

UDC 532.783

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EDGE LOCALIZED MODES IN OPTICS OF PHOTONIC LIQUID CRYSTALS WITH LOCAL ANISOTROPY OF ABSORPTION

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The edge optical modes in spiral photonic liquid crystals are theoretically studied for the certainty on the example of chiral liquid crystals (CLCs) with an anisotropic local absorption. The model chosen here (absence of dielectric interfaces in the studied structures) allows one to get rid off the polarization mixing at the surfaces of the CLC layer and to reduce the corresponding equations to the equations for the light of diffracting in the CLC polarization only. The dispersion equation determining connection of the edge mode (EM) frequencies with the CLC layer parameters (anisotropy of local absorption, CLC order parameter) is obtained. Analytic expressions for the transmission and reflection coefficients of CLC layer for the case of CLC with an anisotropic local absorption are presented and analyzed. It is shown that the CLC layers with locally anisotropic absorption reduce the EM lifetimes (and increase the lasing threshold) by the way different from the case of CLC with an isotropic absorption. Due to the Bormann effect revealing of which is different at the opposite stop-band edges in the case of CLC layers with an anisotropic local absorption the EM life-times for the EM frequencies at the opposite stop-bands edges may be significantly different. The options of experimental observations of the theoretically revealed phenomena are briefly discussed.

Key words: chiral liquid crystals, edge modes, low threshold lasing, local absorption anisotropy, Bormann effect.

DOI: 10.18083/LCAppl.2016.1.52

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ЛОКАЛИЗОВАННЫЕ КРАЕВЫЕ МОДЫ В ОПТИКЕ ФОТОННЫХ ЖИДКИХ КРИСТАЛЛОВ С ЛОКАЛЬНОЙ АНИЗОТРОПИЕЙ ПОГЛОЩЕНИЯ

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Теоретически изучены краевые оптические моды в спиральных фотонных жидких кристаллах на примере хиральных жидких кристаллов (CLCs) с локальной анизотропией поглощения. Используемая модель (отсутствие диэлектрических границ в изучаемых структурах) позволяет пренебречь преобразованием поляризаций на границах CLC слоев и свести соответствующие уравнения к уравнениям для света только дифрагирующей в CLC поляризации. Получено дисперсионное уравнение, связывающее частоты краевых мод (EM) с параметрами CLC слоя (локальная анизотропия поглощения, параметр порядка в CLC). Получены и проанализированы аналитические выражения для коэффициентов прохождения и отражения CLC слоя в случае CLC с локальной анизотропией поглощения. Показано, что в CLC слоях с локальной анизотропией поглощения уменьшается время жизни EM (и возрастает порог лазерной генерации) не так, как в случае CLC с изотропным поглощением. Время жизни EM с частотами на противоположных частотных границах запрещенной для распространения света зоны может оказаться существенно различным из-за проявления эффекта Бормана в CLC слоях с локальной анизотропией поглощения. Кратко обсуждаются перспективы экспериментального наблюдения теоретически выявленных эффектов.

Ключевые слова: хиральные жидкие кристаллы, краевые моды, низкопороговая лазерная генерация, локальная анизотропия поглощения, эффект Бормана.

1. Introduction

Recently there have been much activities in the field of localized optical modes, in particular, edge modes (EM) and defect modes (DM) in chiral liquid crystals (CLCs) mainly due to the possibilities to reach a low lasing threshold for the mirror less distributed feedback (DFB) lasing [1–4] in CLCs. The EMs existing as localized electromagnetic eigenstates with its frequency close to the forbidden band gap were investigated initially in the periodic dielectric structures [5]. The corresponding EMs in CLCs, and more general in spiral media, are very similar to the EMs in one-dimensional scalar periodic structures. They reveal abnormal reflection and transmission [1, 2], and allow distributed feedback (DFB) lasing at a low lasing threshold [3].

Almost all theoretical studies of the EM and DM in chiral and scalar periodic media were performed by means of a numerical analysis with the exceptions [6, 7] where the known exact analytical expression for the eigenwaves propagating along the helix axis [8–10] were used for a general study of the DM. The approach used in [6, 7] looks as fruitful one because it allows to reach an easy understanding of the DM and EM physics, and this is why it deserves further implementation in the study of the EM and DM.

In the cited studies the optical absorption in CLC was regarded as an isotropic. However the case of isotropic absorption in CLC does not cover all options happening in CLC. For example, quite common is alignment of dye molecules in liquid crystals with clearly presented absorption lines. If the director distribution in a liquid crystal in the sample may exist and manifest itself in some circumstances [11, 12]. The corrotal sample is not homogeneous (what is the case of CLC) a local anisotropy of absorptisponding effects depend on the value of liquid crystal order parameter and disappear if the order parameter value is zero, i.e. at the point of liquid crystal phase transition to liquid. The corresponding effects in the CLC transmission and reflection spectra, in particular Bormann effect, were studied both experimentally [13, 14] and theoretically [11, 12, 13]. In the present paper the influence of local anisotropy of absorption on characteristics of localized modes is theoretically studied. Below analytical solutions for the EM (associated with a local anisotropy of absorption in CLCs) are presented and some limiting cases simplifying the problem are considered.

