Modelling light propagation through radial-director liquid crystal waveguides

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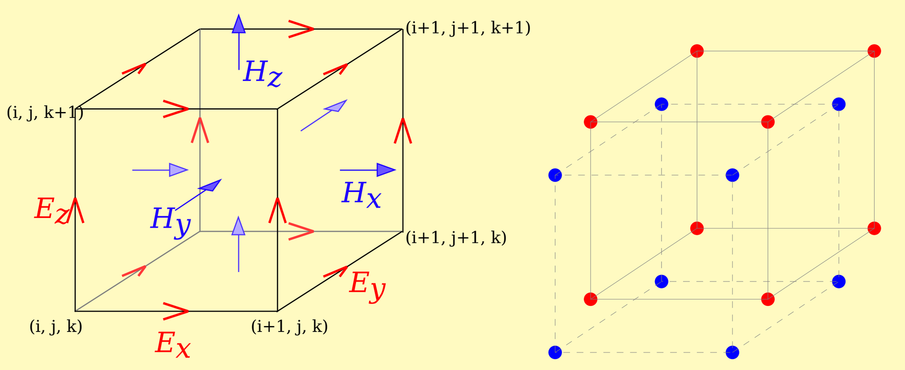
Motivation

- Controlled light guiding is central in complex optics and photonics, for example for efficient data transfer
- Combined birefringence and response to external stimuli in liquid crystal structures could be used for directed guiding of light – such as in waveguides[1].
- Experimentally, smectic A fibres with radial director profile which could be used as new waveguides can be created using 8CB and a surfactant
- Point defect in a nematic droplet turns a Gaussian beam into Laguerre-Gaussian[2] – is there a similar effect caused by the line defect in a fibre?

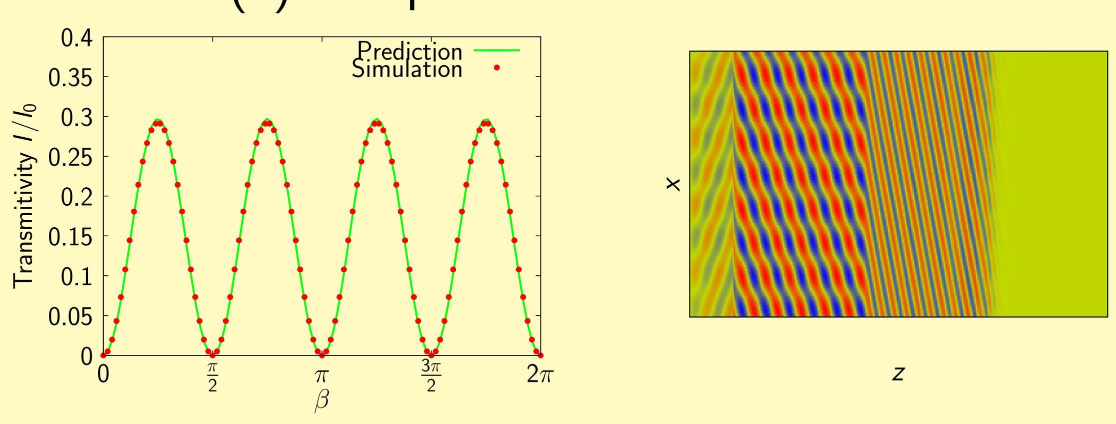
Methods

- FDTD method[3] – direct time evolution of electromagnetic fields in 3D with fully anisotropic ε
- Assumed zero conductivity and empty space permeability in bulk, absorption at edges
- Simulate long cylindrical waveguide with periodic boundary conditions along the axis (z)
- Staggered grid, adapted for dielectric anisotropy



Left: Yee lattice, optimized for diagonal dielectric tensor.
Right: The lattice we used, suitable for full anisotropic ε.
In both cases $\vec{E}$ and $\vec{H}$ are known at different times

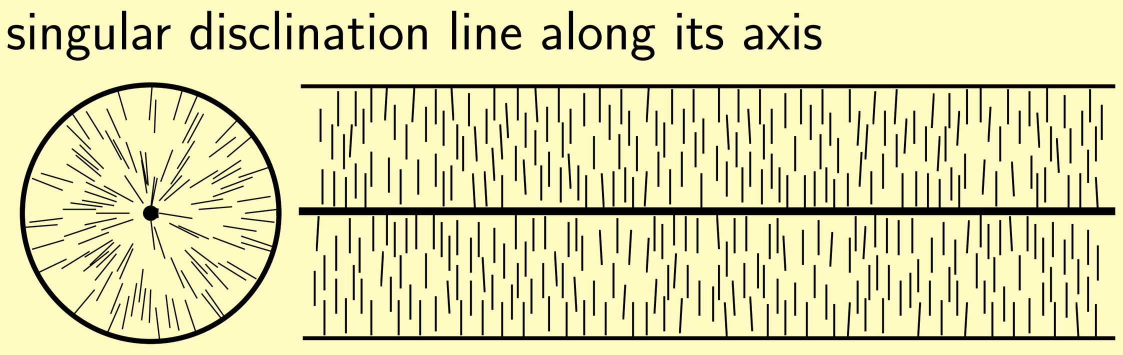
- Tests with uniform director (i), refraction on flat interfaces (ii) and periodic structures



