

# Optical Properties of Cochlospermum Religiosus Wood Sample by Mueller Matrix Polarimetry

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## ABSTRACT

This study investigated the optical properties of wood material by Mueller matrix imaging polarimetry. Polarimetry is an indirect optical method in that information about the physical properties of a sample is obtained in the course of modeling analysis. More advanced techniques like Mueller matrix polarimetry is also known as ellipsometry is used to study the complete and accurate characterization of anisotropic samples which occur in many instances, both in research and real life activities. Mueller Matrix Imaging Polarimetry is a powerful imaging technique used to provide high precision measurements for the Mueller matrices at every pixel of an image captured with a detector. The system used acquires 16 Mueller Matrix images and these images are further processed to investigate the polarization properties of the sample under consideration. In this communication the optical system used to acquire the Mueller Matrix Images functioning in reflection frame is described and the resulting polarization properties of the wood sample like Depolarization, *Diattenuation* and Retardance were presented.

**Keywords:** Mueller matrix, ellipsometry, Polarimetry and polarization.

## 1. INTRODUCTION

The science of polarization measurement is divided into several categories and sample measuring polarimetry is one of these categories in which a relationship between the polarization states of incident and exiting beams for a sample are obtained [1]. The measurements are acquired using a set of polarizing elements located between a source and sample and the exiting beams are analyzed with a separate set of polarization elements between the sample and detector. Complete polarimeter or Mueller polarimeter is thus achieved.

In this paper the Mueller matrix measurement system described consists of a polarization generator and polarization analyzer with sample to be measured in between them, and both of them contain a rotating wave plate as was described in the works of many researchers [2-9]. In this technique the seven independent predefined polarization states i.e open, horizontal, vertical, +45,-45, right circular and left circular states in the state generator that is shining the sample and the state analyser that is recording the intensity information were used to capture the 49 intensity images. Considering pixel by pixel intensity information these images are further processed using polar decomposition technique and then normalized to first element to get 16 elemental Mueller Matrix images. [10]. The optical polarization effects simultaneously occurring in the sample are studied with respect to the 16 Mueller matrix

elements obtained. Further, this work is supposed to provide information related to the nature of composition of material and its influence on the input polarization state.

## 2. THEORY

The polarization state of light can be characterized by four real parameters called the Stoke parameters. This 4-Stoke vector has the standard form expressed as a column vector [8].

$$S = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \text{----- (1)}$$

The principle of optical equivalence first derived by Stokes (G.G. Stokes 1853) shows that the Stokes vector is a complete representation of the polarization state of light beam. When a light beam which is represented by this Stokes vector ( $S$ ) is changed (scattered) by an optical element, the Stokes vector of the light beam undergoes a linear transformation to a new Stokes vector ( $S'$ ) [11]. This transformation is represented by a 4 X 4 matrix called the Mueller or Polarization matrix ( $M$ ) [12] and is generally represented as

$$S' = M \times S \text{ -----(2)}$$

$$\begin{pmatrix} S'_0 \\ S'_1 \\ S'_2 \\ S'_3 \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \text{ -----(3)}$$

This Stokes vector gives measurable polarization information of the output light beam and hence Mueller matrix contains all the polarization information in the process. The Mueller matrix M can be also written as

$$M = m_{11} \begin{pmatrix} 1 & \bar{D}^T \\ \bar{P} & m \end{pmatrix} \text{ ----- (4)}$$

Where  $\bar{D}^T = \frac{1}{m_{11}} (m_{12} \ m_{13} \ m_{14})$  and

$\bar{P} = \frac{1}{m_{11}} (m_{21} \ m_{31} \ m_{41})$  called as Diattenuation and

Polarizance vectors respectively and ‘m’ is a 3 X 3 matrix<sup>5</sup>.

The Diattenuation vector characterizes the intensity transmission of the polarization element. The Depolarization vector describes the polarization state produced from an unpolarized input state. In this paper both the Diattenuation and Depolarization are addressed.

### 3. EXPERIMENTAL PROCEDURE

A 632.8nm, 20mW output from a He-Ne laser was used as excitation source. A set of linear Polarizer (P) and Quarter wave plate (Q1) was used to illuminate the sample with predefined polarization states. Another set of linear Analyzer (A) and Quarter wave plate (Q2) was used to analyze the polarization state of light reflected from the sample collected onto a detector. The Analyzer and collection optics were kept at 45° from the beam direction while performing measurement. To collect the 4 X 4 Mueller matrix images we generated 49 images by suitably rotating the Polarizer and Analyzer.

### 4. DESCRIPTION ABOUT THE SAMPLE

Sample preparation: The sample under consideration is a wood material obtained from natural source (Botanical name **Cochlospermum Religiosus**), Family: Cochlospermaceae, Habitat: Andhra Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh and Bihar; cultivated at Agartala in Tripura.,English name: Golden Silk tree, White silk Cotton tree, Telugu name: Konda gogu. Parts used: leaves, flowers. Properties & uses: A sparsely branched shrub, or ‘naked’ tree of the drier parts of India is cultivated in several areas. The tree yields a gum, katira gum, which is insoluble in water but swells in it and mixed with gum-arabic gives a water-borne adhesive paste. The gum has some value in cigar and ice-cream manufacture

and can be used as a substitute for gum tragacanth in various industrial processes. It is sweetish, cooling and sedative and helpful in cough medicine.

