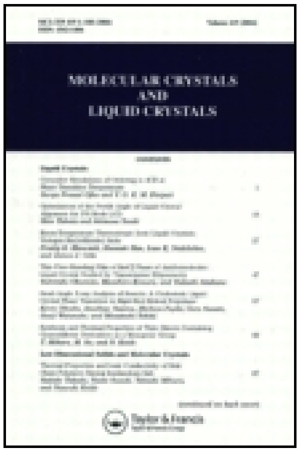

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Theory of Surface Electromagnetic Waves in Cholesteric Liquid Crystals

S. V. Shiyanovskii [a]

[a] Institute for Nuclear Research, Ukrainian Academy of Sciences, Kiev, 252028, USSR
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THEORY OF SURFACE ELECTROMAGNETIC WAVES IN CHOLESTERIC LIQUID CRYSTALS

S.V.SHIYANOVSKII
Institute for Nuclear Research, Ukrainian Academy of Sciences, Kiev, 252028, USSR

Abstract This paper is devoted to the study of the structure and polarization of the predicted[1] surface electromagnetic waves (SEWs), which can propagate along the interface between cholesteric liquid crystal (CLC) and a substrate with small refractive index. It is shown, that these SEWs are generated efficiently by the attenuated total reflection (ATR) method.

INTRODUCTION

SEWs are widely used for the investigation of boundary layers in various media[2]. However two conditions $\varepsilon_1+\varepsilon_2<0$, $\varepsilon_1\varepsilon_2<0$ should be satisfied for SEW existence on the interface of homogeneous media.

Cossel predicted[3,4] another mode of SEW on the boundary of the periodic medium, that is analogous to Tamm surface states[5]. This mode, arising by effect of Bragg diffraction in the periodic medium and total internal reflection in the substrate, has been observed in stratified structures with isotropic layers[4]. The study of this mode in media with nondiagonal susceptibility tensor is of great interest, because the wave equation does not reduce to the scalar form in this case and the number of new features should be observed: dependence of dispersion curves on propagation direction, the complex polarization of SEWs et al. The ideal example of such a medium is CLC with the helical structure.

DISPERSION CURVES OF SURFACE WAVES

SEWs in homogeneous media are TM-modes. SEWs found in papers[3,4] are TE-modes. SEWs in CLC are neither TE-modes nor TM-modes, because decreasing waves in CLC are elliptically polarized. Therefore all decreasing solutions of wave equation in CLC and substrate should be taken into account

$$\underline{E}_{clc}(z>0) = \sum_j \underline{E}_j(z)\cdot \exp\left[i(kx-wt)-g_j z\right]$$
$$\underline{E}_{sub}(z<0) = \underline{E}_o\cdot \exp\left[i(kx-wt)+hz\right] \qquad (1)$$

where $Re(g_j) > 0$, $h^2 = k^2 - \varepsilon_{sub}\frac{w^2}{c^2}$, $\underline{E}_j(z+\frac{p}{2}) = \underline{E}_j(z)$, p is the helical pitch.

SEWs exist if formulas (1) are consistent and satisfy four continuity conditions on the boundary (z=0) for tangential components of electric and magnetic fields. In this case the conditions for normal components are satisfied identically ($D_z = \frac{-k\cdot c}{w}\cdot H_y$, $H_z = \frac{k\cdot c}{w}\cdot E_y$). Continuity of the electric field is adjusted by E_{ox} and E_{oy} whereas two remaining conditions determine the dispersion curves of SEWs.

The decreasing waves caused by first order Bragg diffraction appear in the region $k \approx k_B = \frac{2\pi}{p}\cot\theta_B$, where Bragg angle is determined by[6]

$$\sin \theta_B = \frac{2\pi c}{w \cdot p}\sqrt{\varepsilon_{1c}\left(1 - \frac{\delta}{2}\cos^2\theta_B\right)} \qquad (2)$$

$$\varepsilon_{1c} = \frac{1}{2}(\varepsilon_{\parallel} + \varepsilon_{\perp}), \quad \delta = (\varepsilon_{\parallel} - \varepsilon_{\perp})/(\varepsilon_{\parallel} + \varepsilon_{\perp})$$

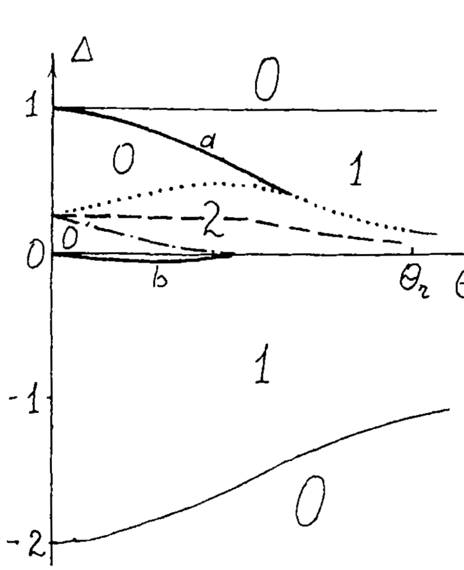
Three cases are possible as a function of θ_B and mismatch parameter

$$\Delta = (k_B - k)\sin^2 2\theta_B \,/\, \left[\delta k_B(1 + \sin^2\theta_B)\right]$$

a) no decreasing waves and therefore no SEWs, b) 1 decreasing wave, c) 2 decreasing waves. Corresponding regions are denoted by 0,1,2 in Fig.1.

let us consider the conditions for the existence of SEWs in regions with decreasing waves. In the regions 1 for a given angle θ_B the continuity conditions determine the value of Δ and angle ψ between SEW vector $\underline{k}$ and director $\underline{N}$ on the interface. Substituting formulas (1) in boundary conditions one can calculate dependences $\Delta(\theta_B)$ and $\psi(\theta_B)$ (curves a and b in Figs. 1 and 2).

