Phase retarders in liquid crystals polymers

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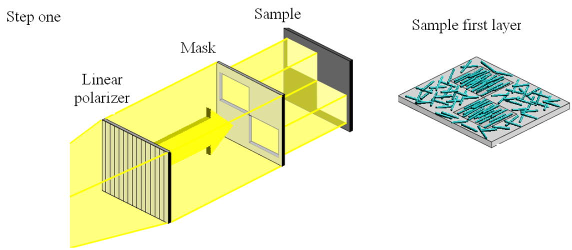
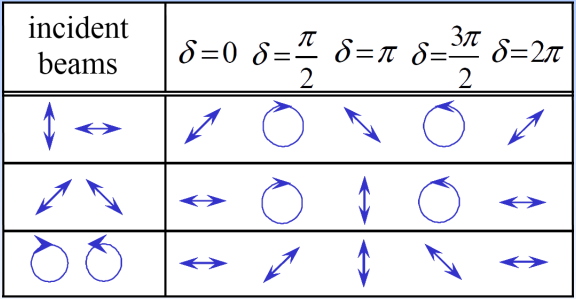
- Goal of the thesis
  - Development of phase retarders in liquid crystal polymers (LCP)
- Liquid Crystal Polymers
  - Liquid crystals connected to chain polymers
    $\Rightarrow$ posses birefringent properties
    $\Rightarrow$ locally orientable
      $\Rightarrow$ space variant retarders
- New recording method
  - Polarization holography
    $\Rightarrow$ recording without mechanical action

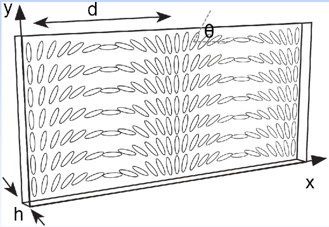
- Realization process in 2 steps
  1. alignment layer with photo sensitive polymers :
     exposed to a UV linearly polarized beam
     ⇒ orient themselves according to the incident polarization
  2. layer of liquid crystals pre-polymer
     liquid crystals orient according the orientation of layer 1
     ⇒ definition of optical axis orientation
     exposed to a UV source to fix them
     ⇒ stable orientation of optical axis

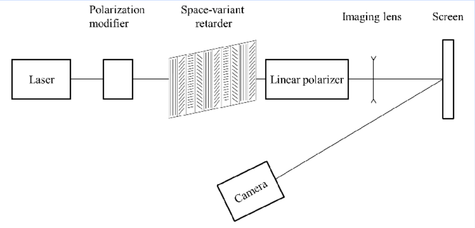


- Superpositon of differently polarized beams
  - beams coming from the same source
    $\Rightarrow$ respect interference conditions
  - differently polarized beams
    $\Rightarrow$ polarization interference
      $\Rightarrow$ no intensity variation
      $\Rightarrow$ non uniformly polarized resulting bream



- Polarization analyzer
  - recording : superpositon 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

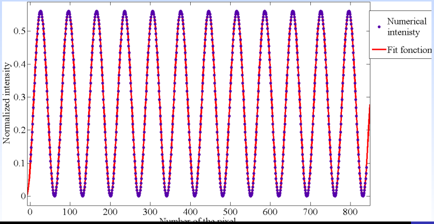
$$I = \frac{S_0}{2} - \frac{S_1}{2}\cos(\frac{\phi}{2})^2 - \frac{S_1}{2}\cos(4\theta) - \frac{S_2}{2}\sin(\frac{\phi}{2})^2\sin(4\theta) + \frac{S_3}{2}\sin(\phi)\sin(2\theta)$$

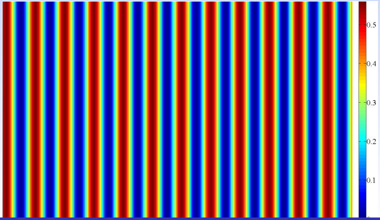
with θ local orientation of the o.a $\theta = \frac{\pi(x+c)}{d}$

ϕ phase shift of the wave plate

S_i Stokes parameters

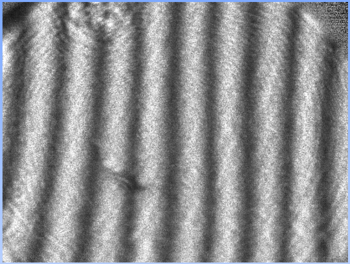
  - error on the numerical Stokes parameters $< 1\%$

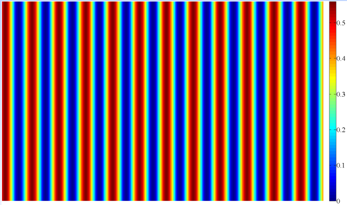




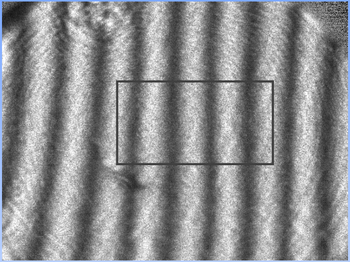
- Measurement process
  acquisition of 3 pictures
  - laser off
  - laser on, no retarder
  - laser on + retarder

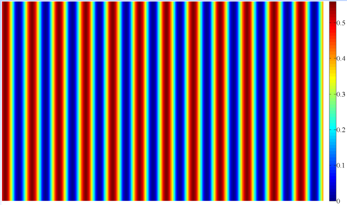
  $\Rightarrow$ normalized picture
  bright and dark areas
  $\Leftarrow \neq$ orientations of o.a