2. The Boundary-Value Problem

To investigate EM in a CLC we have to consider a boundary problem, i.e. transmission and reflection of light incident on a CLC layer along the spiral axis [10–12]. We assume that the CLC is represented by a planar layer with a spiral axis perpendicular to the layer surfaces (Fig.1). We also assume that the average CLC dielectric constant coincides with the dielectric constant of the ambient medium. This assumption practically prevents conversion of one circular polarization into another at the layer surfaces [11, 12], and allows to have only two eigenwaves with diffracting circular polarization taken into account.

The procedure of obtaining the reflection R and transmission T coefficients for a CLC layer with a local anisotropy of absorption is similar to the one for a non-absorbing CLC however some complications arise due to the fact that the elements of CLC dielectric tensor are complex quantities now.

Let us begin from discussing of the dielectric tensor of a substance with locally anisotropic absorption. The principal values of corresponding dielectric tensor are complex and have different imaginary parts depending in the case of CLC on the liquid crystal order parameter S [10]. In general case all three imaginary parts are different. For a CLC the imaginary parts are different for $S=1$ and are equal for $S=0$. Returning to the CLC we assume for simplification of the problem that only one principal value of dielectric tensor is complex at $S=1$. This corresponds to the assumption that the absorption in CLC is due only to dye's molecules and at $S=1$ a complete ordering of the dye's molecules occurs. We assume also that the axis corresponding to the real principal value of the dielectric tensor is directed along the spiral axis and two other axes are rotating around the spiral axis. These rotating axes determine the local, depending on the coordinate along spiral axis, direction of absorption anisotropy. Now we have to insert complex principal values of dielectric tensor in the expressions for dielectric anisotropy [11, 12, 15]. As the result the dielectric anisotropy $\Delta\epsilon$ (see below) becomes a complex quantity. Luckily, the expressions for reflection and transmission coefficients for light propagating in a CLC layer along the cholesteric axis [11, 12, 15] are exact and are applicable to the case of anisotropic absorption which is under consideration here.

Under the accepted assumption the imaginary parts of principal values of the dielectric tensor for S differing from one are by the following way expressed via the imaginary part of the single complex principal value ε_1 , or ε_2 at $S=1$ for the cases of absorption oscillatory axis parallel and perpendicular to the long molecular axis, respectively:

$$\text{Im}[\varepsilon_{\parallel}] = \text{Im}[\varepsilon_1](1+2S)/3, \quad \text{Im}[\varepsilon_{\perp}] = \text{Im}[\varepsilon_1](1-S)/3 \quad (1a)$$

and the local dielectric anisotropy is

$$\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp} = \text{Re}[\varepsilon_{\parallel} - \varepsilon_{\perp}] + i\varepsilon_1 S, \quad (2a)$$

for the oscillatory axis parallel to the long molecular axis;

$$\text{Im}[\varepsilon_{\perp}] = \text{Im}[\varepsilon_2](1+2S)/3, \quad \text{Im}[\varepsilon_{\parallel}] = \text{Im}[\varepsilon_2](1-S)/3 \quad (1b)$$

and the local dielectric anisotropy is

$$\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp} = \text{Re}[\varepsilon_{\parallel} - \varepsilon_{\perp}] - i\text{Im}[\varepsilon_2]S. \quad (2b)$$

for the oscillatory axis perpendicular to the long molecular axis.

In what will be followed below we shall present the results related to the first option, for the case of absorption oscillatory axis parallel to the long molecular axis. If for the first option the Bormann effect reveals itself close to the high frequency stop-band edge, for the second option a similar revealing of the Bormann effect happens close to the low frequency stop-band edge [11, 12].

