

Optical properties of heliconical liquid crystals

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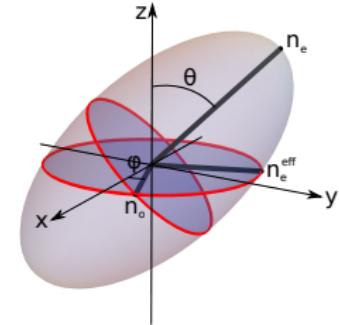
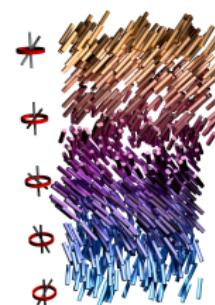
July 19, 2018

Motivation

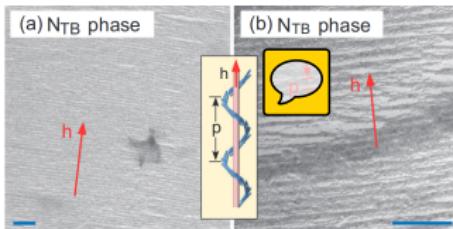


$$\mathbf{n} = \begin{pmatrix} \cos \varphi(z) \sin \theta \\ \sin \varphi(z) \sin \theta \\ \cos \theta \end{pmatrix}$$

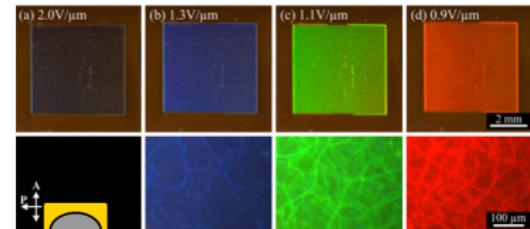
where $\varphi(z) = 2\pi z/p$
and $\theta = \text{const.}$



- Two groups:
 - pitch $p \sim 10 \text{ nm}$ (bent-core LC),
 - pitch in optical range (rod-like & linked by flexible chain)



TEM images, $p \approx 14 \text{ nm}$.
Chen et al., PRE 89, 022506 (2014).

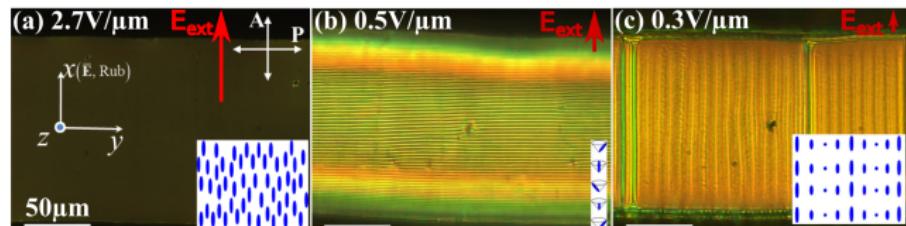


Xian et al., Proc. Natl. Acad. Sci. 113, 12925 (2016).

Experimental examples



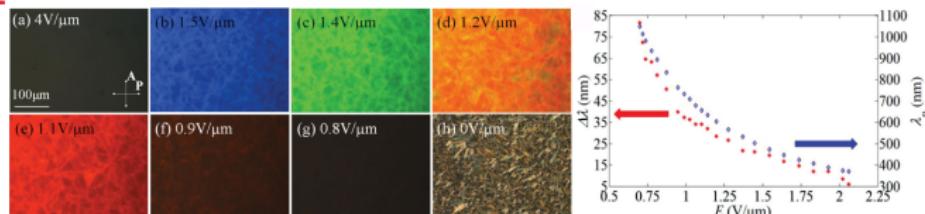
Arises for LC with $K_3 \ll K_2$ for a range of \mathbf{E}_{ext}



Xiang et al., PRL 112, 217801 (2014).



Possibility of shifting p and θ with external electric field \mathbf{E}_{ext}



Xiang et al., Adv. Mater. 27, 3014 (2014).