## 5. SAMPLE PREPARATION & EXPERIMENTAL SETUP

The material obtained is dried for 1 year in order to evaporate the moisture content naturally without losing the chemical composition and was given for chemical analysis (Vitro labs, Hyderabad, India) and the chemical composition is shown in Table-1. The sample is finely polished to have mean thickness of 1.15 mm and average width and length 58.25mm and 136.45mm respectively. The Schematic experimental setup is shown in Figure-1.

Wood sample ( Cochlospermum Religiosus )					
H <sub>2</sub> O%	C%	O%	H%	N%	Traces
68.58	14.8	11.93	1.71	0.91	2.07

TABLE.1 Chemical composition of sample



Figure.1.Experimental setup

## 6. EXPERIMENTAL RESULTS

The Mueller matrix gives the optical finger print of the sample. The 49 intensity images with various orientations of Polarizer and Analyzer are necessary to obtain the 16 elements of Mueller matrix images [12-13]. After acquiring 49 intensity images the 16 elemental Muller matrix images are obtained which are defined as follows

$$\begin{aligned} m_{11} &= I_{OO} \\ m_{12} &= I_{HO} - I_{VO} \\ m_{13} &= I_{PO} - I_{MO} \\ m_{14} &= I_{LO} - I_{RO} \\ m_{21} &= I_{OH} - I_{OV} \\ m_{22} &= (I_{HH} + I_{VV}) - (I_{HV} + I_{VH}) \\ m_{23} &= (I_{PH} + I_{MV}) - (I_{PV} + I_{MH}) \\ m_{24} &= (I_{RV} + I_{LH}) - (I_{RH} + I_{LV}) \\ m_{31} &= I_{OP} - I_{OM} \end{aligned}$$

$$m_{32} = (I_{HP} + I_{VM}) - (I_{HM} + I_{VP})$$

$$m_{33} = (I_{PP} + I_{MM}) - (I_{PM} + I_{MP})$$

$$m_{34} = (I_{RM} + I_{LP}) - (I_{RP} + I_{LM})$$

$$m_{41} = I_{OL} - I_{OR}$$

$$m_{42} = (I_{HL} + I_{VR}) - (I_{HR} + I_{VL})$$

$$m_{43} = (I_{PL} + I_{MR}) - (I_{PR} + I_{ML})$$

$$m_{44} = (I_{RR} + I_{LL}) - (I_{RL} + I_{LR})$$

where the first subscript in the intensity parameters indicates input state, and the second subscript the output state and here, H indicates horizontal polarization, V indicates vertical polarization, P indicates +45°, M indicates -45°, R indicates right circular polarization and L indicates left circular states of polarization. The corresponding images are shown in Figure-2, obtained using a self developed MATLAB program to crop the image for uniform pixel size and get intensity information pixel by pixel for the image.

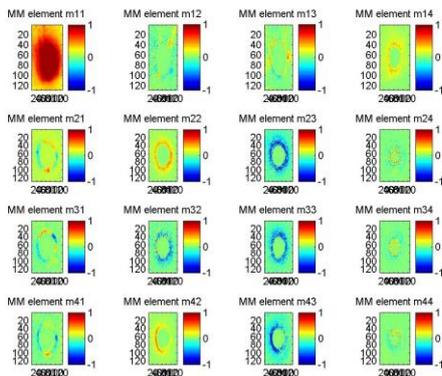


Figure.2. 16 Mueller Matrix Images

Once all 16 images are obtained, the images are processed, again using a developed MATLAB program which calculated the intensity component of each and every pixel of the image and then processed to get the overall intensity information of the image. The Muller matrix hence obtained is normalized to m<sub>11</sub> component which enables the isolation of intensity dependent effects to the polarization effects and also simplifies the analysis. The measured Mueller matrix is shown in Table-2.(below)

1	-0.09195	-0.29885	0.011494
0.21264	0.1092	-0.09195	-0.04598
0.017241	-0.01724	-0.10345	0.022989
-0.05747	0.086207	-0.08046	-0.00575

Table.2.Measured Mueller matrix

From the measured Mueller matrix the Diattenuation, Depolarization and Retardance images are obtained which are shown in Figures 3,4 and 5, respectively. Finally the mean values of Diattenuation and Depolarization for the sample is calculated using a developed MATLAB program for Intensity image analysis and the results are shown in Table-3, and also further processed from 16 elements of Mueller matrix

acquired mean values of stokes vector parameters of S<sub>0</sub>, S<sub>1</sub>, S<sub>2</sub> and S<sub>3</sub> show in Table.4 and the images shown in figure 6.

