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Hysteresis of surface plasmon polariton effective index induced by liquid crystal reorientation

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INTRODUCTION

We present a theoretical study of the effect of the orientational instability of a nematic liquid crystal (NLC) on the value of the effective refractive index of a surface plasmon polariton. A plane-parallel NLC cell with an initial homeotropic orientation of the director is considered. The cell is placed in a constant electric field parallel to its substrates (Figure 1). The external electric field can lead to a change in the orientation of the director in the NLC cell. One of the polymer substrates of the cell is in contact with a thin layer of metal, so that a surface plasmon polariton can propagate at the interface "NLC" — "polymer film" — "metal". Surface plasmon oscillations are very sensitive to the dielectric properties of the medium, therefore, by changing the electric field strength, it is possible to control the propagation properties of the surface plasmon polariton, in particular, its effective refractive index.

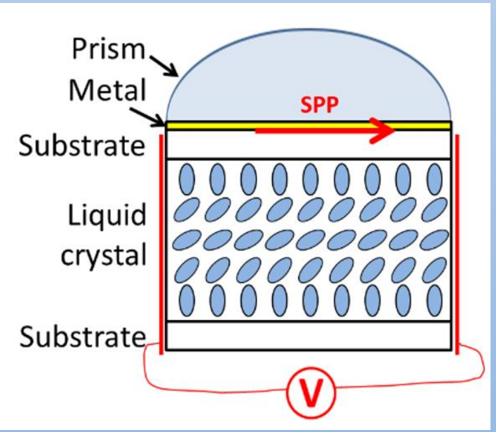

Figure 1. Geometry of the NLC cell

METHODS

The equilibrium distribution of the director vector field in the NLC cell was found by minimization of the free energy functional taking into account different elastic constants and the finite energy of the NLC anchoring with the substrates. In order to establish the hysteresis criterion, both analytical [1] and numeric approaches were used. In order to calculate the analytical expressions for the propagation parameters of the surface plasmon polariton in the structure "NLC" — "polymer film" — "metal" the adapted perturbation theory [2] was used, which was then additionally verified by numerically solving the Maxwell's equations using the finite element method.

HYSTERESIS CRITERIA

Upper hysteresis criterion: $$-\frac{1}{2}(q+3\omega-1)-\frac{2\omega\sin\kappa_{th}L}{\kappa_{th}L}+\frac{\sin 2\kappa_{th}L}{4\kappa_{th}L}(q-\omega-1)<0$$

Lower hysteresis criterion: $$\frac{1}{2}(\tilde{q}-3\tilde{\omega}-1)+\frac{2\tilde{\omega}\sinh\tilde{\kappa}_{th}L}{\tilde{\kappa}_{th}L}+\frac{\sinh 2\tilde{\kappa}_{th}L}{4\tilde{\kappa}_{th}L}(1-\tilde{q}-\tilde{\omega})<0$$

$q = 1 - K_1/K_3$ $\quad \omega = \varepsilon_a/\varepsilon_\parallel$

$\tilde{q} = 1 - K_3/K_1$ $\quad \tilde{\omega} = \varepsilon_a/\varepsilon_\perp$

κ_{th} - first positive root of $\tan\frac{\kappa_{th}L}{2} = \frac{W}{K_3\kappa_{th}}$

$\tilde{\kappa}_{th}$ - first positive root of $\tanh\frac{\tilde{\kappa}_{th}L}{2} = \frac{W}{K_1\tilde{\kappa}_{th}}$

RESULTS

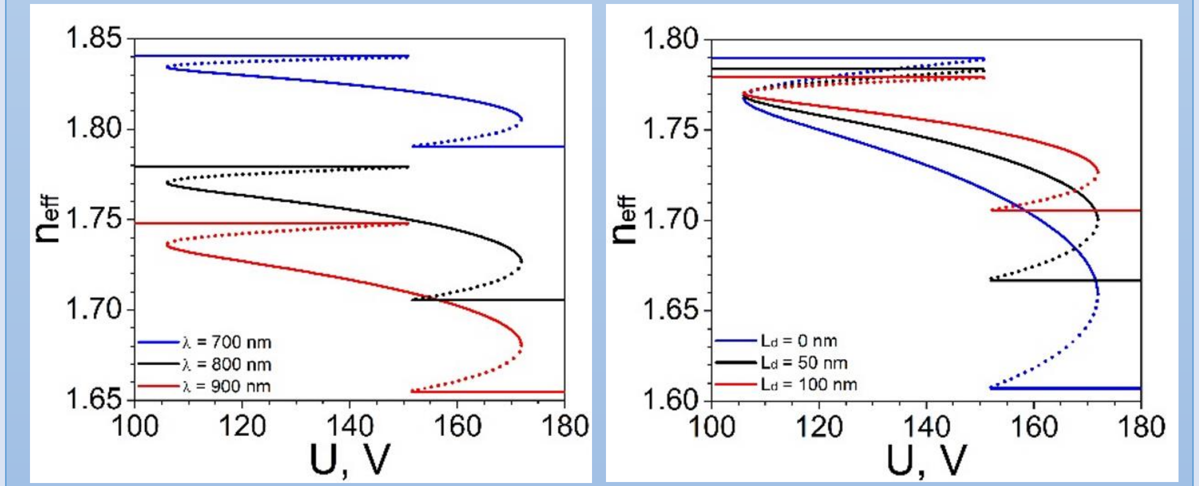

Figure 2. Dependence of the effective refractive index of the surface plasmon polariton on the applied voltage at different wavelengths (left) and at different thicknesses of the polymer film (right).

It was established that the effective refractive index of the surface plasmon polariton in the structure under study (Figure 1) can be accompanied by hysteresis: in certain ranges of applied voltages the value of effective index can have different values depending on the previous state of the system. Analytical expressions for the parameters and conditions for the existence of hysteresis were obtained.

Effective index hysteresis properties depend significantly on the liquid crystal cell parameters. When the coupling energy increases and when the dielectric permittivity ratio $\varepsilon_a/\varepsilon_\parallel$ decreases, the width of the hysteresis decreases. The value of the effective refractive index increases with an increase in the energy of the director's anchoring with the substrate and with a decrease in the values of the wavelength and the applied voltage (Figure 2). The range of possible values of the effective index of the surface polariton expands as the thickness of the polymer film decreases and the wavelength increases.

REFERENCES

[1] Ong, H. L. Optically induced Freedericksz transition and bistability in a nematic liquid crystal. Physical Review A, **28** (1983).
[2] K. Daly, S. Abbott, G. D'Alessandro, D. Smith, M. Kaczmarek. J. Opt. Soc. Am. B. **28** (2011)