Optical properties of heliconical liquid crystals

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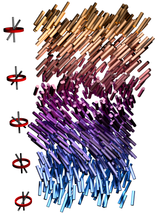
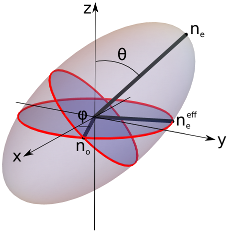
Motivation

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

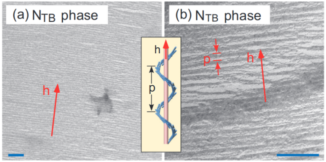
where $\varphi(z) = 2\pi z/p$

and $\theta = \mathrm{const.}$

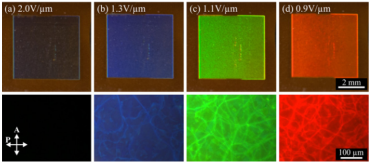




- Two groups: 1.: pitch $p \sim 10\,\mathrm{nm}$ (bent-core LC), 2.: pitch in optical range (rod-like & linked by flexible chain)



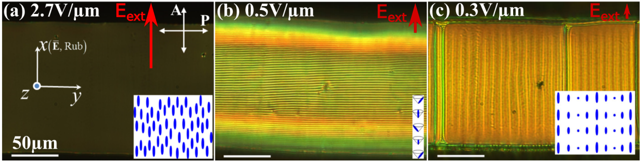
FFTEM images, $p \approx 14\,\mathrm{nm}$.
Chen et al., PRE 89, 022506 (2014).



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

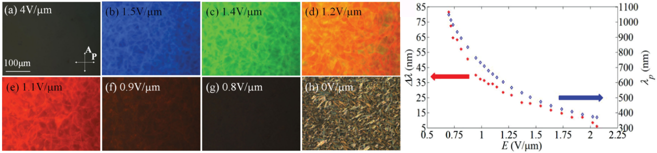
Experimental examples

- 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 $\mathbf{E}_{\mathbf{ext}}$



Xiang et al., Adv. Mater. 27, 3014 (2015).

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

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

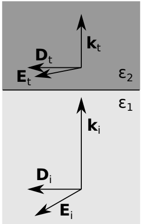
Contents

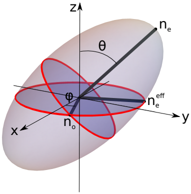
- Determining the position and width of heliconical band gap with changing material properties (θ, p)
- Description of electric **E** and magnetic **H** fields inside heliconics: **E**, **H**-eigenmodes
- Winding of the Poynting vector **P**

- 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 **E** and **D** fields

- On-axis propagation
- **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}
- **E**-field:
  - $\mathbf{E} \nparallel \mathbf{D}$ since $\mathbf{D} = \varepsilon_0 \underline{\underline{\varepsilon}} \mathbf{E}$
  - Effective periodicity: p

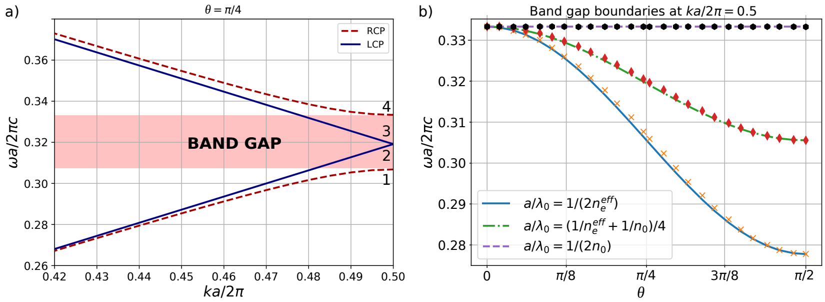




Opening of the BG with θ

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

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



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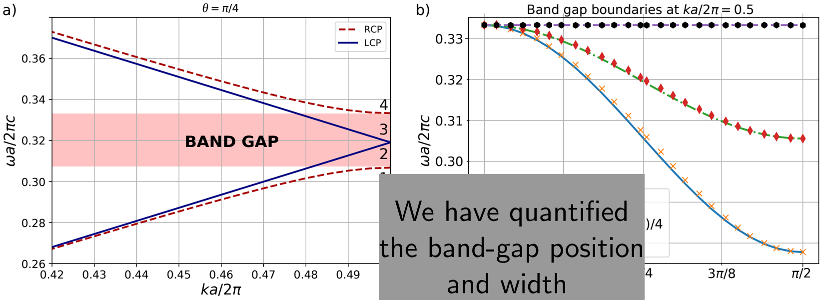
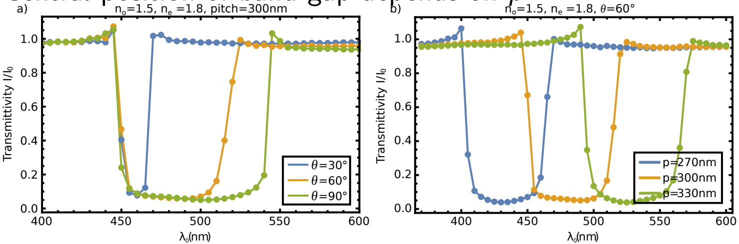