- Theoretical dependence of p and θ vs. \mathbf{E}_{ext} :

J. Xiang, S. V. Shiyanovskii, C. Imrie and O. D. Lavrentovich, Phys. Rev. Lett. 112, 217801 (2014).



Contents

- Determining the position and width of heliconical band gap with changing material properties (θ, p)

- Description of electric **E** and magnetic **H** fields inside heliconics: **E**, **H** eigenmodes

- Winding of the Poynting vector **P**



- Numerical methods used:



- Frequency domain method: eigenvalue method for determining the band diagrams and eigenmodes
 - FDTD: Finite-difference time-domain method: solving time-dependent Maxwell's equation, gives info about light propagation

Analysis of \mathbf{E} and \mathbf{D} fields

- On-axis propagation

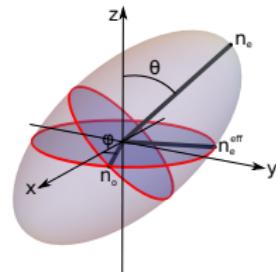
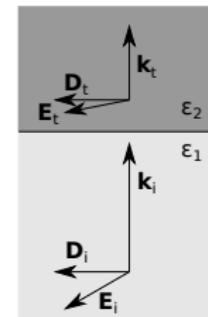


- \mathbf{D} -field:

- $\mathbf{D} \perp \mathbf{k} \rightarrow \mathbf{D}$ stays in plane of boundary
- Since $D_z = 0$ for heliconics, we can follow the derivation of the band-gap for cholesterics
- Light of same handedness as structure: has band gap, opposite handednesses: no band gap
- Effective periodicity: $p/2$ with n_o and n_e^{eff}

- \mathbf{E} -field:

- $\mathbf{E} \nparallel \mathbf{D}$ since $\mathbf{D} = \epsilon_0 \epsilon \mathbf{E}$
- Effective periodicity: p

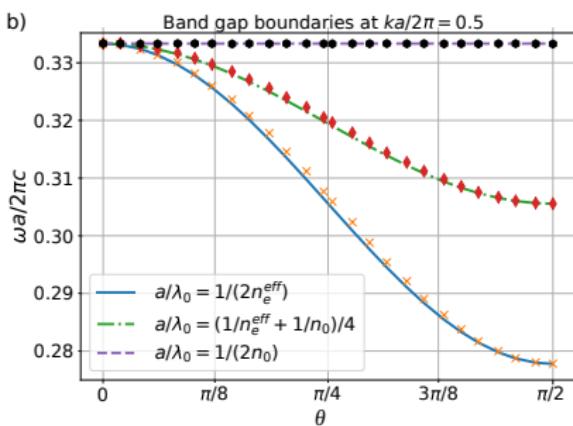
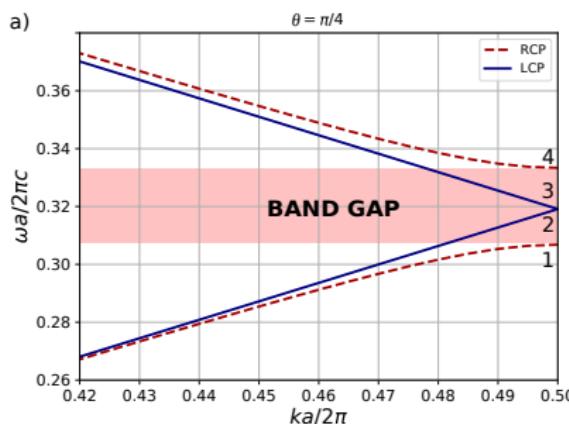