In the view of refs. [10–12, 15, 16], we state here only the final expressions for the amplitude transmission T and reflection R coefficients for light incident on a CLC layer of thickness L . These are given as

$$R(L) = \delta \sin qL / \{ (q\tau/\kappa^2) \cos qL + i[(\tau/2\kappa)^2 + (q/\kappa)^2 - 1] \sin qL \} \quad (3a)$$

$$T(L) = \exp[i\kappa L] (q\tau/\kappa^2) / \{ (q\tau/\kappa^2) \cos qL + i[(\tau/2\kappa)^2 + (q/\kappa)^2 - 1] \sin qL \}, \quad (3b)$$

where

$$q = \kappa \{ 1 + (\tau/2\kappa)^2 - [(\tau/\kappa)^2 + \delta^2]^{1/2} \}^{1/2} \quad (4)$$

and, $\varepsilon_0 = (1 + i\gamma)\text{Re}[\varepsilon_{\parallel} + \varepsilon_{\perp}]/2$, $\delta = \text{Re}[\varepsilon_{\parallel} - \varepsilon_{\perp}]/\text{Re}[\varepsilon_0] + i\varepsilon_1 S/\text{Re}[\varepsilon_0]$ and $\gamma = \varepsilon_1(1-S)/3\text{Re}[\varepsilon_0]$ is the parameter describing the locally isotropic part of absorption. Here δ is the dielectric anisotropy with ε_{\parallel} and ε_{\perp} as the local principal values of the CLC dielectric tensor [10–12], $k = \omega\varepsilon_0^{1/2}/c$ with c as the speed of light, and $\tau = 4\pi/p$ with p as the cholesteric pitch.

Note, that in the case of absorption due solely to the dye molecules solved in CLC only one principal

value of dielectric tensor is complex at $S=1$ if the absorption oscillators of dye molecules are directed along a sole axis in the molecule and the degree of orientational order of the dye molecules is the same as for CLC. In principle, the orientational order parameter for dye molecules may be different from the CLC order parameter S .

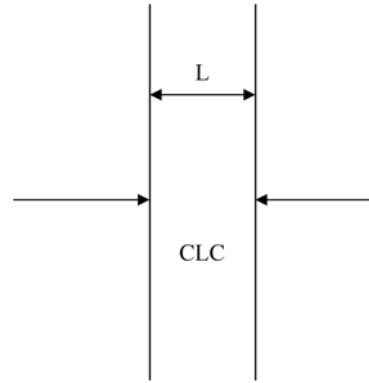


Fig. 1. Schematic of the boundary problem for edge mode

As one expects the CLC local absorption reveals itself in the reflection and transmission spectra due to the Bormann effect (well known in the X-Ray diffraction) [11, 12, 13] revealing itself in the absorption suppression at one of the stop band edges. Contrary to the case of isotropic absorption with the reflection and transmission spectra being symmetric relative the stop band centre in the case of locally anisotropic absorption in CLC the spectra are nonsymmetric relative the stop band centre. In the case of the CLC with a locally anisotropic absorption [11, 12, 13] the absorption suppression at one of the stop band edges, as in the X-ray case, also takes place and is due to orthogonality of the whole optical electric field in the sample to the dye molecular absorbing oscillators at the frequency of one stop band edge. The Figs. 2 and 3 demonstrate the Bormann effect in reflection and transmission, respectively, in a CLC layer with locally anisotropic absorption (the calculations performed according Eqs. (3) for the order parameter $S=1$, however, here and below the notations R and T are different from the ones in the Eqs. (3) and relate to the intensity reflection and transmission coefficients).

The Bormann effect demonstrates itself most clearly in the spectra of total absorption in a sample given by $1-R-T$ (see Fig. 4).

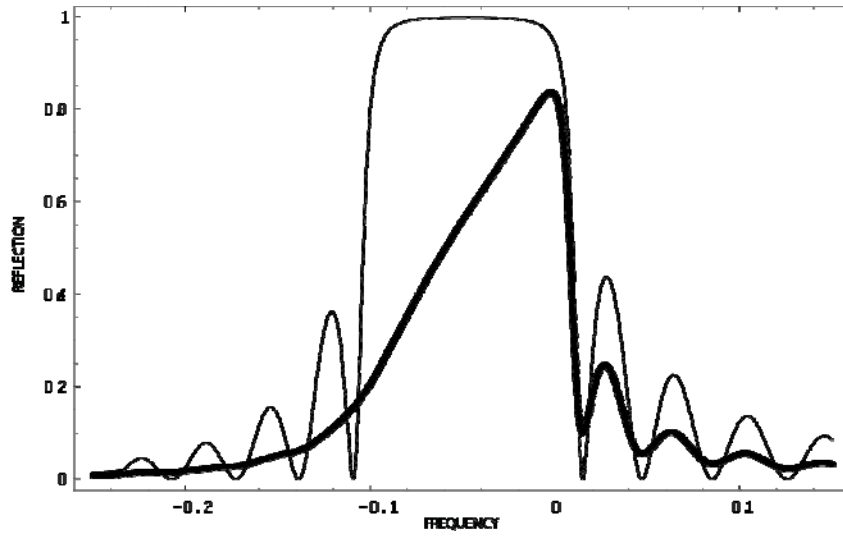


Fig. 2. Reflection (Thin curve corresponds to the complete absence of absorption) versus the dimensionless frequency $\nu = \delta[2(\omega - \omega_B)/(\delta\omega_B) - 1]$ used also in all Figures below for locally anisotropic absorption in CLC layer (see Fig. 1) at $\delta = 0.05 + 0.03i$, $l = 300$ ($l = L\tau = 4\pi N$, where N is the director half-turn number at the CLC layer thickness L)

