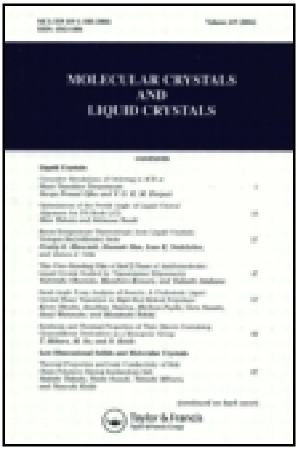

Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl17

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Version of record first published: 22 Sep 2006.

Mol. Cryst. Liq. Cryst. 1990, Vol. 193, pp. 43-50
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Printed in the United States of America

A MODEL FOR THE SPACE-NONUNIFORM ELECTRIC FIELD IN A NEMATIC LIQUID CRYSTAL OVER A DIELECTRIC DEFECT

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Abstract. An injection model for the space-nonuniform electric field over the dielectric defect is discussed. The model is based on the investigation of the orientational electrooptical effect in the nematic liquid crystal with positive dielectric anisotropy at homeotropic initial orientation of the director relative to the substrate in semiconductor-dielectric-nematic liquid crystal-metal structure.

Dielectric film defect detection by nematic liquid crystals (NLC) is based on visualization of space-nonuniform electric fields in the bulk of the NLC over the dielectric defect. In this case electrooptical response of the NLC in layered structure like semiconductor-dielectric-NLC-metal (S-D-NLC-M), which includes the film under study, is investigated. The interpretation of the results of the dielectric film nondestructive check depends on the completeness of theoretical models used as the basis for the NLC defectoscopy method. The physical ground of the NLC defectoscopy method is NLC electrooptics in the space-nonuniform electric field [I], but the nature of the nonuniform field nearby the defect in S-D-NLC-M structure still remains to be investigated.

In this paper it is suggested that the dielectric defect is only the original cause of the space-nonuniform electric field formation and the field itself is formed by liquid crystal (LC) ion charges. For the investigations $Si-SiO_2-NLC-SnO_2$ structure with the defects in SiO_2 layer was chosen. The space-nonuniform electric field configuration and the intensity of the field depend not only on the defect properties, but on the NLC electric conduction [2], dielectric anisotropy sign, power supply mode and sample history as well. These results cannot be explained by the electrostatic model of the field.

To obtain the qualitative pattern of nonuniform electric field distribution along the thickness of the NLC layer over the dielectric defect the orientational electrooptical effect in the NLC with positive dielectric anisotropy ($\Delta\varepsilon > 0$) at homeotropic initial orientation of the director (splay-bend-S-B effect) was used. Note, that bend-effect, traditionally used in the NLC defect detection, showed to be unstable for experiments on the visualization of nonuniform electric field local regions near the substrate for S-D-NLC-M system. S-B-effect, having no analogs in uniform electric field electrooptics [3] allows for applying an alternating voltage to structures like S-D-NLC-M. In the case of nonuniform electric field, NLC with positive dielectric anisotropy of $\Delta\varepsilon > 0$ responds to the tangential component of the field only.

To clarify the nature of the space-nonuniform electric field, responsible for the NLC layer deformation nearby the defect, the following experiments have been conducted. In the layer with S-B-effect under the constant voltage some oxide defects have been visualized. In this case the structure for some period of time has been kept under the constant voltage with the negative electrode on silicon. Upon setting the stationary optical pattern, the upper electrode (SnO_2) was shifted mechanically. If the experiment is repeated at d.c. electric field, these defects can be visualized in the same oxide layer regions. However, at alternating voltage we can visualize both the real defects of the SiO_2 layer in the same regions and "pseudodefects", shifted along the layer with the upper electrode. "Pseudodefects" correspond to the nonuniform electric field regions, formed in the LC layer over the defect before the upper electrode was shifted. Along with the upper electrode the shift of the nonuniform field region occurs, which, evidently, is associated with the shift of the space charge region. This is shown in Fig. 1; on the left-hand side the real defects of oxide SiO_2 are illustrated and the right-hand side shows the space charge regions, formed by the leakage current through the defect. It should be noted, that at positive electrode on silicon "pseudodefects" do not occur. Apparently, in this case negative charge carrier injection from SiO_2 defect region plays a prominent role.

