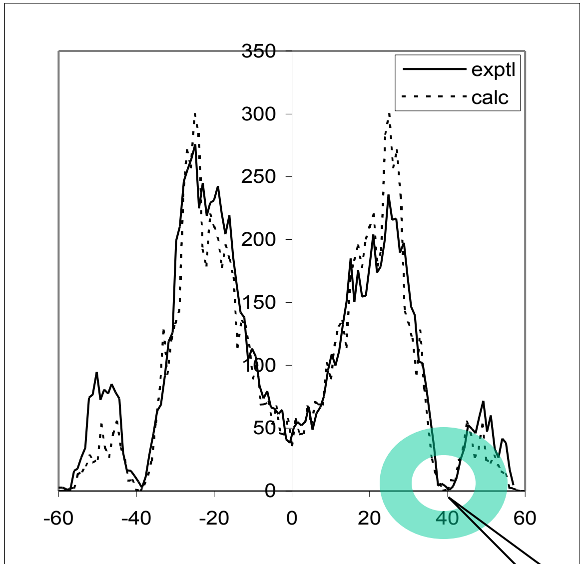


Rubbing parallel to the short side of the cell

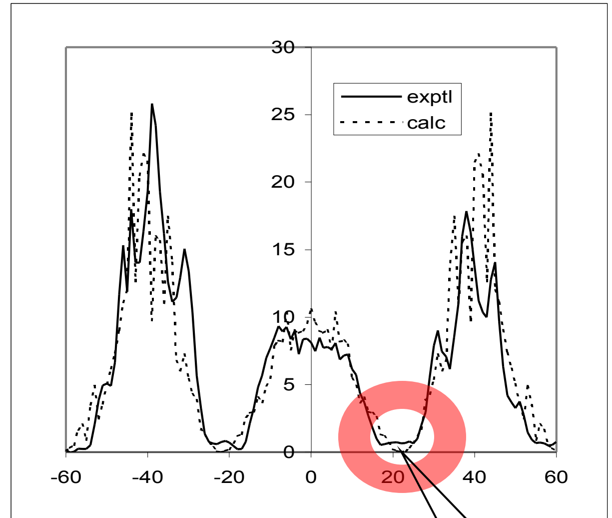
Rubbing parallel to the long side of the cell

Second harmonic generation (SHG) experiment





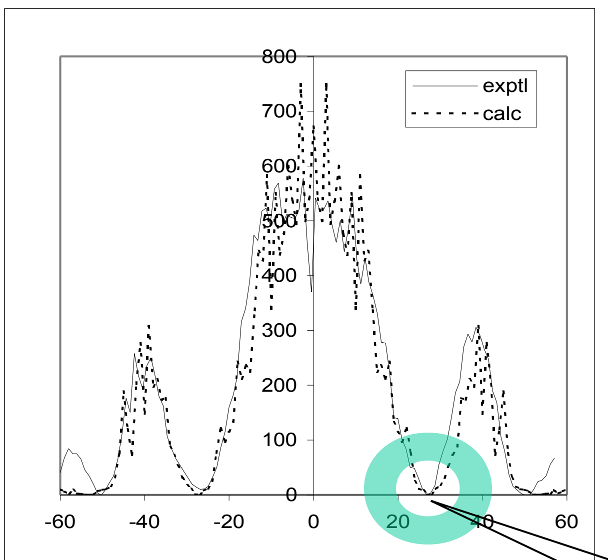
Nitrobenzene



5CB, initial director alignment is orthogonal to the field direction

Parabolic-like shape, homogeneous isotropic liquid

Meander-like shape, possible explanation: inhomogeneous NLC several layers of NLC in the same cell with abrupt change of the director alignment along laser beam. Contradiction: abrupt changes (i.e., narrow borders) are believed impossible inside NLC



5CB, director alignment is along field direction

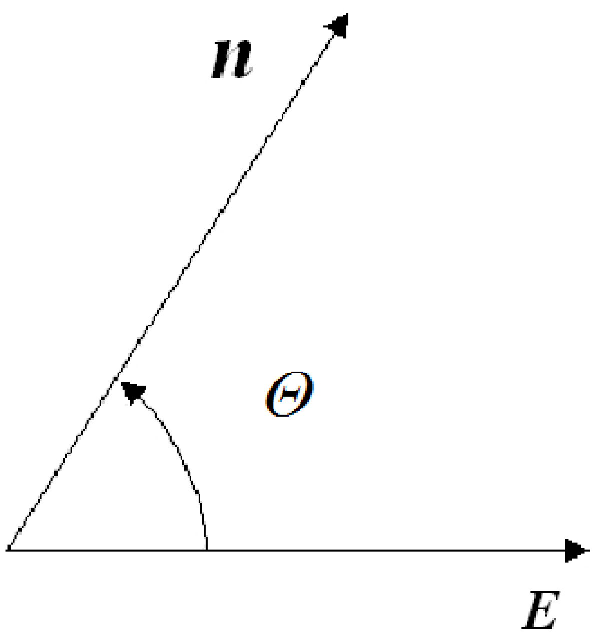
Parabolic-like shape, homogeneous NLC

Horizontal axes - pump incidence angle, deg.
Vertical axes - SH intensity in arb. units.