Left (i): Intensity of light transimitted through a uniform-director liquid crystal between crossed polarizers
Right (ii): Refraction on an interface near Brewster's angle.

Parameters

- Observe propagation of Gaussian laser pulse
- Cylindrical waveguide with a radial director profile and a singular disclination line along its axis

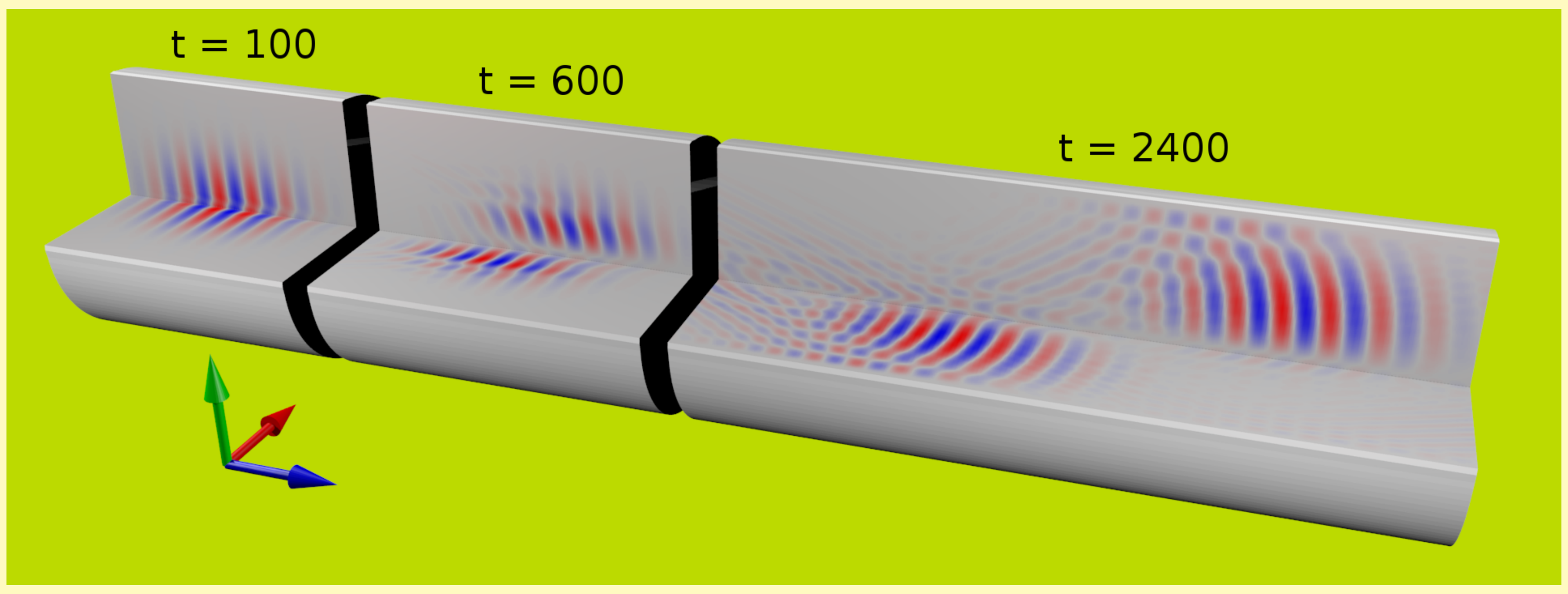


The core radius of the central $+1$ disclination line is much smaller than the wavelength and the change in nematic degree of order can be neglected.

- Fibre radius $5 - 20$ μm, inside 8CB with $n_o = 1.51$ and $n_e = 1.68$, surrounded by water with $n = 1.33$
- Uniform grid, size $512 \times 512 \times 256$.