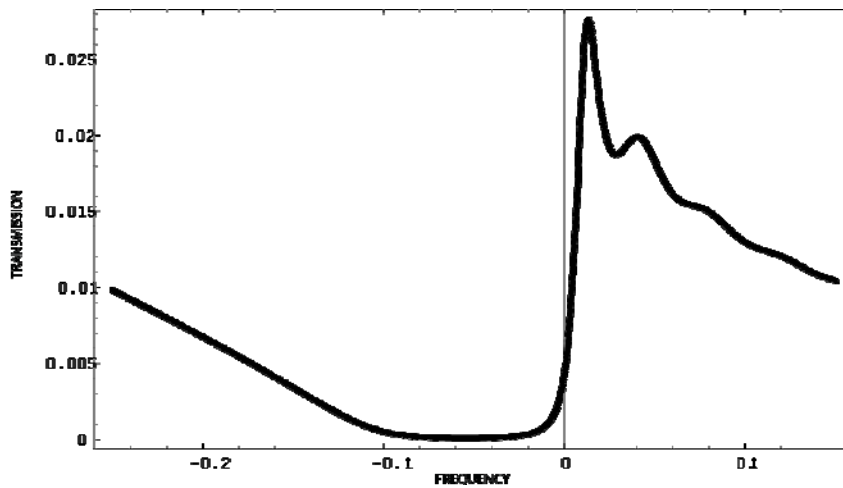


Fig. 3. Transmission versus frequency for locally anisotropic absorption in CLC layer (see Fig. 1) at $\delta = 0.05 + 0.015i$, $l = 300$

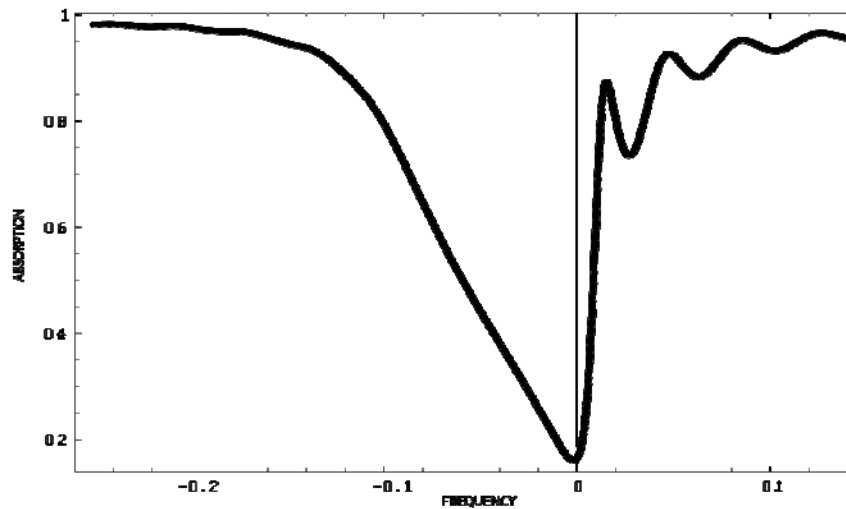


Fig. 4. Total absorption $1-R-T$ versus frequency for locally anisotropic absorption in CLC layer (see Fig.1) at $\delta = 0.05 + 0.015i$, $l = 300$

The Figs. 2–4 demonstrate increasing of reflection and transmission at one stop band edge compared to the other stop band edge and a strong suppression of the absorption at this stop band edge. To illustrate the dependence of the Bormann effect on the value of the order parameter S the Figs. 5, 6 present the calculation results for the reflection and total absorption $1-R-T$ for the values of $S = 1, 0.5, 0.3, 0$, respectively. These figures show that the suppression of absorption effect is decreasing with decrease of the CLC order parameter S . Here should be mentioned that in the above calculations was assumed that the pitch value and δ are the same for all values of S which means that the accepted assumption allows the dye molecules order parameter variations to be different from the corresponding variations of the CLC molecule's order parameter. In real situations the variations of the order parameter is connected usually with the temperature variations (and as it is known the pitch is a temperature dependent CLC parameter). The Fig. 7 demonstrates that the total absorption at the EM frequency decreases with the CLC layer thickness increase (L at the Fig. 7 is 10 times larger than at the Fig. 6). The Fig. 8 demonstrates that the transmission T at the EM frequency decreases with the CLC order parameter S increase and a more pronounced decrease happens at the stop-band edge opposite to the edge where the reflection is increased due to the Bormann effect.

