Calibration of a Nonlinear Optical Polarimeter

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Introduction

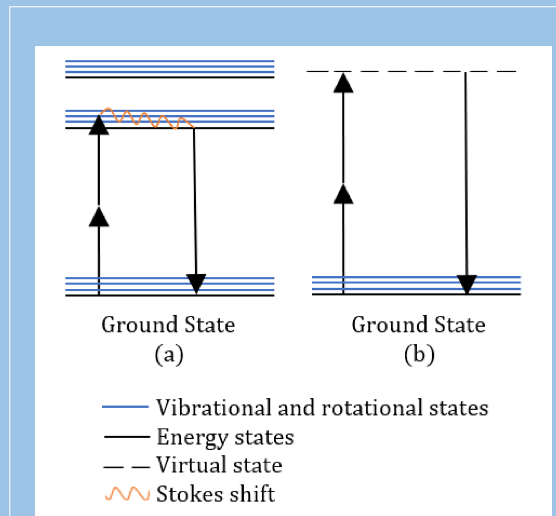


Figure 1: Energy level diagrams for (a) 2PF and (b) SHG.

- Nonlinear polarimetry is a non-destructive technique for measuring nonlinear optical activity in organic and inorganic samples, such as with polarization second harmonic generation (SHG)
- Nonlinearity generally only occurs at very high light intensities, so high peak power lasers are typically required to observe nonlinear processes
- SHG is a nonlinear optical process that differs from two photon fluorescence (2PF) in various ways (Figure 1) including: Reduced photobleaching, coherence, 2PF is isotropic, no need for an added dye
- Polarisation nonlinear microscopy can differentiate between some normal and cancerous pathological tissue sections [1,2]
- A single scan using this technique is limited to one particular wavelength, and it is a rather long process at 22 minutes
- The scan speed will be improved, 1000x faster, and at several wavelengths
- This will be performed by developing a multi-spectral polarimeter based on photoelastic modulators

Theory

- Jones calculus can be used to represent the polarisation of light
- If some of the light is scattered, Mueller calculus must be used [3] where

$$\mathbf{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I_0 + I_{90} \\ I_0 - I_{90} \\ I_{45°} - I_{-45°} \\ I_{rcp} - I_{lcp} \end{pmatrix} \quad (1)$$

$$J_{HLinear} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad M_{HLinear} = \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix} \quad (2) \qquad J_{RCircular} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad M_{HLCircular} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} \quad (3)$$

- A Poincaré sphere is a graphical tool to aid in visualizing the polarisation of light
- The axes of the sphere are the Stokes parameters S_1, S_2, S_3 and the radius corresponds to the total power of the light, S_0.
- Similar to the 2D polarisation ellipse, but provides additional information about light polarisation such as ellipticity angles and the orientation of light
- The induced polarisation, **P**, can be expressed as a power series, where the quantities $\chi^{(1)}$, $\chi^{(2)}$, $\chi^{(3)}$ are the linear susceptibility and the second- and third-order nonlinear optical susceptibilities, respectively [4]

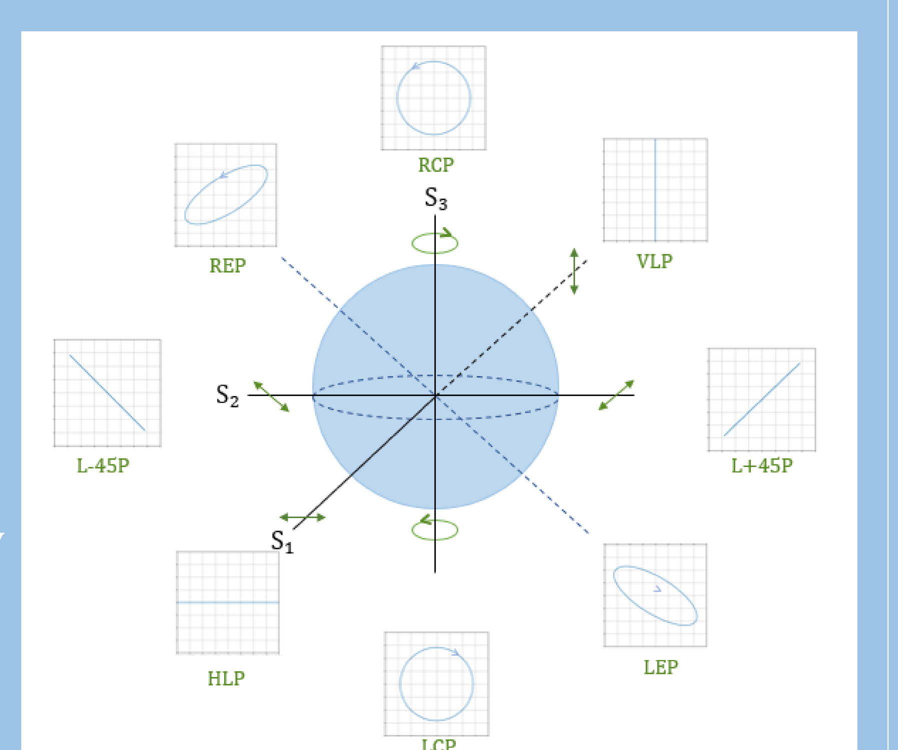


Figure 2: Poincaré sphere showing right and left circular polarisation(RCP/LCP), horizontal and vertical linear polarisation (HLP/VLP), linear polarisation at +/-45° and right and left elliptical polarisation (REP/LEP).

$$\mathbf{P} = \chi^{(1)}\mathbf{E} + \chi^{(2)}\mathbf{EE} + \chi^{(3)}\mathbf{EEE} \quad (4)$$