When voltage is switched off, "pseudodefect" optical trace relaxation time is 600-900 s, which coincides with "apparent" Maxwell relaxation time $\tau = \varepsilon_{eff} \cdot \varepsilon_0 / \sigma$, where ε_{eff} is effective dielectric constant of the LC, representing abnormally large capacity of double electric layers ($\varepsilon_{eff} = 10^3$-10^4) [4]. Thus, double electric layers play an important role in nonuniform electric field formation nearby the dielectric defect. In this case abnormally large capacity of double electric

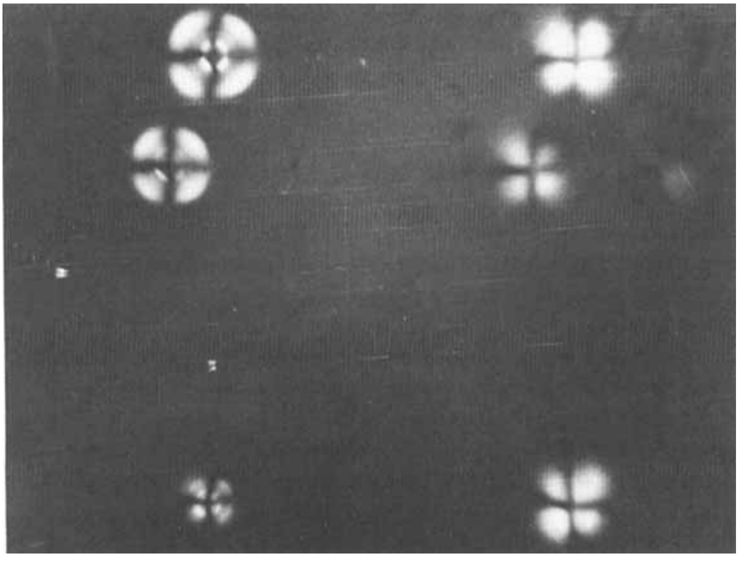

FIGURE 1 Visualization of oxide defects (left-hand side) and of space charge regions (right-hand side) by orientation S-B-effect.

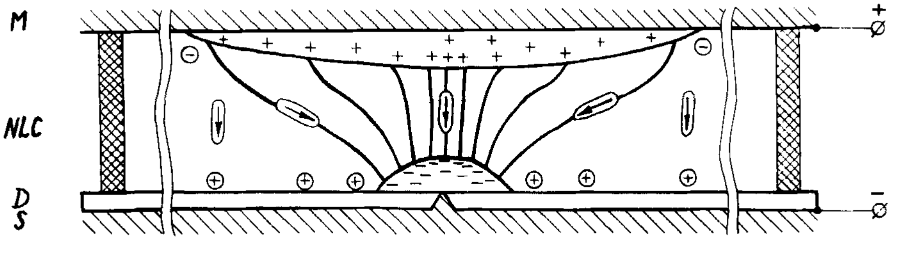

FIGURE 2 A model for the space nonuniform electric field over the dielectric defect.

layer allows for keeping the local charge region nearby the anode and transfering it along with the shift of the anode.

The formation mechanism of this charge region can be explained as follows. A nonuniform electric field region is generated between the negative homocharge, formed nearby the point cathode (defect) by the injected charge carriers, and the plane anode. The field nearby the defect is screened by the homocharge, but in proximity to the anode, as seen from the equation of current continuity, the electric field increases. Thus, there occurs the possibility for positive ion injection from the anode region over the dielectric defect. Therefore in the course of time the configuration of the space-nonuniform electric field over the defect is transformed due to the injection of positive ions from the diffusion region of double electric layer, going into a NLC to a depth of Debye's shielding distance $r_D = (\varepsilon\varepsilon_0 D/\sigma)^{1/2}$. Heterocharges, generated at the polarization of NLC by its own carriers, which can be seen at the visualization of dielectric defects in constant electric fields, also play a particular role in the formation of the space nonuniform electric field configuration in the NLC over the dielectric defect [5]. Consequently, in the external electric field in the bulk of the NLC over the dielectric defect the dynamic process of formation of the space charge region occurs due toothe interdependable homocharge and heterocharge generation processes. Therefore space nonuniform electric field which can be visualized by the nematic, is generated between the negative homocharge nearby the cathode and the positive homocharge nearby the anode as an optical trace of the dielectric defect (Fig. 2). The latter diffuses to relatively large areas as compared to its own defect size. For example, at the defect size of the order 0.5 μm and the thickness of the NLC layer of 20 μm, the size of the diffusion region of the defect optical trace region amounts to 100 - 200 μm. Along with the anode shifting also the positive homocharge is shifted, which can be visualized in the alternating electric field in the form of the optical trace, shown in the right-hand side of Fig. 1.

