

Optical properties of heliconical liquid crystals

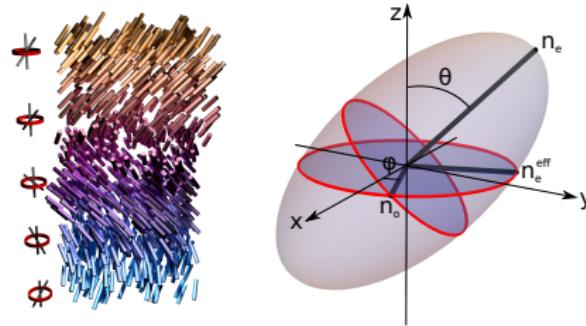
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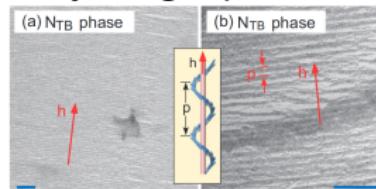
July 17, 2018

Motivation

- $\mathbf{n} = (\cos \varphi(z) \sin \theta, \sin \varphi(z) \sin \theta, \cos \theta)$, where $\varphi(z) = 2\pi z/p$ and $\theta = \text{const.}$



- Early experiments: X-ray range, pitch $\sim 10\text{nm}$ (bent-core LC)



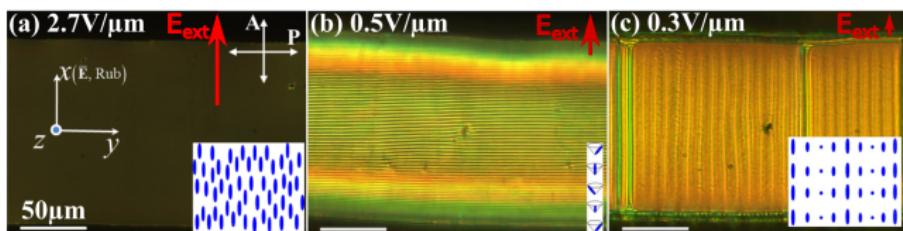
FFTEM images, $p \approx 14\text{ nm}$.
Chen et al., PRE 89, 022506 (2014).

- Optical range: LC of rod-like units linked by a flexible chain



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).

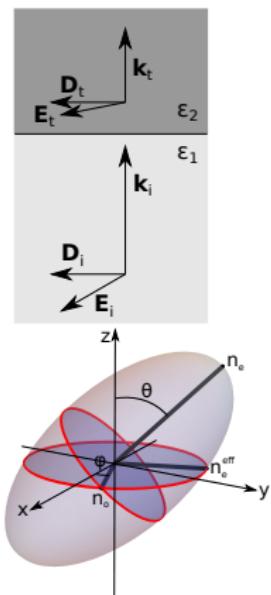
- Possibility of shifting p and θ with external electric field \mathbf{E}_{ext}
- Theoretical dependence of p and θ vs. \mathbf{E}_{ext} J. Xiang, S. V. Shiyanovskii, C. Imrie and O. D. Lavrentovich, Phys. Rev. Lett. 112, 217801 (2014).

Contents

- Shifting of heliconical band gap with changing material properties
- Electric **E** and magnetic **H** fields inside heliconics – eigenmodes
- Winding of the Poynting vector **P**
- Outlook

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

- On-axis propagation: $\mathbf{D} \perp \mathbf{k} \rightarrow \mathbf{D}$ 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 handedness: no band gap
- Effective periodicity: $p/2$

