Improved ray-tracing for slowly varying director field: Simulation of optical micrographs of nematic and cholesteric droplets

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Outline

1. Ray-tracing method in birefringent media
2. Validation on a simple test-case
3. Application to the visualisation of cholesteric and nematic droplets
4. Conclusion
Motivations

Transmission of an arbitrary birefringent sample between polariser and analyzer: Jones method
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- First limitation: numerical aperture
  ⇒ generalized Jones method by Mur et al

Question: Can we design an efficient method to simulate natural light micrographs of LC samples, including light deviation effects?
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Transmission of an arbitrary birefringent sample between polariser and analyzer: Jones method

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- Second limitation: deflection of the extraordinary rays.

How to explain the non-zero contrast of natural light micrographs?
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  How to explain the non-zero contrast of natural light micrographs?

Question

Can we design an efficient method to simulate natural light micrographs of LC samples, including light deviation effects?
The improved ray-tracing method

Working hypotheses: $|\nabla n| \sim \frac{1}{L} \ll \frac{1}{\lambda} + \text{Mauguin regime}$

- Evolution of extraordinary and ordinary rays: Hamilton Eqs.
The improved ray-tracing method

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- Evolution of extraordinary and ordinary rays: Hamilton Eqs.
- New result: $n_{\text{eff}} \sqrt{q} E$ and $\sqrt{q} B$ are conserved along a ray
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Setup

Incident plane wave on a transverse cholesteric helix: Poynting vector field $\mathbf{S}$ inside the cholesteric phase?

Two methods of resolution:

- Our improved ray-tracing method
- Exact resolution of Maxwell Eqs. (FDTD)
Validation on a simple test-case

Results

FDTD simulation

Ray tracing simulation

Horizontal profile

Vertical profile
Validation on a simple test-case

Results

Fast and accurate reconstruction of $S$ far from the caustic boundaries
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Two studied mixtures, with two different origin for the twist:

- CCN-37 + R811: spontaneous twist $q_0$ of the cholesteric phase
- SSY + water: giant elastic anisotropy $K_2 \ll K_{1,3}$
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Natural light micrographs: average over all polarisation states.
Applications

Cholesteric twisted bipolar droplet (CCN-37+R811)

Deflection map (extraordinary rays)

simulation

experiment

Deflection amplitude (μm)

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Improved ray-tracing

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Nematic twisted bipolar droplet (SSY in water)

Deflection map (extraordinary rays)
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Conclusion and outlook

- New method with fast and accurate reconstruction of $S$ far from caustics.
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- Good agreement with experimental micrographs of twisted bipolar droplets.
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- Good agreement with experimental micrographs of twisted bipolar droplets.
- Perspectives:
  - Beyond the Mauguin regime: elliptic polarisations
  - Role of numerical aperture?
  - Link between chirality and symmetry-breaking in micrographs?
  - New systems: skyrmions, cholesteric fingers, banded droplets...
Thank you for your attention!
Two sources of discontinuity

Mapping $\mathbf{x}_i \rightarrow \mathbf{x}_f$:

- No caustics: one-to-one correspondance
- Caustic domains: many-to-one correspondance
Conclusion

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Optical index discontinuity: generic Fresnel boundary conditions