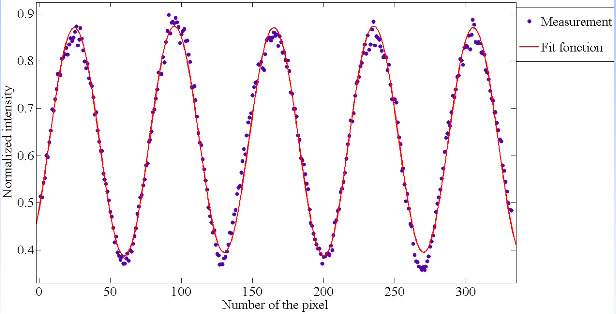


- Numerical treatment
  - nearly vertical areas
    $\Rightarrow$ rotation of the picture
    angle $\leftarrow$ Hough transform
  - computation of a mean line inside the rectangle



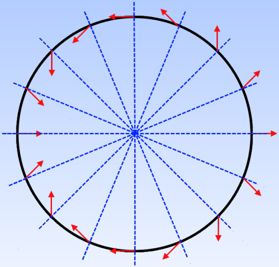


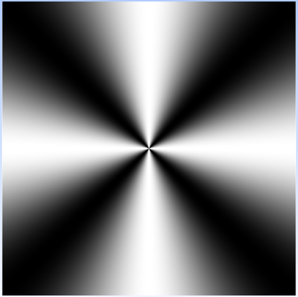
- Calibration process = measurement of incident beams with specific polarization state (↕, ↔, ⤢, ⤡ polarization)
  $\Rightarrow$ period d
  $\Rightarrow$ phase shift ϕ
  $\Rightarrow$ orientation of optical axes in the first pixel c
- Measurement = fit of the mean line by equation 1
  $\Rightarrow$ value of the Stokes parameters



- Results for several linearly polarized beams with degree of polarization = 1 (orientation of 22.5° 67.5° 112.5° 157.5°)
  $\Rightarrow$ error on the experimental Stokes parameters $\approx$ 10%
  - $\Rightarrow$ method not accurate enough
  - $\Rightarrow$ future possible ameliorations
    - more complex computational process
      $\Leftrightarrow$ 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
      $\Leftrightarrow$ reduced aberrations
    - small changes in the realization process
      $\Leftrightarrow$ modification of the period of the retarder

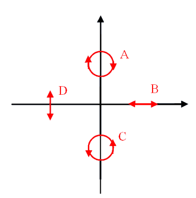
- Phase mask coronagraph
  - coronagraphy = eclipse simulation
    $\Rightarrow$ reveal faint companions
  - half wave plate with radial orientation of o.a
  - at the center phase singularity
    $\Rightarrow$ central light attenuation
  - recording using a radially polarized beam

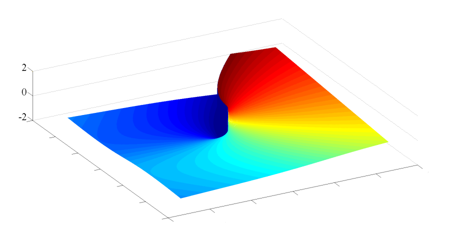


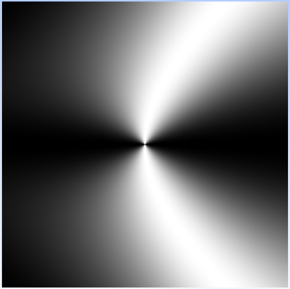


- Recording system

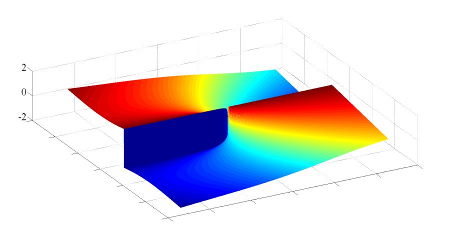
- 4 beams differently polarized
  - A Left circular
  - B Horizontal
  - C Right circular
  - D Vertical

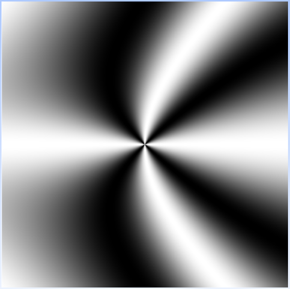




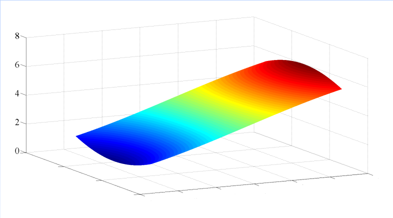


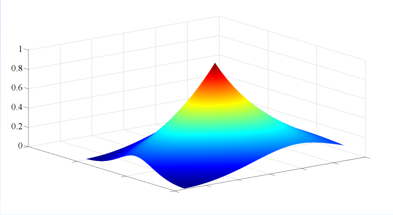
- Characterization angle
  - $\theta \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$ rotation 2 times to slow
    $\Rightarrow$ realize a half-wave plate for UV with this θ
    $\Rightarrow$ creation of a localy radially polarized beam
    $\Rightarrow$ simulation to predict the coronagraphic effect





- Characterization intensity
  - $I_{recording}$ sufficient everywhere
  - region of $\frac{I_{small}}{I_{large}} > 0.75 \approx 150\mu m$ 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 $< 1\%$
    practicaly it works with an error $\approx 10\%$
    $\Rightarrow$ 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
    $\Rightarrow$ practical tests with several recording with different ellipticity
    in the neighborhood of a center radially polarized
    $\Rightarrow$ numerical tests to obtain coronograph characteristics
    $\Rightarrow$ prototype realization

- Questions

- Realization
  - layer 1 exposed to the overlap of 2 circularly polarized beams of opposite handedness : ⟳ + ⟲
    ⇒ beam with a constant intensity
    and non-uniform polarization : serie of linear polarizations
    ⇒ continuous variation of the optical axes orientation