The calculated at Figs. 6,7 absorption spectra are directly related to the luminescence spectra if the dye absorption line overlaps with the stop-band. Because the absorbed optical photons of the incident beam are reemitted as luminescence photons the absorption maximum results in a luminescence intensity maximum, naturally, at the frequency being shifted in the direction of lower frequencies. By this way the luminescence spectra occurred to be dependent on the local absorption anisotropy revealing different luminescence intensity for the pumping wave frequency coinciding with the opposite stop-band edges frequencies.

3. Edge mode influenced by local absorption anisotropy

In a non-absorbing CLC $\gamma = 0$ in the general expression for the dielectric constant $\varepsilon = \varepsilon_0(1 + i\gamma)$. The calculations of the reflection and transmission coefficients as functions of the frequency give the well-known results [8–12] different from the curves pre-sented at the Figs. 3–6, in particular, at $\gamma = 0$ $T + R = 1$ for all frequencies. Let us study how a locally anisotropic absorption in CLC influences on the properties of EM existing at discrete frequencies outside the stop band [15, 16], in particular, on the EM life-time.

To do this we have to solve the corresponding dispersion equation. Following the reference [15] one gets the dispersion equation in the form similar to the case of zero absorption

$$\operatorname{tg}qL = i(q\tau/\kappa^2)[(\tau/2\kappa)^2 + (q/\kappa)^2 - 1], \quad (5)$$

however the entering in this equation parameters occur to be given by the Eqs. (1,2,4), i.e. are dependent on some additional quantities compared to the case of zero absorption.

Generally, solutions to Eq. (5) are discrete EM

frequencies ω_{EM} situated outside of the stopband edges which may be found only numerically. The EM frequencies ω_{EM} turn out to be complex and may be presented as $\omega_{EM} = \omega(1 + i\Delta)$ where in real situations Δ is a small parameter determining the EM life-time. From a general analysis of Eq. (5) one concludes that the EM life-times at the frequencies outside the opposite stop band edges are different in the case of locally anisotropic absorption (there is no symmetry in their values relative to the stop band centre).

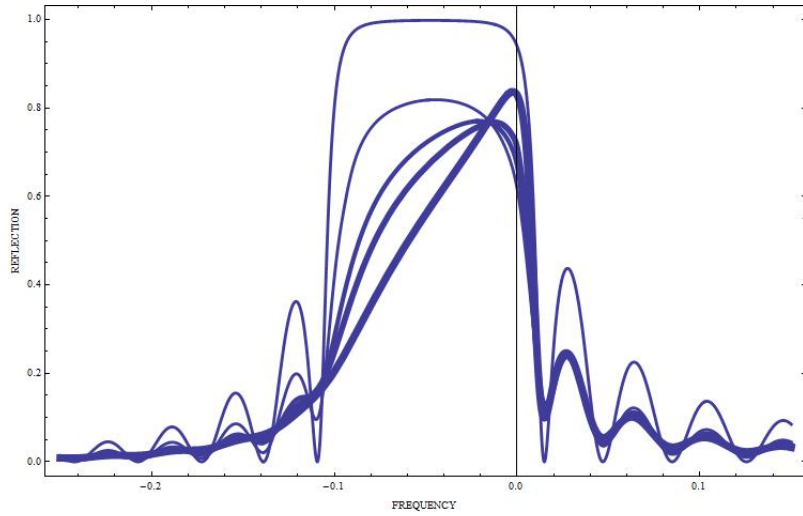


Fig. 5. Reflection for a CLC layer with local anisotropy of absorption versus the frequency for $S = 0, 0.3, 0.5, 1$ (The curve thickness is growing with increase of S) at $\operatorname{Im}[\varepsilon_1]/\operatorname{Re}[\varepsilon_0] = 0.03$, $\delta = 0.05$, $l = 300$, (The thinnest curve corresponds to complete absence of absorption)