Opening of the BG with θ

- BG boundaries depend on n_o and effective extraordinary refractive index $n_e^{eff} = \frac{n_o * n_e}{\sqrt{n_o^2 \sin^2 \theta + n_e^2 \cos^2 \theta}}$
- BG for vacuum wavelengths between

$$p n_o < \lambda_0 < p n_e^{eff}, \quad n_o < n_e$$

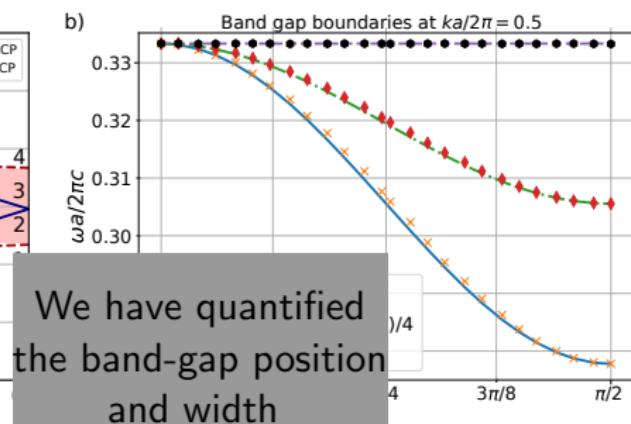
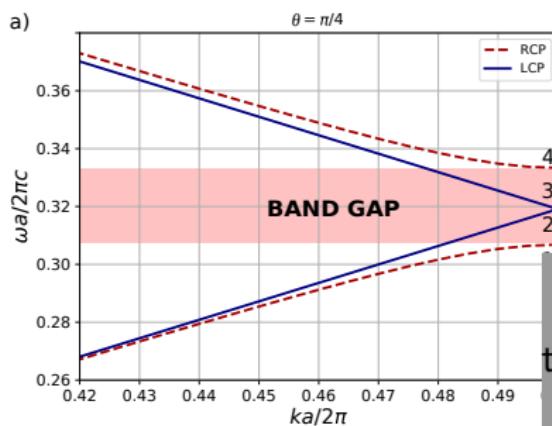
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Opening of the BG with θ

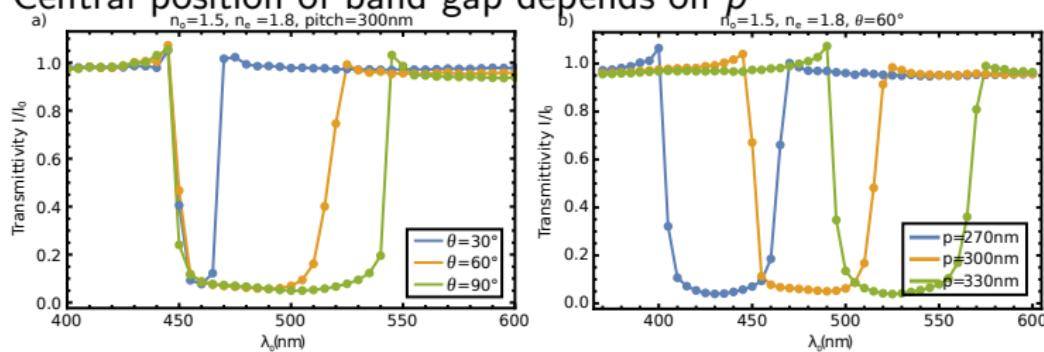
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Transmittivity