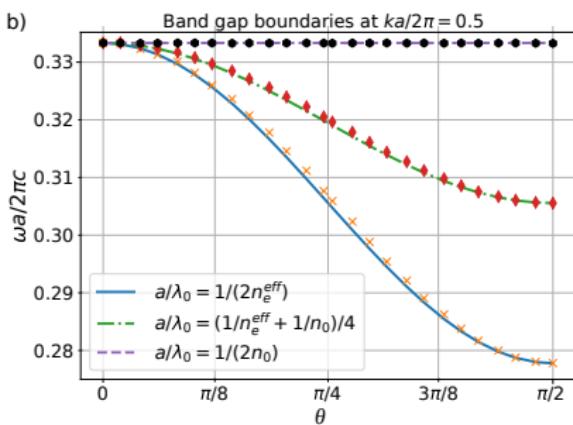
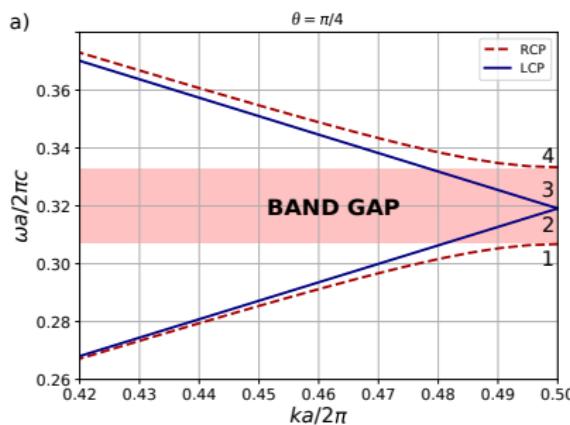


Opening of the BG with θ

- 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

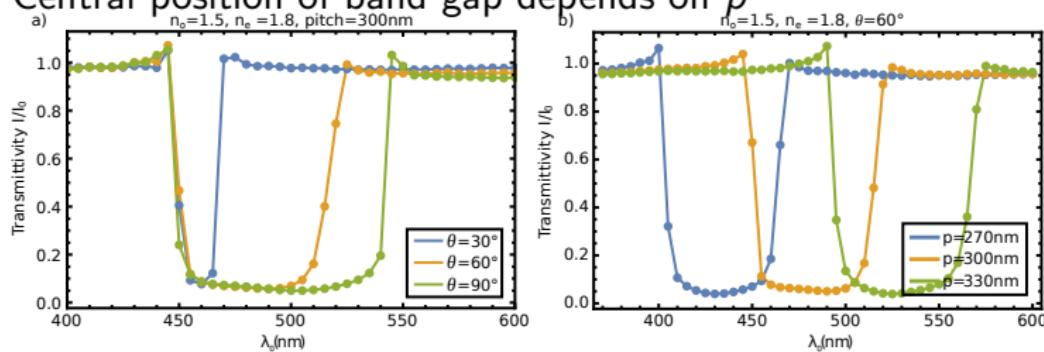
$$p n_o < \lambda_0 < p n_e^{eff}, \quad n_o < n_e$$

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



Transmittivity

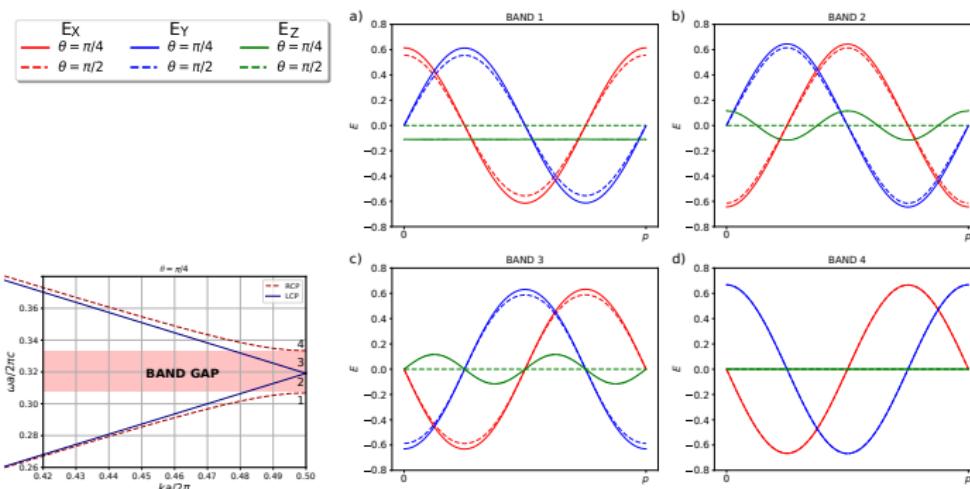
- Band gap width depends on θ
- Central position of band gap depends on p