We have quantified the band-gap position and width

Transmittivity

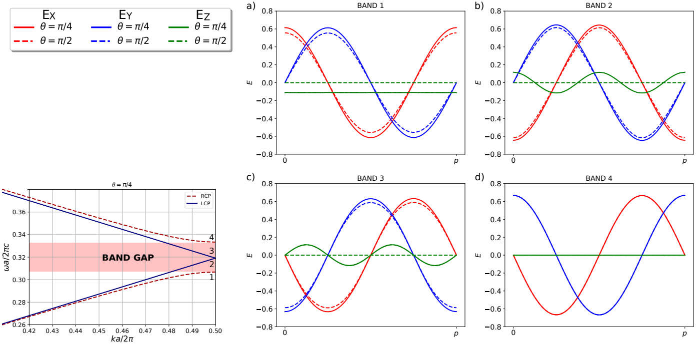
- Band gap width depends on θ
- Central position of band gap depends on p



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

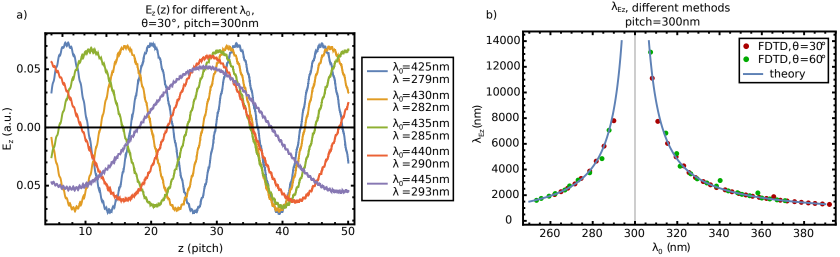
Band gap edge modes

- $\mathbf{E} \nparallel \mathbf{D}$ since $\mathbf{D} = \varepsilon_0 \underline{\underline{\varepsilon}} \mathbf{E}$
- 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 $2m\pi$, $m \in \mathbb{Z}$.
- $\lambda_z^{LCP} = \dfrac{\lambda p}{p+\lambda}$, $\quad \lambda_z^{RCP} = \pm\dfrac{\lambda p}{p-\lambda}$, always $\lambda_z^{RCP} > \lambda_z^{LCP}$
- RCP: E_z constant, $\lambda_z \to \infty$ when on edge of BG, otherwise it is smaller and depends on λ/p
- LCP: $\lambda_z = \lambda/2$ on edge of BG



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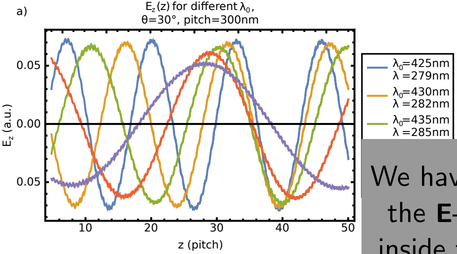
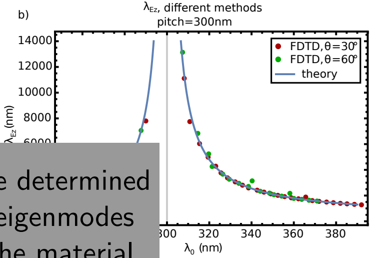
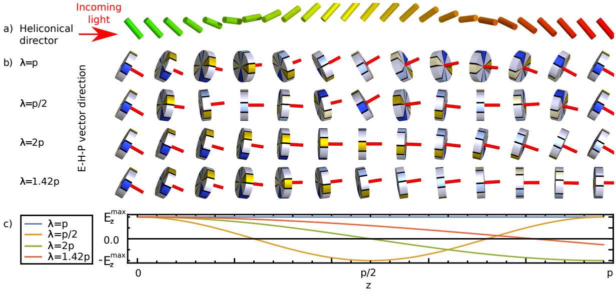




We have determined the **E**-eigenmodes inside the material

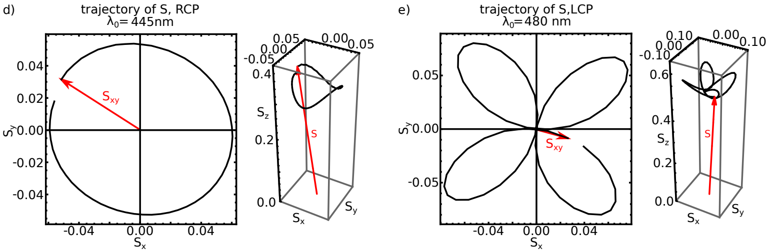
Poynting vector

- 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 **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: **P** of RCP rotating circularly, **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 **E** eigenmodes, the introduction of E_z component