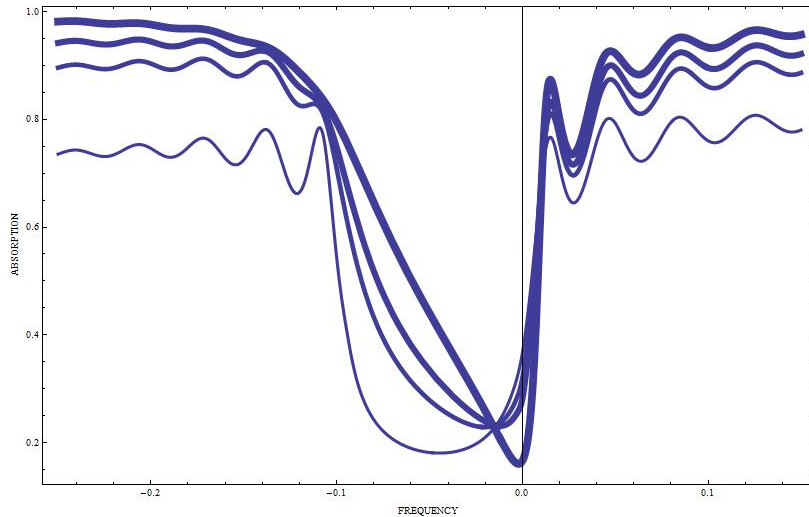


Fig. 6. Absorption for a CLC layer with local anisotropy of absorption versus the frequency for $S = 0, 0.3, 0.5, 1$ (The curve thickness is growing with increase of S) at $\operatorname{Im}[\varepsilon_1]/\operatorname{Re}[\varepsilon_0] = 0.03$, $\delta = 0.05$, $l = 300$

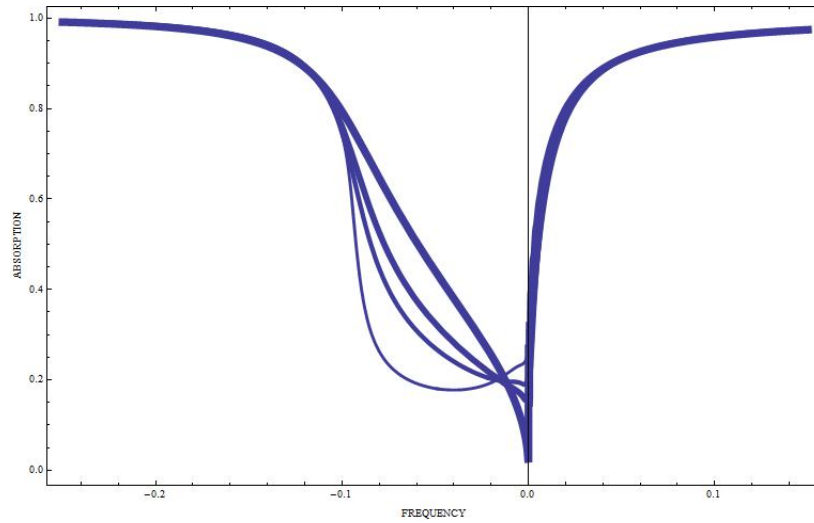


Fig. 7. Absorption for a CLC layer with local anisotropy of absorption versus the frequency for $S = 0, 0.3, 0.5, 1$ (The curve thickness is growing with increase of S) at $\text{Im}[\varepsilon_1]/\text{Re}[\varepsilon_0] = 0.03$, $\delta = 0.05$, $l = 3000$

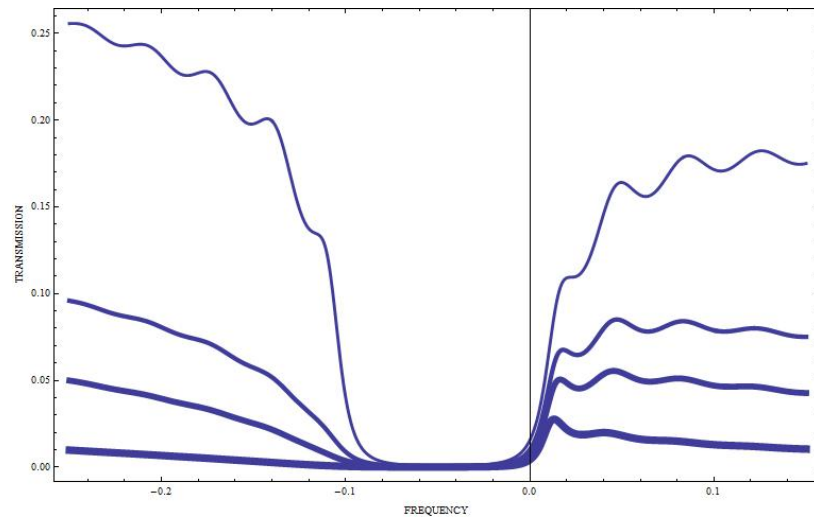


Fig. 8. CLC layer transmission versus frequency for locally anisotropic absorption in CLC layer for $S = 0, 0.3, 0.5, 1$ (The curve thickness is growing with increase of S) at $\text{Im}[\varepsilon_1]/\text{Re}[\varepsilon_0] = 0.03$, $\delta = 0.05$, $l = 300$

Fortunately, an analytical solution can be found for thick CLC layers and a sufficiently small Δ ensuring the condition $L\text{Im}(q) \ll 1$. In this case, ω and Δ are determined by the conditions $qL = n\pi$ and the EM life-times at the case of isotropic absorption may be presented as:

$$\tau_{\text{EM}} = 1/\Delta\omega_{\text{EM}} = 2/\omega_{\text{EM}}[\delta(n\pi)^2/(\pi\delta Lp)^3 + \gamma], \quad (6)$$

where the integer number n is the edge mode number [15] ($n = 1$ corresponds EM frequency (reflection coefficient minimum) closest to the stop-band edge)

and γ is the parameter determining the isotropic fraction of absorption in CLC. So, in the case of isotropic absorption the localized mode life-time is limited by $2/\omega_{\text{EM}}\gamma$.