The direct experiment results have shown the increased ion concentration nearby the anode over the defect. In these experiments a split in SiO_2 layer (linear cathode) as the source of injected ions was chosen to increase the optical pattern contrast. As in the above experiments, the structure was kept under a d.c. voltage for some time with the negative electrode on silicon. Upon shifting of the upper electrode in alternating electric field both the split itself and its "imprint" in the form of the diffusion region can be visualized (Fig. 3,a). Then, the conditions of the experiment has been modified: instead of applying external alternating voltage the structure was gradually heated. In diffusion regions just before the NLC-isotropic substance phase transition, which occurs at temperature lower than that of the remaining area of the sample, homeotropy-planar transition takes place (Fig. 3, b). Similar experiments are easily duplicated for point defects. In the nematic mesophase directly preceding NLC-isotropic substance phase transition, interaction between mesogenic molecules is lower than that of the molecules with the substrate, i.e. there is some increase of cohesive energy of the NLC with the substrate, which is the cause of the homeotropy-planar transition. The investigations showed that this effect can be applied for the visualization of ion charge accumulation areas in the NLC over integrated circuits. The above experimental results indicate the increased concentration of ions nearby the anode over the defect, which like any other impurities lower the phase transition temperature.

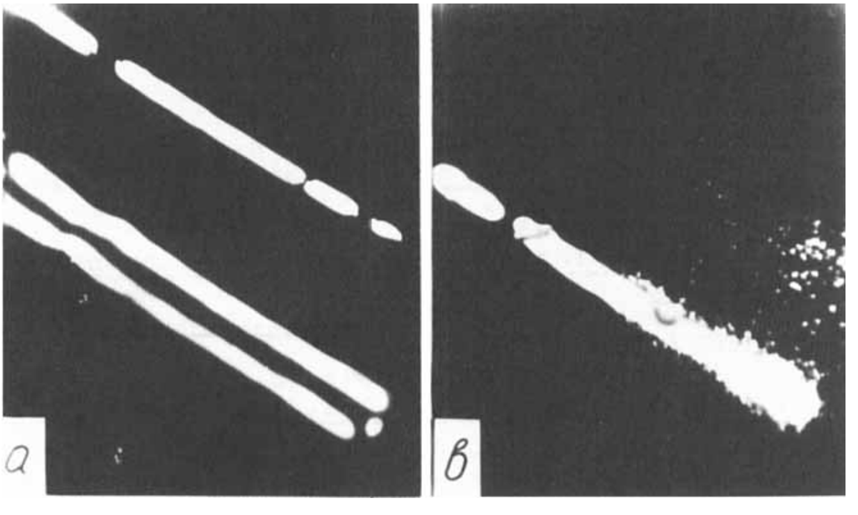

FIGURE 3 Visualization of the oxide SiO_2 split (the upper optic trace) and space charge region (double line) by Frederiks' transition (a); visualization of space charge region by homeotropy-planar transition (b).

Similar experiments with the observation of the peculiar optical hysteresis, associated with the space charges and double electric layers also easily duplicated in the case of more complex structures such as integrated circuit components and another thin film devices.

Hence, the basic physical principle of non-destructive check method, using the NLC, can be formulated as follows: liquid crystal ion charges generate the space-nonuniform electric field regions in the bulk of a NLC over the defects or thin film components and the NLC propoerly visualizes these fields through its electrooptical response.

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