Table.3.Polarization values obtained from sample

Sample	Mean values
S <sub>0</sub>	1
S <sub>1</sub>	0.3971
S <sub>2</sub>	0.6467
S <sub>3</sub>	0.2033

Polarization parameter	Mean values
Depolarization	0.833
Retardance	2.0865
Diattenuation	0.3129

Table.4.Mean values obtained from sample

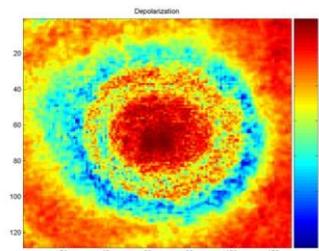


Figure.3.Depolarization of the Sample

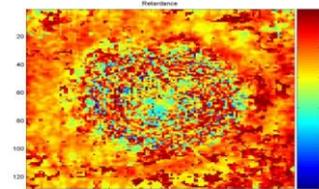


Figure4. Retardance of the Sample

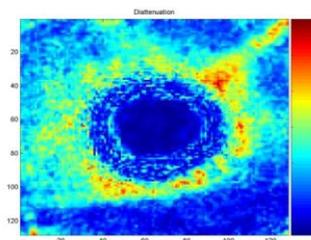


Figure5. Diattenuation of the Sample

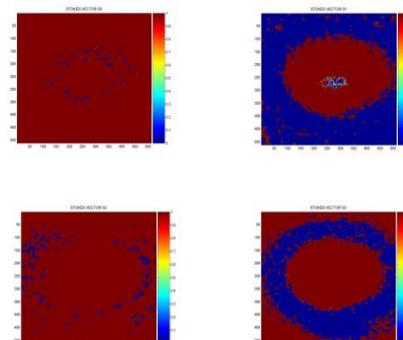


Figure6. Stokes vector images of sample.

## 7. RESULTS AND DISCUSSIONS

Analysis in these experiments, where data is in the form of images was done in the following manner. The obtained images were processed and cropped up to the bright spot's size (100 X 100 pixels). These cropped images were then decomposed to give diattenuation, depolarization and retardance values for each pixel. The values of these parameters were averaged over all the pixels and plotted. The Mueller images were also calculated and are compared. These images were normalized with respect to first element of Mueller matrix ( $M_{11}$ ). The decomposition plots were averaged column wise and corresponding values were plotted for comparison between two or more samples and distinguishing one sample from the other. Also calculated stokes vector parameters of the sample. Similar treatment was also done with the Mueller images.

## 8. CONCLUSIONS

From our experimental methods we could achieve optical signature in the form of Mueller matrix of the wood sample *Cochlospermum Religiosus*. As expected wood sample is exhibiting polarization anisotropic character which is evident from the results. Depending on different physical parameters variation in the Depolarization, Diattenuation and Retardance is a subject of interest which reveals the complete character of the sample.

## REFERENCES

- [1] Edward Collette. 1993. Polarized Light Fundamentals and Applications. Chapter15, Marcel Dekker, New York.
- [2] R.M.A. Azzam. 1978. Photopolarimetric measurement of the Mueller matrix by fourier analysis of a single detected signal. *Opt. Lett.* 2(6): 148-150.
- [3] R.W. Collins, J. Koh. 1999. Dual rotating-compensator multichannel ellipsometer: Instrument design for real-time Mueller matrix spectroscopy of surfaces and films. *JOSA (A)*. 16(8): 1997-2006.
- [4] D.H. Goldstein. 1992. Mueller matrix dual-rotating retarder polarimeter. *Appl. Opt.* 31: 6676-6683.
- [5] R.A. Chipman. 1995. Polarimetry Handbook of Optics. 2<sup>nd</sup> Ed. McGraw-Hill, New York. Vol. 2, Ch. 22.
- [6] Soe-Mie F. Nee. 2003. Error analysis for Mueller matrix measurement. *JOSA (A)*. 20(8): 1651-1657.
- [7] Kiyoshi Ichimoto, Kasuya Shinoda, Tetsuya Yamamoto and Junko Kiyohara. 2006. Photopolarimetric measurement system of Mueller matrix with dual rotating waveplates. *National Astronomical Observation, Japan*. 9: 11-19.
- [8] W.A. Shurcliff. 1992. Polarized Light: Production and Use. Oxford University Press, London (1980) 1962, E. Collette.
- [9] K. Srinivasa reddy, V. Mohan kumar, S. Chandralingam, P.Ranghavendra Rao, P.V. Kanaka Rao, "Optical signature of wood sample-Mueller matrix imaging polarimetry", *ARPN Journal*, vol 5, No. 9, September 2010.
- [10] G.G. Stokes. 1852. On the composition and resolution of streams polarized light from different sources. *Trans. Cambridge Phill. Soc.* 9: 399-416.
- [11] H. Mueller. 1948. The Foundation of optics. *J. Opt.Soc. Am.* 38: 468-478.
- [12] Ramachandra P *et al.* 1993. Wrightial, a new terpene from *wrightia tinctoria*. *Journal of natural products*. 56(10): 1811-1812.
- [13] C.F. Bohren and D.R. Huffman. 1988. Absorption and scattering of light by small particles. Wiley, New York.