- Band gap width depends on θ
- Central position of band gap depends on p



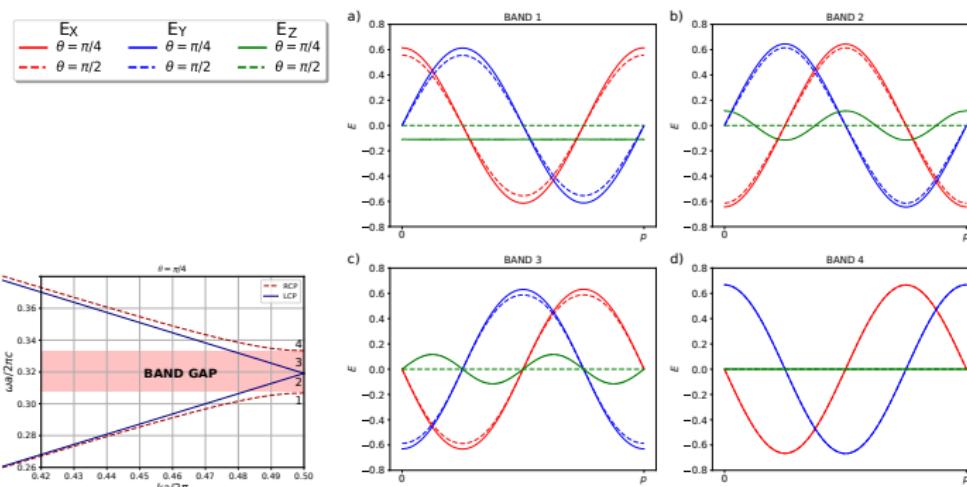
- From transmittivity spectra $\rightarrow p$ and θ determined uniquely
- Connection between E_{ext} and p and θ : Xiang et al., PRL 112, 217801 (2014)

Band gap edge modes



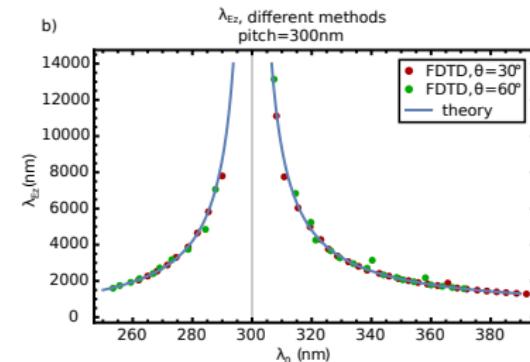
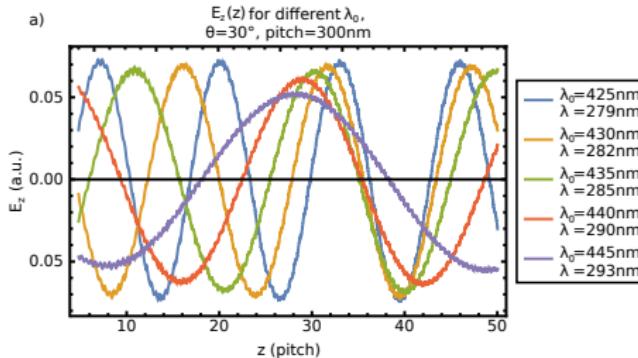
|| \mathbf{D} since $\mathbf{D} = \epsilon_0 \epsilon \mathbf{E}$

- In cholesterics: $E_z = 0$, in heliconics: $E_z \neq 0$
- On band gap edge: Eigenmodes right- or left-circularly polarized waves with additional E_z -component



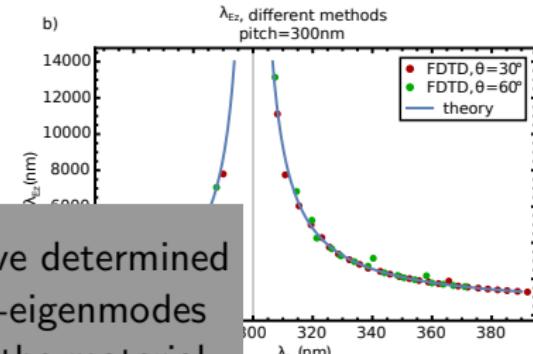
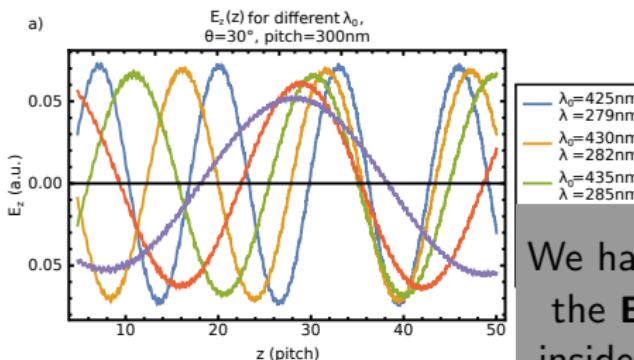
Dependence of E_z on λ