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

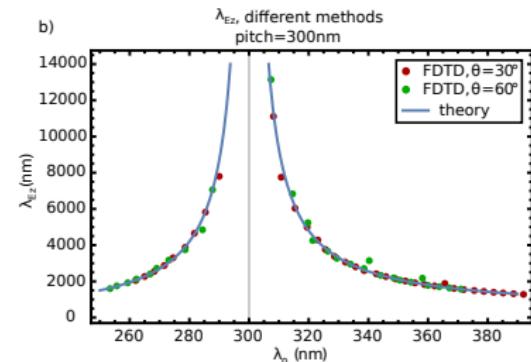
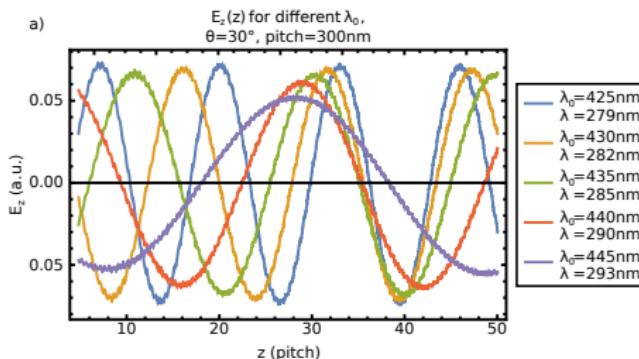
Band gap edge modes

- $\mathbf{E} \nparallel \mathbf{D}$ since $\mathbf{D} = \epsilon_0 \underline{\epsilon} \mathbf{E}$
- 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



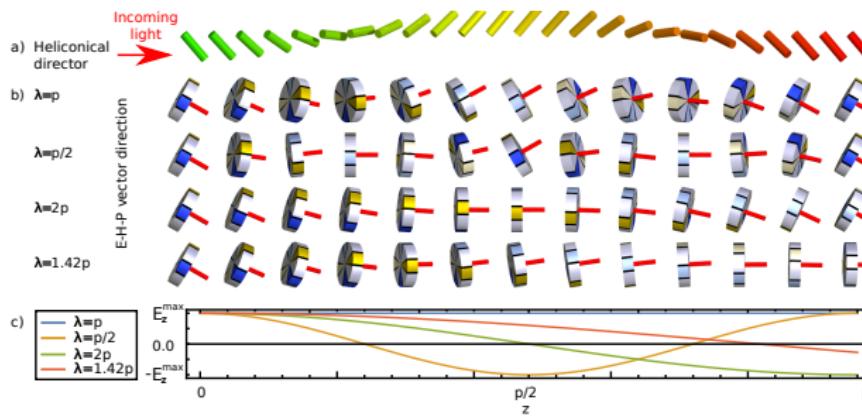
Dependence of E_z on λ

- E_z oscillates sinusoidally: E_z will be the same in size when xy -angle between \mathbf{D} and \mathbf{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



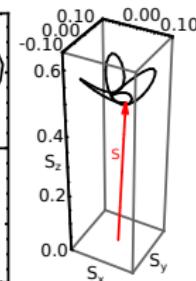
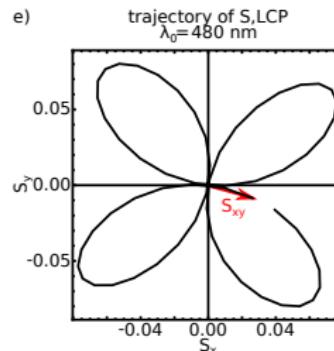
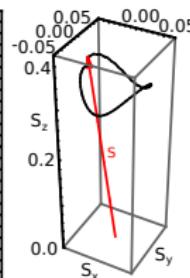
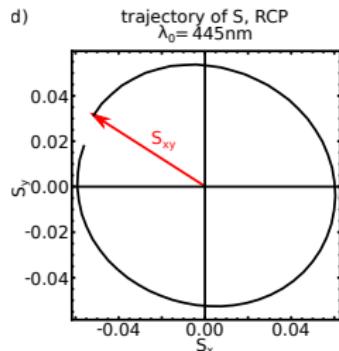
Poynting vector