Frederiks transition

Frederiks transition - reordering of the LC director in relatively strong electric E or magnetic H field

<u>One-dimensional model</u>



$$K\frac{\partial^2\theta}{\partial z^2}+\varepsilon_0\,\Delta\varepsilon E^2\sin\theta\cos\theta=\gamma_1\frac{\partial\theta}{\partial t}$$

$\theta\,(z,\ t)$ - deformation angle,

Distance between glass platelets: d = 100 μm

5CB parameters:

$K = 3.60\cdot 10^{-12}$ N,
$\Delta\varepsilon =$ 11.5
$\gamma_1 =$ 0.064 Pa·s

Numerical method

The implicit finite difference approximation of the equation can be considered on the uniform mesh:

$$\gamma_1 \frac{\theta_i^{k+1} - \theta_i^k}{\tau} = K_{22} \frac{1}{h^2} \left[\theta_{i-1}^{k+1} - 2\theta_i^{k+1} + \theta_{i+1}^{k+1}\right] + \frac{1}{2} \varepsilon_0 \Delta\varepsilon \left(E^k\right)^2 \sin\left(2\theta_i^k\right),$$

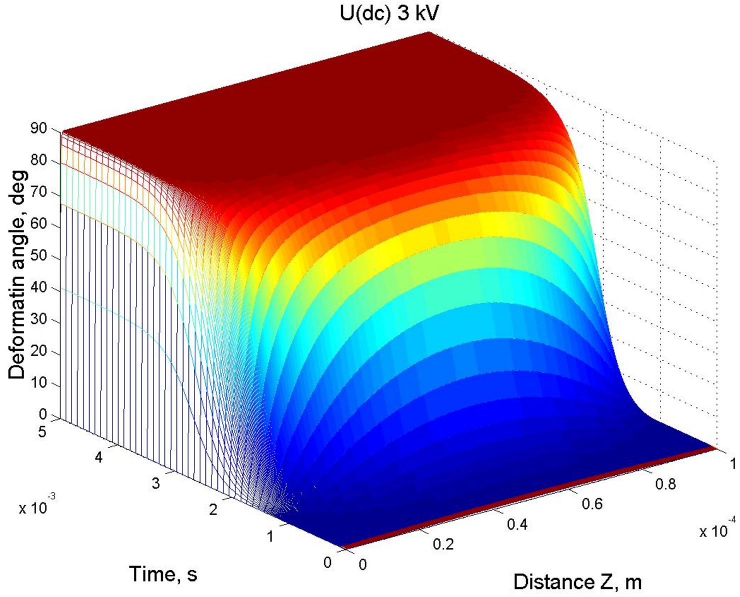
$$\begin{aligned} \overline{\omega} \;\; = \{(t,z) \;\; | \;\; & 0 \le t < \infty, \quad t_i = k \cdot \tau, \quad k \in \mathbb{N}_0; \\ & 0 \le z \le 10^{-4}, \quad z_j = j \cdot h, \quad j = 0 \ldots N_z\}. \end{aligned}$$