Electric field

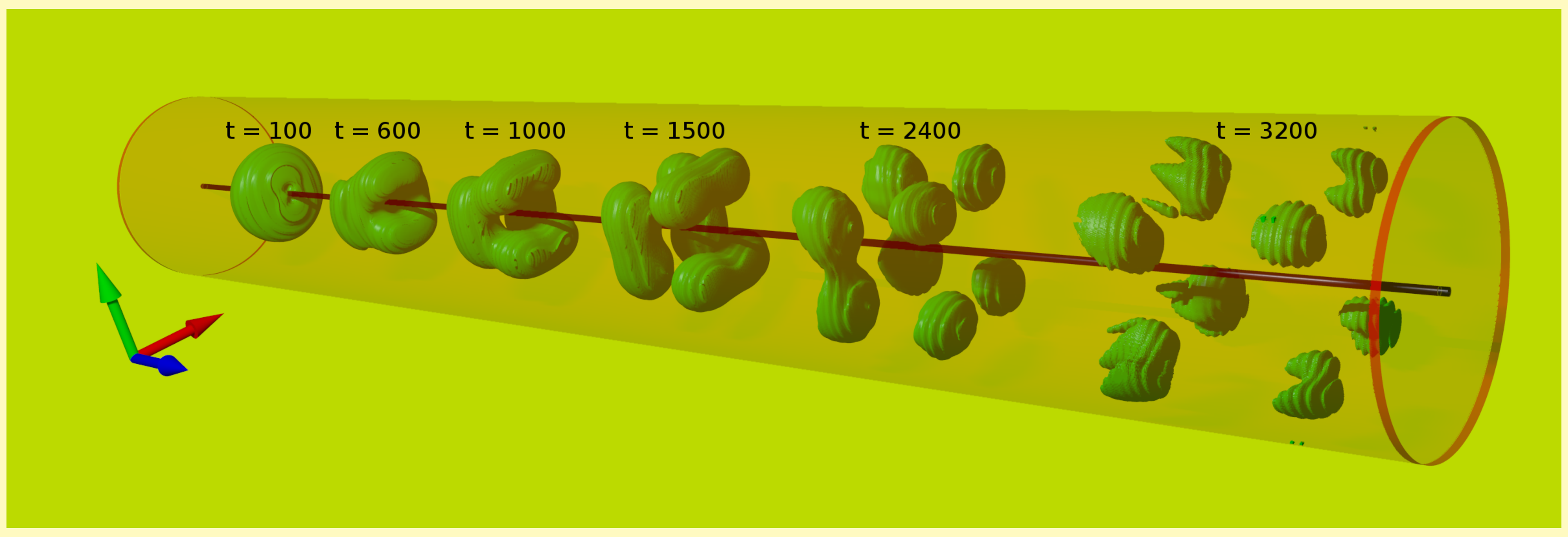
- A Gaussian beam entering a fibre turns into a Laguerre-Gaussian beam
- The difference in refraction index deforms the beam



Snapshots of electric field $\vec{E}$ at three different times. Incident light is polarized along the x axis (red arrow). Left: The Gaussian pulse just after entering the waveguide. Center: After a short time, a dark spot forms near the axis. Regions near the xz and yz planes differ in propagation velocity and have opposite phase. Right: After a longer time, the difference in velocity greatly distorts the pulse. Reflection from waveguide walls causes noticeable interferrence and waveforms lose clarity, although the pattern remains visible.

Pulse shape and polarization

- The pulse deforms, then gradually splits into multiple intensity regions, positioned diagonally to the incident light polarization.



Shape of the originally Gaussian pulse at different times after entering the waveguide. Plotted are the isosurfaces where local field amplitude is greater than 5% of the maximum. At first, the pulse is roughly spherical. Soon a minimum forms at the axis, and the upper and lower parts start overtaking the left and right ones, due to the difference in refraction indexes. The pulse gradually splits into 8 parts, which appears to be a stable configuration.

- At room temperature, the stable 8-region configuration only forms in fibres with diameter of at least 10μm. Thinner fibres do not guide light.
- TODO: Determine the polarization of light in each region. Probably each of the two ranks has different polarization.

Conclusions

- A method was developed to model the propagation of light through media with non-uniform fully-anisotropic dielectric tensor, such as liquid crystals
- The method was tested to produce correct results for refraction and reflection on an interface, transimitivity of uniform-director liquid crystal between crossed polarizers, and for the photonic band-gap caused by periodic modulation of refraction index
- When applied to a radial-profile liquid crystal waveguide, the method predicts the splitting of a single pulse into eight intensity regions, aligned diagonally around the axis in two ranks
- The stability of the 8-region configuration depends on waveguide size and birefringence, hinting at possibility of switching by changing the temperature

References

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[3] A. Taflove and S. C. Hagness. *Computational Electrodynamics: The Finite-Difference Time-Domain Method*. Artech House (2005).