- 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

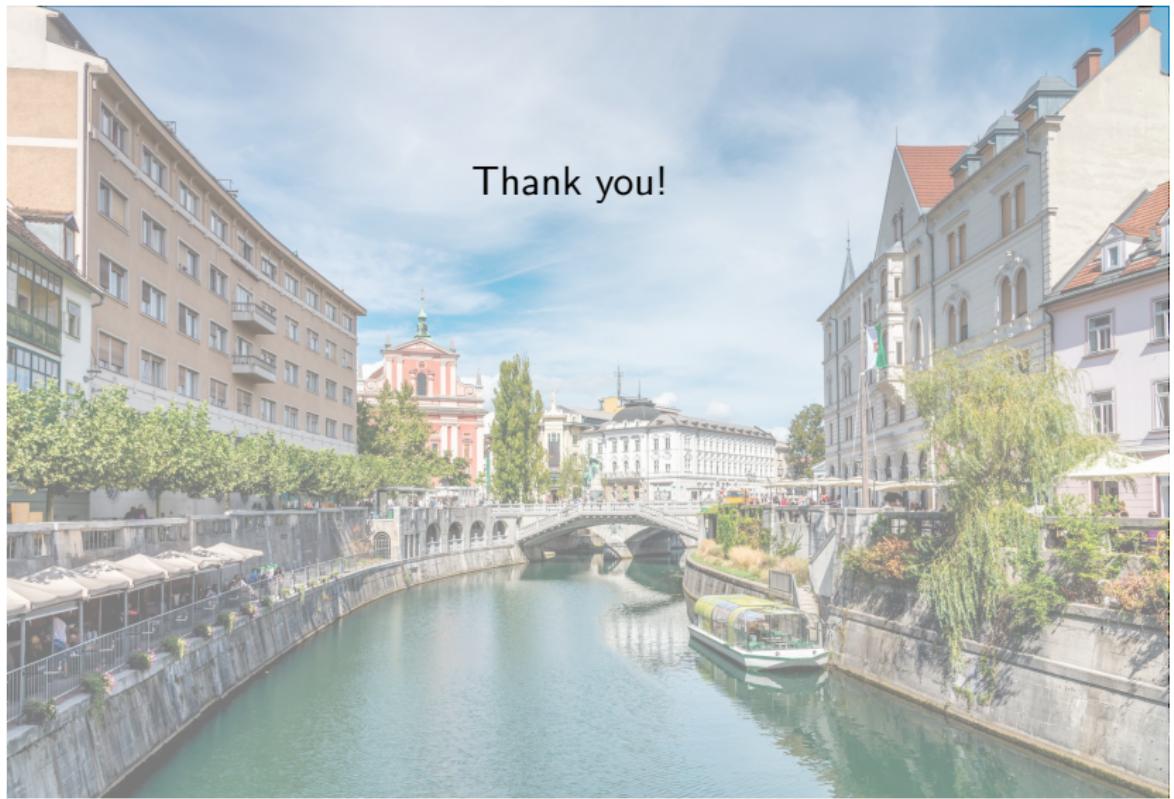
- if $E_z \neq 0 \rightarrow P_{xy} \neq 0$
- Poynting vector rotates about the propagation axis
- On BG edge in one pitch length: \mathbf{P} of RCP rotating circularly, \mathbf{P} of LCP describing a four-leaf clover



Conclusion & Outlook

Heliconical liquid crystals offer a possibility to control the properties of LC with external \mathbf{E}_{ext} :

- Tuning of photonic band gap with tuning p and θ : controllable transmission with E_{ext}
- Introduction of E_z component: complex winding of beams



Thank you!

Methods

- FDTD
- MPB

Free energy approach to heliconics

Analytical expressions for \mathbf{E} inside heliconics

Winding of \mathbf{P}_{xy} for different λ/p