In the case of a locally anisotropic absorption in CLC the EM life-time depends on the EM frequency position relative to the stop-band center and may exceed the value given by Eq. (6) due to the Bormann effect. For example, if the CLC layer thickness L is sufficiently large and the condition $L\text{Im}(q) \ll 1$ holds

the ratio of life-times at the opposite stop band edge frequencies may be estimated by the following expression:

$$\tau_B/\tau_{AB} = [\omega_{EM} \varepsilon_1(1 + 5S)/3 + 1/\tau_m] / (\omega_{EM} \varepsilon_1(1 - S)/3 + 1/\tau_m), \quad (7)$$

where τ_B , τ_{AB} , τ_m are the life-time at the stop-band edge where the Bormann effect happens, at the opposite edge, at the edges in the case of non-absorbing CLC (see (6) at $\gamma = 0$), respectively, and γ is determining the isotropic component of absorption. If γ is approaching zero what is happening when the order parameter is approaching 1 (if we neglect all sources of absorption except the dye molecules) τ_B is coinciding with τ_m given by (6) at $\gamma = 0$ what corresponds suppression of absorption for EM at the stop-band edge frequency in the case of CLC with local anisotropy of absorption. Note, to be accurate, that a complete suppression of absorption for EM is achievable in the limit of infinity thick CLC layer only. At the opposite stop-band edge frequency the absorption is enhanced and the EM life-time being proportional to $1/2 \varepsilon_0 \text{Im}\delta$ is shorter than τ_m .

The Fig. 9 presents the calculated according Eq. (7) dependence of the life-times ratio of the first EM at the high and low frequency stop band edge on the value of the order parameter S for several values of the layer thickness. It shows that the growth of the the EM life-time at $S = 1$ due to the Bormann effect at one stop band edge compared to the opposite one disappears at $S = 0$ and the suppression of absorption (the Bormann effect) is growing with the layer thickness L increase.

What is concerned of the luminescence spectra if the dye absorption line overlaps with the stop-band

the intensity of the luminescence is enhanced for the pump wave frequency at the stop band edge corresponding to the shorter EM life-time and suppressed for the pump wave frequency at the stop band edge corresponding longer EM life-time. That gives the estimate of the pumping wave intensity ratio ensuring equal luminescence intensity for the pump wave frequency coinciding with the opposite stop-band edges according to the Eq. (7) i.e. $I_B/ I_{AB} = \tau_B/\tau_{AB}$, where I_B/ I_{AB} are the pumping wave intensities ensuring equal luminescence intensity at the opposite stop band edges.

4. Lasing threshold at local anisotropy of absorption

The reflection, transmission and absorption spectra studied above give hints that the DFB lasing in the case of a locally anisotropic absorption in CLC is also significantly influenced by the anisotropy. To study the lasing threshold we have to solve dispersion equation at the EM frequency relative to the negative imaginary part of dielectric tensor.

The imaginary addition to dielectric tensor in the case of assumed absorption isotropy may be taken into account by introducing into the dielectric tensor a factor of the form $(1 - ig)$ where g is a small positive quantity. In the case of nonabsorbing CLC the threshold problem was studied in [15] and in the limit of a thick CLC layer the threshold is given by the following expression:

$$g = \delta(n\pi)^2 / (\delta L\tau / 4)^3. \quad (8)$$

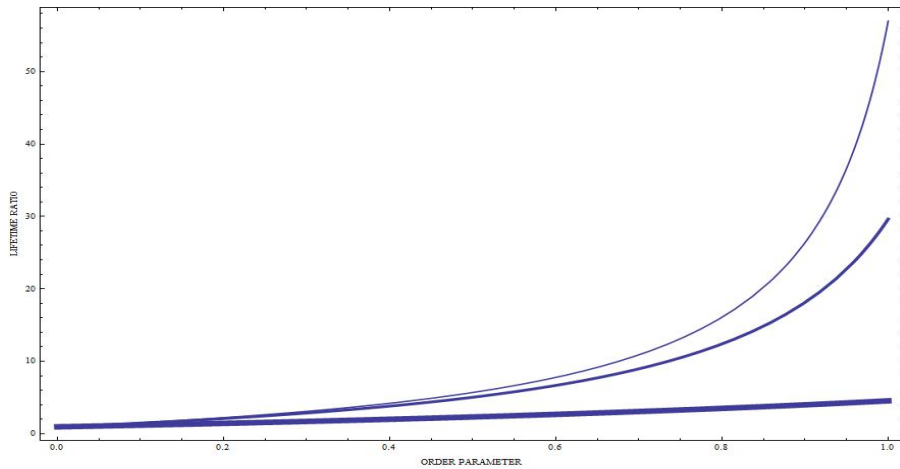


Fig. 9. Calculated life-times ratio of the first EM at the high and low frequency stop band edges versus the value of the order parameter S for locally anisotropic absorption $\text{Im}[\varepsilon_1] = 0.015$, $\text{Im}[\varepsilon_2] = 0$ (see Eqs. (1)), $\delta = 0.05$, $L/(p/d) = 1; 2; 2,5$ (the curves from the bottom to top)

In the case of isotropically absorbing CLC in the same limit the threshold is given by the next expression:

$$g = \delta(n\pi)^2 / (\delta L\tau / 4)^3 + \gamma, \quad (9)$$

where γ is a small positive parameter determining the isotropic absorption in CLC.

So, naturally, the threshold gain becomes higher if an absorption in the CLC exists. In the case of a locally anisotropic absorption the values of the threshold gain are dependent on the order parameter S and are different for the EM frequencies at the opposite stop-band edges. At one edge (where the Bormann effects reveals) it may approach to the value given by the Eq. (8) and at the opposite stop-band edge the threshold gain may be essentially higher. If the absorption is due only to the dye molecules the threshold gain becomes dependent on the order parameter S and its minimal value is given by the following expression

$$g = \delta(n\pi)^2 / (\delta L\tau / 4)^3 + \varepsilon_1(1 - S)/3\text{Re}[\varepsilon_0], \quad (10)$$

where ε_1 is the imaginary part of the dielectric tensor principal value at $S = 1$ determined by the dye molecules absorption i.e. under the assumption that the CLC absorption is due exclusively to the dye molecules.

Note, that anomalously strong absorption effect [11, 17] at the frequency of pumping wave may influence the lowering of lasing threshold gain in the case of a locally anisotropic absorption in CLC even stronger than in the case of an isotropic absorption [18, 19]. Really, if the absorption oscillators (at the pumping wave frequency) in the dye molecules and the oscillators corresponding to the lasing frequency have the same orientations the lasing wave absorption will be suppressed and the pumping wave absorption will be enhanced if the lasing frequency coincides with the low frequency stop-band edge where the Bormann effect takes place and the pumping wave frequency coincides with the high frequency stop-band edge where the absorption is enhanced.

5. Conclusion

In the proceeding sections the influence of the Bormann effect (studied previously for CLC transmission and reflection spectra [11–14]) on the properties of the edge modes in the case of local absorption anisotropy in CLC was studied in the first

time. The performed analytical description of the EM (neglecting the polarization mixing) allows one to reveal typical EM features related to existence of a local absorption anisotropy in CLC. For example, dependence of the EM mode live-time and lasing threshold on the position of EM mode frequency relative to the stop-band edges.

The results obtained here for the EM (see also [20]) clarify the physics of the absorption suppression due to the Bormann effect and the dependence of the EM life-times on their frequency positions relative to the stop-band edges. The predictions formulated above (for example, on different lasing threshold at the lasing frequencies at opposite stop-band edges) are open for an experimental verification and may be used for the optimization of experiments related to the DFB lasing in CLC. As a positive specific of the corresponding experiments in CLCs should be mentioned the option to study lasing at the opposite stop-band edges without actual changing the lasing frequency changing instead of this the CLC pitch by temperature variations or by application of magnetic or electric field at LCL.

The studied above Bormann effect influence on the CLC layer absorption spectra predicts new options for experimental investigation of this effect by the means of the luminescence technique (or vice versa to study the luminescence under the conditions of the Bormann effect realization). And here the most pronounced effect is the dependence of the luminescence intensity on the pumping wave frequency coincidence with the opposite stopband edge frequencies (at one stopband edge the luminescence is enhanced and at the opposite stopband edge is suppressed).

Note, that the obtained results are qualitatively applicable to the corresponding localized electromagnetic modes in any periodic media, and may be regarded as a useful guide in the studies of the localized modes under the conditions of the Bormann effect existence. For example, the results related to CLCs with local anisotropy of absorption may be useful for optimizing of DFB lasing in general. Really, the corresponding theoretical predictions show which one of the two stop-band frequencies is preferable for obtaining the most lower lasing threshold.

The work is supported by the RFBR grants № 16-02-01180_a, № 16-02-0679_a and № 16-02-0295_a.

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Поступила в редакцию 18.01.2016 г.
Received 18 January, 2016