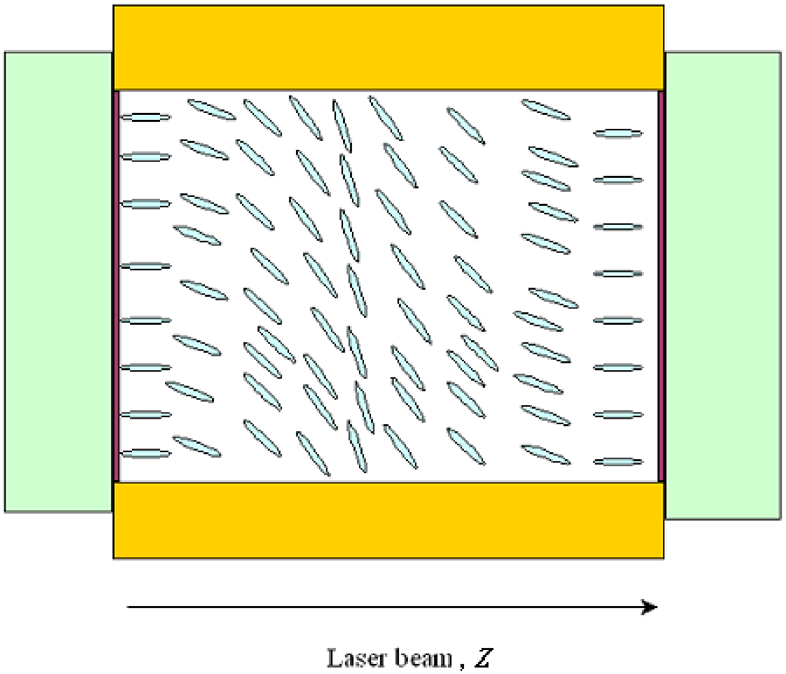
where h and τ are spatial and time steps correspondingly.

Boundary and initial conditions are following:

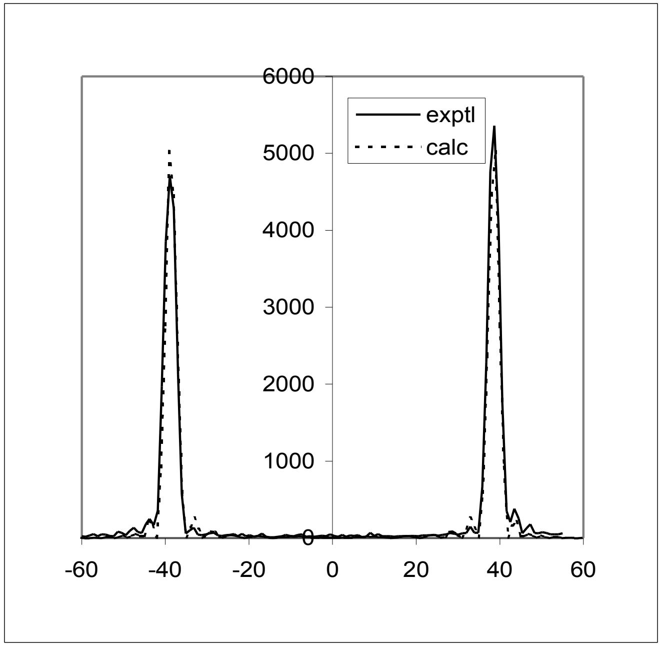
$$\theta_{i=0}^k = 0.0174, \qquad \theta_{i=N_z}^k = 0.0174 \qquad \forall k$$

$$\theta_i^{k=0} = 0.0174, \qquad \forall i$$





One-dimensional case solution. There are smooth changes of deformation angle. No layers and no borders between layers. Most part of the LC is effected by electric field.

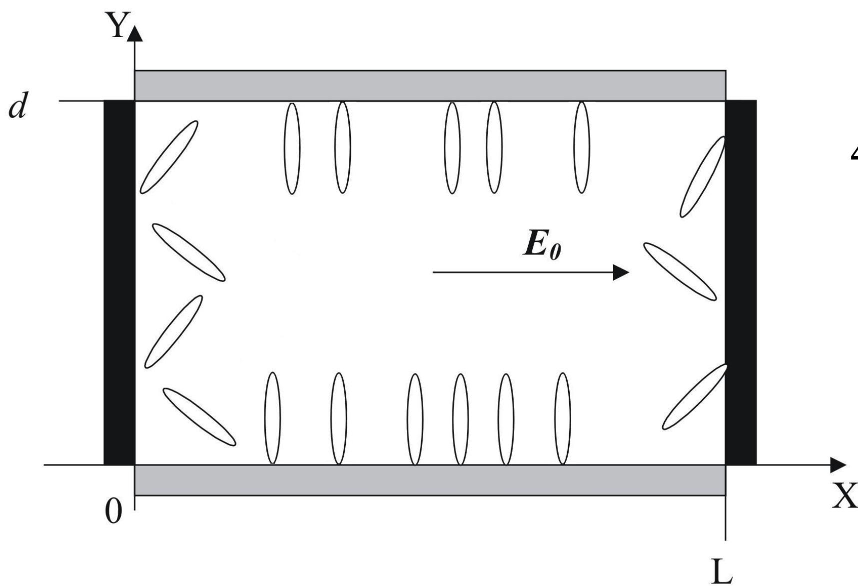


Phase matching SHG angles correspond to unperturbed director alignment (0°), i.e., significant part of LC is not effected by electric field

<u>Conclusion</u>:

One-dimensional model is in contradiction with the experiment and have to be replaced by

Two-dimensional model: the effect of electrodes



$$4K\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}\right)+\frac{1}{2}\varepsilon_0 \Delta\varepsilon E^2 \sin 2\theta = 0$$

Cell dimensions:
Distance between glass platelets: $d = 100\ \mu m$
Distance between electrodes: $L = 2$ mm

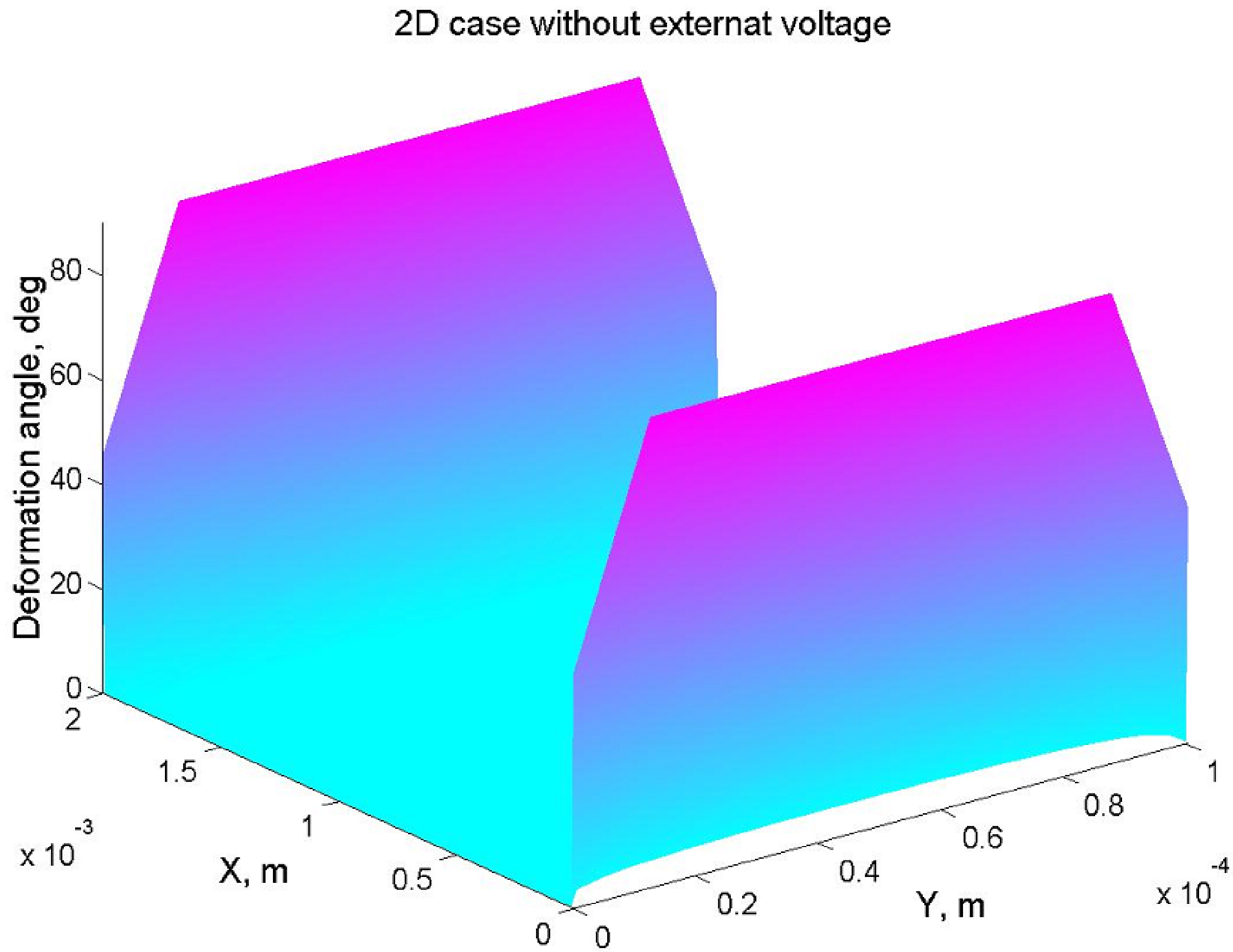
Border conditions:
as in previous case, at the surfaces of glass platelets:

$$\theta(x, 0) = \theta(x, d) = 0$$

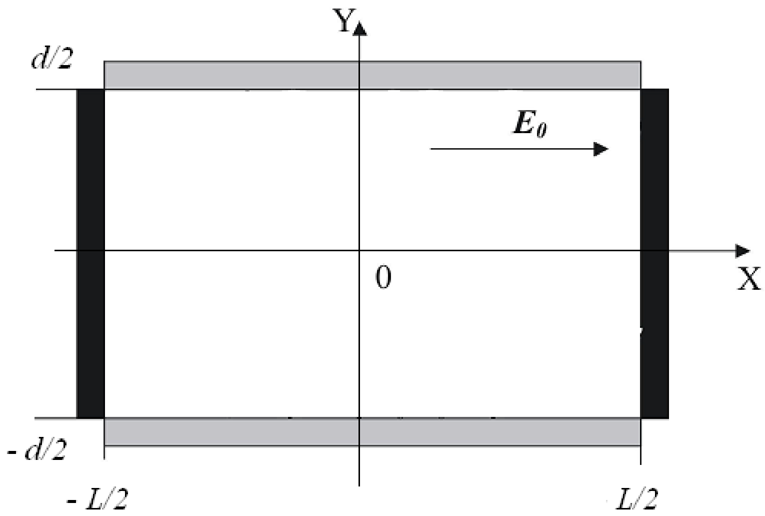
In 2D case additional borders are introduced, the surfaces of electrodes with the alignment approximated by:

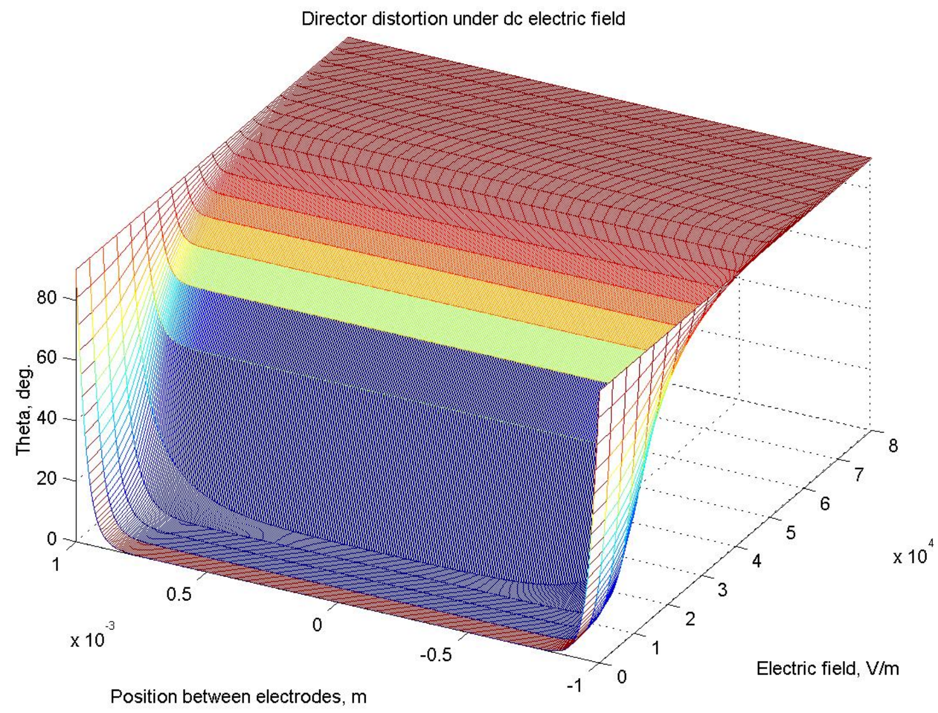
$$\theta(0, y) = \theta(L, y) = \pi/2$$

Electrodes disturb NLC alignment introduced by glass surfaces

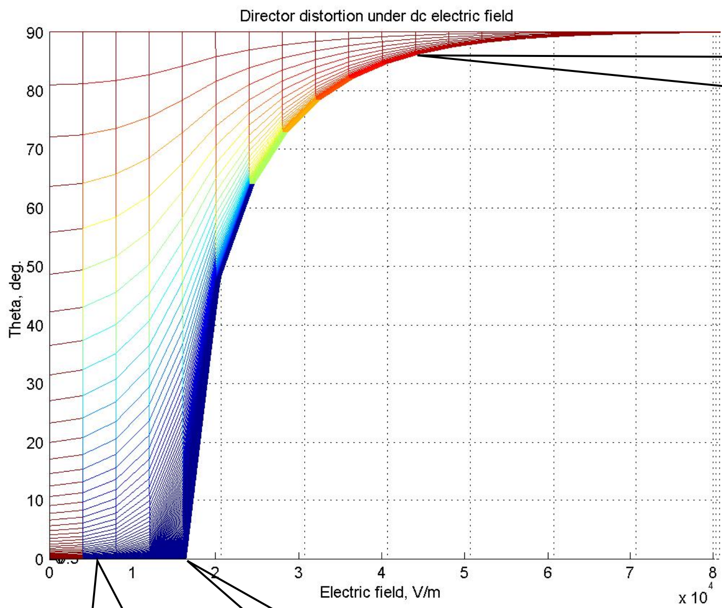


The size of distorted region is comparable to the distance between glass platelets