- E_z oscillates sinusoidally: E_z will be the same in size when xy -angle between **D** and **n** increases by $2m\pi$, $m \in \mathbb{Z}$.
- $\lambda_z^{LCP} = \frac{\lambda p}{p + \lambda}$, $\lambda_z^{RCP} = \pm \frac{\lambda p}{p - \lambda}$, always $\lambda_z^{RCP} > \lambda_z^{LCP}$
- RCP: E_z constant, $\lambda_z \rightarrow \infty$ when on edge of BG, otherwise it is smaller and depends on λ/p
- LCP: $\lambda_z = \lambda/2$ on edge of BG



Dependence of E_z on λ

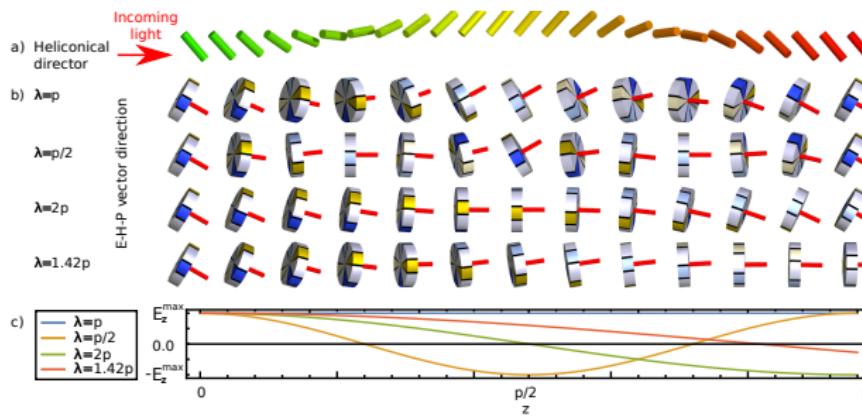
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We have determined
the **E**-eigenmodes
inside the material

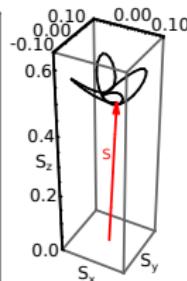
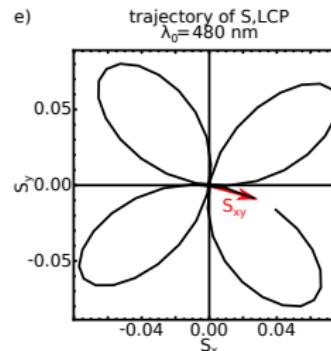
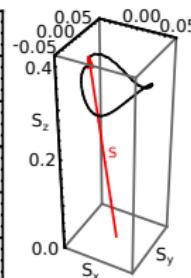
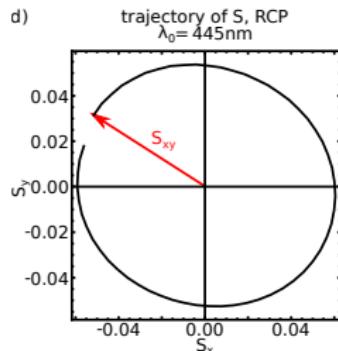
Poynting vector

- if $E_z \neq 0 \rightarrow P_{xy} \neq 0$
- Poynting vector rotates about the propagation axis
- RCP: wavelength of E_z rotation increases when nearing the band gap \rightarrow tilt of \mathbf{P} constant



Poynting vector

- if $E_z \neq 0 \rightarrow P_{xy} \neq 0$
- Poynting vector rotates about the propagation axis
- On BG edge in one pitch length: \mathbf{P} of RCP rotating circularly, \mathbf{P} of LCP describing a four-leaf clover



Conclusion & Outlook

We have determined the photonic properties of heliconical liquid crystals:

- Quantifying of the photonic band gap opening with p, θ
- Analysis of \mathbf{E} eigenmo^o the introduction of E_z component