- The greater the susceptibility, the more the material will polarise in response to the electric field
- Nonlinear susceptibilities can be determined by modulating the polarisation of the laser and detecting the polarisation of the nonlinear signal

Method and Results

- A Python simulation was created to obtain optimal polarisation states using two photoelastic modulators in series [5]
- The ideal optical system was found to contain two photoelastic modulators, the first at 45° and the second at 0°

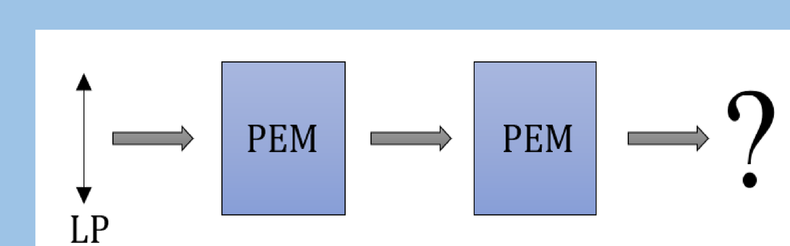


Figure 3: Schematic of the simulation where linearly polarised light (LP) passes through a photoelastic modulator (PEM) at 45° and a second PEM at 0°.

- To produce all possible polarisations with the two PEMs
  - The phase retardance of the first PEM was varied from 0 to 2π
  - The phase retardance of the second PEM was varied from 0 to π
- Results were evaluated by plotting polarisation states on a Poincaré sphere
  - Allow visualizing the distribution of polarisations
  - Polarisation states are mostly evenly distributed except at the poles

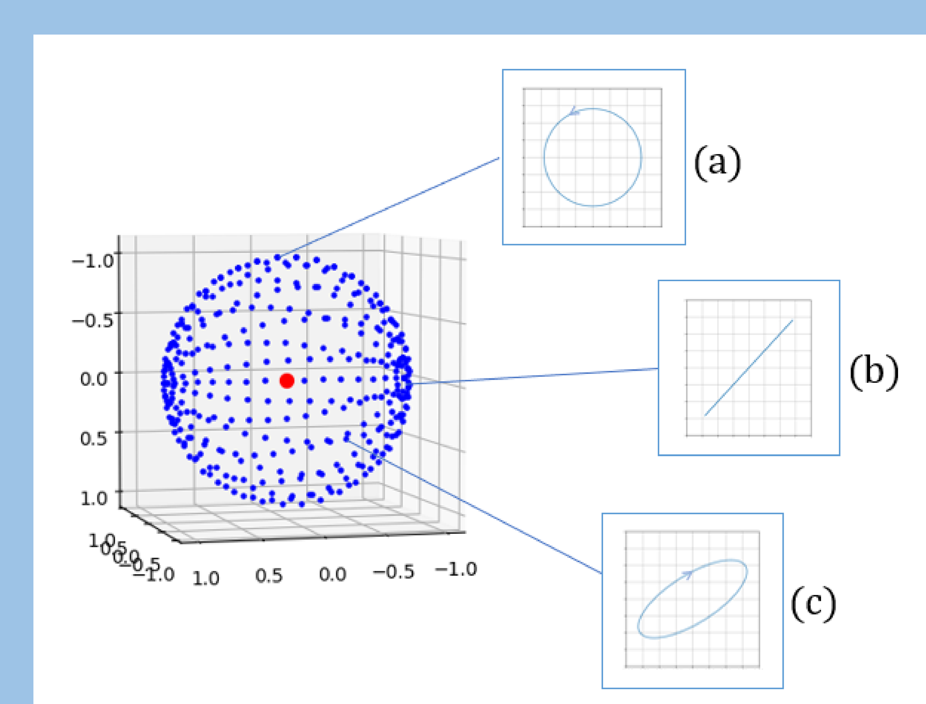
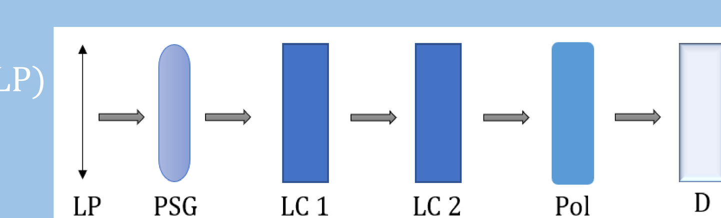


Figure 4: Results of the Python simulation are presented via Poincaré sphere. [5]

Future Steps

- Using the new calibration method introduced in [3], it is possible to calibrate a polarimeter without requiring any previous knowledge of its components
  - This is done by constructing a matrix for each polarisation state, and right pseudoinverting it to produce a data reduction matrix
  - Using singular value decomposition (SVD), it is possible to calculate a more accurate pseudoinverse of I, the light intensity, and optimize uncertainties
- Further improvements to data reduction matrix
  - SVD will also aid in creating a more precise data reduction matrix, as typical pseudoinversion can create discrepancies in the matrix
  - A truncated pseudoinverse will further improve the data reduction matrix, as it will guarantee more stability and lower the susceptibility to measurement uncertainties
- This calibration technique will be tested using two liquid crystal (LC) phase retarders

Figure 5: Schematic of optical setup containing linearly polarised light (LP) passing through a polarisation state generator (PSG), two liquid crystal retarders (LC), a polariser and a detector (D)



Conclusion

- Using the Python simulation, it was possible to select proper photoelastic modulator orientations and modulations
- Polarisation state bunching occurs, and must be reduced to avoid unnecessary redundancy
- The Python code can simulate a wide range of modulators and resulting polarisations for pinpointing essential performance specifications
- This approach can aid in reducing the cost of materials for the creation of a nonlinear optical polarimeter [3]

References

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5. Python Software Foundation. Python Language Reference, version 3.6.