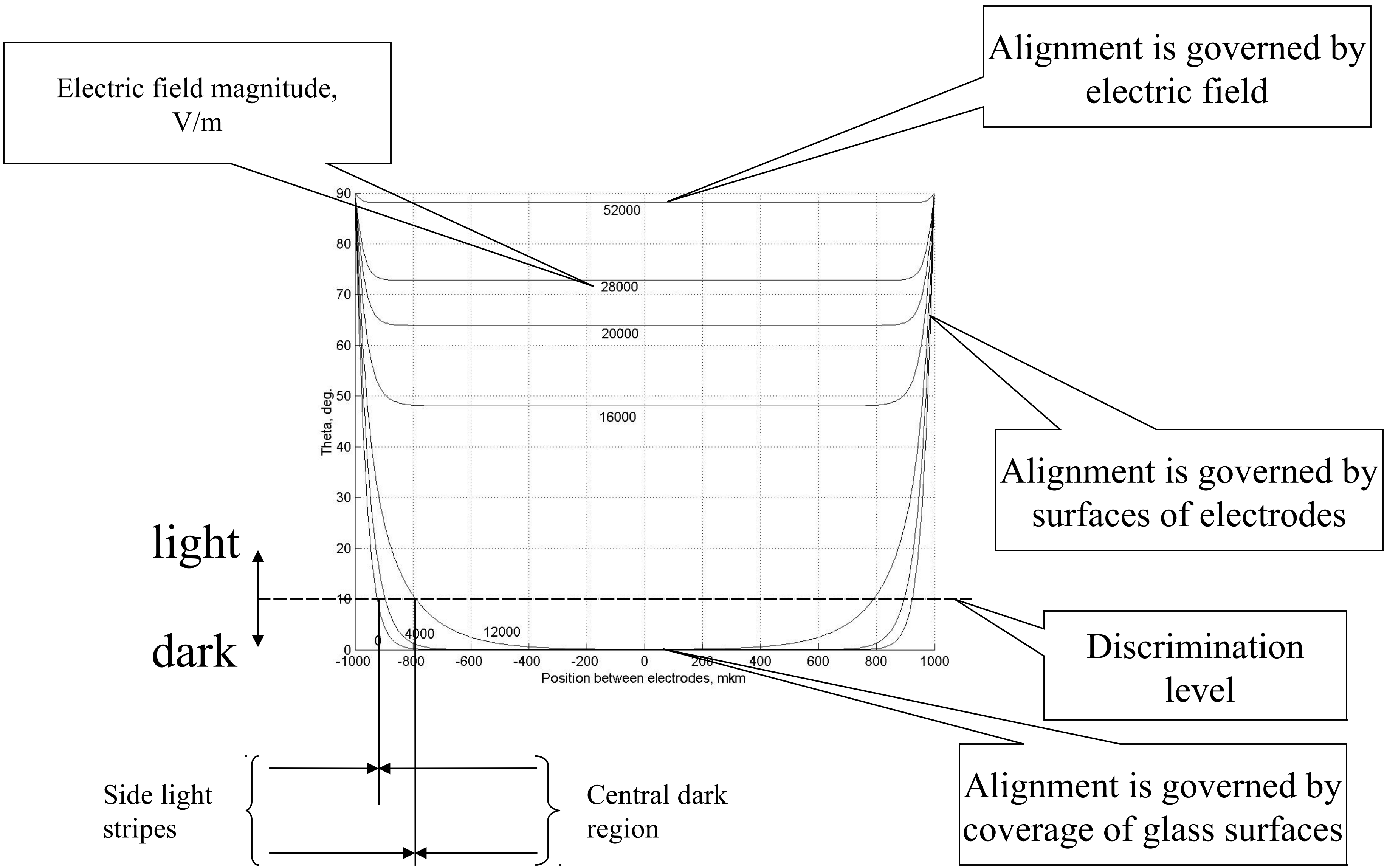
Solutions for cross-section $y = 0$

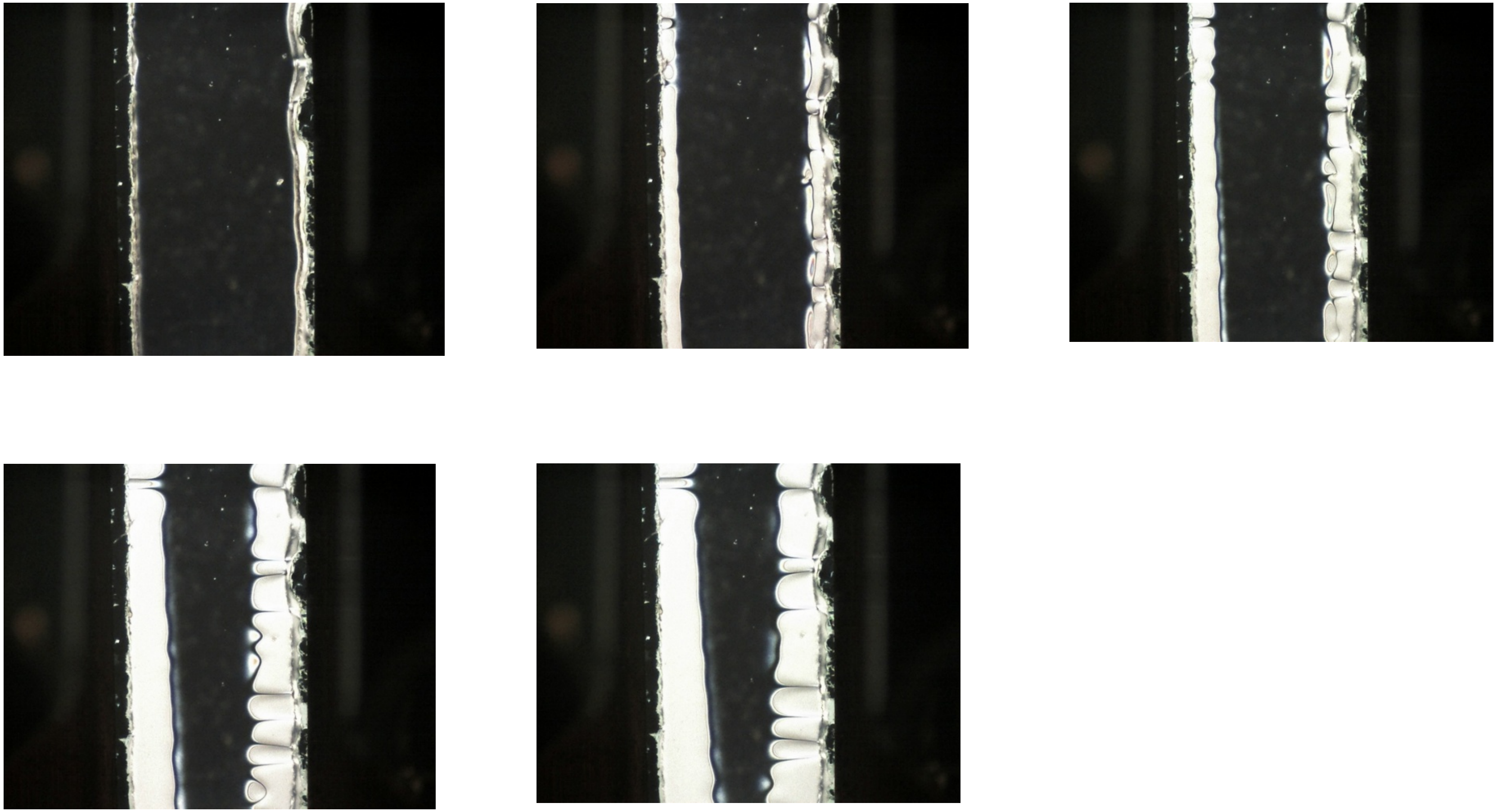


Alignment is governed by electric field

Alignment is governed by coverage of glass surfaces

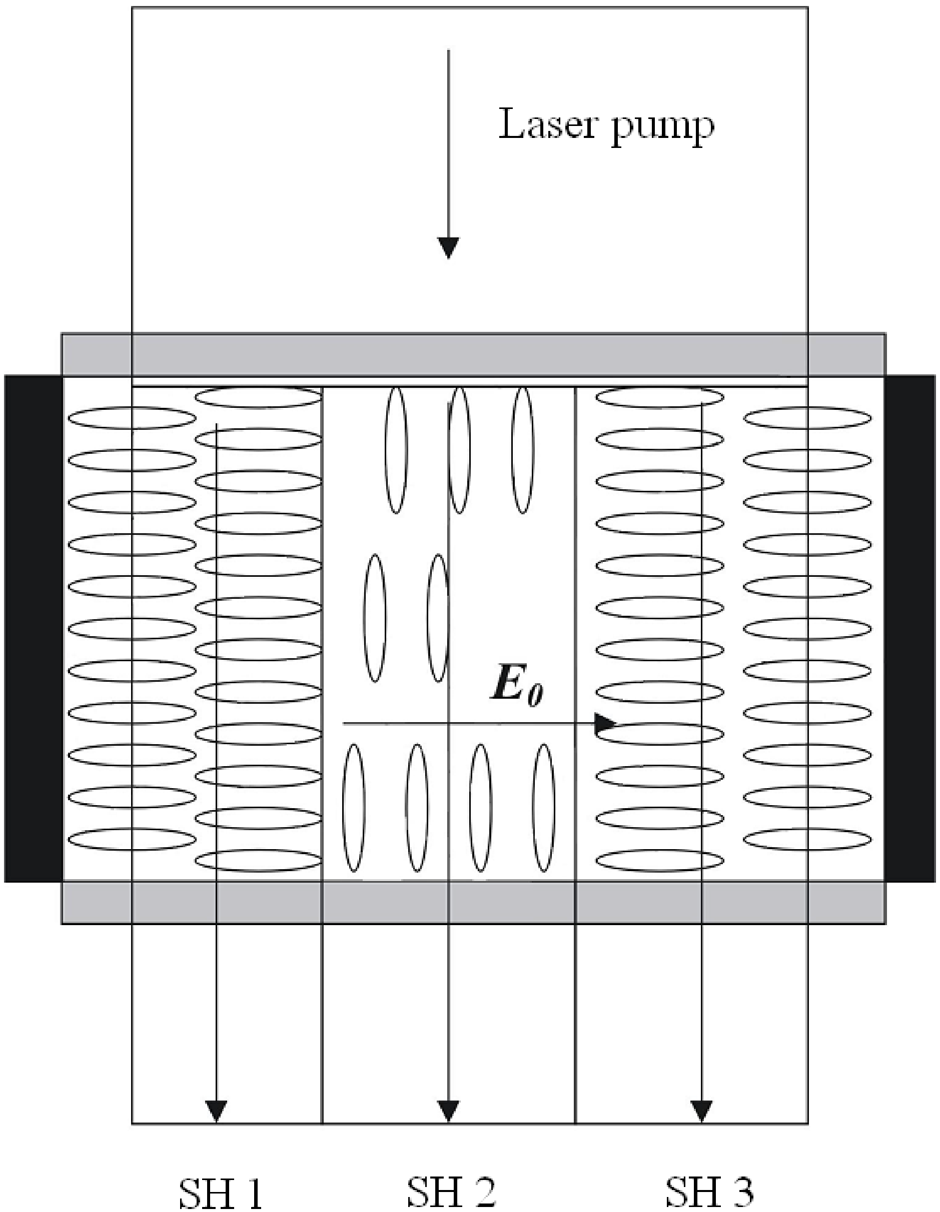
Frederiks threshold for point (x = 0, y = 0)


Electric field magnitude, V/m
Alignment is governed by electric field
Alignment is governed by surfaces of electrodes
Discrimination level
Alignment is governed by coverage of glass surfaces
light
dark
Side light stripes
Central dark region
Theta, deg.
Position between electrodes, mkm
52000
28000
20000
16000
12000
4000
0
90
80
70
60
50
40
30
20
10
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000



Polarisation microscopy images of NLC cell.

Central undistorted region (dark) is between two distorted regions (light stripes). Opaque electrodes are outside of light stripes. The electric field was applied: 1-st image - initial, without field, 2-nd - 2 min, 3-rd - 4 min, the last- 16 min.



Explanation of SHG results:
This is an aperture effect.
Laser pump beam passes
LC regions with quite different
director alignment and produces several SH beams.
The interference of SH beams results in observed
complicated angular dependencies.

Explanation of another contradiction:
Needed narrow borders at this geometry are
due to glass surfaces, not between different parts
of the NLC.

Summary

Two-dimensional model of Fredericks effect was used for the investigation of the static electric field influence on nematic liquid crystal director orientation in the side–electrode cell. The solutions were obtained by finite-difference methods.

The programs for numerical solution of two-dimensional parabolic partial differential equation were developed by using both FORTRAN and C/C++.

Fredericks transition threshold for the central part of the cell, as well as dependencies of the distribution of the director orientation patterns on the electric field and location were obtained. The results of the calculation were compared to the experiment.

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Thanks for attention!