In region 2 SEWs in the CLC are the superposition of two decreasing waves and the ratio of wave amplitudes is the additional adjustable parameter for continuity conditions. As a result the existence ranges for SEWs extend considerably, because only one condition is surviving for Δ and ψ, and one of them may be preset independently. There are two SEWs for each value of θ_B and Δ in region 2. Propagation directions of these SEWs are determined by angles ψ_1 and ψ_2 (Fig.2). The dependences shown in Figs. 1 and 2 were calculated at $\varepsilon_{sub}/\varepsilon_{1c} = 0.4$, however features of SEWs were almost independent of this ratio.



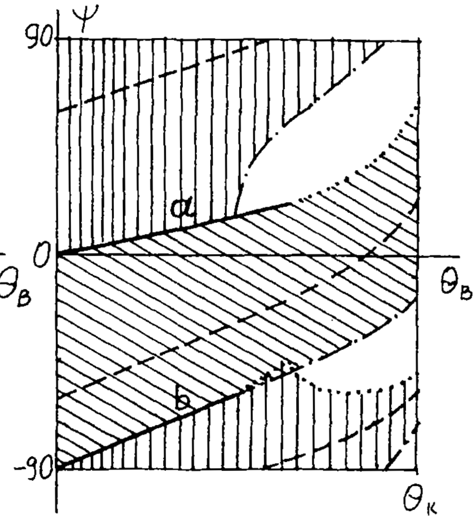


FIGURE 1. Regions with different number of decreasing waves. Dispersion curves of SEWs, existing in regions 1, are denoted a and b.

FIGURE 2. Propagation directions of SEWs. Denotion as in Fig.1. Regions with different hatching correspond to two directions (angles ψ_1 and ψ_2). Propagation is forbidden in unhatched regions.

Thus the calculation showed that SEWs with frequency w at $w>w_1=(\sqrt{2}-1)2\pi c\sqrt{\varepsilon_{1c}}/p$ ($\theta_B<\theta_1$, $\theta_1=24.5°$) can propagate in any direction, whereas for $w_1>w>w_r=2\pi c\,\varepsilon_{1c}/(p\sqrt{\varepsilon_{1c}-\varepsilon_{sub}})$ ($\theta_1<\theta_B<\theta_r$ - total reflection angle) propagation is possible in the confined sectors only. The SEW penetration depth in CLC is of the order of p/δ and depends strongly on the propagation direction. At $w<w_r$ no SEW exists.

EXCITATION OF SEWS BY ATR METHOD

The SEWs considered above do not interact with radiative modes and propagate along the interface of the nonabsorbing media without damping. The phenomenological correction for absorption $\varepsilon_{lc} \to \varepsilon_{lc}(1+i\gamma)$ provides the imagine addition into wave vector $k \to k + i\gamma k/(2\cos\theta_B)$, but the SEW structure is maintained when $\delta > \gamma$.

The various methods, developed for investigation of the surface polaritons in homogeneous media,[2] can be used for SEWs excitation. Let us consider the ATR method. ATR spectrum can be obtained in the modified Otto configuration (Fig.3), where half-spherical coupling prism and CLC are spaced by the thin layer of the isotropic substrate with small permittivity $\varepsilon_{sub} < \varepsilon_{pr}, \varepsilon_{lc}$. In this case the preset value of Δ is adjusted by the light incidence angle θ and the coupling prism rotation determines the angle ψ.

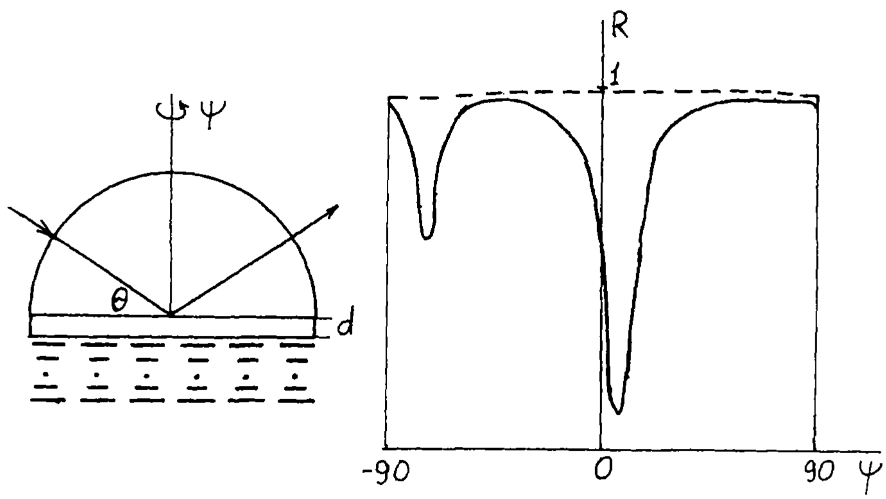


FIGURE 3. Excitation of SEWs by the ATR method. Extremal reflection coefficients R_{max}(- - -) and R_{min}(——) are calculated at $\varepsilon_{pr} = \varepsilon_{lc} = 2$, $\varepsilon_{sub} = 1$, $\theta = \theta_B = 40°$, $\Delta = 0.12$, $d/p = 4$, $\gamma/\delta = 0.01$.

The extremal reflection coefficients are shown in Fig.3 as functions of angle ψ at typical values in the region 2. Two dips are observed that are corresponding to two SEWs. An elliptically polarized beam should be used to obtain the maximum dip. For a linearly polarized beam the dip amplitudes are about half of the maxima. Thus SEWs can be excited efficiently by the ATR method.

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