Phase retarders in liquid crystals polymers

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12 March 2012
Goal of the thesis

- Development of phase retarders in liquid crystal polymers (LCP)

Liquid Crystal Polymers

- Liquid crystals connected to chain polymers
  ⇒ possesses birefringent properties
  ⇒ locally orientable
  ⇒ space variant retarders

New recording method

- Polarization holography
  ⇒ recording without mechanical action
- **Realization process in 2 steps**
  1. alignment layer with photo sensitive polymers:
     - exposed to a UV linearly polarized beam
     - ⇒ orient themselves according to the incident polarization
  2. layer of liquid crystals pre-polymer:
     - liquid crystals orient according the orientation of layer 1
     - ⇒ definition of optical axis orientation
     - exposed to a UV source to fix them
     - ⇒ stable orientation of optical axis
Superposition of differently polarized beams

- beams coming from the same source
  \[ \Rightarrow \text{respect interference conditions} \]
- differently polarized beams
  \[ \Rightarrow \text{polarization interference} \]
  \[ \Rightarrow \text{no intensity variation} \]
  \[ \Rightarrow \text{non uniformly polarized resulting beam} \]
- **Polarization analyzer**
  - recording: superposition of two circularly polarized beam with opposite handedness ⊗ + ⊗
  - wave plate with a constant phase shift
  - continuous and periodical rotation of its optical axes
  - measurement of the Stokes parameters
  - variation of the optical axis orientation in the x direction ⇒ transmitted beam non uniformly polarized
  - analyzer + linear polarizer ⇒ variation of the intensity variation function of the Stokes parameters
Numerical simulation

- computation of the transmitted intensity
- fit of the intensity by equation

\[ I = \frac{S_0}{2} - \frac{S_1}{2} \cos\left(\frac{\phi}{2}\right)^2 - \frac{S_1}{2} \cos(4\theta) - \frac{S_2}{2} \sin\left(\frac{\phi}{2}\right)^2 \sin(4\theta) + \frac{S_3}{2} \sin(\phi) \sin(2\theta) \]

with \( \theta \) local orientation of the o.a \( \theta = \frac{\pi(x + c)}{d} \)

\( \phi \) phase shift of the wave plate

\( S_i \) Stokes parameters

- error on the numerical Stokes parameters < 1%
- Measurement process
  acquisition of 3 pictures
  - laser off
  - laser on, no retarder
  - laser on + retarder
  ⇒ normalized picture
  bright and dark areas
  ⇐ ≠ orientations of o.a
Numerical treatment

- nearly vertical areas
  $\Rightarrow$ rotation of the picture angle $\leftarrow$ Hough transform
- computation of a mean line inside the rectangle
Calibration process = measurement of incident beams with specific polarization state (↕, ↔, ⦿, ⊶ polarization) ⇒ period $d$
⇒ phase shift $\phi$
⇒ orientation of optical axes in the first pixel $c$

Measurement = fit of the mean line by equation 1 ⇒ value of the Stokes parameters
Results for several linearly polarized beams with degree of polarization = 1
(orientation of $22.5^\circ, 67.5^\circ, 112.5^\circ, 157.5^\circ$)
⇒ error on the experimental Stokes parameters $\approx 10\%$
  ⇒ method not accurate enough
  ⇒ future possible ameliorations
  • more complex computational process
    ⇔ more equations in the process
    $S_0 > 0, \ S_0^2 \geq S_1^2 + S_2^2 + S_3^2, \ldots$
  • better imaging system
    ⇔ reduced aberrations
  • small changes in the realization process
    ⇔ modification of the period of the retarder
Phase mask coronagraph

- coronagraphy = eclipse simulation
  ⇒ reveal faint companions
- half wave plate with radial orientation of o.a
- at the center phase singularity
  ⇒ central light attenuation
- recording using a radially polarized beam
Recording system

- 4 beams differently polarized
  - A Left circular
  - B Horizontal
  - C Right circular
  - D Vertical
- **Characterization angle**
  - \( \theta \in \left[ -\frac{\pi}{2}, \frac{\pi}{2} \right] \) rotation 2 times to slow
    - \( \Rightarrow \) realize a half-wave plate for UV with this \( \theta \)
    - \( \Rightarrow \) creation of a locally radially polarized beam
    - \( \Rightarrow \) simulation to predict the coronagraphic effect
- Characterization intensity
  - $I_{\text{recording}}$ sufficient everywhere
  - region of $\frac{I_{\text{small}}}{I_{\text{large}}} > 0.75 \approx 150\mu m$ around the center
    (on a sample of 6700$\mu m$ large)
    $\Rightarrow$ test on elliptically recording beam to perform
    $\Rightarrow$ determination of the threshold of ellipticity
Conclusion

- polarization analyzer
  numerically it works with an error < 1%
  practically it works with an error ≈ 10%
  ⇒ several upgrades to implement (equations, optics, period, ...)
- phase mask coronagraph
  4 beams superposition recording in two steps
  intensity everywhere but circular polarization at the center
  ⇒ practical tests with several recording with different ellipticity in the neighborhood of a center radially polarized
  ⇒ numerical tests to obtain coronograph characteristics
  ⇒ prototype realization
Questions
- **Realization**
  - layer 1 exposed to the overlap of 2 circularly polarized beams of opposite handedness: \( \odot + \odot \)
    - beam with a constant intensity and non-uniform polarization: serie of linear polarizations
    - continuous variation of the optical axes orientation